October 27–30, 2015
Houston, Texas

Program

LUNAR AND PLANETARY INSTITUTE

USRA

First Landing Site/Exploration Zone Workshop for Human Mission to the Surface of Mars

October 27–30, 2015 • Houston, Texas

Organizer

Lunar and Planetary Institute
Universities Space Research Association
National Aeronautics and Space Administration

Co-Chairs, Human Landing Sites Study Steering Committee

Benjamin Bussey
National Aeronautics and Space Administration

Richard Davis
National Aeronautics and Space Administration

Abstracts for this workshop are available in electronic format via the workshop website at **www.hou.usra.edu/meetings/explorationzone2015/** and can be cited as Author A. B. and Author C. D. (2015) Title of abstract. In *First Landing Site/Exploration Zone Workshop for Human Mission to the Surface to Mars,* Abstract #XXXX. LPI Contribution No. 1879, Lunar and Planetary Institute, Houston.

Lunar and Planetary Institute   3600 Bay Area Boulevard   Houston TX 77058-1113

Agenda

Tuesday, October 27, 2015

12:30 p.m.	Great Room	Registration
1:00 p.m.	Lecture Hall	Opening Plenary Guest Speakers: Ellen Ochoa, *Director, Johnson Space Center* Jim Watzin, *Director, Mars Exploration Program*
4:40 p.m.	Lecture Hall	Equatorial I

Wednesday, October 28, 2015

8:00 a.m.	Lecture Hall	Equatorial II
2:00 p.m.	Lecture Hall	Equatorial III

Thursday, October 29, 2015

8:00 a.m.	Lecture Hall	Equatorial IV
9:50 a.m.	Lecture Hall	High-Latitude I
2:15 p.m.	Lecture Hall	High-Latitude II
immediately followed by	Lecture Hall	Special Lecture Guest Speaker: James Green, *Director, Planetary Science Division*
immediately followed by	Great Room	Poster Session

Friday, October 30, 2015

8:00 a.m.	Lecture Hall	Group Discussion

Abstracts for this workshop are available in electronic format via the workshop website at www.hou.usra.edu/meetings/explorationzone2015/ and can be cited as Author A. B. and Author C. D. (2015) Title of abstract. In *First Landing Site/Exploration Zone Workshop for Human Mission to the Surface to Mars,* Abstract #XXXX. LPI Contribution No. 1879, Lunar and Planetary Institute, Houston.

Lunar and Planetary Institute 3600 Bay Area Boulevard Houston TX 77058-1113

Program

Tuesday, October 27, 2015
OPENING PLENARY
1:00 p.m. Lecture Hall

1:00 p.m. Ochoa E. *
Opening by Johnson Space Center Director

1:10 p.m. Davis R. and Bussey D. B. J. *
Introduction and Welcome

1:40 p.m. Niles P. *
Scientific Objectives for the Human Exploration of Mars Science Analyses Group (HSO-SAG)

2:00 p.m. Hoffman S. *
ISRU and Civil Engineering Working Group (ICEWG)

2:20 p.m. Hoffman S. *
Evolvable Mars Campaign

2:40 p.m. Zurek R. *
Mars Next Orbiter Science Analysis Group (NEX-SAG)

3:00 p.m. Spry A. *
Planetary Protection

3:20 p.m. QUESTION AND ANSWER

3:40 p.m. *Break*

Tuesday, October 27, 2015
EQUATORIAL I
3:55 p.m. Lecture Hall

3:55 p.m. McEwen A. * Chojnacki M. Miyamoto H. Hemmi R. Weitz C. Williams R. Quantin C. Flahaut J. Wray J. Turner S. Bridges J. Grebby S. Leung C. Rafkin S.
Landing Site and Exploration Zone in Eastern Melas Chasma **[#1007]**
Eastern Melas Chasm may be the best human Exploration Zone for science and resources if enough water can be extracted from either the abundant recurring slope lineae or voluminous hydrated sulfates in this region.

4:10 p.m. Mojarro A. * Ruvkun G. Zuber M. T. Carr C. E.
Human Exploration of Mars at Valles Marineris: The Past, Present, and Future of Life on Mars **[#1036]**
ROIs conceivable of harboring extant life at RSL sites, preserved microfossils beneath sedimentary deposits or biosignatures within impact glasses. Potentially exploitable aquifers and favorable environmental conditions for human habitation.

4:25 p.m. Farrell K. W. Jr. *
Mars Landing + 50 Years: Repurposing the First Viking Landing Site on Chryse Planitia as an Exploration Zone for Automated Infrastructure Construction **[#1019]**
The proposed Chryse Planitia EZ centered near the VL-1 landing site has evidence for adequate water ice, silica, and load-bearing bedrock surface resources to utilize as infrastructure for long-term missions to support humans.

4:40 p.m. Kochemasov G. G. *
Vallis Marineris Mouth as the Best Location for Exploration Zone (EZ) **[#1006]**
The mouth of Vallis Marineris is a particularly interesting location where the widest rock varieties could be expected. The Vallis crosses chaotic terrains and equatorial zone where water ice could be discovered. Pathfinder and Viking were nearby.

4:55 p.m. Clifford S. M. * Kring D. A. Treiman A. H.
The Eastern Outlet of Valles Marineris: A Window into the Ancient Geologic and Hydrologic Evolution of Mars **[#1054]**
The proposed EZ, at the eastern end of Valles Marineris, provides direct access to a Noachian stratigraphic whose exposure and accessibility is unequalled by any other location on the planet.

5:10 p.m. INTEGRATING DISCUSSION

5:40 p.m. DAILY WRAP-UP

Tuesday, October 27, 2015
POSTER SESSION
6:15 p.m. Great Room

Fries M. Hynek B. Osterloo M. Zolensky M.
Martian Halite: Potential for Both Long-Term Preservation of Organics and a Source of Water **[#1039]**
Deposits containing halite on Mars are both rich scientific targets and potentially a resource for manned Mars exploration. This abstract discusses halite deposits in a general sense without specifying a landing site.

Oosthoek J. H. P. Arriazu P. Marco Figuera R.
Shall We Send Humans to Holden Crater? How a Geodesic GIS Approach Can Aid the Landing Site Selection for Future Missions to Mars **[#1049]**
We present the first results of a geodesic-GIS approach to landing site selection for future missions to Mars.

Conrad P. G. Bleacher J. E. van Susante P.
Environmental Dynamics of the EZ: A Priority for Science and Resource Exploration **[#1055]**
We advocate a program of environmental monitoring during surface ops to determine environmental impact of the exploration on science, safety and planetary protection. We argue that the potential for implementation be a factor in the selection rubric.

Lee P. Braham S. Fong T. Glass B. Hoffman S. J. Hoftun C. Huffman S. Johansen B. W. Lorber K. McKay C. P. Mueller R. Schutt J. W. Schwartz K. Weaver J. T.
Haughton-Mars Project: Lessons for the Selection of Landing Site/Exploration Zone for Human Missions to the Surface of Mars **[#1058]**
Important lessons for designing, planning and implementing future human Mars surface activities have been learned from science and exploration investigations at the Haughton-Mars Project (HMP) on Devon Island, High Arctic.

Wednesday, October 28, 2015
EQUATORIAL II
8:00 a.m. Lecture Hall

8:00 a.m. Mitchell J. L. * Christensen P. R. PhD
Equatorial Opportunities for Humans on Mars **[#1023]**
The equatorial exploration zone presented in this abstract includes both geologic and resource-based sites of interest. Proximity to recurring slope lineae, chloride deposits, and representation of major geologic processes are included in this EZ.

8:15 a.m. Calef F. J. III * Archer D. Clark B. Day M. Goertz W. Martin-Torres J. Zorzano Mier M.
Assessing Gale Crater as a Landing Site for the First Human Mission to Mars **[#1020]**
We've assessed Gale crater's potential as the first human landing site. Besides being a well-characterized and benign landing site for EDL, it contains many science ROIs and identifiable ISRU ROIs meeting most if not all requirements proposed.

8:30 a.m. Yun P. *
NASA Landing Site/Exploration Zone Proposal for Human Missions **[#1022]**
Gale Crater meets engineering constraints and has a great potential for past and present habitability; its geological diversity meets science site criteria in astrobiology, atmospheric science, and geoscience.

8:45 a.m. Montaño S. * Johnstone S. Lanza N. Delapp D.
Ground Truth Assessment of the Gale Crater Region Using Mars Science Laboratory Data for Characterization of Potential Human Mission Landing Site and In Situ Resource Utilization **[#1040]**
We discuss the benefits of Gale crater as an exploration zone for a future crewed Mars mission, using MSL data to describe science and resource regions of interest as well as engineering constraints.

9:00 a.m. INTEGRATING DISCUSSION

9:20 a.m. *Break*

9:35 a.m. Wilkinson M. J. McGovern P. J. *
Sinus Meridiani Landing Site for Human Exploration —- A Mesoscale Fluvial System **[#1042]**
SW Sinus Meridiani is proposed as an EZ as seen through the lens of the still poorly recognized large fluvial fan model. Hematite distribution, regional and Miyamoto Crater sedimentary stacks, sediment inundation of craters, and the rover traverse path are suggested ROIs.

9:50 a.m. Clarke J. D. Willson D. Smith H. D. *
First Landing: Southern Edge of Meridiani Planum **[#1057]**
The Endeavour Crater Region is well characterized by the Opportunity rover with good attributes for a first landing site, access to water and mineral resources, and has Noachian, Hesperian, and Amazonian units for science investigations.

10:05 a.m. Cohen B. A. * Seibert M. A.
The Land of Opportunity: Human Return to Meridiani Planum **[#1030]**
Meridiani Planum possesses extremely safe landing characteristics, extensive areas with high trafficability, compelling science motivations to decipher the climatic and hydrologic evolution of Mars, and potential for resource extraction.

10:20 a.m. Longo A. Z. *
A Landing Site for Human Missions to Mars in Gusev Crater **[#1008]**
Gusev Crater is the ideal location for a manned mission to Mars because of Spirit ground truth, a rich diversity of targets for exploration, and resources to sustain a human presence on the surface of Mars without jeopardizing planetary protection.

10:35 a.m. INTEGRATING DISCUSSION

10:55 a.m. *Break*

11:10 a.m. Rice J. W. Jr. * Ruff S. W. Longo A. Z.
Manned Mars Mission Exploration Zone: Gusev Crater-Apollinaris Sulci **[#1046]**
Our proposed 200 km diameter Exploration Zone includes portions of the floor and NE rim of Gusev crater and distal flanks of Apollinarus Mons.

11:25 a.m. Kerber L. * Mueller R. P. Sibille L. Abbud-Madrid A. Bertrand T. Stack K. M. Nicholas A. K. Parcheta C. E. Piqueux S. Daubar I. J. Malaska M. J. Ashley J. W. Diniega S. Dickson J. L. Fassett C. I.
A Human Landing Site at Apollinaris Sulci: Life Inside a Yardang **[#1043]**
An Exploration Zone centered on Apollinaris Sulci would offer a variety of diverse science targets and a unique resource in the form of the nearby Medusae Fossae Formation, which could provide shelter and large amounts of building material.

11:40 a.m. Yakovlev V. V. *
Hills Zephyria Planum — A Source of Deep Resources **[#1016]**
It is assumed to have access to deep water resources, minerals, gas and heat contained in the large injection structures in the implementation of the first humanitarian mission to the hills Zephyria Planum.

11:55 a.m. Davila A. Fairén A. G. Rodríguez A. P. Schulze-Makuch D. * Rask J. Zavaleta J.
The Hebrus Valles Exploration Zone: Access to the Martian Surface and Subsurface **[#1012]**
The Hebrus Valles EZ represents a diverse setting with multiple geological contacts and layers, possible remnant water ice and protected subsurface environments, which could be critical for the establishment of long-term human settlements.

12:10 p.m. INTEGRATING DISCUSSION

12:25 p.m. *Lunch*

Wednesday, October 28, 2015
EQUATORIAL III
2:00 p.m. Lecture Hall

2:00 p.m. Gupta S. Sefton-Nash E. * Adler J. Rice M. Fawdon P. Warner N. Grindrod P. Davis J. Balme M. Bell J. F. III Stetson C. Richard J.
The Hypanis Fluvial-Deltaic-Lacustrine System in Xanthe Terra: A Candidate Exploration Zone for the First Human Mission to Mars **[#1051]**
The Hypanis Exploration zone indicates displays clear evidence for the long-lived action of water in the Early Hesperian with high potential for ancient habitability.

2:15 p.m. Mustard J. F. * Goudge T. A. Bramble M. S. Ehlmann B. L. Head J. W. Dickson J. L. Fassett C. I.
Jezero Crater Watershed, Isidis Basin, Sulfate Deposits and Syrtis Major: A Compelling Exploration Zone for Human Exploration **[#1034]**
The science merit for the Jezero-Syrtis-Isidis EZ is tied to: diversity of rocks and minerals, regional geologic context, habitability (i.e. water history), and the biosignature preservation potential. Resources are tied to hydrated mineral deposits.

2:30 p.m. Markle L. M. *
Nili Fossae Resource and Science ROIs **[#1010]**
The Nili Fossae region presents multiple resource and science ROIs for establishing a permanent colony on Mars. Water ice appears to cover a large are and multiple geological formations provide opportunity for science missions.

2:45 p.m. Sibille L. * Mueller R. P. Niles P. B. Glotch T. Archer P. D. Bell M. S.
Aram Chaos: A Long Lived Subsurface Aqueous Environment with Strong Water Resource Potential for Human Missions on Mars **[#1048]**
Aram Chaos is a 280-km-wide near-circular structure near the outflow channel Ares Vallis and Aureum Chaos. It is a compelling landing site for human explorers featuring multiple science ROIs with a compelling resource ROI with polyhydrated sulfates.

3:00 p.m. INTEGRATING DISCUSSION

3:20 p.m. *Break*

3:35 p.m. Wright S. P. * Niles P. B. Bell M. S. Milbury C. Rice J. W. Jr. Burton A. S. Archer P. D. Jr. Rampe E. B. Piqueux S.
An Exploration Zone in Cerberus Containing Young and Old Terrains, Including Fossae/Faults and Shergottite Distal Ejecta **[#1017]**
Cerberus contains Amazonian lava flows embaying a range of photogeologic units: ridged plains, heavily cratered terrain, highland knobs, and perhaps the Medusa Fossae Fm. Zunil Crater distal ejecta produced secondary crater fields (of shergottites?).

3:50 p.m. Boatwright B. D. *
Southern Nectaris Fossae: A Microcosm of Martian Geology **[#1005]**
The proposed Exploration Zone is located at the southwestern terminus of Nectaris Fossae near Protva Valles. It is ideal in its close proximity to a number of fluvial, volcanic, and impact features as well as sites for potential resource utilization.

4:05 p.m.	Skinner J. A. Jr. * Hare T. M. Fortezzo C. M. Rickman D. L.
Considerations for Human Exploration of an Exhumed, Intercrater Basin in the Martian Cratered Highlands: The Hadriacus Palus and Cavi Example **[#1052]**
Hadriacus Palus and Cavi represent an exhumed, structural (principally non-crater) basin that we contend is a highly relevant "type example" exploration zone wherein scientific objectives can be reasonably achieved and broadly extrapolated to Mars.

4:20 p.m.	Horgan B. * Loizeau D. Poulet F. Bishop J. Noe Dobrea E. Z. Farrand W. Michalski J. Gross C. Kleinhenz J. Linne D.
Habitable Noachian Environments and Abundant Resources in the Mawrth Vallis Exploration Zone **[#1009]**
The Mawrth Vallis EZ contains the most extensive exposed outcrop of clay-rich rocks on Mars, offer substantial and accessible resources for water extraction, as well as Fe, Al, and Si feedstock, and have high biosignature preservation potential.

4:35 p.m.	INTEGRATING DISCUSSION

4:55 p.m.	DAILY WRAP-UP

Thursday, October 29, 2015
EQUATORIAL IV
8:00 a.m. Lecture Hall

8:00 a.m. Michalski J. R. * Niles P. B. Sutter B. Bell M. S.
McLaughlin Crater as a Candidate Landing Site for Humans on Mars **[#1025]**
McLaughlin Crater is a deep, Noachian impact crater containing clay minerals and carbonates that likely formed an ancient lake.

8:15 a.m. Ori G. G. * Pondrelli M.
Exploration Zone for Human Mission to Mars: The Area South of Firsoff Crater in Arabia Terra **[#1026]**
We are proposing an area south of Firsoff Crater that scientifically includes: reconstruction of the stratigraphy at global scale, the identification of sedimentary environment and paleoclimatic conditions and large astrobiological potentiality.

8:30 a.m. Lynch K. L. * Wray J. J.
Exploring Habitability, Hydrology, and Climate Change on Mars at Columbus Crater **[#1041]**
Columbus crater is groundwater fed paleolake basin located in the northwest region of Terra Sirenum and is known for hosting a large diversity of aqueous deposits and therefore hosts a variety of science ROIs and potential resource ROIs.

8:45 a.m. Ackiss S. E. Wray J. J. Seelos K. D. Niles P. B. *
Huygens Crater: Insights into Noachian Volcanism, Stratigraphy, and Aqueous Processes **[#1032]**
Huygens crater is a well preserved peak ring structure in the Noachian highlands. It uplifted pre-Noachian crustal materials and experienced subsequent aqueous activity and volcanic resurfacing making it an ideal location to explore.

9:00 a.m. Lee P. * Acedillo S. Braham S. Brown A. Elphic R. Fong T. Glass B. Hoftun C. Johansen B. W. Lorber K. Mittlefehldt D. Tagaki Y. Thomas P. West M. West S. Zolensky M.
Noctis Landing: A Proposed Landing Site/Exploration Zone for Human Missions to the Surface of Mars. **[#1050]**
Noctis Landing offers a large number and wide range of ROIs for short-term and short-range Mars exploration, and is located strategically between Tharsis and Valles Marineris, which is key for longer-term and longer-range exploration.

9:15 a.m. INTEGRATING DISCUSSION

9:35 a.m. *Break*

Thursday, October 29, 2015
HIGH-LATITUDE I
10:00 a.m. Lecture Hall

10:00 a.m. Head J. W. III * Dickson J. Milliken R. Scott D. Johnson B. Marchant D. Levy J. Kinch K. Hvidberg C. Forget F. Boucher D. Mikucki J. Fastook J. Klaus K.
Mars Human Science Exploration and Resource Utilization: The Dichotomy Boundary Deuteronilus Mensae Exploration Zone **[#1033]**
Deuteronilus Mensae EZ combines: 1) Fundamental MEPAG scientific objectives; 2) Samples from the Noachian, Hesperian and Amazonian); 3) ISRU access to abundant water ice mapped by SHARAD; 4) Civil engineering to reduce reliance on Earth supplies.

10:15 a.m. Rice J. W. Jr. * Crown D. A. Feldman W. C. Pathare A. V. Feustel A. J. Gertsch L. S.
Manned Mars Mission Exploration Zone: Eastern Rim of Hellas Impact Basin **[#1038]**
Our proposed 200 km diameter Exploration Zone centered near 40°S; 104°E is located along the eastern rim of the Hellas basin which will allow astronauts to study and collect very ancient deep seated materials which were excavated in the impact event.

10:30 a.m. Levy J. S. * Holt J. W.
A Human Landing Site on the Hellas Rim: Ancient Craters, Flowing Water, and Abundant Ice **[#1037]**
Hellas basin rim/Ancient highlands and lavas/Lots of ice to drink.

10:45 a.m. Plaut J. J. *
A Resource-Rich, Scientifically Compelling Exploration Zone for Human Missions at Deuteronilus Mensae, Mars **[#1044]**
The Deuteronilus Mensae region of Mars is promising as a potential landing site for human exploration because it contains vast, readily accessible deposits of water ice in a setting of key scientific importance.

11:00 a.m. INTEGRATING DISCUSSION

11:20 a.m. *Break*

11:35 a.m. Mangold N. * Dehouck E. Poulet F. Ansan V. Le Mouélic S.
Ismenius Cavus: Ancient Lake Deposits and Clay Minerals Surrounded by Amazonian Glaciers **[#1027]**
Landing site at the bottom of a 600 m deep paleolake nearby thick clay-rich sediments at lake bottom and deltaic deposits. Strong exobiological interest including ice-rich glacial landforms as water resource in same location.

11:50 a.m. Gallegos Z. E. * Newsom H. E.
A Human Exploration Zone on the East Rim of Hellas Basin, Mars: Mesopotamia **[#1035]**
This abstract highlights a previously unexplored area in the Hellas Planitia region of Mars. The exploration zone proposed offers scientifically compelling regions of interest, as well as abundant resources for reoccurring human missions.

12:05 p.m. Stillman D. E. * Grimm R. E. Robbins S. J. Michaels T. I. Enke B. L.
Hale Crater — Ancient Water Science, Contemporary Water Resource **[#1028]**
Hale has easy access to liquid water via RSL. Scientifically the site has a rich history of water via outflow channel, fluidized ejecta, hydrothermal activity, gullies, and RSL. Lastly, the site would allow age dating of Aryge and Hale crater.

12:20 p.m. Hill J. R. * Christensen P. R.
Western Noachis Terra Chloride Deposits: Aqueous Minerals with High Astrobiological Preservation Potential **[#1021]**
The chloride deposits located in western Noachis Terra represent the closest occurrence of chloride deposits to glacier-like forms separated by traversable terrain and located within the human exploration zone latitude and elevation constraints.

12:35 p.m. INTEGRATING DISCUSSION

12:55 p.m. *Lunch*

Thursday, October 29, 2015
HIGH-LATITUDE II
2:15 p.m. Lecture Hall

2:15 p.m. Barker D. C. * James G. Chamitoff G. Clifford S.
Site Selection for the First Sustainable Mars Base **[#1002]**
Water is the most valuable resource needed for human habitability and its location and ease of extraction should be the main constraint for defining a sustainable and growing human settlement on Mars followed by exploration and scientific objectives.

2:30 p.m. Viola D. * McEwen A. S. Dundas C. M.
Mid-Latitude Ice as a Target for Human Exploration, Astrobiology, and In-Situ Resource Utilization **[#1011]**
We propose two EZs in the northern mid-latitudes of Mars, where near-surface excess ice offers a readily-available source of water.

2:45 p.m. Laine P. E. *
Exploration Zone in Newton Crater **[#1015]**
Newton is a large crater (300 km) located in Terra Sirenum. This region is heavily cratered, preserves crustal magnetism, and has ground ice present. Within this EZ there are many potential science and resource ROIs, e.g. indicatives of past water.

3:00 p.m. Gallegos Z. E. * Newsom H. E.
A Human Exploration Zone in the Protonilus Mensae Region of Mars **[#1053]**
This abstract highlights an area in the Protonilus Mensae region of Mars. Noachian through Amazonian materials are available for sampling in the EZ and there are abundant resources for use in civil engineering.

3:15 p.m. INTEGRATING DISCUSSION

3:35 p.m. *Break*

3:50 p.m. Stoker C. R. * Heldmann J.
Midlatitude Ice-Rich Ground on Mars: An Important Target for Science and In Situ Resource Utilization on Human Missions **[#1018]**
Midlatitude ice-rich ground on Mars is an attractive target to search for evidence of modern life, study Mars climate evolution, and for In Situ Resource Utilization on human missions.

4:05 p.m. Westenberg A. A. M.A. * Zucker R. A. J.D.
That First Step Should Resonate for Millennia to Come **[#1029]**
The first human landing site on Mars should be selected based on its intrinsic historical significance. Picking a site named after a scientist carries meaning beyond the moment of first landing as it honors those on whose shoulders we stand today.

4:20 p.m. Hamilton J. C. * Lundblad S. Clark D. L. Purves N. G. Milovsoroff C. T. Thomas N.
Ausonia Cavus and Kasei Valles: Complementary Exploration Zone Sites for Biology, Geology and ISRU **[#1045]**
Two complementary EZs are proposed that are rich in geologic history and exhibit water evidence for astrobiology. Both sit midway down flow features in erosional valley networks. These are Ausonia Cavus (paleolake) and Kasei Valles (flow channel).

4:35 p.m. INTEGRATING DISCUSSION

4:55 p.m. DAILY WRAP-UP

Friday, October 30, 2015
GROUP DISCUSSION
8:00 a.m. Lecture Hall

8:00 a.m.	GROUP DISCUSSION / SITE EVALUATION
9:45 a.m.	*Break*
10:00 a.m.	GROUP DISCUSSION / PATH FORWARD
11:45 a.m.	CLOSING REMARKS *Ben Bussey, Rick Davis*

CONTENTS

HUYGENS CRATER: INSIGHTS INTO NOACHIAN VOLCANISM, STRATIGRAPHY, AND AQUEOUS PROCESSES. S. E. Ackiss[1], J. J. Wray[2], K. D. Seelos[3], and P. B. Niles[4], [1]Dept. of Earth, Atmospheric, and Planetary Sciences, Purdue University, West Lafayette, IN (sackiss@purdue.edu), [2]School of Earth & Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, [3]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, [4]NASA Johnson Space Center, Houston, TX.

Rationale: Huygens crater (Figure 1) is a well preserved peak ring structure on Mars centered at 13.5°S, 55.5°E in the Noachian highlands between Terras Tyrrhena and Sabaea near the NW rim of Hellas basin. With a diameter of ~470 km, it uplifted and exhumed pre-Noachian crustal materials from depths greater than 25 km, penetrating below the thick, ubiquitous layer of Hellas ejecta. In addition, Huygens served as a basin for subsequent aqueous activity, including erosion/deposition by fluvial valley networks and subsurface alteration that is now exposed by smaller impacts. Younger mafic-bearing plains that partially cover the basin floor and surrounding intercrater areas were likely emplaced by later volcanism.

Regional Geology: *Noachian Crustal Units:* Huygens and the surrounding region has been mapped as early to late Noachian in age with one outcrop of middle Noachian aged material partially covering the crater floor from the western wall eastward to the peak ring [1]. Mineralogy of Huygens has been examined in detail as well [2]. Two types of plains delineated within Huygens consist of olivine-rich and high-calcium pyroxene (HCP)-rich units, both of which exhibit relatively high thermal inertia and lack large amounts of eolian materials (e.g. dunes). As described in [3], the most probable origin of the mafic plains is effusive volcanism, where magma rose to the surface via a dense network of fractures created by the Hellas impact. Subsequent impacts also could have initiated magma formation and assent through decompression melting [4], as craters in the region are also commonly filled with mafic-rich, high thermal inertia material. Exposures of low calcium pyroxene (LCP) occur as well, usually in distinct massif-forming terrain that may be remnants of deep crustal material exhumed by the Hellas impact. LCP-bearing outrcrops are predominantly located outside Huygens but a few occurrances have been identified on the floor.

Aqueous Alteration: Aqueously altered materials are identified both inside (on the floor of) and outside Huygens and include Fe/Mg smectites, Al-bearing phyllosilicates, and Fe/Ca carbonates (see also [5]). These minerals are observed in crater rims/walls, central peaks, and ejecta of smaller subsequent impacts, and therefore inferred to have formed in the subsurface prior to the impacts, not via impact-driven, hydrothermal alteration [6, 7]. Aqueous alteration could have coincided with formation of fluvial valley networks post-Huygens or may have been pre-exisiting (or both); no spatial relationship between alteration mineral outcrops and Huygens-related structures is evident.

Biosignature and Habitability Preservation Potential: The carbonates within the Huygens basin (exposed by the cratering process) are associated with phyllosilicates and occupy layered rocks [5]. These materials record ancient neutral-to-alkaline fluid chemistry of at least regional extent, and may be an important reservoir for paleo-atmospheric CO_2. If formed via subaqueous sedimentation, their preservation potential is high, and in any case their isotope systematics will be valuable tracers of magmatic, atmospheric, and biochemical processes.

Stratigraphic Context and Cross Cutting Relationships: While the Huygens impact itself and all mapped surface units date from early to late Naochian, a finer relative stratigraphy may be discerned using mineralogic information. If the LCP-bearing massifs do indeed represent excavated deep crust from the Hellas impact, this is the oldest exposed material in the region. The Huygens impact panetrated through the Hellas ejecta blanket, potentially sampling pre-Hellas crust and uplifting/redistributing any pre-exisiting alteration minerals. Post-Huygens the surface was modified by fluvial activity, with associated ground water potentially leading to the formation of subsurface alteration minerals. The mafic plains units are the youngest materials, and embay the fluvially dissected terrain. By sampling these types of materials and depositional environments, a mission to Huygens would arguably be exploring the most geologically active time period in martian history.

Acknowledgements: K. S. thanks NASA Mars Data Analysis Program (grant number NNX10AO25G). S. A. thanks an appointment at the JHU Applied Physics Lab (APL) administered by the Oak Ridge Institute for Science and Education through an agreement between the U.S. DOE and APL; J. W. thanks the MRO/CRISM and MRO/HiRISE teams for support.

References: [1] Tanaka et al. (2014), Geologic map of Mars: U.S. Geological Survey Scientific Investigations Map 3292, [2] Ackiss et al. (2014), Eighth Mars Conference, Abstract #: 1038, [3] Rogers and Nazarian (2013), *JGR: Planets*, 118(5), 1094–1113 [4] Edwards et al. (2014), *Icarus*, 228, 149–166, [5] Wray et al. (2011), LPSC 42, Abstract #: 2635. [6] Ehlmann et al. (2011), *Nature*, 479(7371), 53–60, [7] Loizeau et al. (2012), *Icarus*, 219, 476–497 .

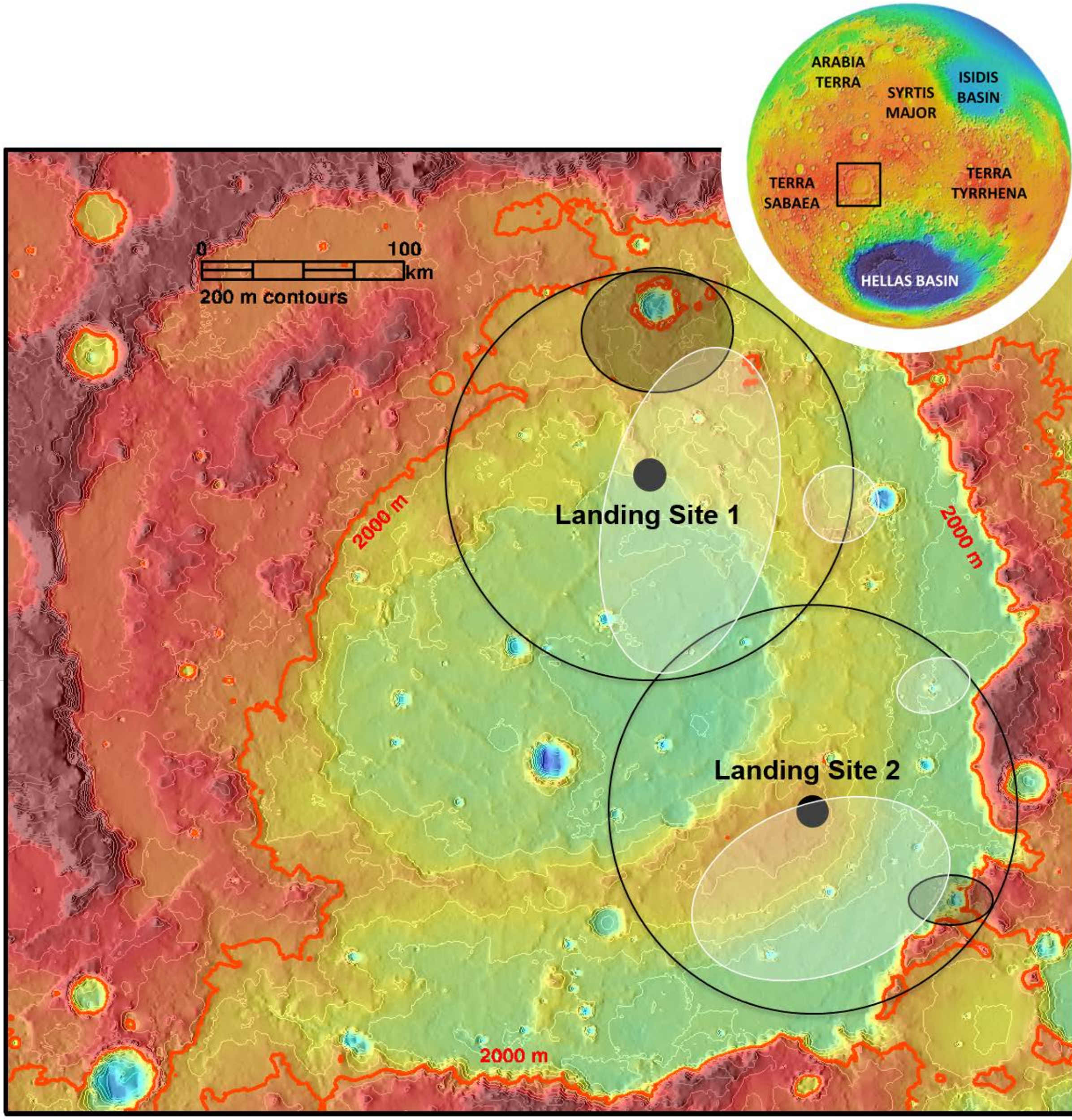


Figure 1. Huygens crater exploration zone over MOLA topography with 2km elevation denoted. Inset shows location on the globe. Black circles indicate resource regions of interest and white cirlces indicate regions covered with expanisve mafic material. Landing site 1 has a larger phyllosilicate/carbonate deposit and mafic plains that can be age dated while Landing site 2 gives access to the crater wall and valley networks that flow into the crater.

SITE SELECTION FOR THE FIRST SUSTAINABLE MARS BASE. D. C. Barker[1], G. James[2], G. Chamitoff[3] and S. Clifford[4], [1]MAXD, Inc. PO Box 58915 Houston TX, 77059, [2]NASA, JSC, [3]Texas A&M University and [4]LPI.

Introduction: We propose a landing site for establishing a sustainable and expandable Martian base, intended for permanent habitability, and based on the identification of an accessible local supply of water. Currently there are few data sets that can be used to accurately identify the presence and distribution of surface and near-subsurface water (e.g., the MARSIS and SHARAD orbital radar sounders on ESA's Mars Express and NASA's Mars Reconnasaince Orbiter and the Gamma Ray Spectrometer (GRS) on NASA's Mars Odyssey spacecraft).

Site selection based on resource utilization requires proven reserves (defined by mining industry standards as an amount of a resource estimated with reasonable certainty and deemed recoverable from well-established or known reservoirs and ultimately producible given known techniques). Given current data, few locations, especially ones containing multiple resources in close proximity, have yet to be identified on Mars.

Because our primary motivation is to establish a permanent human settlement on Mars, our landing site selection is constrained, not only by the collocation of local opportunities for scientific discovery, but more importantly by the availability and accessibility of extractable reservoirs (i.e., producible reserves) of water ice [1, 2]. Under our modified criteria, there are 3 general regions that satisfy our selection process – all of which lie within the northern plains (Fig. 1). Once the presence of adequate resource has been established, then these regions can be further assessed in terms of their scientific priority (e.g., as determined by the MEPAG Goals, Objectives and Investigations document).

We believe that a Landing Site (LS) located in Arcadia Planetia, along the Phlegra Dorsa, at 39°N 172°E, is the best candidate for the given constraints (Fig. 2 and 3). Besides a high water content (Fig.4), the site is located in an area of low dust content (Fig. 5), moderate thermal ineritas (Fig. 6), and low rock abundances (Fig. 7), well below the mean surface datum (to maximize atmospheric braking performance in support of entry, descent, and landing of heavy (>10 mt) vehicles, provide greater shielding against solar and cosmic radiation and serve as a resource reservoir (e,g., CO_2).

Resource ROI: As stated, this site was selected based on the need to access water. The GRS map inidicates a water content of >4 wt% throughout the exploration zone (EZ), while a MARSIS-derived surface permittivity of ~4 is consistent with either a porosity of ~35% or a volumetric ice content of ~60% for the top ~60-80 m of the near-subsurface [8]. The site is further situated in a area of moderate albedo and thermal inertia indicating fine grained materials, which are useful for ISRU processing and construction. Sheet silicates (Fig. 8) may be useful for engineering and manufacturing purposes.

Science ROI: While identifying a landing site with an accessible source of water is our primary selection criteria, our proposed site has an EZ that encompasses many points of high scientific interest. The geology (Fig. 9) in the EZ is confined within the Early Hesperian transition (eHt) unit [9]; yet, HiRise and CTX indicates many local and complex morphologies, including several ~10-15 km diameter fuidized ejecta craters (to the north and south of the LS) and numerous exposures of hydrated minerals (Fig. 10). Lastly, the large (~75 km diam.) crater Tyndall, lies tanailizingly just outside our 100 km EZ.

Discussion: In order to assure a sustainable presence on Mars, Mars exploration must be driven by programmatic goals that are themselves sustainable, and at a cost that is sufficient to ensure progress and maintain long-term public and political support [11]. Identifying landing sites based solely on science objectives, before reliable and sustainable resource acquisition will limit future missions and jeopardize exploration and permanent habitation of the planet.

Additional high-resolution measurements (by gamma-ray and neutron spectroscopy, ground penetrating radar, and mineralogically-sensitive mapping spectrometers) are needed to accurately identify the presence of surface and near-subsurface volatile and mineralogical resources. Ultimately, given the need to secure quantities of easily extractable water, landing sites at even higher latitudes within the northern plains (e.g., 49°N, 126°E; 49.5°N, 160°E; and 47°N, 13°W), will need to be considered.

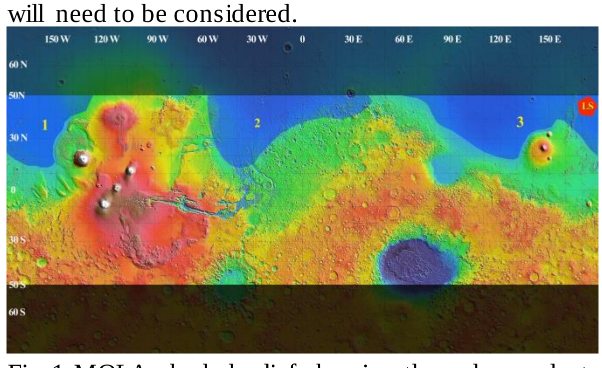


Fig 1 MOLA shaded relief showing three downselect-

ed priority regions and proposed landing site as indicated by the red LS marker in region 3.

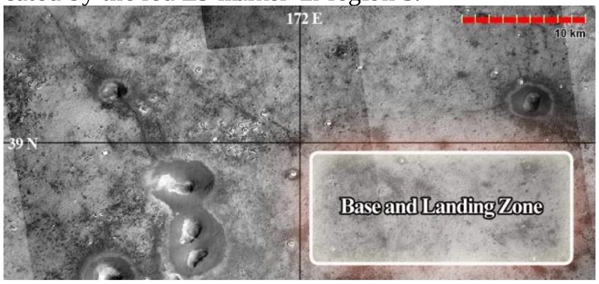


Fig. 2 CTX image showing base and landing zone.

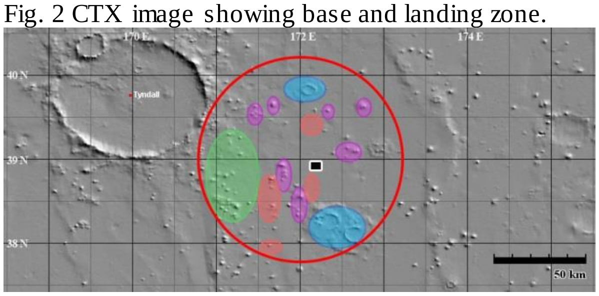


Fig. 3 MOLA shaded relief showing 100 km EZ; landing site in black; Science/Resource ROIs: blue-fluidized impact ejecta, green-hydradted minerals, purple-domes and red-sheet silicates.

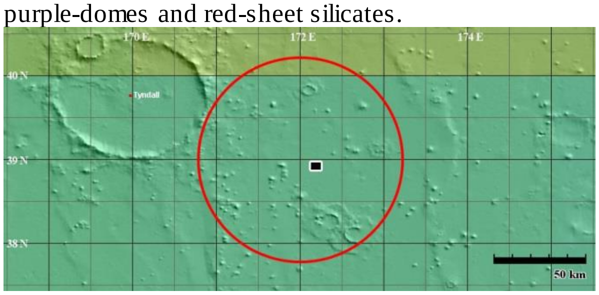


Fig. 4 GRS water content (> 4 wt% in green) map [3].

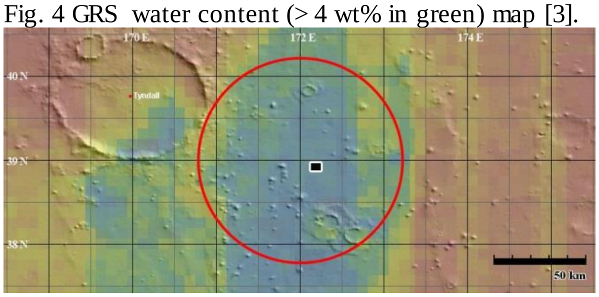


Fig. 5 OMEGA dust map [4].

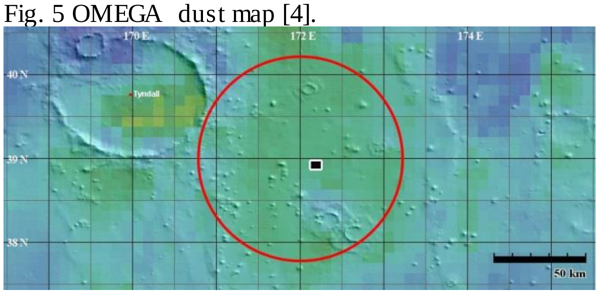


Fig. 6 TES thermal inertia map [5].

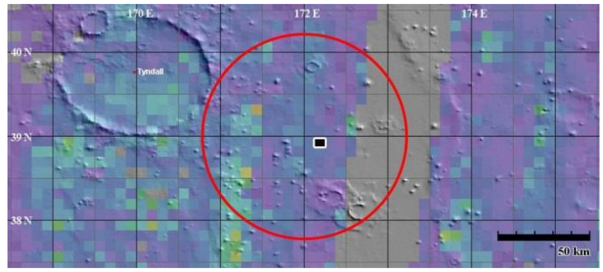


Fig. 7 TES global rock abundance map [6].

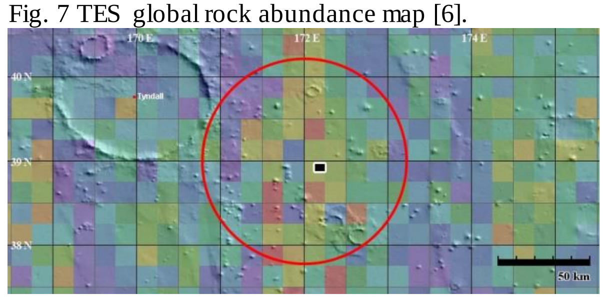


Fig 8 TES sheet silicates and glass map [7].

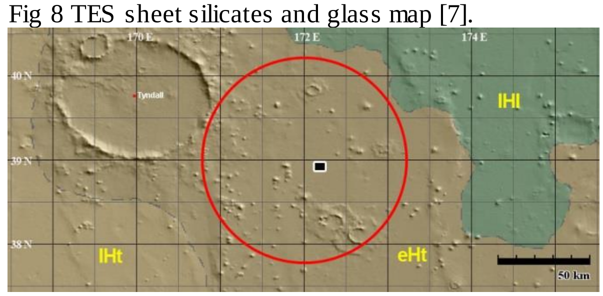


Fig 9 EZ geology within plains-forming deposits [9].

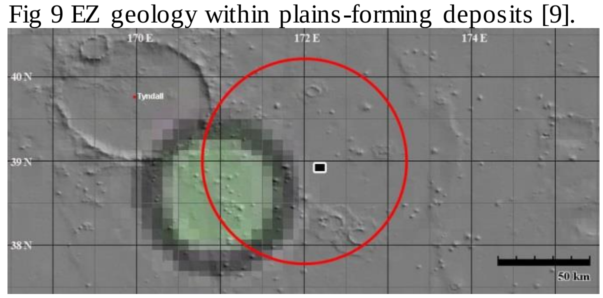


Fig 10 OMEGA/CRISM hydrated mineral map [10].

Additional Information: All landing region maps were created using J-Mars [12] and color map registrations are from low relative values (blue) to high values (red).

References: [1] Chamitoff, G., et. al. (1998) NASA/TM-98-206538. [2] Chamitoff, G., et. al. (2005) Acta Astronautica, 56. [3] Boynton, W. V., et. al. (2007) J. Geophys. Res., 112, E12S99. [4] Ody, A., et. al., (2012) J. Geophys. Res. Planets, 118. [5] Christensen, P. R., and H. J. Moore (1992), The martian surface layer, in Mars, pp. 686-729, University of Arizona Press, Tucson, AZ. [6] Nowicki, S. A., and P. R. Christensen (2007) J. Geophys. Res., 112, E05007. [7] Bandfield, J. L., (2002) J. Geophys. Res., 107. [8] Mouginot et al., (2012) Geo. Res. Let., 39, L02202. [9] Tanaka et. al., (2014) USGS Mars Map 3292. [10] Carter, J., et. al.,. (2013) J. Geophys. Res. Planets, 118. [11] Barker, D. C., (2015) Acta Astronautica, 107. [12] Christensen, P. R. et.al. (2009) JMARS–A Planetary GIS, AGU, IN22A-06.

SOUTHERN NECTARIS FOSSAE: A MICROCOSM OF MARTIAN GEOLOGY. B. D. Boatwright, Department of Earth and Planetary Sciences, Harvard University, 20 Oxford St., Cambridge, MA 02138 (bboatwright@g.harvard.edu).

Introduction: The proposed Exploration Zone (Figure 1) encompasses an area within 100 km radius of a landing site located at approximately 28.88˚S 300.29˚E, at the southwestern terminus of Nectaris Fossae near Protva Valles [1].

The EZ lies in a geologically complex transition zone between the Late Noachian volcanic units of Thaumasia Planum to the northwest and the Middle to Late Noachian cratered highland units of Noachis Terra to the south and east [2]. The topography of the region is indicative of extensive reworking by tectonism and subsequent incision of valley networks [3]. The EZ also lies in an area that is yet to be explored by landers or rovers [4].

The Southern Nectaris Fossae EZ is ideal in its close proximity to a number of distinct geologic features and sites for potential resource utilization; in addition to Protva Valles and Nectaris Fossae, the science ROIs include a volcanic edifice and an unusual double crater. The extensive fluvial deposits associated with Protva Valles could provide a source of water in the form of hydrated clay minerals. As they are marked in Figure 1, the ROIs are rough outlines; in reality, one would be likely to find a mix of fluvial, volcanic, and impact features throughout the EZ [2].

Landing site: The 25 km^2 landing site is situated at the northern end of a gently rolling floodplain with sparse meter-scale dunes [5] at ~1.8 km altitude [6]. This floodplain would provide ample space for a habitation site, resource utilization and infrastructure development over hundreds of km^2. Much of the EZ lies at elevations greater than 2 km, but grades are generally shallow enough to allow ready access to ROIs from the lower-elevation landing site.

Science ROIs:

ROI 1: Valley networks. Some of the most fascinating geologic features on the Martian surface are those that are thought to have been formed by fluvial processes, particularly within the southern highland regions of the planet [7]. There is general agreement [8-10] on the timing of valley network formation during the Late Noachian into the Early Hesperian, but the mechanism by which they formed is less clear. Some studies based primarily on geomorphology [11-12] indicate evidence of a "wet and warm" early Mars, but related climate modeling exercises [13-14] are generally unable to produce surface temperatures above freezing.

Protva Valles, which have been independently dated to Late Noachian/Early Hesperian age [3], are considerably degraded but would still provide an opportunity to observe the hydrologic and stratigraphic characteristics of Martian valley networks in unprecedented detail; this in turn could revolutionize our understanding of the early Martian climate. Proposals for ROIs throughout Noachis Terra should be seriously considered in order to take advantage of the rich and ancient geologic history of the area.

ROI 2: Double crater. Recent interest in crater interiors has been piqued by the exciting discoveries of the MSL *Curiosity* rover, which has been traversing the basal layers of Aeolis Mons inside Gale crater. Apart from abundant evidence of lacustrine and deltaic sedimentation, the rover has also made significant advances in understanding the character of enhanced levels of atmospheric methane and chlorinated hydrocarbons in soils at the site [15].

While Gale crater is certainly unusual, perhaps unique, in its history as a sedimentary basin, the crater in the ROI may have its own secrets to reveal. Like Gale, its morphology is complex and asymmetrical, although there are no obvious sedimentary landforms at the surface. Instead, the crater appears to have undergone significant reworking by eolian processes and perhaps even ice flows [5], which are known to exist at higher elevations outside polar latitudes [16]. Unlike outcrops that have been exposed to water in the past, ices have the potential to preserve present-day geochemical and biochemical signatures, which should make this and other nearby craters a prime target for exploration within the EZ. The main crater also overprints a second crater of similar size to the east; such an area could exhibit unusual impact structures worthy of additional investigation.

ROI 3: Volcanic edifice. Perhaps the most difficult areas of Mars to access are those with significant outcrops of basaltic igneous suites. The Tharsis volcanic province is inaccessible to human exploration given the present constraints on altitude and would nevertheless be treacherous due to steep, rocky terrain. This ROI features a more manageable volcanic edifice with a maximum elevation of slightly less than 4.3 km (2.5 km higher than the landing site) [6].

The volcanoes of the Thaumasia region may actually be more useful than Tharsis in revealing the earlier, more dynamic history of Martian volcanism and magmatic evolution [3]. The edifice is likely Noachian in age and represents some of the best-preserved examples of early highland volcanism, including pyroclastic deposits from volatile-rich magmas [3]. Sampling of such primitive crustal material would be invaluable to geochemical studies of Mars, which thus far are based almost completely on a handful of meteorites [17]. With a pristine igneous sample, the entire geologic history of Mars could be rewritten in a stroke with precise radiometric dating and trace element data.

ROI 4: Fossae. The early tectonic history of Mars is also preserved in the fault structures of Nectaris Fossae. The formation of Nectaris Fossae began sometime in the Noachian and may have continued until the Late Hesperian, with evidence of a genetic relationship to Valles Marineris [3]. Faults and rift structures are numerous throughout the Thaumasia region [3], but the structural geology of Mars has remained largely uncharacterized on the local scale due to a general lack of such features at past landing sites [4]. Nectaris Fossae could be used to vastly improve our knowledge of small-scale deformational structures on Mars.

As with Protva Valles, the exploration of Nectaris Fossae would inevitably reveal stratigraphic sections and cross-cutting relationships of Noachian crustal units. The sharper relief of these features suggests that they may also be better preserved, although evidence of subsequent fluvial reworking may also be present [3].

Resource ROI: The primary resource available within the EZ is in the form of hydrated clay minerals, which are likely to be found anywhere within the floodplain of Protva Valles south and west of the landing site; smectites in particular are known to occur elsewhere in the region [18]. In addition, mafic rocks associated with the Thaumasia volcanic sequences could be mined for iron, magnesium, and aluminum if desired.

References: [1] JMARS/ASU (2008) Mars Global Data Sets, THEMIS Day IR w/MOLA Color (jmars.mars.asu.edu); [2] Tanaka K. L. et al. (2014) USGS Sci. Invest. Map 3292; [3] Dohm J. M., Tanaka K. L. (1999) *Plan. & Space Sci.* 47, 411-431; [4] Nat'l Space Sci. Data Ctr. (2014) NSSDC Master Catalog, Spacecraft (nssdc.gsfc.nasa.gov); [5] NASA/JPL/MSSS (2011) Google Earth CTX Mosaic; [6] Wash. U. St. Louis (2011) Mars Orbital Data Explorer, MOLA PEDR Query (ode.rsl.wustl.edu); [7] Coleman N. M. (2003) *JGR* 108, E5, 5093; [8] Fassett C. I., Head J. W. III (2008) *Icarus* 195, 61-89; [9] Howard A. D. et al. (2005) *JGR* 110, E12S14; [10] Irwin R. P. III et al. (2005) *JGR* 110, E12S15; [11] Craddock R. A., Howard A. D. (2002) *JGR* 107, E11, 5111; [12] Craddock R. A. et al. (2013) *LPSC 44*, Abstract #1984; [13] Scanlon K. E. et al. (2013) *GRL* 40, 4182-4187; [14] Wordsworth R. et al. (2013) *Icarus* 222, 1-19; [15] Vasavada A. R. (2015) *LPSC 46*, Abstract #2715; [16] Fastook J. L., Head J. W. III (2014) *Plan. & Space Sci.* 91, 70-76; [17] Nyquist L. E. et al. (2001) *Space Sci. Revs.* 96, 105-164; [18] Buczkowski D. L. et al. (2013) *LPSC 44*, Abstract #2331.

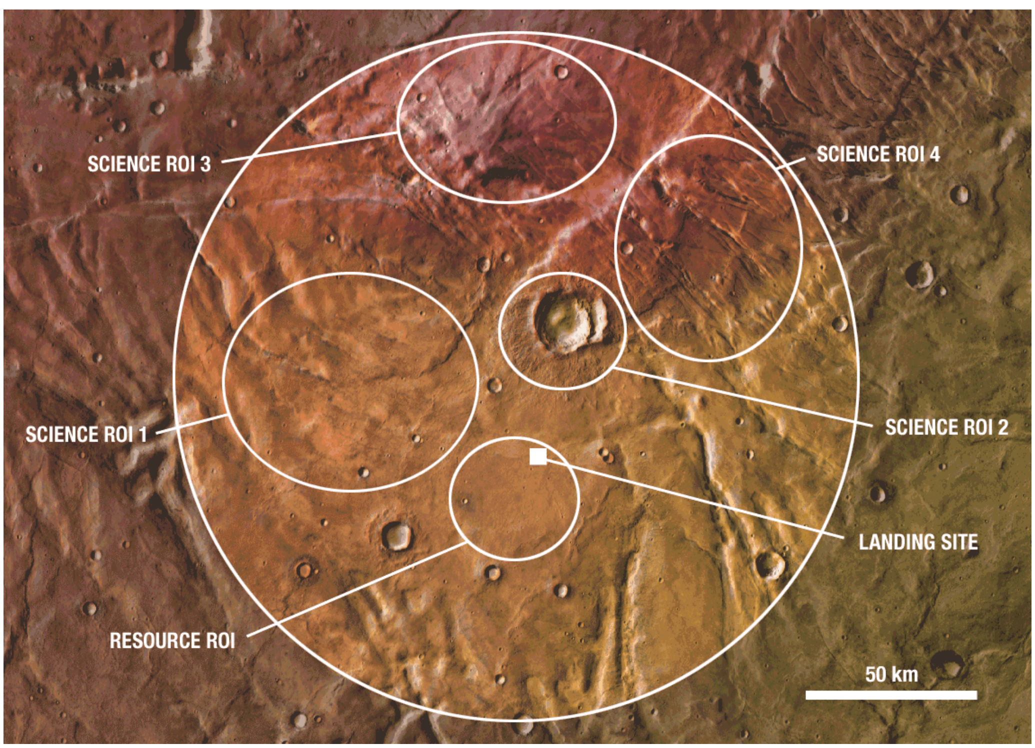


Figure 1. Context image of the Southern Nectaris Fossae EZ [1].

ASSESSING GALE CRATER AS A LANDING SITE FOR THE FIRST HUMAN MISSION TO MARS. A. F. J. Calef III[1] D. Archer[2], B. Clark[3], M. Day[4], W. Goetz[5], J. Lasue[6], J. Martin-Torres[7], and M. Zorzano Mier, [1]Jet Propulsion Laboratory-Caltech, fcalef@jpl.nasa.gov, [2]Jacobs Technology, Inc., doug.archer@nasa.gov, [3]Space Science Institute, bclark@spacescience.org, [4]University of Texas-Austin, mdday@utexas.edu, [5]Max Planck Institute for Solar System Research, Goetz@mps.mpg.de, [6]L'Irap Soutient Sciences En Marche, jlasue@irap.omp.eu, [7]Instituto Anda-luz de Ciencias de la Tierra (CSIC-UGR), javiermt@iact.ugr-csic.es, [8]Centro de Astrobiología (INTA-CSIC), zorza-nomm@cab.inta-csic.es.

Introduction: Mars is the "horizon goal" for human space flight [1]. Towards that endeavor, one must consider several factors in regards to choosing a landing site suitable for a human-rated mission including: entry, descent, and landing (EDL) characteristics, scientific diversity, and possible insitu resources [2]. Selecting any one place is a careful balance of reducing risks and increasing scientific return for the mission.

"Go where you know": Proposed future landing sites such as Eberswalde delta or Mawrth Vallis received extensive analysis during the MSL landing site selection workshop and are well characterized. More candidates sites are being evaluated for the Mars2020 rover, e.g. Jezero Crater, and contain almost equal orbital data coverage [3]. For legacy and current Mars missions, three are landers, and one lander/rover, all with limited areal extent: Viking 1 Viking 2, Phoenix, and Pathfinder/Sojourner. The remaining rover missions, MER Spirit, MER Opportunity, and MSL Curiosity offer the most ground truth over several to tens of kilometers both in and outside their nominal landing ellipses. While the HiRISE instrument provides unprecedented detail of Mars' surface for current and future missions, the insitu observations of rock density, soil mechanics, temperature fluctuations, dust opacity, radiation (via Curiosity), traversability, not to mention insitu science, are not readily measureable or resolvable by orbital assets. While we can make well-educated and higher-order assessments of landing sites, revisiting anywhere we've gone before can only reduce risk by removing uncertainty or shrinking errors bars in science and engineering landing site analysis. Insitu data decreases risk compared to other potential landing sites that have never been visited because of this ability to remove the unknown at the surface. However, a human-rated mission will likely require reducing risk by an order of magnitude, thereby requiring an order of magnitude better data than we currently have; only insitu data provides this level of certainty. From a financial perspective, insitu data is 'priceless' for a human-rated mission, not replicable for many sites.

Why Gale crater: The following is a breakdown of reasons Gale crater makes an excellent landing site for the first human mission to Mars.

EDL: Gale crater is one of the lowest elevation landing sites at ~4.5 km MOLA elevation. This increased atmospheric density will decrease requirements for landing from increased velocity reduction with parachutes or other methods like low-density supersonic deceleration. Dynamic entry data and a well-understood atmospheric profile, including additional seasonal data (temperature, pressure, wind speed) from the Rover Environmental Monitoring Station [REMS] package onboard Curiosity for at least a Martian year, adds to reducing uncertainty during any landing. This landing site easily meets the latitude, slope, and dust constraints.

Exploration Zone: Our proposed landing site is located at the center of the final MSL landing ellipse at 137.4019° longitude and -4.5965° latitude (Figure 1). Besides the nominal 100 km radius Exploration Zone (EZ, in red), we've also identified a smaller 25 km radius EZ (pink) to emphasize the scientific and ISRU ROIs closer to the landing site. Several 'camps' were also identified within small ~100 m diameter craters with a 2-5 m high crater walls that could serve as infrastructure points within a few kilometers of the landing site (purple, Figure 1 inset).

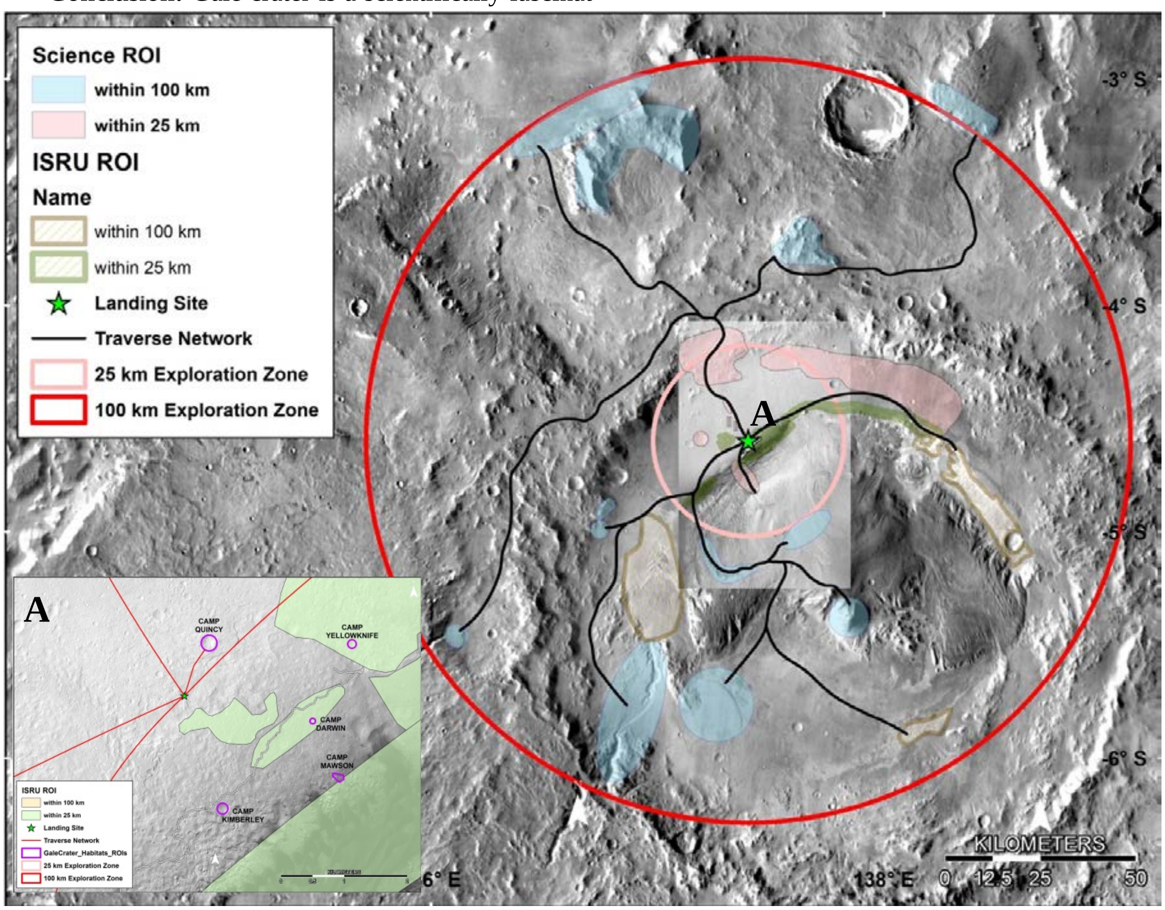
S***cientific Diversity:*** At Gale crater, the Peace Vallis delta deposits [4], confirmed habitable environments [5], evidence of a lake [5], insitu methane observations [6], and existence of indigenous Martian carbon both ancient and active [7], not to mention the yet fully explored 5 km sedimentary stack of Mt. Sharp (Aeolis Mons) are a scientific cornucopia for an human mission to expand upon and explore, meeting many of the nominal science requirements for a human mission. Gale crater offers access to both northern plains and southern highland material within a relatively short distance (Figure 1, inset A).

Water Resources: There is little chance of near-surface water-ice for resource utilization in Gale, but water bound in minerals and adsorbed to loose grains could serve as a water source [8]. Some 'easy' water is found extracting adsorbed atmospheric water in ripple and dune sediments [9]. [10] estimates 3-6 weight% water in amorphous sediments at Rocknest. Calculations from [11] using 2 weight% estimated a cubic meter of Rocknest soil would contain ~32 L of water. A back-of-the-envelope estimate for total sand volume in dunes, sand sheets, and transverse aeolian ridges (TARs) is 6.51 km^3. Assuming a 30% porosity gives a material volume of 4.56 km^3. Conservatively assuming an average density of 2500 kg/m^3, yields a total sand mass of ~10^{13} kg. Using 3 wt% water result from Rocknest [10], yields a total of ~10^{11} kg of water, or 10^8 metric tons. Such water sources may be renewable as REMS measurement indicate new adsorbtion of atmospheric water as humidity increases during the night[8]. Rocks at Yellowknife bay [12] and the Kimberley drill sites [Planetary Data System release] yielded ~2 wt% water, so additional water may be recoverable from mining efforts. Sand water ISRU ROIs have been delineated based (Figure 1).

Feedstock Resources: Using geochemical results from the CHEMCAM instrument on MSL, we've identified an ROIs for Al, Fe, and Si (Figure 1). Rocks that occur in and around Yellowknife bay and in rocks associated with 'highly cratered surfaces' around the lower reach of the Gale mound have on average higher wt% Fe at 15-24%. Higher wt% Al (>10%) and Si (>50%) occur in the Bradbury Rise area. An additional ISRU resource for growing plants is nitrogen in the form of nitrates discovered at Rocknest (~45 ppm) and rock samples (20-250 ppm) [13] making Gale crater soils potentially suitable for growing plants insitu. Together, these ISRU ROIs are starting points for assessing mining and processing of these resources.

Conclusion: Gale crater is a scientifically fascinating site on Mars with abundant orbital and ground data for assessing a human mission. The MSL science team has already shown Gale crater to harbor ancient habitable environments and abundant liquid water in the past. ISRU resources for H_2O, Fe, Al, and Si have been identified and quantified. A human mission to this location comes with the assurance to what we'd find on arrival and the strong potential for future discoveries.

References: [1] Pathways to Exploration, ISBN: 978-0-309-30507-5, 2014. [2] Human Exploration of Mars DRA v5.0, NASA-SP-2009-566, 2009. [3] Golombek et al., *Space Sci Rev*, 2012. [4] Palucis et al., *JGR*, 2013. [5] Grotzinger et al., *Science*, 2013. [6] Webster et al., *Science*, 2014. [7] NASA/JPL press release, http://mars.nasa.gov/msl/news/whatsnew/index.cfm?FuseAction=ShowNews&NewsID=1767, 2014. [8] Martin-Torres et al., Nature, 2015, doi:10.1038/ngeo2412. [9] Meslin et al., *Science*, 2013. [10] Leshin et al., *Science*, 2013. [11] Archer et al., *JGR*, 2014, doi:10.1002/2013je004493. [12] Ming et al., *Science*, 2014, doi:10.1126/science.1245267. [13] Stern et al, 2015, doi:10.1073/pnas.1420932112.



Study of MARS for Explorations of Landing Sites using Microwave Remote Sensing

Prof OPN Calla
opnc06@gmail.com

Director, International Centre for Radio Science Jodhpur

The location where we plan to send Human Mission the knowledge of Atmospheric conditions, the local wind conditions and physical temperature along with Soil Condition has to obtained and its effect on the mission has to be studied. For this the first the knowledge about the behaviour of Soil has to be obtained in the Laboratory. This can be done using Terrestrial Analog of Martian Soil. In Laboratory the conditions as far as possible could be created and the behaviour of Soil (TAMS) could be studied by creating a reduced Scale model in Laboratory. The dust devil, the streaks both dark and bright could be created in laboratory and its effect on the Soil could be studied.

Also before human mission one can send Microwave Sensors to Orbit Mars to provide the information regarding Soil Moisture conditions, the wind speed and direction and also regarding dust devils. The Microwave Sensors will provide information about the surface features of Martian Surface in presence of dust storms. The atmosphere constituents like Co_2 also could be monitored. The lenders and rovers that will land on Martian Soil also could be equipped with Microwave Sensors so that detailed in depth information about Soil and surrounding including measurement of Co_2 and frost created b y Co_2 could be mentioned.

This presentation will high highlight the role of Microwave Sensors in exploration of MARS and the type of Sensors that could be used for providing information about MARS and give some details of the Laboratory experiments using Terrestrial Analog of Martian Soil.

First Landing: Southern edge of Meridiani Planum

J.D.A Clarke[1], D. Willson[2], H.D. Smith[2]
(1) Mars Society Australia (jon.clarke@bigpond.com), (2) NASA Ames Research Center, Moffett Field CA 94035

Exploration Zone/Landing site Location: Longitude 4°31'2.33"W, Latitude 3°10'26.25"S

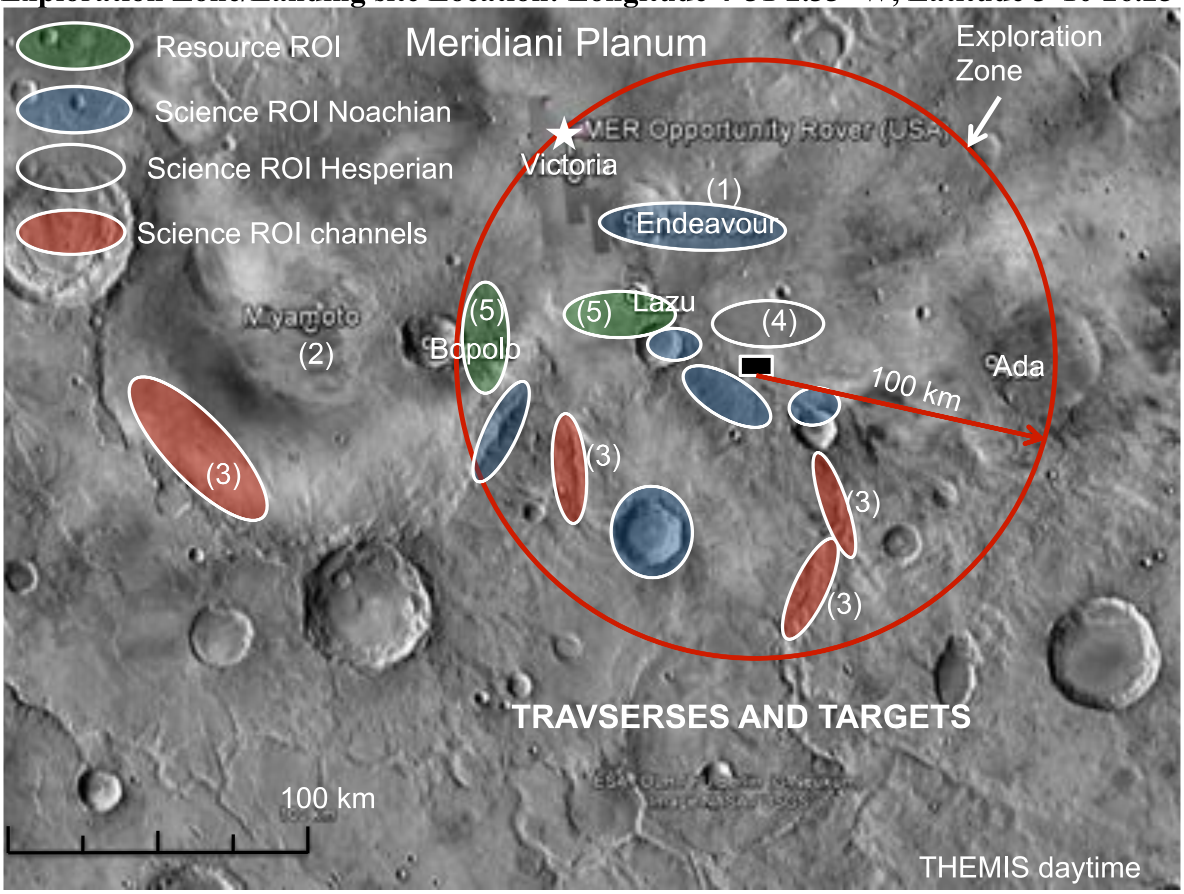


Fig 1: The Southern edge of Meridiani Planum region. Refer to text for numbered location descriptions.

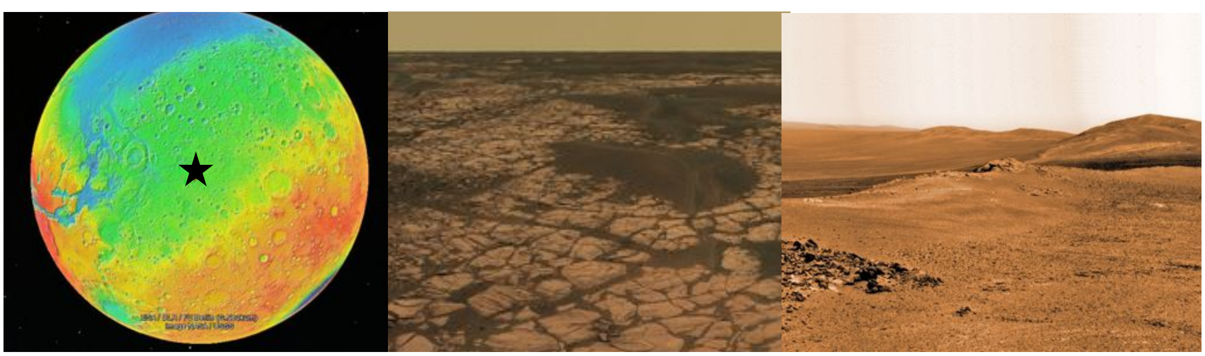


Fig 2: (Left) The Southern edge of Meridiani Planum region. (Middle) A natural hardened landing pad. (Right) Endeavour Crater, a Noachian bedrock example providing water and magma history hydrothermal processes and potential past habitats.

Introduction

The Endeavour Crater Region is well characterized by the Opportunity rover with good attributes for a first landing site, access to water and mineral resources for long term human habitation, and has Noachian, Hesperian and Amazonian units for science investigation providing water & magma history, and potential past habitable locations.

Landing site features

The landing site is located at a low elevation (-1.5 km below datum) on the equator providing high atmosphere density enabling good vehicle drag during descent, thus maximizing the vehicle landed payload mass. The equatorial location enables lowest DeltaV for Earth returning rockets. It has large craters to assist pilot navigation during landing and the landing site has large naturally hard flat surfaces for landing pads with minimal dust and only thin patch sand cover that can resist rocket blast and provide a stable foundation for large crewed landers. The equatorial location also allows maximum solar irradiance for photo-electric power generation.

Resource potential for Long term human habitation

The exploration zone provides: a) Optimum insolation for solar power generation; b) Access to hydrated evaporitic sulfates for water & Mg extraction (zones 3); c) Possible past or present subsurface ice in pedestal crater ejecta (zone 5); d) Surficial hematite-rich eolian deposits (blueberries) for Fe extraction (zone 1); and d) Potential resource extraction of Cu, Zn, Pb, As, and Se from sulfide mineralized bedrock (zone 1).

Science Regions of Interest

The science ROIs include: a) Middle Noachian bedrock, clay altered (zone 1), providing hydrothermal, water and magma history, and potential past habitats; b) Late Noachian dendritic channels (zone 2) and Hesperian inverted channels (zone 3) on a long range mission; c) Early Hesperian depositional environments (zone 4); and, d) Amazonian pedestal craters providing past and present ice and habitability potential (zone 5).

Potential objections

Some might consider Meridiani Planum to be flat and comparatively boring, much like Australia, based on the traverse of the *Opportunity* rover. We would counter this perception in three ways. First, the landing site is centered on the margin of the plain, where it abuts against higher relief Noachian uplands to the south. The "flat and boring" description is less applicable to these areas. Second, the landscape is eminently trafficable, especially by crewed rovers which could cover the distance that *Opportunity* needed a decade to cross in a few hours. Thirdly, while widely scattered, there are a sufficient number of accessible regions of interests to justify a crewed mission.

Access to historic hardware

An additional bonus to the region is that it will allow visits to historic hardware on the martian surface, the *Opportunity* rover and descent hardware, the *Schiaparelli* lander may also be in reach. Visiting these assets will enable assessment of the effects of long duration (decades in the case of *Opportunity*) martian exposure on spacecraft materials and systems.

The Eastern Outlet of Valles Marineris: A Window into the Ancient Geologic and Hydrologic Evolution of Mars

Stephen M. Clifford[1], Jeffrey A. George[2], David A. Kring[1], and Allan H. Treiman[1],
[1]Lunar and Planetary Institute/USRA, 3600 Bay Area Bvld., Houston, TX 77058
[2]NASA Johnson Space Center, Houston, TX 77058

Over its 3,500 km length, Valles Marineris exhibits enormous range of geologic and environmental diversity. At its western end, the canyon is dominated by the tectonic complex of Noctis Labyrinthus while, in the east, it grades into an extensive region of chaos - where scoured channels and streamlined islands provide evidence of catastrophic floods that spilled into the northern plains [1-4]. In the central portion of the system, debris from the massive interior layered deposits of Candor, Ophir and Hebes Chasmas, and identified as possible lucustrine sediments that may have been laid down in long-standing ice-covered lakes [3-6], spills into the central trough. The potential survival and growth of Martian organisms in such an environment, or in the aquifers whose disruption gave birth to the chaotic terrain at the east end of the canyon, raises the possibility that fossil indicators of life may be present in the local sediment and rock. In other areas, 6 km-deep exposures of Hesperian and Noachian-age canyon wall stratigraphy have collapsed in massive landslides that extend many tens of kilometers across the canyon floor. Ejecta from interior craters, aeolian sediments, and possible volcanics (which appear to have emanated from structurally controlled vents along the base of the scarps), further contribute to the canyon's geologic complexity [2,3].

The proposed landing site is located at the eastern end of Vallis Marineris (-4.1^o, -35.2^o), to the northeast of Aurorae Chaos, where a single 50-75 km-wide channel represents the sole exist of the canyon system to the northern plains. The landing site has an elevation of -3.9 km, has local slopes of <8^o, does not contain thick deposits of fine-grained dust, and provides a suitable landing and habitation site.

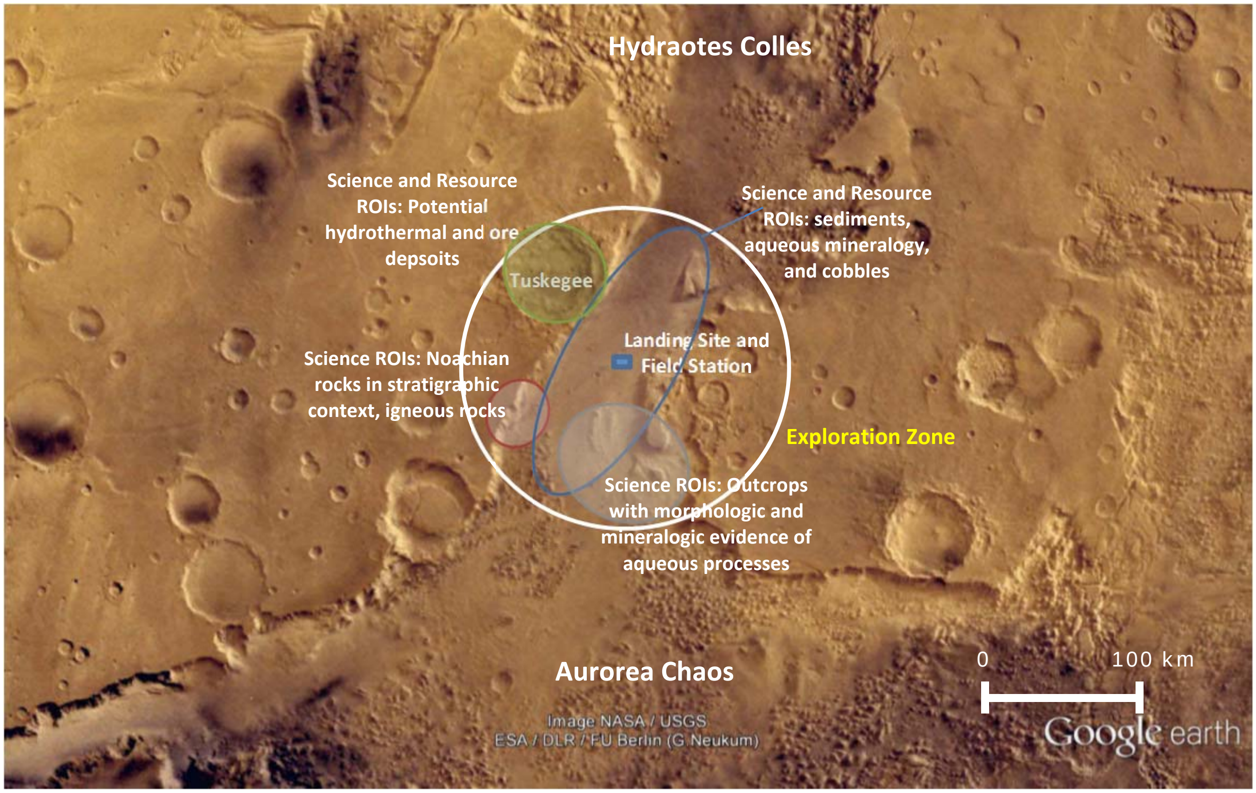
Within the Exploration Zone (EZ), which extends 100 km around the landing site (latitudes: -3.0^o to -6.2^o, longitudes: -36.7^o to -33.6^o), there are multiple locations where each of the 6 Threshold (and several 'Qualifying') Scientific Regions of Interest (ROIs) (addressing astrobiology, atmospheric science, and geoscience) can be accessed -- as well as all of the Threshold and several of the Qualifying Resource ROIs identified in the Exploration Zone Rubric (including hydrated minerals [which can serve as a source of water], abundant cobble-sized and smaller rocks [which can serve as construction materials and be found throughout the EZ], and potential sites for the acquisition of metal or silicon feedstock [associated with likely sites of past igneous and hydrothermal activity]) [4,7,8].

The proposed EZ lies near the point of maximum constriction in the sole channel that drains Valles Marineris to the northern plains. It lies on smooth canyon floor material that is likely a mixture of rocks and sediment transported from both local and distant sources [4]. The canyon and surrounding plateau display considerable evidence of the planet's fluvial history, including (1) several regions of chaotic terrain, streamlined islands, and likely paleo lakes, on the canyon floor, that are believed to have been eroded or fed by Hesperian-age catastrophic floods [4, 9] and (2) valley networks, dating from the Late Noachian to Early Hesperian, that are found on the nearby plateau – which caps ~3-km exposures of older Noachian stratigraphy [3,7]. These landforms provide important clues to understanding the distribution and cycling of water in the ancient Martian crust.

Summary. The proposed EZ, at the eastern end of Valles Marineris, offers a unique potential for conducting geologic, hydrologic, and astrobiologic investigations of the planet's past. For this reason, it is an ideal target for future robotic and human investigations. Its location provides direct access to a stratigraphic record whose exposure and accessibility is unequalled by any other location on the planet.

Given the geometry, and hydraulic history of the canyon, eastward flowing floodwaters may have deposited rocks and sediments that represent a wide range of physical environments, origins, and ages, within the stratigraphic column – with a high potential for preserving evidence of past life. In addition, the local canyon walls provide access to ~3 km of Noachian stratigraphy, which is thought to preserve a record of the planet's most active period of volcanism, hydrologic activity, and possible evidence of an episodically warm early climate. For this reason, Valles Marineris represents an optimal location for conducting both an initial human reconnaissance and establishing a sustainable, long-term base of operations where long-distance traverses, geologic and hydrologic fieldwork, shallow and deep drilling, geophysical investigations, and astrobiological exploration, can be conducted for decades to come.

References: [1] Lucchitta et al**.,** Mars, University of Arizona Press, 453-492, 1992; [2] Witbeck et **al.,** Geologic map of Valtes Marineris Region, Mars, USGS Map 1-2010, 1991; [3] Carr, M.H., Head, J.W., Earth Planet. Sci. Lett. 294, 185–203. 2010; [4] Rodriguez, J. A. P., et al. Geophysical Research Letters 33.18, 2006; [5] Lucchita, B., NASA TM-85127, 233-234, 1982; [6] Nedell et al., Icarus 70, 409-441, 1987; [7] Weitz et al. , Icarus 205.1, 73-102, 2010; [8] Chojnacki, B. Hynek, JGR: Planets, 113.E12, 2008; [9] Komatsu et al, Icarus 201.2, 474-491, 2009.



THE LAND OF OPPORTUNITY: HUMAN RETURN TO MERIDIANI PLANUM. B. A. Cohen[1] and M. A. Seibert[2], [1]NASA Marshall Space Flight Center, ZP13, Huntsville AL 35812 barbara.a.cohen@nasa.gov, [2]Jet Propulsion Laboratory, 4800 Oak Grove Drive, M/S 264-528, Pasadena, CA 91109; seibert@jpl.nasa.gov.

Introduction: Meridiani Planum is a broad expanse of Martian real estate possessing extremely safe landing characteristics and extensive areas with high trafficability, with compelling science motivations to decipher the climatic and hydrologic evolution of Mars and potential for resource extraction. We propose southwestern Meridiani Planum as a potential landing site for human exploration of Mars. Figure 1 shows our proposed exploration zone (EZ) and several potential science regions of interest (ROIs), described below.

Science Interest: The Martian hydrological cycle is spectacularly displayed at Meridiani Planum, where a combination of orbital and in situ observations have revealed abundant evidence for interaction of water and rock. High-resolution images from the MGS Mars Orbiter Camera (MOC) reveal finely layered rocks of apparent sedimentary origin concentrated in this region of Mars [1]. The Mars Exploration Rover Opportunity provided the first in situ evidence for persistent liquid water on the surface of early Mars, demonstrating that Meridiani bedrock is composed of sulfate salts mixed with weathered basalt exhibiting both aeolian and fluvial sedimentary structures [2] with later groundwater interaction that formed hematite concretions [3].

Meridiani Planum itself is part of a geologic unit referred to as the etched terrain [4]. In addition to the deposits in Meridiani, widespread layered deposits of apparent sedimentary origin are seen throughout Arabia Terra. High-resolution MOC images reveal these deposits to consist of finely layered sedimentary rocks [5]. These plains deposits embaying older, phyllosilicate- bearing terrain cut by fluvial features. ROIs have previously been identified throughout Meridiani Planum that satisfy some or all of the science and exploration objectives [6]. Here, we chose southwestern Meridiani, where a juxtaposition of phyllosilicates and sulfates occurs at a regional boundary. The ROIs include areas meeting all the science objectives identified for human exploration sites:

(a) *Access to deposits with a high preservation potential for evidence of past habitability and fossil biosignatures and/or sites that are promising for present habitability* are provided by the phyllosilicates and sulfates detected at Endeavour Crater (ROI2) and in the channeled terrain (ROIs 2 and 3).

(b) *Noachian and/or Hesperian rocks in a stratigraphic context that have a high likelihood of containing trapped atmospheric gases*, fulfilled by ROIs 2 and 3, where CRISM phyllosilicate spectral signatures correlate with polygonally-fractured bedrock in HiRISE, meaning that the phyllosilicates are in place and have appropriate stratigraphic context.

(c) *Exposures of at least two crustal units that have regional or global extents, that are suitable for radiometric dating, and that have relative ages that sample a significant range of Martian geological time*. The EZ includes an intact Noachian / Hesperian contact, where older, altered Noachian basement (ROI3) underlies younger sedimentary sulfate-rich deposits (ROI1). Both phyllosili-

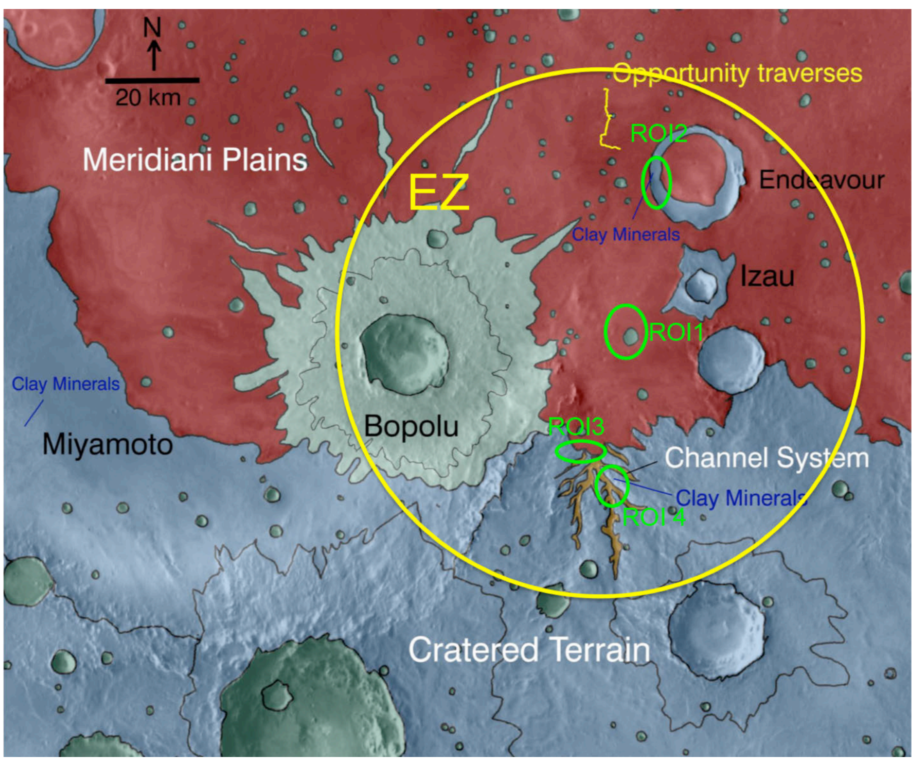


Figure 1: Meridiani Planum EZ and ROIs.

cates and jarosite (K-rich sulfate) are datable minerals; units of basaltic composition units may be present that may also be datable by multiple radiometric methods.

(d) *Access to outcrops with morphological and/or geochemical signatures (with preference for sites that link the two) indicative of aqueous or groundwater/mineral interactions*, fulfilled by reexamination and/or sample return of the Meridiani plains themselves (ROI1) and veins found on the rim of Endeavor (ROI2).

(e) *Identifiable stratigraphic contacts and cross-cutting relationships from which relative ages can be determined*, fulfilled at ROI3, an identifiable contact between the plains and cratered terrain, conveniently cut by a channel for access.

Engineering Constraints: Meridiani Planum meets all engineering criteria for the Landing Site, Habitation Zone, and Exploration Zone outlined in the Supplemental Background Document.

Landing Site. Meridiani's elevation is below -1km MOLA providing extra timeline margin for descent to landing. The terrain of Meridiani is predominately shallow ripples with craters ranging from meters to tens of kilometers in diameter. While craters are present, their coverage is sparse enough as to allow for optimal positioning of the 1km "blast zone" around the landing site.

Rock abundance on the ripple fields of Meridiani is best described as very sparse, once away from crater ejecta fields (Fig. 2a). Landing on the ripples will meet all landing circle requirements.

Fig. 2b shows typical Meridiani rippled terrain. The hills on the left portion of the horizon are the far East rim of Endeavour Crater approximately 21km from the rover. The darker horizon features are the near Western rim 1.3km from the rover.

Trafficability. The benign terrain of Meridiani's ripple field allows for elements delivered on subsequent landings to be directly transported to their appropriate location be it the Habitation Zone or Exclusion Zone. The effective lack of mobility hazards for large rovers will also allow for minimization of traverse times from the Landing Site to the Habitation Zone and from the Habitation Zone to Regions of Interest.

The benefits to initial infrastructure emplacement provided by landing at Meridiani may also allow for long distance repositioning of surface assets as the exploration campaign evolves after each crewed exploration mission.

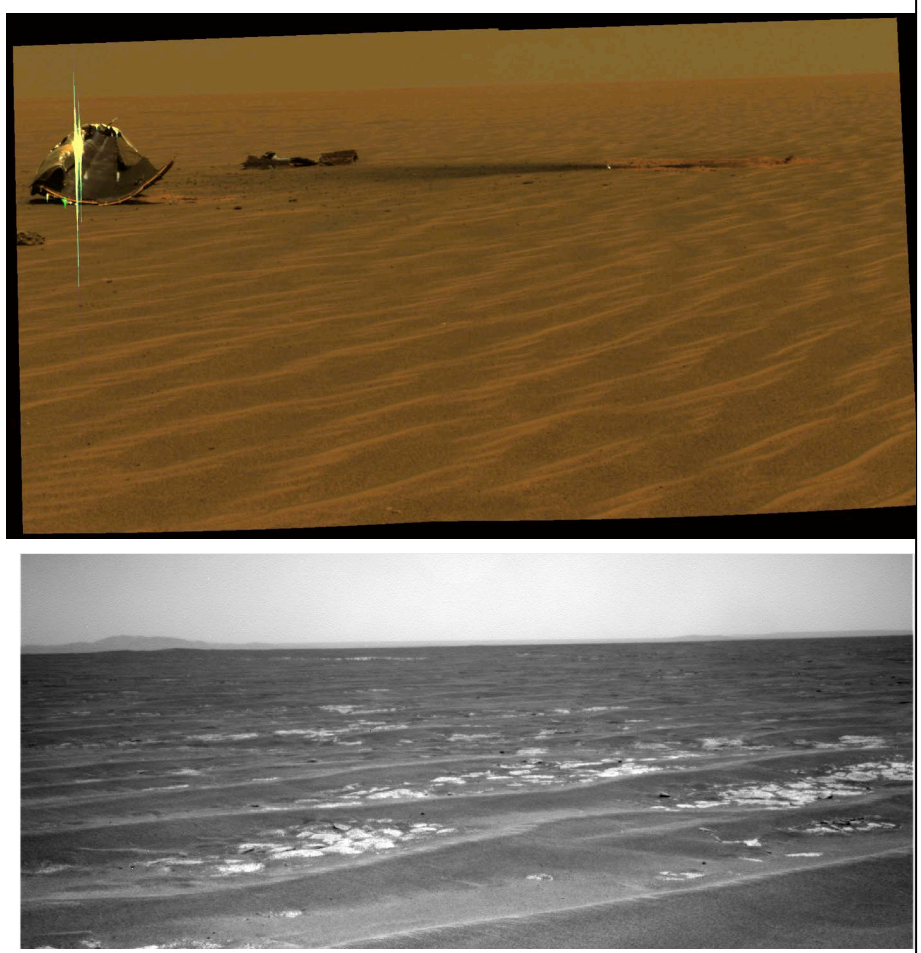


Figure 2: Expansive areas of easy trafficability characterize Meridiani Planum.

References: [1] Malin, M. C. & Edgett, K. S. *Science* **290**, 1927-1937 (2000). [2] Grotzinger, J. P. *et al*. *Earth Planet. Sci. Lett.* **240**, 11-72, doi:10.1016/j.epsl.2005.09.039 (2005). [3] Squyres, S. W. & Knoll, A. H. *Earth Planet. Sci. Lett.* **240**, 1-10, doi:10.1016/j.epsl.2005.09.038 (2005). [4] Hynek, B. M. *Nature* **431**, 156-159 (2004). [5] Edgett, K. S. & Malin, M. C. *Geophys. Res. Lett.* **29**, 2179 (2002). [6] http://marsoweb.nas.nasa.gov/landingsites/msl/workshops/2nd_workshop/program.html

ENVIRONMENTAL DYNAMICS OF THE EZ: A PRIORITY FOR SCIENCE AND RESOURCE EXPLORATION. P. G. Conrad[1], J. E. Bleacher[1], and P. van Susante[2], [1]NASA Goddard Space Flight Center, Code 699, Greenbelt, MD 20771 Pamela.G.Conrad@nasa.gov, jacob.e.bleacher@nasa.gov, [2]Michigan Technological University, Houghton, MI 49931 pjvansus@mtu.edu.

Introduction: The mineralogy and geochemical character of the exploration zone (EZ) only tells part of the story about how habitable the martian environment will be for human explorers and possibly other accompanying Earth life. There are physical aspects to the martian environment that are also important factors—diurnal variation in ground and air temperature, cosmic radiation, solar flux, wind velocity and variability, atmospheric pressure cycles, surface stability with respect to hardness, slope, porosity, permeability, magnetic character and electrostatic charging are examples.

From the perspective of resource exploration, the prospecting, discovery and potential for exploitation of resources is also dependent on both chemical and physical factors, so it is prudent to develop an approach for exploration that also includes a comprehensive plan for baseline and continued monitoring of both chemical and physical environmental dynamics as the human explorers invariably alter the exploration zone, even if only minimally.

We propose to interrogate the potential sites from the perspective of the ease with which the integrated set of environmental monitoring measurements can be deployed in semi-permanent array at intervals around the exploration zone, with outward looking observation posts that extend the data set to include data relevant to human safety and environmental preservation at larger spatial scales. Examples of candidate measurements for those outposts are slope stability (on crater walls or other proximal slopes), oncoming dust storms and coronal mass ejection (CME) events, galactic cosmic radiation (GCR) and water-table monitoring.

Rather than advocating for a specific site at this time, we propose analysis of environmental dynamics as part of the process for site high grading downstream. We will apply our measurement approach and site analysis using a few crater sites studied for previous mission landing site consideration.

Specific Measurements for the EZ: Because of the existing datasets from Mars Science Laboratory's meteorological instrument suite REMS [1] and what will have been acquired by ESA's ExoMars [2] and NASA's Mars 2020 [3] missions (as well as potential TBD precursors), we have a good idea of the range of meteorological measurements that are relevant to the characterization of environmental dynamics. Ground and air temperature, relative humidity, atmospheric pressure, and variation of ionizing (background galactic cosmic rays, ultraviolet, etc.) radiation are key measurements to make at a frequency of at least a few minutes per hour. Dust characterization and the presence and heading of dust devils are another, as is the approach of dust storms.

An upward looking observatory for tracking tau and other astronomical observations would also be important for understanding relationships between the dynamical elements of the environment.

Because of the nearly ubiquitous observation oxychlorine species with their oxidative power, and the effect of redox environment on both the preservation potential for biosignatures and on the processing approach for resources, the monitoring of surface chemistry at some TBD interval would be an important element for determining the mechanism for formation and distribution of the oxychlorine phases that will affect the science, ISRU and mission safety (for both humans and hardware) in the EZ.

Human or robotic measurement? Both scientific and ISRU exploration efficiency in the exploration zone will be improved if the sites under consideration can be evaluated with respect to determining the ratio of automated robotic measurement to human measurement. If the human explorers do only those things for which they are needed and a high proportion of exploration measurements can be conducted either completely or semi-autonomously, mission objectives are most likely to be achieved. Crater environments with relatively fewer navigation hazards in the EZ allow micro-rover surveying as a first pass to characterizing the geologic environment. An EZ with an easily traversable perimeter allows rapid deployment of environmental monitoring and communications hardware packages. So exploration zones within craters such as those that were high-graded during the recent Mars 2020 landing site workshop [4] can be situated and placement of environmental dynamics measurement packages and approaches for their use are described by considering craters studied for 2020 and earlier missions such as Gale, Jezero and Eberswalde as example sites for demonstrating the approach of using environmental dynamics monitoring as an additional mechanism for synthesis of science and ISRU objectives as a ranking tool for the sites.

The ISRU rubric requirement for less well-consolidated material must be placed next to a science requirement for in-place exposures of rock units from which to understand the stratigraphy of the EZ as well as safe landing locations with a stable rock foundation. Relatively easy access to ice or liquid water is another ISRU rubric requirement that is at odds with planetary protection (PP) considerations. The careful distribution of work between robotic and human explorers could enable the seemingly conflicted rubric requirements to be resolved.

Planetary Protection: A significant amount of attention is being paid to PP considerations, and abstracts and presentations from a recent NASA workshop on human exploration and planetary protection can be found at [5]. Modeling environmental dynamics from the straw man measurements we suggest may provide input to planetary protection due diligence, particularly as regular measurement of relative humidity and mapping the distribution of brine deliquescence of frost formation [6,7] can be useful in predicting areas for more frequent PP witness measurements within the EZ.

References: [1] Gómez-Elvira, J., et al. *Space science reviews* 170.1-4 (2012): 583-640. [2] Bettanini, C., et al. *Metrology for Aerospace (Metro Aerospace), 2014 IEEE*. IEEE, 2014. [3] Rodriguez-Manfredi, J. A., et al. *Lunar and Planetary Science Conference*. Vol. 45. 2014.
[4] http://marsnext.jpl.nasa.gov/workshops/wkshp_2015_08.cfm
[5]http://planetaryprotection.nasa.gov/humanworkshop2015/. [6] Harri, A-M., et al. *Journal of Geophysical Research: Planets* 119.9 (2014): 2132-2147. [7] Martín-Torres, F. Javier, et al. *Nature Geoscience* (2015).

THE HEBRUS VALLES EXPLORATION ZONE: ACCESS TO THE MARTIAN SURFACE AND SUBSURFACE.

A. Davila[1], A.G. Fairén[2], A.P. Rodríguez[3], D. Schulze-Makuch[4], J. Rask[5], J. Zavaleta[5]. [1]SETI Institute, Mountain View, CA (adavila@seti.org); [2]Centro de Astrobiología, Madrid, Spain, and Cornell U., Ithaca, NY (agfairen@cab.inta-csic.es); [3]Planetary Science Institute, Tucson, AZ (alexis@psi.edu); [4]Technical U. Berlin, Germany, and Washington State U., Pullman, WA (dirksm@wsu.edu); [5]NASA Ames, Moffett Field, CA (jon.c.rask@nasa.gov; jhony.r.zavaleta@nasa.gov).

Introduction: The candidate landing site (LS) and Exploration Zone (EZ) are located in the middle reaches of Hebrus Valles (Fig 1, centered at 20º05' N, 126º38' E). An important fraction of the science and exploration efforts at this site would focus on the characterization of an extensive subsurface cavern network, and its scientific, enginereing and insitu resource utilization (ISRU) potential for follow-up missions. Protective subsurface environments could be adapted for the establishment of long-term human exploration, providing potential access to water-ice and other key resources.

Regional context: The EZ occurs within a broad outflow channel system in western Elysium Mons that dissects boundary plains materials along the southwest perimeter of the Utopia Impact basin. The lower reaches of the channels dissect into the Vastitas Borealis Formation (VBF), a possible remnant of a Late Hesperian ocean. This geologic formation exhibits widespread evidence for recent periglacial resurfacing, which along with fluvial bedforms, are not buried by aeolian mantles.

Scientific merit: The VBF consists of a sedimentary deposit 30 to 170 m thick, formed during the Late Hesperian/Early Amazonian when sediment-laden water effluents of the outflow channels ponded in the northern lowlands, rapidly froze solid and sublimed [1,2]. *Exposures of the VBF would be suitable for radiometric dating* (minimum ROI requirement).

Hebrus Valles is an intricate system of individual pits, pit chains, troughs and channels that extends for ~500 km in a NW direction. The troughs and channels have been tentatively identified as outflow channels carved by large, catastrophic floods due to melting of subsurface ice [3]. At some locations within and around the EZ, features interpreted as mud volcanoes cluster into linear ridges, and are further indicators of liquid water activity at regional scales [3]. *Hence, the EZ includes recently extruded water-rich sediments with geochemical signatures indicative of aqueous or groundwater/mineral interactions that could date back to the ocean's emplacement, freeze over and evaporation histories* (minimum ROI requirement 2).

The lower reaches of Hebrus Valles consists of pits and trough interpreted as apertures that captured the catastrophic floods into networks of caverns [3]. The total extent of partially collapsed cavern sections in the Hebrus region include ~2400 km of troughs, and ~3600 km as indicated by the pattern of aligned sinkholes. *Both the fluvial features with their associated sediments, the remnants of water ice, and the subsurface caverns have a high preservation potential for evidence of past habitability and fossil biosignatures* (minimum ROI requirement).

A ~900 m deep (15 km diameter) crater located in the eastern portion of the EZ would provide accesss to explore subsurface materials, likely composed of Hesperian deposits buried beneath the VBF sediments. *The stratigraphic contact beteeen these units can be used for relative age determinations* (minimum ROI requirement).

Engineering merit: The proposed LS is located in the middle of the EZ, between two large fluvial features (Fig 1). Dissected near surface VBF materials in the EZ likely consist of dissicated permafrost and bouldery outwash materials (a few meters/tens of meters thick) overlying massive ice (tens/hundreds of meters thick). *If confirmed, the presence of near surface massive ice would be a key resource for humans* (minimum ROI requirement 5). Regionally, there are abundant, small and shallow craters that appear to be partially infilled. Slope at the LS is <1º and surface materials have relatively low thermal inertia (<200 J m^{-2} K^{-1} $sec^{-1/2}$), pointing to loose, fine surface dust and very few rocks. Practically no boulders larger than 1 m are observed near the LS area in HIRISE images at 24 cm/pixel resolution, satisfying safety constrains for EDL operations.

The inferred magnitude of floodwater infiltration in the EZ points to the existence of structurally stable caverns that were largely evacuated of

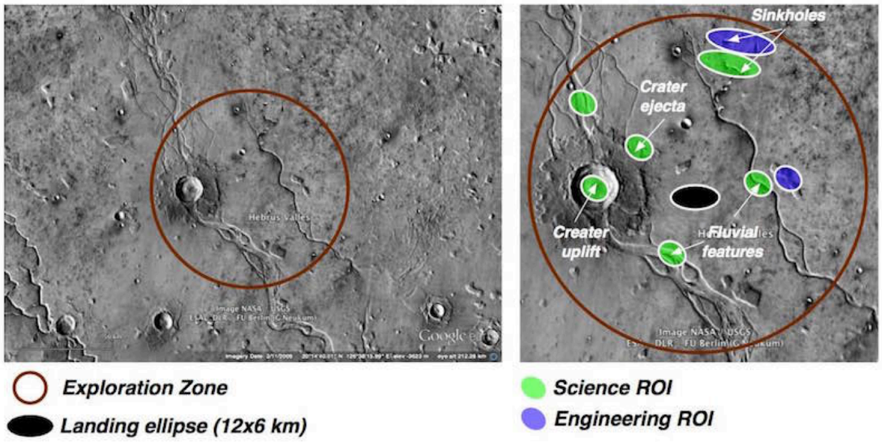


Figure 1. Proposed landing site, EZ and ROIs in the Hebrus Valles region.

fluids and sediments prior to Hebrus Valles outflow channel activity [3]. The predicted typical mean annual surface temperature for the EZ investigated latitudes is -60ºC [5]. At these temperatures, permafrost could have a mechanical strength close to that of limestone [6, 7], which could have stabilized evacuated caverns. Chemical precipitation from circulating brines in terrestrial cold springs can produce cements along the periphery of feeder conduits, thereby enhancing their overall structural stability [8]. Cements developed in association with cold water circulation include calcite, aragonite, Fe-Mn oxides, sulfides and sulfates [9,10]. On Earth, caverns are known to occur in ice-welded sediments such as in association with networks of ice wedges in permafrost [11] and ice-welded moraine deposits [12]. Some glacier caverns are known to have remained stable over decades [13]. *Subsurface caverns and steep walls in Hebrus Valles might represent natural terrain features that can be adapted for construction purposes* (minimum ROI requirement)., *Hence, infrastructure can be emplaced or constructed the LS* (minimum ROI requirement).

Summary: The suggested Hebrus Valles EZ fulfills a significant number of minimum ROI requirements, and also represents a diverse setting with multiple geological contacts and layers. Further, it provides an opportunity to explore possible remnant water ice and protected subsurface environments, which are critical resources for the establishment of long-term human settlements, and present ideal targets for exobiological exploration.

References: [1] Kreslavsky, M.A., Head, J.W. J. Geophys. Res., 107(E12), 5121; [2] Tanaka et al (2005) U.S. Geological Survey Scientific Investigations Map 2888; [3] Rodriguez, J. A. P., et al. (2012), Geophys. Res. Lett., 39, L22201; [4] Carr, M.H., Malin, M.C. (2000), Icarus, 146(2), 366–386; [5] Mellon, J.T. et al. (2004) Icarus, 169, 324–340; [6] Kuribayashi, E. et al. (1985), Proceedings of the 4th Internat. Symposium on Ground Freezing, 177–182, Balkema, Rotterdam, Netherlands; [7] Ladyani, B. (2003), in Permafrost, edited by M. Phillips, S. M. Springman, and L. U. Arenson, pp. 621–626, Swets and Zeitlinger, Lisse, Netherlands. [8] Pentecost, A. et al. (2003), Can. J. Earth Sci. 40(11), 1443–6; [9] Jones, B. et al. (2007) Journal of the Geological Society, London, 164, 227-242; [10] Guo, X., Chafetz, H.S. (2012) Sedimentology, doi: 10.1111/j.1365-3091.2011.01315.x; [11] Costard, F. et al. (2012) Proc. Lunar Planet. Sci. Conf., 43rd, Abstract 1822; [12] Moorman, B. J. (2005) in Cryospheric Systems: Glaciers and Permafrost, vol. 242, edited by C. Harris and J. B. Murton, pp. 63–74, Geol. Soc., London; [13] Halliday, W. R. (2007), J. Cave Karst Stud., 69(1), 103–113.

MARS LANDING + 50 YEARS: REPURPOSING THE FIRST VIKING LANDING SITE ON CHRYSE PLANITIA AS AN EXPLORATION ZONE FOR AUTOMATED INFRASTRUCTURE CONSTRUCTION

K. W. Farrell,[1] [1]Department of Computational Social Sciences, George Mason University (kfarrel7@gmu.edu).

Introduction: Return to America's first landing site on the surface of Mars allows a well-studied landing site in the Chryse Basin -- a level expanse with a complex geological history [1], interpreted as a volcanic plain [2] resurfaced by deposits from floodwaters and deflation from aeolian processes -- to be re-purposed as an Landing Site (LS)/Exploration Zone (EZ) well suited for automated construction of infrastructure for human habitation on Mars [3,4,5]. The proposed EZ, centered at latitude 22.3°N and longitude 48.3°W, provides a location with ground truth of available resources for human infrastructure and habitation, confirmed through analysis of imagery and experiments conducted at the first Viking Lander (VL-1) landing site decades ago [6,7,8]. Figure 1 shows the EZ against Viking orbiter images as a context image with approximate dimensions of the EZ and identified six Regions of Interest (ROIs) [9].

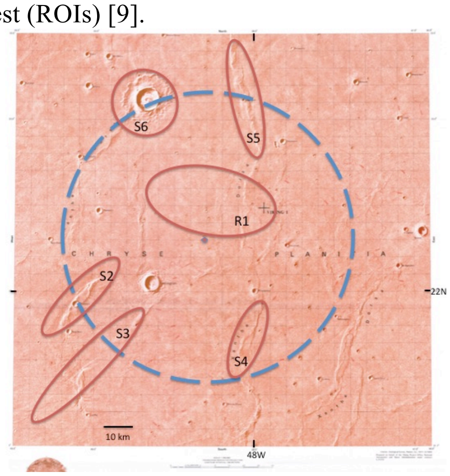


Figure 1: Context image from USGS I-1059 of Chryse Planitia EZ, showing landing site center (red diamond), EZ 50km reference margin in dashed blue, and six ROIs (R1, S2-6) described in the text as red ellipses.

Rationale: The proposed EZ on in the Xanthe Dorsa region of Chryse Planitia gives access to closely accessible scientific ROIs, including outcrops of volcanic bedrock [10], impact crater ejecta and stratified drift deposits in the immediate vicinity, a rich assemblage of petrologic samples showing evidence of trapped atmospheric gases in vesicles [11], and proximity to datable volcanic wrinkle ridges [12] and landforms shaped by water floods and later aeolian erosion [13,14]. The Chryse Planitia EZ has substantial evidence, confirmed through ground truth gathered by VL-1, that the EZ is capable of providing adequate resources for human crews: cobbles, regolith, and basalt-based silica and metal feedstocks are available in a centralized area. These resources can be readily used for LS and Habitation Zone (HZ) in-situ resource utilization (ISRU) and infrastructure construction by highly automated equipment. The proposed EZ site has the potential for readily accessible ice, and centers near an extensive resource ROI that allows for the retrieval and study of VL-1 lander hardware subjected to the Martian environment for a half-century, offering an unique insight into the impact of sustained exposure of infrastructure to conditions on the Martian surface.

The original selection and return to the VL-1 landing site and its environs has been proposed for robotic landers largely on the basis of scientific investigations for the site [15,16,17]. The proposed EZ site's five scientific ROIs collectively meet threshold criteria for trapped atmospheric gases, datable crustal units, aqueous processes and stratigraphic contacts. However, direct experiments performed on the sampled soils at the VL-1 site have not provided clear evidence of either current habitability or fossil biosignatures at the EZ site. However, this proposed EZ affords an unique opportunity to investigate the rate of weathering and morphological, meteorological and mineralogical changes to the Martian surface in the location of VL-1 in the decades since the lander's initial operations ceased in 1982 [18,19]. The extensive resource ROI that contains the VL-1 lander (Figure 1.R1) has a well-imaged surface subject to change, and could include changes to ventifacts subject to aeolian erosion, downslope movement of pebbles and clasts, dust accumulation and scouring near the VL-1 lander, dust tail orientations and pitting of coarsely granular cobbles.

The proposed EZ lies at the western margin of the Chryse Basin, a depositional plain that may retain the outflow of three significant late Hesperian channel systems in catchment areas from the distant headlands to the west and south of the EZ. Of the five scientific ROIs identified in the EZ beyond the VL-1 site, two ROIs (Figure 1.S2, S3) concern outflow channel morphologies and impact crater ramparts of "Princeton" and "Lexington", another two ROIs (Figure 1.S4, S5) explore along one of the prominent Xanthe Dorsa wrinkle ridges for evidence of early Hesperian volcanism, and a sixth ROI (Figure 1.S6) examines a substantial impact crater "Yorktown" that may have exhumed Noachian crustal material, mafic bedrock and volatiles into its ejecta field [20].

The Chryse Planitia EZ itself may center on the confluence of several channel systems whose origins have been subject to numerous interpretations, and recent analytical consensus indicates that these channel structures were created by floodwaters during the late Hesperian era, and may have terminated in a standing body of water [21]. The two outflow channel ROIs in the EZ include (1.) outflow areas of Maja Valles from the south draining Juventae Chasma, and (2.) outflow areas of Kasei Vallis from the northwest which may have had more than one episode of erosion, as well as landforms that may have been created from floodwaters from either Bahram, Vedra, or Maumee Valles flowing from the west of the EZ. Well-sorted material, which appears to include fairly well rounded pebbles, may have been deposited in the EZ area from floodwaters that coursed through these channel systems. Traversals to ROIs in the EZ could travel upstream towards the Maja fan [18] to reveal clues to the complex history of these flooding events and their deposits. Statistical variations in the numbers and types of cobbles, boulders and sediments present in each of the outflow ROIs could give clues to the timing and extent of episodic flooding events and origin of the parent rocks found in the deposits [22]. Evidence of pre-Amazonian (Noachian?) astrobiologic habitats could have been formed upstream of the Chryse Basin and placed in the EZ area as a result of floodwaters depositing detritus in downstream locations.

Engineering factors important to the EZ ISRU include: (1.) latitude near 30°N for likelihood of near surface water ice in excess of 100MT, (2.) elevation (−2 km) for sufficient atmosphere for a safe descent of robotic and human landers, (3.) relief of <100 m, for ease of construction of large planar platforms and transportation corridors, (4.) slopes of <10° for stability at touchdown of robotic and human landers, (5.) accessible rocks, drift deposits and moderate sized boulders for construction material and (6.) a load-bearing surface that shows evidence of bedrock in outcrops. The EZ is uniquely suited to provide detailed study of the VL-1 site to discern morphologic changes to the landscape and weathering changes since 1982.

Summary: The proposed Chryse Planitia EZ centered near the VL-1 landing site has evidence for adequate water ice, silica, and load-bearing bedrock surface resources to utilize as infrastructure for long-term missions to support humans. Significant scientific inquiries into environments conducive to possible astrobiosignatures, Martian surface processes and the geologic history of Mars could be enhanced through extention of investigations begun in the Viking era into the 2030’s and beyond.

References: [1] Crumpler L. S. (1997) *JGR, 102,* 4201-4218. [2] Arvidson R. E. et al. (1989) Rev. Geophys. 27, 39-60. [3] Chapman M. G. and Kargel J. S. (1999) *JGR, 104, E4,* 8671-8678. [4] Chapman M. G. et al. (2003) *JGR, 108, E10,* 5113, doi: 10.1.029/2002JE002009. [5] Cutts J. A. and Blasius K.R. (1981) *JGR, 86*, 5061-5074. [6] Mutch T. A. et al. (1976) *Science, 193,* 791-801. [7] Binder, A. B. et al. (1977) *JGR, 82,* 4439-4451. [8] Greeley R. et al. (1977) *JGR, 82,* 4093-4109. [9] Rotto S. L. and Tanaka K. L. (1995) *U.S. Geo. Surv. Misc. Inv. Ser. Map I-2441*. [10] Salvatore M. R. et al. (2010) *JGR, 115, E07005,* doi: 10.1029/2009JE003579. [11] The Viking Lander Imaging Team (1978) *NASA SP-425*. [12] Head J. W. et al. (2002) *JGR, 107, E1, 5003,* doi: 10.1029/2000JE001445. [13] Carr M. H. (1979) *JGR, 84,* 2995-3007. [14] Rice J.W. and Edgett K.S. (1997) *JGR, 102, E2,* 4185-4200. [15] Masursky H. and Crabill N.L. (1976) *Science, 192,* 809-812. [16] Golombek M. P. et al. (1997) *JGR, 102, E2,* 3967-3988. [17] Craddock R. A. (1990) *LPSC XXI,* 116-117. [18] Jones K. L. et al. (1979) *Science, 204,* 799-806. [19] Guinness E. A. et al. (1979) *JGR, 84,* 8355-8364. [20] Garvin J. B. et al. (1981) *Moon Planets, 24,* 355-387. [21] Head J. W. et al. (1998) *Geo. Phys. Lett., 25,* 4401-4404. [22] Craddock R. A. et al. (1992) *LPSC XXIII,* 335-336.

MARTIAN HALITE: POTENTIAL FOR BOTH LONG-TERM PRESERVATION OF ORGANICS AND A SOURCE OF WATER

M. Fries[1], B. Hynek[2], M. Osterloo[2] A. Steele[3] and M. Zolensky[1], [1]NASA ARES, Johnson Space Center, Houston TX, [2]Laboratory for Atmospheric and Space Physics, University of Colorado-Boulder, [3]Geophysical Laboratory, Carnegie Institution for Science, Washington, DC. Contact email: marc.d.fries@nasa.gov

Summary: Deposits containing halite on Mars are both rich scientific targets and potentially a resource for manned Mars exploration. Halite on earth exhibits excellent preservation potential for organics. The entrainment of organics occurs through a relatively low energy evaporative process. Therefore deposits on Mars are excellent materials to search for evidence of ancient martian organics. Halite also tends to entrain a portion of its parent brine, potentially storing a quantity of water for resource utilization. Halite-bearing deposits have been identified in ~640 locales throughout the southern highlands of Mars [1], presenting surface-accessible science and resource utilization targets. The intent of this abstract is to discuss the science and resource ROI potential for manned landing sites in general, without singling out a specific site to suggest as a landing site.

Science Potential: Identifying ancient martian organic species is a very important aspect of the search for ancient martian life. Also, understanding the geochemistry of the ancient martian water would allow for a better assessment of past habitability for a given site. Halite is of special interest in these pursuits because it can preserve organics for extraordinary lengths of time. Terrestrial halite deposits are known to preserve organics to include carbonaceous solids, gases, and petroleum liquids for time scales in the range of hundreds of millions of years [2,3]. Tectonic activity and terrestrial aqueous processing, however, limit the survival of terrestrial halite deposits. Halites can preserve organics much longer in dry, tectonically stable extraterrestrial settings as seen in ~4.3-4.5 Ga old, organics- and water-bearing halite found in the Zag and Monahans meteorites [4-7]. Based on crater age-dating results from [8,9] halite deposits on Mars date from the late Noachian to early Hesperian and correspond in time with the end of widespread surface water activity on the planet. As such the halite-bearing deposits may contain organics dating from that time period.

Halite has exceptional potential for preserving organics because it protects entrained carbonaceous material from martian surficial oxidants such as perchlorates as long as the halite remains intact. The entrained carbonaceous material would still undergo alteration due to ambient radiation exposure, but radiation damage does not remove carbon from the halite interior. This is shown in halites from Zag and Monahans meteorites, which have been irradiated to a blue/purple color over an extended exposure residence in an asteroidal regolith (Figure 1) but which retain ancient brine, carbonaceous solids and aliphatic compounds [4-7].

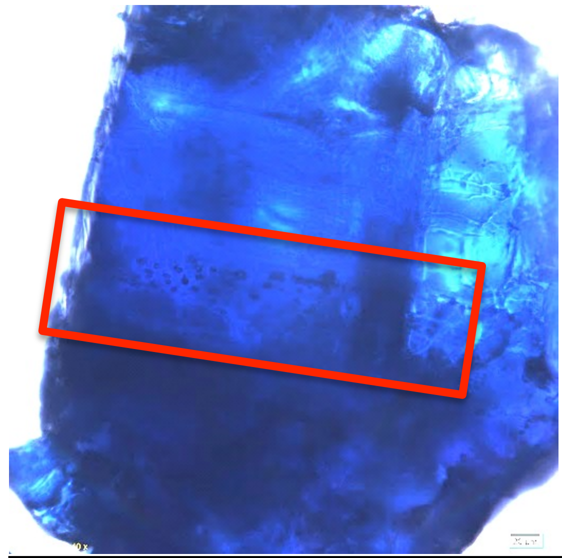


Figure 1: A 4.3-4.5 Ga old halite grain from the Zag meteorite. The blue color is a consequence of radiation damage. The red box highlights a chain of brine-bearing fluid inclusions in the halite, preserving 4.3-4.5 Ga water from the parent body. Scale bar is 20 μm long.

Resource Potential: Halite tends to trap a small amount of its parent brine as it solidifies (e.g. Figure 1). This suggests that martian halite deposits may contain a component of ancient martian water. From a human exploration standpoint, martian halite deposits might be a surface-accessible source of a useful amount of water for future manned missions. Halite is regularly mined on Earth and is amenable to extraction of entrained water. The amount of water present depends on the amount entrained during deposition and on survival factors to include exposure to heat, shock, and aqueous processing since the halite was originally deposited.

Halite Deposits on Mars: Previous work using the Thermal Emission Imaging System (THEMIS) has identified ~640 chloride-bearing deposits on the martian surface, mostly in the southern hemisphere (Figure 2)[1] and within Noachian- and Hesperian-aged terrains. Spectroscopic observations using THEMIS and higher spectral resolution data from the Thermal Emis-

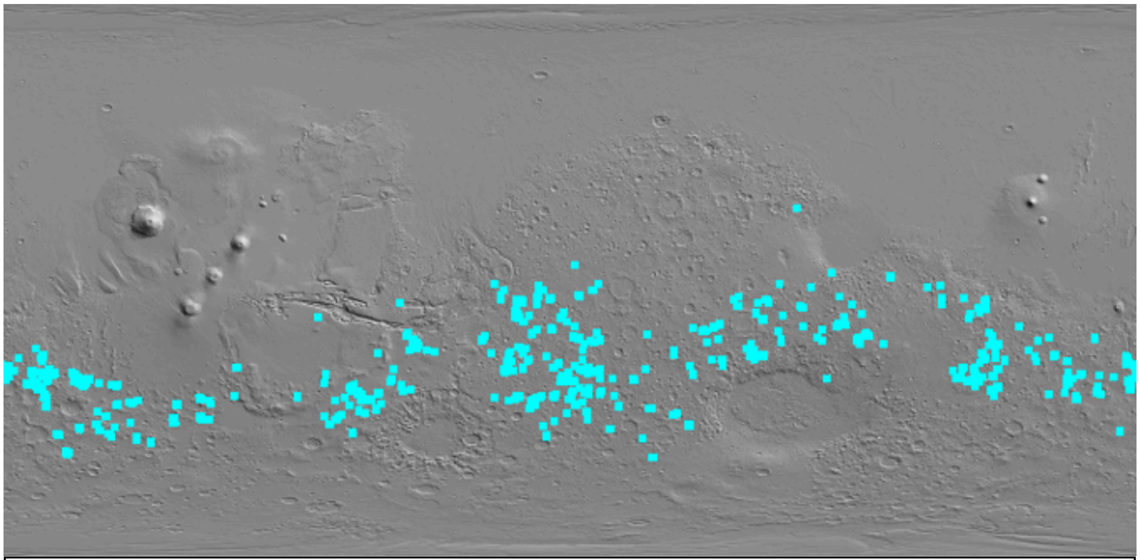


Figure 2: Global Mars elevation map indicating the locations of chloride deposits (blue squares) identified to date (see [1]). The blue squares are enlarged relative to the areal extent of the deposits for ease of viewing.

sion Spectrometer (TES) as well as visible to near-infrared data from the Compact Reconnonaissance Imaging Spectrometer for Mars (CRISM) indicate the best spectral matches to the martian material include a mixture of an anhydrous chloride salt (i.e., halite) and silicates [9-11]. Geologic investigations indicate that most geomorphological observations are consistent with formation by ponding of surface water runoff and evaporation, although formation by hydrothermal processes or efflorescence may have occurred in some locales [1,8,9].Additionally, given the overlap in the ages of the martian halite deposits with the ages of the valley networks, it is possible that these materials represent the last vestiges of surface water activity on the planet [8].

References: [1] Osterloo M., Anderson F., Hamilton V., Hynek B., JGR 115 (2010) E10012. [2] Melvin J., ed., Evaporites, Petroleum and Mineral Resources (1991). [3] Schoenherr J. et al, Geo. Res. Abstracts 7 (2005). [4] Zolensky M. et al, *Workshop on the Potential for Finding Life in a Europa Plume* (2015) Abstract #3004. [5] Fries M., Steele A. and Hynek B., 46th LPSC (2105) Abstract #3017. [6] Fries M. Messenger S., Steele A., Zolensky M., *Workshop on Habitability of Icy Worlds*, (2013) Abstract #4078. [7] Fries M., Messenger S., Steele A., Zolensky M., 76th MetSoc (2013) Abstract #5266. [8] Osterloo M. and Hynek B., 46th LPSC (2015) Abstract #1054. [9] Osterloo M., et al *Science* 319 (2008) p. 1651-1654. [10] Glotch, T. D. et al. 44th LPSC (2013) Abstract #1549, [11] Jensen, H. and Glotch T. D., JGR 116 E00J03 (2011).

A HUMAN EXPLORATION ZONE IN THE PROTONILUS MENSAE REGION OF MARS.

Z. E. Gallegos[1] and H. E. Newsom[1,2], [1]University of New Mexico (zachegallegos@gmail.com; Institute of Meteoritics, MSC03 2050, 1 University of New Mexico, 87131), [2]ChemCam (Mars Science Laboratory).

Introduction: The exploration zone concept for the human exploration of Mars provides the opportunity to consider many new scientifically compelling areas for future human missions. These exploration zones (EZ) offer a wide variety of scientific value from astrobiology to geochronology and direct new attention at the potential for resources, including access to useful materials and H_2O in the form of ice or mineralogically bound H_2O.

Astrobiology investigations may answer some of humanity's deepest scientific and philosophical questions. Currently, one of NASA's highest priorities is understanding if life ever arose, or even still exists, on Mars. Identifying areas with geomorphologic and/or chemical potential for preservation of biosignatures is central to the scientific goals for the EZ concept. A qualifying EZ will also provide outcrops that lead to understanding Mars' past and present. Observations can lead to inferences about the regional climate, and past environments for the planet as a whole.

Establishing a semi-permanent base for reoccurring missions to Mars requires *in situ* resource utilization (ISRU). Possibly the most important commodity for a Mars missions will be H_2O. Too heavy to transport from Earth, most water used by the astronauts for feedstock and civil engineering purposes must be locally derived. Silicon and metals (Fe, Al, Ti, Mg, etc.) will need also be mined on site.

Landing Site (Figure 1): The proposed EZ (48.062E, 42.187N) is in the Protonilus Mensae region of Mars, located just to the east of Moreux Crater and situated on the planetary dichotomy boundary.

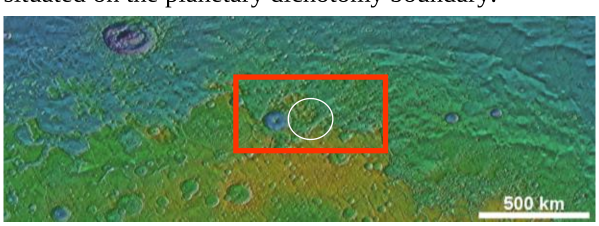


Figure 1a. Regional context for the proposed EZ. Figure 1b outlined in Red with EZ outlined in white.

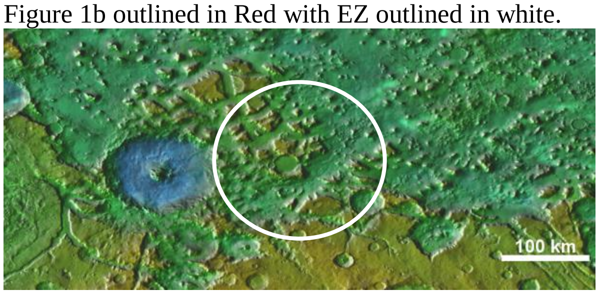


Figure 1b. EZ outlined in white.

Geologic units [1]. The oldest unit in the EZ is the Middle Noachian highland unit (mNh - brown). This unit is characterized by rolling topography and high relief outcrops of undifferentiated impact and volcanic material. The next oldest unit is the Hesperian and Noachian transition unit (HNt - tan). The unit comprises knobs and mesas of Noachian age and intervening aprons of Hesperian age. The Early Hesperian transition unit is (eHt - light brown) is at the very northeast edge of the EZ. It comprises small, degraded knobs and mesas separated by extensive plains. The Amazonian and Hesperian impact unit (AHi - yellow) is also represented within the EZ. The youngest unit is an Amazonian and Noachian apron unit (ANa - dark yellow); the unit comprises mesa forming primitive Noachian crustal remnants (fretted terrain), most likely mNh, draped by ice-rich Amazonian materials.

Figure 2. Geologic context in the EZ region. EZ outlined in white.

Other features. Moreux Crater (~138 km) is the largest crater in the vicinity of the EZ. Observations have shown intense glacial modification in the past, evidence for large amounts of H_2O ice [2]. An unnamed crater (~33 km) near the center of the EZ appears to have been host to glacial processes and a crater lake as there is an outflow channel cutting through the eastern rim. Another unnamed crater (~42 km) in the southeast quadrant of the EZ will also be available for investigating.

There are four large, unnamed outflow channels within the EZ. Two of the channels originate from the mNh unit while the other two are breaches in the rims of Moreux crater and the unnamed crater near the EZ center. All four channels are accessible for exploration.

This EZ is located in an area of remnant magnetism as seen in MAG/ER data. Investigations of magnetic fields within samples may shed light on the issue of Mars' past magnetic field history and interior. The nearest patches of positive magnetism would require unmanned, base-controlled rovers for sampling return.

Mission Requirements: The proposed EZ lies at ~42°N, within the ±50° latitudinal constraints set for the mission. The maximum altitude in the EZ is also well below the +2 km limit. Low thermal inertia and high albedo in the EZ signifies a relative lack of thick, fine grained dust deposits.

Landing site (LS). A moderately large crater (~25 km^2), dubbed LS crater, to the east of the EZ center has been chosen as a reoccurring LS. The area appears to be adequate for EDL constraints, however no HIRISE observations are available within the LS.

Habitation zone (HZ). At the center of the EZ lies the HZ, where the base of operations will be established. The HZ is located just outside LS crater in the outflow channel that resulted from the breach of the crater rim. A pair of HIRISE observations is available in the HZ.

Regions of Interest: The initial stages of site selection for human missions rely on the identification of regions of interest (ROI). An ROI must be within 100 km of the HZ; however, unmanned, base-driven rovers may be able to traverse farther and retrieve samples. ROIs qualify an EZ on the basis of science and/or resource value. There are many potential ROIs in this EZ (**Figure 3**).

Science ROIs. This is a compelling site for astrobiology studies. The ANa unit (ROI 1), the multiple valley networks (ROI 2), and Moreux Crater (ROI 3) will be investigated for past and present signs of life. ANa may be a current refugium for life, as the thick ice deposits may create pressures conducive for liquid H_2O, and possibly life. The valley networks are evidence for large amounts of past water flow and current H_2O ice. Whether they were long lived enough to preserve, or even harbor, life is still to be determined. Moreux Crater offers a look at past atmospheric gasses trapped within its impact glass; impact glass is also a potential medium for biopreservation. Large impacts like Moreux Crater can create long-lived hydrothermal systems capable of supporting life; hydrothermal systems have yet to be confirmed in or near the EZ.

This site is also intriguing geologically. Units in the area range in age from Noachian to Amazonian, providing a large variety of rocks and environments to study. Noachian age highlands material (RIO 4), Hesperian and Noachian transition units (ROI 5), and Hesperian transition units (ROI 6) will provide a glimpse into an environmentally dynamic period on Mars. The outflow channel networks (ROI 2) are of interest for the processes that accompany large amounts of water flow. The networks incise the units through which they flow, exposing thick sequences of outcrops and depositing altered materials.

Resource ROIs. The fretted terrain of the ANa unit (ROI 1) contains large supplies of H_2O ice [3]. The lineated valley fill features in the area (ROI 2) are a geomorphologic indication for large supplies of H_2O ice. The older Noachian and Hesperian aged units (ROI 4, ROI 5, ROI 6) are high in Fe and other metals, which will be useful for civil engineering purposes.

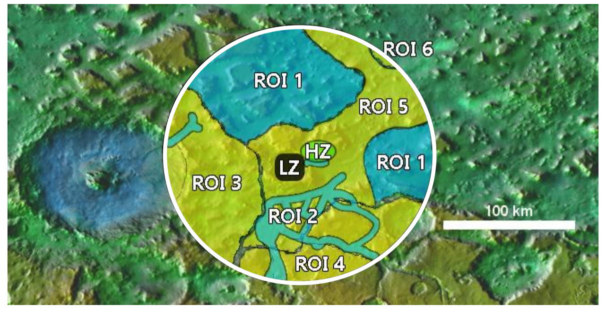


Figure 3. Science ROIs: yellow. ISRU ROIs: blue.

HIRISE, CRISM, and Future Datasets: There are abundant HIRISE and CRISM observations in all the units of the EZ (**Figure 4**). More complete coverage will be needed in LS crater as well as in the HZ. Current and future orbiting missions should target this area to enable future lander, rover, and human missions.

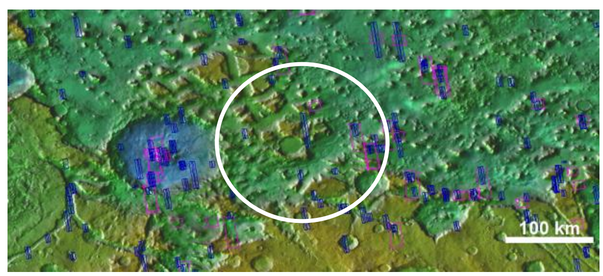


Figure 4. HIRISE (blue) and CRISM (magenta) coverage in the EZ region.

Conclusions: The proposed EZ in the Protonilus Mensae region offers a new, scientifically exciting area with abundant resources for future human missions to Mars.

References: [1] Tanaka K. L. *et al*. (2014) USGS, Scientific Investigations Map 3292. [2] Merchant D. R. *et al.* (2006) *LPSC XXXVII*. [3] Dickson J. L. *et al.* (2008) *Geology* 36(5):411.

A HUMAN EXPLORATION ZONE ON THE EAST RIM OF HELLAS BASIN, MARS: MESOPOTAMIA.

Z. E. Gallegos[1] and H. E. Newsom[1,2], [1]University of New Mexico (Institute of Meteoritics, MSC03 2050, 1 University of New Mexico, 87131; zachegallegos@gmail.com), [2]ChemCam (Mars Science Laboratory).

Introduction: The exploration zone concept for the human exploration of Mars provides the opportunity to consider many new scientifically compelling areas for future human missions. These exploration zones (EZ) offer a wide variety of scientific value from astrobiology to geochronology and direct new attention at the potential for resources, including access to useful materials and H_2O in the form of ice or mineralogically bound H_2O.

Astrobiology investigations may answer some of humanity's deepest scientific and philosophical questions. Currently, one of NASA's highest priorities is understanding if life ever arose, or even still exists, on Mars. Identifying areas with geomorphologic and/or chemical potential for preservation of biosignatures is central to the scientific goals for the EZ concept. A qualifying EZ will also provide outcrops that lead to understanding Mars' past and present. Observations can lead to inferences about the regional climate, and past environments for the planet as a whole.

Establishing a semi-permanent base for reoccurring missions to Mars requires *in situ* resource utilization (ISRU). Possibly the most important commodity for a Mars missions will be H_2O. Too heavy to transport from Earth, most water used by the astronauts for feedstock and civil engineering purposes must be locally derived. Silicon and metals (Fe, Al, Ti, Mg, etc.) will need also be mined on site.

Landing Site (Figure 1): The proposed EZ (94.02E, 35.352S) is located on the east rim of the Hellas Basin, between Niger/Dao Vallis and Harmakhis Vallis: Mesopotamia. This area is of scientific interest, however no past mission has ever landed in the region.

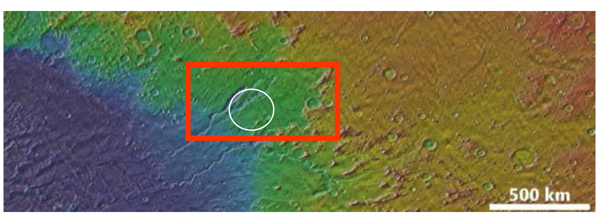


Figure 1a. Regional context. Figure 1b outlined in red.

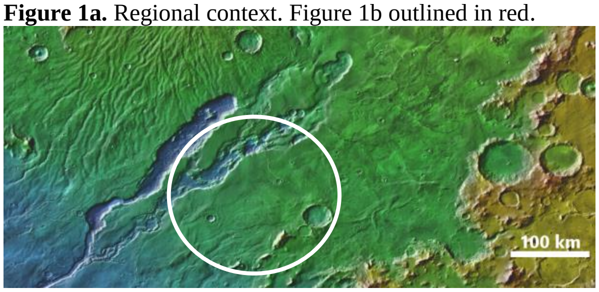


Figure 1b. EZ outlined in white.

Geologic units (**Figure 2**). The oldest geologic unit in the area (eNhm - grey) is the Early Noachian highland massif unit, and is the result of uplift from the Hellas impact. It comprises high-relief massifs separated by broad troughs and valleys. The next oldest unit (eHv - dark purple) is an Early Hesperian volcanic unit. Superposed on this unit is a Late Hesperian volcanic unit (lHv - light purple). Hadriacus Mons (Hve - red) is a volcanic edifice in close proximity to the EZ. The Amazonian and Hesperian impact unit (AHi - yellow) is also represented within the EZ. The youngest unit is an Amazonian and Noachian apron unit (ANa - light brown); the unit comprises primitive Noachian crustal remnants, most likely eNhm, draped by ice-rich Amazonian materials.

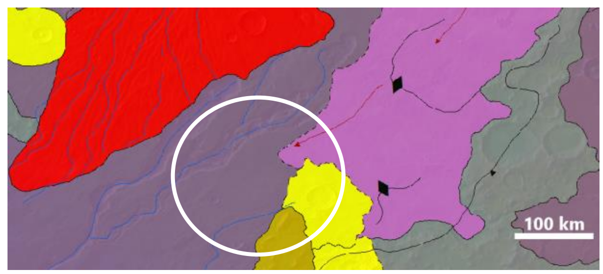


Figure 2. Geologic context in the EZ region [1].

Other features. This site is crosscut by a number of valley networks, of multiple scales, for investigation. Niger Valles, and other small networks to the south, are within the EZ and accessible by away missions. The margin of Dao Valles is within the EZ but may be inaccessible due to Niger Valles. Harmakhis Valles, the other large valley network in the region, is outside the EZ by ~75 km.

There are a number of impact craters, of varying scales, in the EZ area. Negele Crater is a young, complex impact crater ~37 km in diameter. Craters of this size can significantly alter the local geology/hydrology and are worth investigating. There are many simple craters to study in the area, the largest of which is Cue Crater (~11 km). Gander Crater (~36 km) and Nazca Crater (~15 km) are outside of the EZ by ~90 km, but proximal enough to potentially provide sampling of the Hve unit by their ejecta.

This EZ is located in an area of remnant magnetism as seen in MAG/ER data. Investigations of magnetic fields within samples may shed light on the issue of Mars' past magnetics and interior. The nearest band of negative magnetism would require unmanned, base-controlled rovers for sampling return.

Mission Requirements: The proposed EZ lies at ~35°S, within the ±50° latitudinal constraints set for the mission. The maximum altitude in the EZ is also well below the +2 km limit. Moderately low thermal inertia and moderately high albedo in the EZ signifies a relative lack of thick, fine grained dust deposits.

Landing Site (LS). A large area (~25 km^2) to the NW of the EZ center has been chosen as a reoccurring LS. The area is relatively flat lying, contains few craters, and no inescapable bedforms are currently observed within the LS.

Habitation Zone (HZ). At the center of the EZ lies the HZ, where the base of operations will be established. The location of the HZ is not final; this is an approximate location and can be up for discussion.

Regions of Interest: The initial stages of site selection for human missions rely on the identification of regions of interest (ROI). An ROI must be within 100 km of the HZ; however, unmanned, base-driven rovers may be able to traverse farther and retrieve samples. ROIs qualify an EZ on the basis of science and/or resource value. There are many potential ROIs in this EZ (**Figure 3**).

Science ROIs. This is a compelling site for astrobiology studies. The ANa unit (ROI 1), the multiple valley networks (ROI 2), and Negele Crater (ROI 3) will be investigated for past and present signs of life. ANa may be a current refugium for life, as the thick ice deposits may create pressures conducive for liquid H_2O, and possibly life. The valley networks are evidence for large amounts of past water flow and current H_2O ice. Whether they were long lived enough to preserve, or even harbor, life is still to be determined. Negele Crater offers a look at past atmospheric gasses trapped within its impact glass; impact glass is also a potential medium for biopreservation. Giant impact structures like Hellas can produce hydrothermal systems that persist for millions of years. This may have been a nursery for early life on Mars. Hydrothermal systems have yet to be confirmed in or near the EZ.

This site is also intriguing geologically. Units in the area range in age from Noachian to Amazonian, providing a large range of rocks and environments to study. ROI 1 offers a chance to sample Noachian age rocks within the moraines and till eroded from the high-relief massifs. Two identifiable volcanic units (eHv - ROI 4, iHv - ROI 5), will provide radiometric dating within the EZ to relate with the regional, and global, geologic context. Craters in the EZ are also of scientific interest. Negele Crater (ROI 3) offers a look at a young, complex crater impacting into Hesperian volcanics and possibly the ice-rich apron units as well. Several simple craters in the EZ (e.g. Cue Crater) will be investigated but are not considered ROIs. Craters Gander and Nazca are not ROIs themselves because they are outside the EZ, but they do offer a chance to sample Hve (a possible ROI 6) through their ejecta.

ISRU ROIs. The ANa unit (ROI 1) offers a large supply of H_2O ice [2]. Previous studies using SHARRAD radar data confirms these lobate debris aprons to contain one of the largest amounts of H_2O ice on Mars accessible with current engineering parameters [3]. The lineated valley fill features in the area (ROI 2) are a geomorphologic indication for large supplies of H_2O ice. The two volcanic units within the EZ (ROI 4, ROI 5) show localized concentrations of Fe in TES observations. TES observations also show sheet silicates/hi-Si glass within the EZ. They are concentrated in the volcanic units (ROI 4, ROI 5) and around Negele Crater (ROI 3) possibly as impact glass.

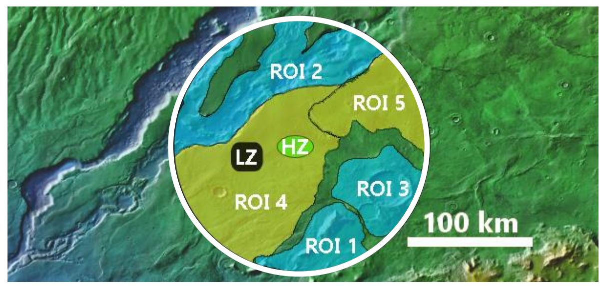


Figure 3. Science ROIs: yellow; ISRU ROIs: blue.

HIRISE, CRISM, and Future Datasets: There are abundant HIRISE and CRISM observations of the valley networks in the EZ (**Figure 4**); however, other units in the area would benefit from more data. Current and future orbiting missions should target this area to enable future lander, rover, and human missions.

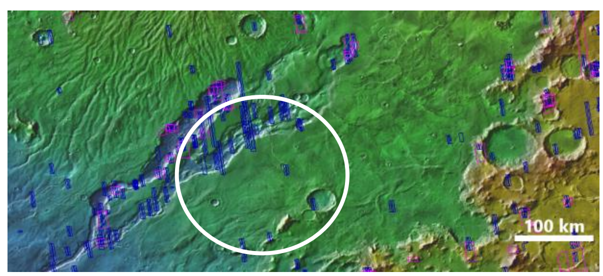


Figure 4. HIRISE (blue) and CRISM (magenta) coverage in the EZ region.

Conclusions: The proposed EZ, dubbed Mesopotamia, offers a new, scientifically exciting region with abundant resources for future human missions to Mars.

References: [1] Tanaka K. L. *et al*. (2014) USGS, Scientific Investigations Map 3292. [2] Levy J. S. *et al*. (2014) *JGR Planets*, *119*. [3] Holt J. W. (2008) *Science*, V322, 1235-1238.

THE HYPANIS FLUVIAL-DELTAIC-LACUSTRINE SYSTEM IN XANTHE TERRA: A CANDIDATE EXPLORATION ZONE FOR THE FIRST HUMAN LANDING ON MARS, S. Gupta[1], E. Sefton-Nash[2], J. Adler[3], M. Rice[4], P. Fawdon[5], N.H. Warner[6], P. Grindrod[2], J. Davis[7], M. Balme[5], J.F. Bell III[3], C. Stetson[4], J. Richard[8], [1]Dept. of Earth Science & Engineering, Imperial College, London, UK (s.gupta@imperial.ac.uk), [2]Dept. of Earth and Planetary Sciences, Birkbeck, University of London, UK, [3]School of Earth and Space Exploration, Arizona State University, Tempe, AZ, USA, [4]Western Washington State Univ., Bellingham, WA, USA, [5]Dept. of Physical Sciences, The Open University, Milton Keynes, UK, [6]Dept. of Geological Sciences, SUNY Geneseo, USA,[7]Dept. of Earth Sciences, University College London, UK. [8]Deltion Innovations Ltd, Capreol, Ontario, Canada.

Introduction: The human exploration of Mars is a major future goal of Solar System exploration. Here we propose a region of Xanthe Terra at the edge of the Chryse basin that harbors a major deltaic sedimentary system – the Hypanis delta - that likely fed into a major lacustrine basin, even potentially a Chryse sea, as an Exploration Zone (EZ) for a future human mission to Mars. We propose that this site has high potential for major scientific discoveries in terms of: the habitability of ancient Mars and the opportunities for preservation of fossil biosignatures, the history of aqueous processes and climate evolution on Mars, relative stratigraphic reconstruction, and the exploration of Noachian and Hesperian crustal units that have potential to contain rock units dateable by radiometric methods. The Hypanis Exploration Zone also fulfills the ISRU and Civil Engineering (CE) requirements for a human mission to Mars.

Overview: The Hypanis EZ in northern Xanthe Terra is situated on the dichotomy boundary. Our study area includes fluvio-deltaic deposits at the termini of Sabrina Vallis and Hypanis Vallis [1, 2]. Mapped Sabrina terminal deposits are constrained to within the buried crater, Magong. The Hypanis deltaic system is more extensive, with multiple mapped depositional lobes extending to the north and east (Fig. 1) [1]. Onlapping relationships with superposing deposits and crater ejecta reveal that both deltaic formations occupy the lowest stratigraphic position in the study area.

Significant aeolian modification has occurred since formation, with crater counts on both Sabrina [2, 3] and Hypanis [4] delta units revealing crater-retention ages of < 100 Ma, supported by the presence of ubiquitous aeolian features and suggesting recent exhumation from overburden. The large crater population classifies the study area as mid to late Noachian terrain [5]. Cross-cutting relationships of channels and crater ejecta blankets in the headwaters demonstrate that Hypanis Vallis formed >3.7 Ga ago in the Early Hesperian [6].

Landing and trafficability: Closely-spaced transverse aeolian ridges (TARs) on top of delta units (Fig. 1) prevent landing directly on upper delta material, because TAR morphology produces adverse slope conditions for EDL and rover locomotion. However, extensive smooth plains units, are less hazardous for landing and traversing, and occupy a significant areal fraction of the ellipse.

Science ROIs: An extensive array of science ROIs are present in the 100 km EZ (Fig. 1):

1. *High Preservation Potential Deposits:* ROIs with high preservation potential for past habitability and fossil biosignatures are provided by deltaic sediments from two systems: the Hypanis and Sabrina deltas. Downstream and laterally to their margins are extensive exposures of finely-layered likely sedimentary materials that may represent ancient lacustrine deposits that have high preservation potential for organics if ever they were present. These form compelling science targets because they formed in low energy depositional environments caused by suspension sediment fallout downstream of deltas.

2. *Aqueous Mineralogical Signatures:* There are two full-resolution short (FRS) CRISM hyperspectral observations within the study area. FRS0003157E shows a 1.9 µm hydration signature that spatially aligns with exposed strata in eroded deltaic sediments, indicating putative hydrated minerals in discrete layers A spectral unit in FRS0003134F just east of the rim of Magong crater is defined by the combined presence of the 1.9 µm absorption plus a strong 2.3 µm dropoff in reflectance, indicative of the presence of Fe/Mg-phyllosilicates. These spectral signatures spatially correspond to fractured areas within polygonally ridged terrain. The unit is between, but not immediately adjacent to, the Sabrina or Hypanis deltas, perhaps indicating that extensive ancient fluvial activity has influenced mineralogy throughout the region. Extensive CRISM coverage of the Sabrina Vallis delta deposits in Magong crater also indicates a weak Fe/Mg-phyllosilicate signature that is consistent with the presence of nontronite, verminculite or saponite in delta sediments [3, 4].

3. *Pertinent/Regional Stratigraphic Contacts.* The fluvial-deltaic units provide abundant stratigraphic contacts that would enable reconstruction of the aqueous evolution of the region and provide relative age constraints. In the southern part of the EZ, valleys

that cross-cut the Noachian bedrock units along the dichotomy provide excellent opportunities to characterize the stratigraphic relationship between Highland Plains and Lowland Plains units. These rocks potentially contain ash beds and lava flows, the ages of which might be constrained by radiometric dating methods. In the northern part of the EZ, extensive large crater rims preserve examples of fine scale layering and complex crater rim topography with highly interesting geologic relationships.

4. *Other ROIs:* A fresh, complex impact crater in the southeastern EZ preserves an ejecta blanket and rays, exposes bedrock units and allows an opportunity to study cratering mechanics. Finally, the northern EZ allows access to wrinkle ridges that extend to the north, covering Hesperian lava plains.

Resource ROIs: In-situ water resources are potentially provided by the extensive aeolian dune sands. Observations by MSL of atmospheric water adsorbed in dune sands [7] and 3-6 wt. % H_2O in sands at Rocknest [8] show potential for mining sands within the EZ for water resources. Within a 5 km radius of the proposed landing site, there areal extent of TAR sand deposits is roughly 23.5 km^2. The absence of crater retention indicates that the TARs are weakly indurated and could be easily mobilized to a processing facility constructed on adjacent, level bedrock.

The presence of Fe-Mg clays also offers the potential to recover water from hydrated mineral resources. These deposits, together with silicon and metals in mafic minerals, would also provide metal and silicon resources. TAR sands would provide important building materials. In addition, abundant overhanging ledges in the deltaic stratigraphy would provide habitation construction with radiation shielding.

Summary: The Hypanis site displays clear evidence for the long-lived action of water in the Early Hesperian across the Martian dichotomy boundary. Low-energy depositional environments that formed downstream of prominent delta bodies may have concentrated any potential biosignatures. A variety of Resource ROIs are also present that together with the diverse Science ROIs make Hypanis a compelling future human EZ.

References: [1] Gupta, S. et al., (2014), ExoMars 2018 First Landing Site Selection Workshop (LSS WS#1), ESAC, Spain. [2] Platz, T. et al., (2014) First Mars 2020 Landing Site Workshop, Crystal City, VA, USA. [3] Hauber, E. et al., (2015) 2nd Mars 2020 Landing Site Workshop, Pasadena, CA, USA. [4] Hauber, E. et al., (2009), *Plan. Space Sci.* 57, p. 944-957. [5] Werner (2014) *Pers. Comm.* [6] Eckes et al. (2015) GSA Annual Meeting abs. [7] Meslin et al., *Science*, 2013. [8] Leshin et al., *Science*, 2013.

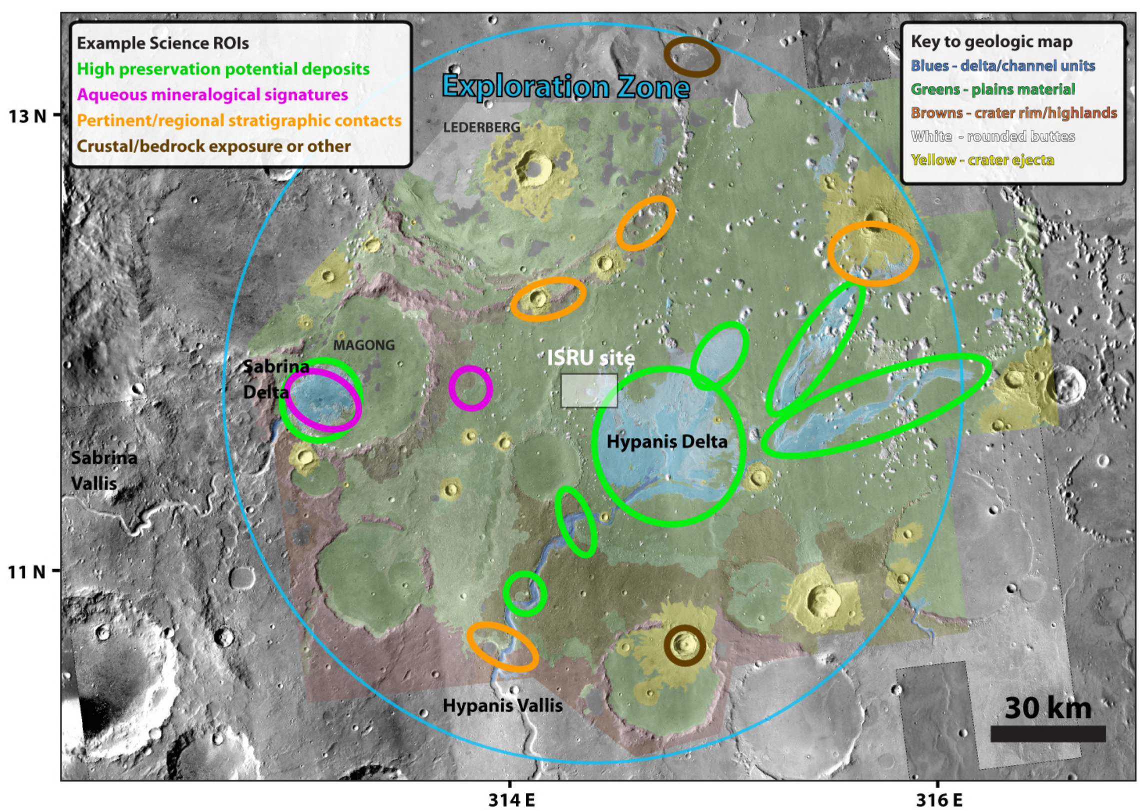


Figure 1. Exploration Zone (EZ) map of the Hypanis region in Xanthe Terra with key regions of interest (ROIs).

AUSONIA CAVUS AND KASEI VALLES: COMPLEMENTARY EXPLORATION ZONE SITES FOR BIOLOGY, GEOLOGY AND ISRU. J.C. Hamilton[1,3], S. Lundblad[2], D.L. Clark[4], N.G. Purves[1], C.T. Milovsoroff[2], N. Thomas[1]. [1]Dept. of Physics & Astronomy, University of Hawai`i at Hilo. jch@hawaii.edu, purves@hawaii.edu & nthomas@hawai.edu. [2]Dept. of Geology, University of Hawai`i at Hilo, Hilo, HI 96720, lunblad@hawaii.edu & colinmil@hawaii.edu. [3]Pacific International Space Center for Exploration Systems, 99 Aupuni St., Hilo, HI 96720 [4]Space Resource Technologies, LLC, Denver CO, david.clark11@comcast.net.

Introduction: Two candidate EZs are proposed that are rich in geologic history and exhibit water evidence for astrobiology. Both sit midway down flow features in erosional valley networks.

Ausonia Cavus (Figure 1) lies at the beginning of the drainage features Dao and Niger Valles downslope of the Noachian volcano Tyrrhenus Mons on the Hesperia Planun which continues past Ausonia Caves down to Hellas Planetia (one of the lowest elevation features in the southern hemisphere). Its geologic attraction is the ability to sample ancient lava flow basalt rocks from the Tyrrhenus Mons erosional deposits and glacial flow. The major lava channel from the caldera and pit craters flows to this area. By analogy with terrestrial shield volcanoes, this area should contain extensive lava tube systems. A nearby Hesperian volcano (Hadriacus Mons) dominates the eastern topography, allowing sampling of that era in close proximity. Ausonia Mensa, a large remnant mountain of the Noachian era, is SSE rising above basaltic sheet flow layers. Many early Noachian highlands massifs exist here. The EZ is NNE of a proposed Mars Science Lab landing site in Hellas Basin/Dao Vallis.

Ausonia Cavus and nearby Peraea Cavus may be paleolakes from the Hesperian Age or earlier. Phyllosilicates and hydrated sulfates (or lack thereof) in or near these would help constrain the Hesperian environment.[1] There is evidence of ice-rich lobate debris features to the west on the low features at base of mound in Promethei Terra. CRISM imagery shows nearby glacial cirques, fan shaped deposits and drop moraines [2].

These lobate debris features are believed to be glaciers covered with a layer of rocks and dust [3]. These features offer an easily accessible source of water without having to go to higher latitudes. These glacial feature offer water concentration of 70% or greater and can reduce the quantity of raw material required by a factor of 10 or greater compared to hydrated minerals [4]. The energy required to extract this resource would also be lower due to the high temperatures required for complete extraction of mineral-bound water.

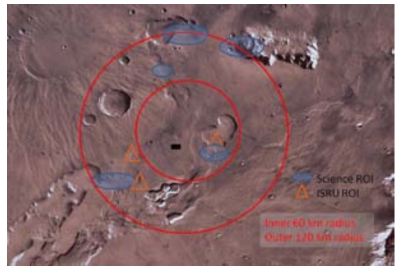
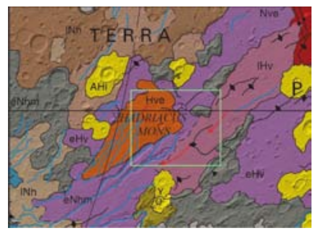
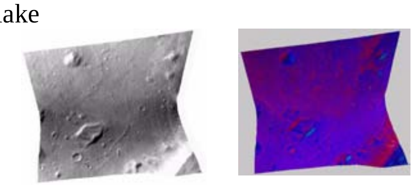


Figure 1- Ausonia Caves (32.0S, 96.5E)



From an exploration viewpoint, the floor of Ausonia Cavus is easily accessible from the south shore with a gentle sloping terrain. MRO imagery shows outflow and runoff near this southern area. This appears to be a breach of the lake with small sediment fans, although outcrops of what may be Fe/Mg phyllosilicates are seen which likely formed in-situ during the period of lake activity. Outcrops of clay minerals (Fe/Mg phyllosilicates) that likely formed under conditions favorable life may contain fossil biosignatures. Clay hydrogels may have been a vector for chemicals to form complex biomolecules in the early evolution of life [5]. Multiple 30-50 m outcrops populate the lake bottom. [6] The lake draining episode may have been short lived with large discharge velocities, creating scablands downstream.*Science ROIs:* Ausonia Mensa - Noachian Massif, Peraea Cavus – paleolake, Hadriacus Mons channel (Hesperian), Upper Niger Valles. *Resource ROIs:* Lobate debris features, Regolith medium dust, Ausonia Mensa - iron regolith filled lake


CRISM images for floor: Visible and Iron/Phyllosilicates

LZ (black box); Landing zone terrain supports ISRU for landing pad with sintered basalt tiles.

Kasei Valles (Figure 2) is attractive because it cuts through and surrounds an early Hesperian highland area exposing the Noachian highland base. It resides at the lower end of the Tharsis region drainage basin/aquifer system thought to be active during the Noachian Period. [7] The basin was subsequently filled lava, sediments, and volatiles partly infilling the basin, resulting in an enormous and productive regional aquifer. Strong flow features abound in this area, with teardrop outcrops to the south west in Sacra Sulci indicating depositional opportunities downslope with evidence for several episodes of flooding and possible glacial activity. [8] MOLA profiles of these outflow channels show several narrow, inner channels which is interpreted that the system was active over a significant period of time and likely involved several separate flood events, and a longer fill time to form the northern Martian ocean. [9]

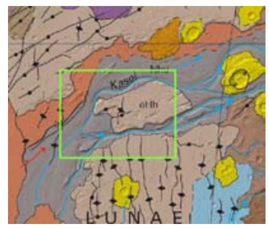
Noachian era terrains are of great astrobiological interest due to evidence of large bodies of water and a denser atmosphere.Exposure of of the Noachian and Hesperian boundary can provide more information on early Martian environmental processes leading to insight on potential mechanisms of biosignature preservation.

Kasei Valles is west of the Viking 1 and Pathfinder landing zones in the Chryse Planitia. There are two subareas in this zone worthy of further consideration.

Both areas sample a wide variety of rock types and ages from surrounding highlands. The first area lies near an outflow channel with access into the lower channel and a large filled crater (Lat and Long). The crater has exposed impact ejecta and infilling sediment. Subarea 2 is at an abrupt change in channel direction, and upstream from the area of thick dust accumulation, as indicated by bright IR night thermal images. This is the likely site of significant deposition in the form of gravel and boulder-rich point bars. The main channels are potential sites of fine-grained material well-suited for ISRU processing. Analog sites exist at glacial outwash plains on Mauna Kea [10], Keanakāko`i Tephra Drainage Network, Ka'u Desert) [11] and the Channeled Scablands of Washington State.

South of this site lie extensive lava flows. Access into the channel appears to be allowed from the northern bank, where the channel bottom should be rocky and firm as it is cut bank of the gully. This extensive outflow region could harbor subsurface ice left behind in mud flows in the waning stages of fluvial activity. [12]

Figure 2 - Kasei Valles (24.81N, 287.37E)



It has been suggested that platy surface textures are formed by large ice plates carried along in the mud flow. There are also multiple examples of lobate debris aprons that suggest high ice content resulting in ice-assisted creep features. [13] The authors would like to acknowledge these technical contributions from HI-SEAS (Kim Binsted) on astronaut exploration ranges and PISCES (Rodrigo Romo) for rover mobility ranges and construction & sintering ISRU assessments (Christian Andersen).

References:

[1] Dehouck et al. Planetary and Space Science 58 (2010) 941-946. [2] Kadish S.J. et al. Planetary and Space Science 91 (2014) 52-59. [3] Holt, J. W. et al., LPS. XXXIX: (2008) 2441. [4] Supplemental Background Information, workshop. [5] Yang, D., Peng, S., Hartman, M.R., et al. *Scientific Reports* (2013). [6] MRO Context Camera images CTX: P18_008175_1480_XN_32S263W (EAST) & CTX: P02_001648_1476_XN_32S263W (WEST). [7] Dohm J.M. et al (2001) JGR*,* 106*(*E12*),* 32943–32958
[8] Williams, R., Phillips, R., Malin, M. http://tharsis.gsfc.nasa.gov/grl_kasei.PDF. [9] Carr, M. A&G (2000) (3): .20-3.26. [10] Sanders et al. Vol. 6 EPSC-DPS2011. [11] Craddock R.A. et al. Journal of Geophysical Research 117 (2012) 1-19
[12] R.Williams and M. Malin JGR, VOL. 109, E06001, 2004. [13] S. van Gaselt, et.al. 41st Lunar and Planetary Science Conference (2010)

MARS HUMAN SCIENCE EXPLORATION AND RESOURCE UTILIZATION: THE DICHOTOMY BOUNDARY DEUTERONILUS MENSAE EXPLORATION ZONE

James Head[1], James Dickson[1], John Mustard[1], Ralph Milliken[1], David Scott[1], Brandon Johnson[1], David Marchant[2], Joseph Levy[3], Kjartan Kinch[4], Christine Hvidberg[4], Francois Forget[5], Dale Boucher[6], Jill Mikucki[7], James Fastook[8], Kurt Klaus[9].
[1]Brown University, Providence, RI USA; [2]Boston University, Boston, MA USA; [3]University of Texas Institute for Geophysics, Austin, TX USA; [4]Nils Bohr Institute, University of Copenhagen, Copenhagen, Denmark; [5]Laboratoire de Météorologie Dynamique, Université Pierre et Marie Curie, Paris, France; [6]Deltion Innovations, Capreol, Ontario CA; [7]Middlebury College, Middlebury, VT USA; [8]University of Maine, Orono, ME USA; [9]Boeing Company, Houston, TX USA. James_head@brown.edu

The Dichotomy Boundary Deuteronilus Mensae (DBDM) Exploration Zone (EZ) (39.11˚ N, 23.199˚ E) combines: 1) Fundamental MEPAG scientific objectives for the exploration of Mars (geology, atmosphere/climate history, hydrology, astrobiology)(1-6; 8-18); 2) Samples/questions from each of the three major geologic eras (Noachian, Hesperian, Amazonian); 3) The certainty of ISRU (I), including access to abundant stores of water ice mapped by SHARAD (16); and 4) Civil Engineering (CE) opportunities, including manipulating material/ice and reducing reliance on Earth supplies. We combine these four themes into the term *Science/ICE*. We illustrate the *Science/ICE* theme in the selection of our current top priority EZ along the DB (Figure 1), among numerous candidate DB EZ sites we have investigated (Figure 2).

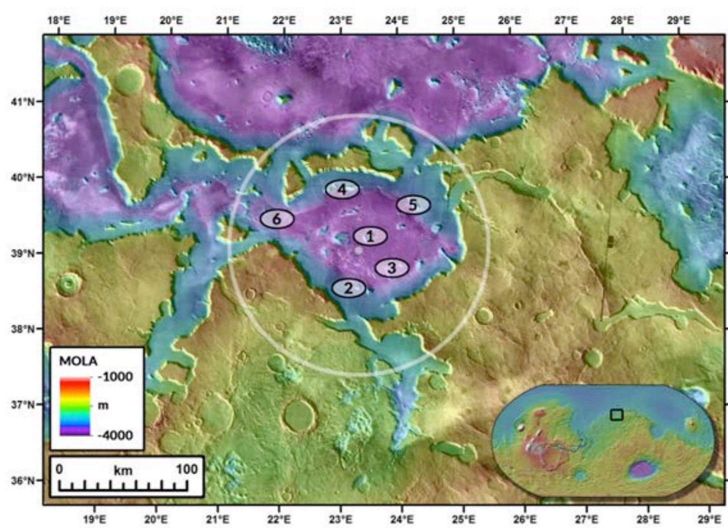


Figure 1. The Dichotomy Boundary Deuteronilus Mensae (DBDM) Exploration Zone (EZ) outlined as a circle of 100 km radius, with the Landing Site/Surface Field Station (denoted by star) centrally located and slightly separated to assure safe descent and ascent. Science and Resource ROIs (always combined) are indicated by numbers and described in the text. For geological units within EZ, see (18); floor is HNps (smooth plains); LDA is Ada (debris aprons); Flat plateaus are Nplsu (upper smooth plateau material). Basemap is a THEMIS daytime IR mosaic overlain on MOLA gridded topography.

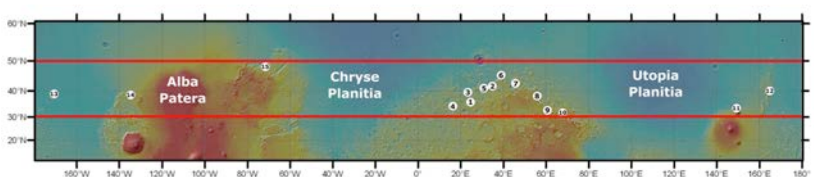


Figure 2: Location of additional EZs with similar objectives that have been investigated. See references for guide.

EZ Rationale: Science goals/ROIs are based on abundant study and analysis by our group (see selected references), span the entire geologic history of Mars, and include: 1) *Amazonian* climate record and nature of glacial processes in Latitude-Dependent Mantle (LDM) deposits on the crater floor, and ice in Lobate Debris Aprons (LDA) and Lineated Valley Fill (LVF); 2) *Hesperian/Noachian* Ridged Plains (NHr), composition and mode of emplacement (basaltic talus in LDA), and possibility of a northern lowlands ocean. 3) *Noachian* crustal composition, diversity, history of alteration (hydrothermal, groundwater, surface, subsurface; relation to global remote sensing signatures), climate history (comparison of A/H/N suite of rocks), and origin of the dichotomy boundary (shocked rocks from Borealis basin?) in surface materials and LDA talus.

All of our Science ROIs (Figure 1) are in the same areas as our I/CE ROIs as the LDAs and surrounding terrains provide access to water and CE tasks for surface manipulation, resource access and infrastructure emplacement and protection. This DBDM/EZ *Science/ICE* concept is very robust as it has abundant backup EZs (Figure 2) for exploring trade space and optimizing science and engineering synergism.

ISRU Activities: These activities should focus on life support and mission support. Water ice is the most important commodity, and the most important factors are: *grade* (how clean or chemically contaminated is the product) and *concentration* (how much ice per kg of debris "waste"), followed very closely by *site logistics and extraction feasibility*. Atmospheric modeling suggests ice cement at shallow depths, and layered deposits similar to the LDM are prominent on the floor and may provide relatively pure ice or ice lenses. The key locations for water ice resources, however, are the LDA, shown by SHARAD results to be *high-grade*, *high concentration* (nearly pure) water ice, lying below less than 10-15 meters of sublimation till, itself a major resource for construction and shelter, as well as of fundamental scientific interest.

Science-Resource ROI 1: Located nearby the landing site, this ROI is represented by the Noachian-aged crater central peak, uplifting and exposing deeper crustal material, and by LDM fragments that expose the climate record and are a potential water resource. **Science-Resource ROI 2:** Base of the LDA with water ice resources at shallow depths and a rock material suite that will include samples brought from the broader region to the south. **Science-Resource ROI 3:** Extensive flat-lying LDM several tens of meters thick, containing an Amazonian climate record and nearly pure ice intercalated with ice-cemented debris. **Science-Resource ROI 4:** Distinctive LDA protruding through ridge representing potential peak ring of Noachian-aged crater (Figure 3). Access to water ice in near subsurface and suite of samples from terrain to the north. **Science-Resource ROI 5:** Ridge representing potential peak ring of Noachian-aged crater; LDA banked behind with LDA lobes on both sides of the outcrop of ancient crustal material. **Science-Resource ROI 6:** Outlet from Noachian-aged crater floor to west provides access to additional LDA and wrinkle-ridge-like structure that may mark the location of ancient lavas.

We utilize our Apollo experience in site selection and mission operations and engage our Immersive Virtual Reality (IVR) capability (7) in visualizing mission concepts and architectures, Landing Site selection, Surface Field Station placement, traverse planning, and resource extraction planning. We also engage IVR in EDL, surface operations and public impact and outreach assessments. Detailed exploration concepts are being developed for each ROI.

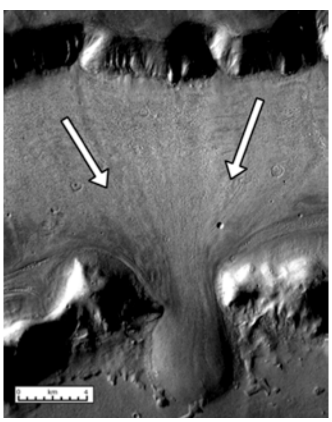


Figure 3. LDA at ROI 4

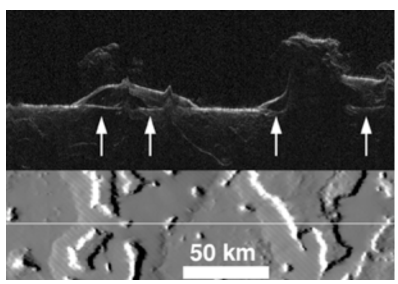


Figure 4. SHARAD profile N-S across central DBDM EZ (16).

Selected References: 1) D. Baker et al. (2010) Flow patterns of lobate debris aprons and lineated valley fill north of Ismeniae Fosse, Mars: Evidence for extensive mid-latitude glaciation in the Late Amazonian, *Icarus, 207,* 186-209, doi: 10.1016/j.icarus.2009.11.017. 2) J. Dickson and J. Head (2008) Late Amazonian glaciation at the dichotomy boundary on Mars: Evidence for glacial thickness maxima and multiple glacial phases, *Geology, 36,* 411-414, doi: 10.1130/G24382A.1. 3) J. Dickson et al. (2012) Patterns of accumulation and flow of ice in the mid-latitudes of Mars during the Amazonian, *Icarus, 219,* 723-732, doi: 10.1016/j.icarus.2012.03.010. 4) J. Fastook and J. Head (2014) Amazonian mid- to high-latitude glaciation on Mars: Supply-limited ice sources, ice accumulation patterns, and concentric crater fill glacial flow and ice sequestration, Planet. Space Sci., 91, 60-76, doi: 10.1016/j.pss.2013.12.002. 5) J. Fastook et al. (2011) Evidence for Amazonian northern mid-latitude regional glacial landsystems on Mars: Glacial flow models using GCM-driven climate results and comparisons to geological observations, *Icarus, 216,* 23-39, doi: 10.1016/j.icarus.2011.07.018. 6) J. Fastook et al. (2014) Formation of lobate debris aprons on Mars: Assessment of regional ice sheet collapse and debris-cover armoring, Icarus, 228, 54-63, doi: 10.1016/j.icarus.2013.09.025. 7) J. Head et al. (2005) ADVISER: Immersive Scientific Visualization Applied to Mars Research and Exploration, *Photogrammetric Engineering and Remote Sensing, 71,* 1219–1225. 8) J. Head et al. (2006a) Modification of the dichotomy boundary on Mars by Amazonian mid-latitude regional glaciation, *Geophys. Res. Lett., 33,*L08S03, doi: 10.1029/2005GL024360. 9) J. Head et al. (2006b) Extensive valley glacier deposits in the northern mid-latitudes of Mars: Evidence for Late Amazonian obliquity-driven climate change, Earth Planet. Sci. Lett., 241, 663-671, doi: 10.1016/j.epsl.2005.11.016. 10) J. Head et al. (1998) Oceans in the past history of Mars: Tests for their presence using Mars Orbiter Laser Altimeter (MOLA) data, *Geophys. Res. Lett., 25,* 4401-4404. 11) J. Head et al. (2010) Northern mid-latitude glaciation in the Late Amazonian period of Mars: Criteria for the recognition of debris-covered glacier and valley glacier landsystem deposits, *Earth Planet. Sci. Lett., 294,* 306-320, doi: 10.1016/j.epsl.2009.06.041. 12) J. Holt et al. (2008) Radar sounding evidence for buried glaciers in the southern mid-latitudes of Mars, *Science, 322,* 1235-1238, doi: 10.1126/science.1164246. 13) J. Levy et al. (2007) Lineated valley fill and lobate debris apron stratigraphy in Nilosyrtis Mensae, Mars: Evidence for phases of glacial modification of the dichotomy boundary, J. Geophys. Res., 112, E08004, doi: 10.1029/2006JE002852. 14) J. Levy et al. (2014) Sequestered glacial ice contribution to the global martian water budget: Geometric constraints on the volume of remnant, midlatitude debris-covered glaciers, J. Geophys. Res., 119, 1-9, doi: 10.1002/2014JE004685. 15) S. Mackay et al. (2014) Cold-based debris-covered glaciers: Evaluating their potential as climate archives through studies of ground-penetrating radar and surface morphology, J. Geophys. Res., 119, 2505-2540, doi: 10.1002/2014JF003178. 16) J. Plaut et al. (2009) Radar evidence for ice in lobate debris aprons in the mid-northern latitudes of Mars, *Geophys. Res. Lett., 36,* L02203, doi: 10.1029/2008GL036379. 17) J. Head et al. (2002) Recent ice ages on Mars, Nature, 426, 797-802. 18) F. Chuang and D. Crown (2009) Geologic map of MTM 35337, 40337, and 45337 quadrangles, Deuteronilus Mensae region of Mars: U.S. Geological Survey Scientific Investigations Map 3079.

WESTERN NOACHIS TERRA CHLORIDE DEPOSITS: AQUEOUS MINERALS WITH HIGH ASTROBIOLOGICAL PRESERVATION POTENTIAL.

J. R. Hill[1] and P. R. Christensen[1], [1]Arizona State University, Tempe, AZ 85287, jonathon.hill@asu.edu.

Introduction: The chloride deposits located in western Noachis Terra at 350.5°E, -37.2°N represent the closest occurrence of chloride deposits [1] to glacier-like forms [2] on the Martian surface separated by potentially traversable terrain and located within the human exploration zone latitude and elevation constraints. Chloride deposits provide ideal conditions for the long-term preservation of biosignatures in the form of fluid inclusions, microbial fossils and organics [3]. Glacier-life forms (GLFs) are indicators that near-surface water ice, shielded by dust and regolith, is present and has undergone deformation in the recent geologic past [2].

The exposed chloride deposits are located at the center of an ~40km diameter basin with both inlet and outlet channels, suggesting it was once an overfilled paleo lake system where water would have ponded and evaporite minerals could have formed. The basin lies in Middle Noachian-aged terrain and the proposed exploration zone contains contacts with surrounding Early Noachian and Late Noachian surfaces [4].

A ~25km diameter crater to the southeast of the proposed landing site contains many morphologic features associated with subsurface water ice, including lineated valley fill [5], pasted terrain [6], viscous crater fill [7], gullies [8], and possibly recurring slope lineae [9] along the eastern rim.

Table 1: Landing Site Characteristics

Coordinates (Center)	350.5785°E, -37.4214°N
Elevation	1,181 m – 1,219 m
Area	28.3 km^2 (3 km radius)
Slope	0.0997° – 1.1488° (MOLA)
Thermal Inertia	206 – 286 J m^{-2} K^{-1} s$^{-½}$
Albedo	0.15

Table 2: Regions of Interest - Science Requirements

Requirement	ROIs
High Preservation Potential Deposits	1
Potentially Habitable Environments	2
Noachian Rocks in Stratigraphy	3,4,5,6
Aqueous Mineral Deposits	1
Contacts and Superposition Sites	1,3,4,5,6

Table 3: Regions of Interest - Resource Requirements

Requirement	ROIs
H_2O (<100MT) ISRU Feedstock	7,8
H_2O (>100MT) ISRU Feedstock	9
Metal/Silicon ISRU Feedstock	10

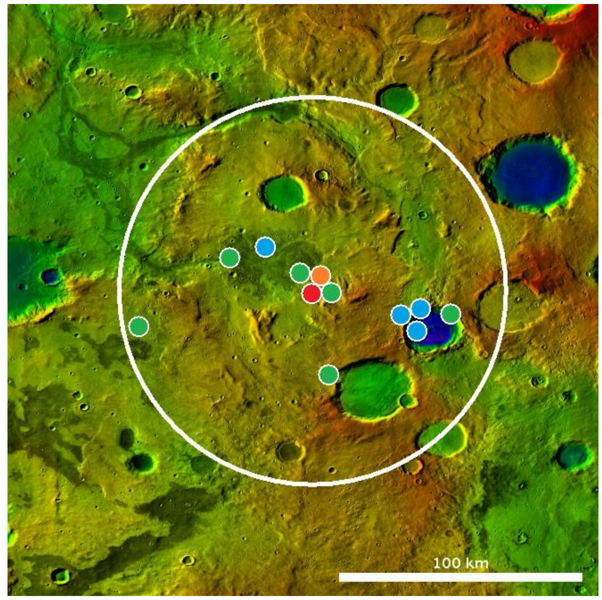


Figure 1: Location of the proposed exploration zone (white), centered at 350.5°E, -37.2°N, west of Argyre Planitia in Noachis Terra, including the proposed landing site (red), habitation site (orange), science ROIs (green) and resource ROIs (blue). MOLA [10] topography over THEMIS Day IR mosaic [11].

Chloride Deposits: Deposits of chloride bearing materials were first identified on Mars by their distinctive appearance in THEMIS decorrelation stretched infrared images [12] (Figure 2). A global survey of the deposits revealed that they are almost exclusively constrained to Noachian and early Hesperian terrains in the southern highlands, usually occur in local topographic lows, are consistent with formation via ponding of surface runoff or groundwater upwelling, and are likely the result of one or more globally ubiquitous processes early in Mars' history [1].

Additional studies have shown that the chloride deposits often occur along phyllosilicates [13,14] and that both their near-infrared [15] and thermal infrared [1,16] spectra are consistent with chloride minerals mixed with basaltic material.

The existence of chloride mineral deposits on Mars has significant astrobiological implications. As noted by [1], studies of ancient terrestrial chloride salt deposits have demonstrated that they preserve microbial fossils [17], cellulose fibers [18], halophilic microorganism biomarkers [19], and fluid inclusions that preserve water chemistry and can serve as long-term refuges for halophilic microorganisms [20,21,22,23,24,25,26].

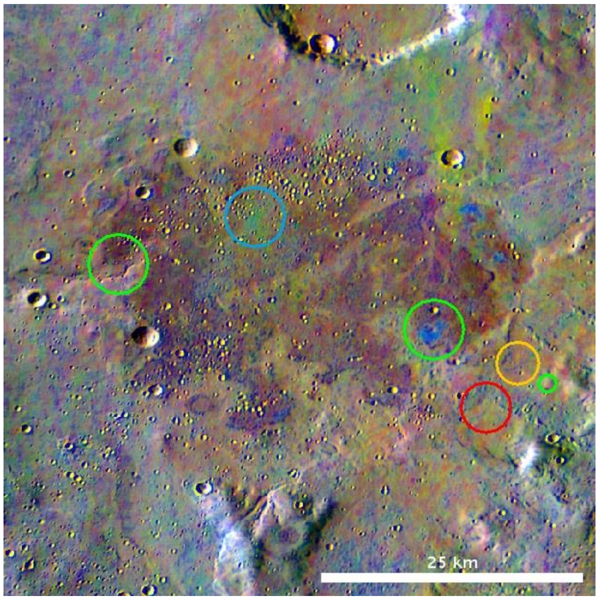


Figure 2: Chloride deposits (dark blue units) with the proposed landing site (red), habitation site (orange), science ROIs 1, 3, 6 & 10 (green), and resource ROI 10 (light blue). THEMIS DCS 875 mosaic [27].

Regions of Interest: The proposed exploration zone surrounding the western Noachis Terra chloride deposits contains a wide variety of potential science and resource regions of interest (ROIs).

ROI 1: Chloride Deposit. The largest of the exposed chloride deposits [1] provides access to geologic materials with high astrobiological preservation potential [3] that were emplaced in an aqueous environment that may have been habitable. Distance from landing site: ~10km.

ROI 2: Gullies and Potential RSL. The eastern rim of the ~25km diameter crater to the southeast of the proposed landing site has been incised by numerous gullies and may be the location of some limited recurring slope lineae (RSL) activity. Distance from landing site: ~60km.

ROI 3: Middle Noachian Outcrop. An outcrop sample of the Middle Noachian materials surrounding the chloride deposits may be obtainable from a high thermal inertia region to the east of the proposed landing site. Distance from landing site: ~6km.

ROI 4: Early Noachian Outcrop. Outcrops of Early Noachian materials may be available in a high thermal inertia region to the south of the landing site. Distance from landing site: ~45km.

ROI 5: Late Noachian and Remnant Magnetism Outcrop. Outcrops of Late Noachian material that lie within a region of remnant crustal magnetism [28] may be obtainable from a high thermal inertia region east of the landing site. Distance from landing site: ~75km.

ROI 6: Channel with Exposed Stratigraphy. The outflow channel from the chloride deposit basin potentially contains a large cross-section of exposed stratigraphy. Distance from landing site: ~40km.

ROI 7: Lineated Valley Fill. Two small (~100m x ~1.25km) channels with possible lineated valley fill (LVF). If the presence of lineated valley fill in these channels can be confirmed, it would represent a large concentration of subsurface water ice in relatively close proximity to the proposed landing site. Distance from landing site: ~35km.

ROI 8: Pasted Terrain. Larger deposits of subsurface water ice are likely available in the form of pasted terrain along the upper rim and south-facing ejecta slopes of the ~25km diameter crater to the southeast of the landing site. Distance from landing site: ~40km.

ROI 9: Viscous Crater Fill. The largest potential source of subsurface water ice in the exploration zone is on the floor of the ~25km diameter crater in the form of viscous crater fill material similar to concentric crater fill (CCF). Distance from landing site: ~45km.

ROI 10: Silica Enriched Material. The basaltic material that surrounds, and presumably lies stratigraphically above, the exposed chloride deposits contains a ~25km^2 area of silica enrichment identified in TES spectra. Distance from landing site: ~30km.

References: [1] Osterloo et al., (2010) *JGR*, 115, E10012. [2] Souness. et al. (2012) *Icarus*, *217*, 243-255. [3] J. D. Farmer and D. J. Des Marais (1999) *JGR*, 104, E11, 26977. [4] Tanaka et al. (2014) *USGS*, Map 3292. [5] Squyres, (1978) *Icarus*, 34, 600. [6] Christensen, (2003) *Nature*, 422, 45. [7] Squyres, (1979) *Icarus*, 84, B14. [8] Main and Edgett, (2000) *Science*, 288, 5475. [9] McEwen et al., (2011) *Science*, 333, 6043. [10] Smith et al., (2001) *JGR*, 106, 23689. [11] Edwards et al., (2011) *JGR*, 116, E10008. [12] Osterloo et al., (2008) *Science*, 319, 1651. [13] Murchie et al., (2009) *JGR*, 114, E00D06. [14] Glotch et al., (2010) *GRL*, 37, L16202. [15] Jensen and Glotch, (2011) *JGR*, 116, E00J03. [16] Lane and Christensen, (1998) *Icarus*, 135, 528. [17] Huval and Vreeland, (1992) *General and Applied Aspects of Halophillic Bacteria*, ed. Rodriguez-Valera, 53-60. [18] Griffith et al., (2008) *Astrobiology*, 8, 215. [19] Barbieri et al., (2006) *Planet. Space Sci.*, 54, 726. [20] Norton and Grant., (1988) *J. Gen. Microbiol*., 134, 1365. [21] Javor, (1989) *Hypersaline Environments*, pp. 334. [22] Norton et al., (1993) *J. Gen. Microbiol*., 139, 1077. [23] Vreeland et al., (2000) *Nature*, 407, 897. [24] Fish et al., (2002) *Nature*, 417, 432. [25] Satterfield et al., (2005) *Geology*, 33(4), 265. [26] Schubert et al., (2009) *Geology*, 37(12), 1059. [27] Hill et al., (in prep). [28] Connerney et al., (2005) *PNAS*, 102, 14970.

HABITABLE NOACHIAN ENVIRONMENTS AND ABUNDANT RESOURCES IN THE MAWRTH VALLIS EXPLORATION ZONE. B. Horgan[1], D. Loizeau[2], F. Poulet[3], J. Bishop[4], E.Z. Noe Dobrea[5], W. Farrand[6], J. Michalski[5], C. Gross[7], J. Kleinhenz[8], D. Linne[8]. [1]Purdue University (briony@purdue.edu), [2]Université de Lyon, [3]IAS, CNRS/Univ. Paris Sud, [4]SETI Institute, [5]Planetary Science Institute, [6]Space Science Institute, [7]Freie Univeristät Berlin, [8]NASA/Glenn Research Center.

Brief Rationale: The plateau above the Mawrth Vallis outflow channel near 340.8°E, 24.3°N contains the most extensive exposed outcrop of clay-rich rocks on Mars. These rocks are thought to have been emplaced as sediments and weathered *in situ* to form clay-rich soils. The clays offer a promising and substantial resource for water extraction, as well as Fe, Al, and Si feedstock, and have high biosignature preservation potential. This site allows access to deep crustal rocks at the base of Mawrth Vallis, two dateable volcanic surfaces, and many ancient habitable surface and near-surface environments with diverse geochemistries.

Site Geology: The plateau surrounding Mawrth Vallis exhibits a thick stack (200m+) of light-toned layered deposits that have near-infrared spectral characteristics consistent with a variety of clay minerals [1-14]. These clay-rich layers extend over much of western Arabia Terra, and are thought to represent a sedimentary sequence [1]. The regional extent of the upper altered sequence is consistent with a sub-aerial weathering origin for the clays, either due to top-down leaching of the stack or weathering concurrent with sedimentation to form a paleosol sequence [4,12,14]. However, the large thickness of the stack compared to

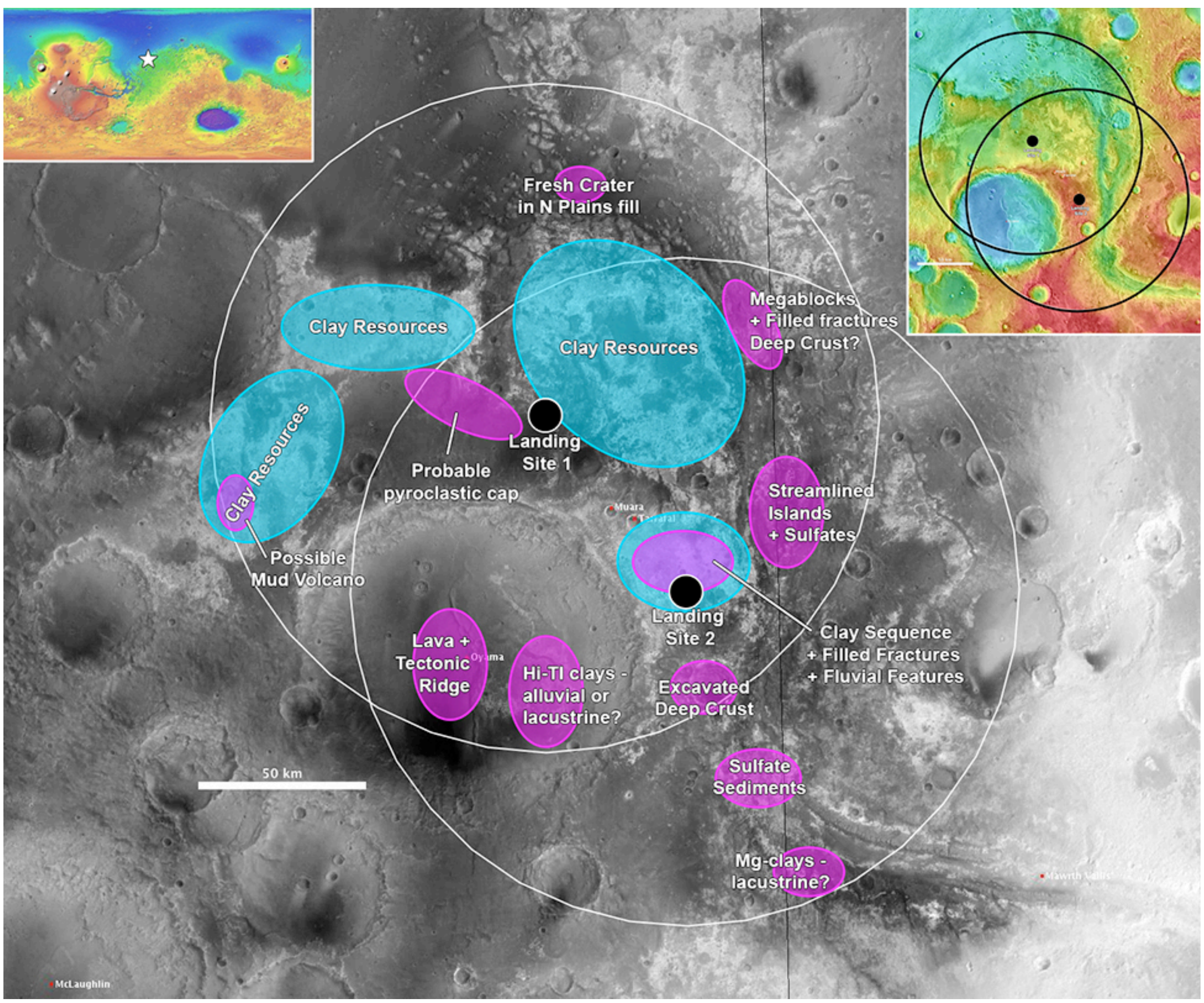


Figure 1: Mawrth Vallis Exploration Zone, HRSC red channel mosaic. Top left box shows location of site on MOLA global map, top right box shows local topography from MOLA. Blue circles indicate resource ROIs and pink circles indicate science ROIs. Landing Site 1 allows access to additional resource ROI's, the mouth of Mawrth Vallis, and the northern plains, while Landing Site 2 allows better access into Oyama Crater and to mineral deposits on the southern flanks of Mawrth Vallis.

other weathering profiles on Mars [15], the high mineralogical diveristy [3], and the presence of apparent unconformities and paleosurfaces within the units [7] are more consistent with a paleosol sequence [14,16].

The stratigraphy is divided into an upper unit containing mainly Al-phyllosilicates/hydrated silica and a lower Fe/Mg-smectite-rich unit. Within these units, variations in mineralogy include moderately weathered smectites, highly leached kaolins, Al/ferric acid sulfates, ferrous clays, and various poorly crystalline phases. An abundance of inverted channels preserved in the capping unit at the top of the sequence indicate aqueous processes that may have been active throughout the sequence [4,17]. Thus, these minerals likely formed in both soils and local aqueous environments (rivers, ponds, wetlands, lakes, aquifers, springs, etc.) with significant redox, pH, and saturation gradients providing clear energy pathways for microbes [18].

The age of the clays is constrained by a regional Early Hesperian dark capping unit of probable pyroclastic origin as well as several cratered paleosurfaces within the units, suggesting that the whole package was laid down between the Early and Late Noachian [6,16]. Thus, the Mawrth paleosol sequence has the potential to provide a record of ancient surface environments and, in particular, climate throughout the Noachian, more so than any other known site on Mars.

The Mawrth Vallis EZ also offers access to several other notable geologic features, including the dichotomy boundary and the outflow channel. Within Mawrth Vallis, there are streamlined islands potentially preserving flood deposits, sulfate sediments, fresh craters into northern lowlands materials, and co-occurring megablocks and filled fractures at several scales that may represent deep crust exposed by the outflows. Hydrothermal deposits may be present within halo-bonded fractures on the plateau, perhaps related to the Oyama impact during deposition of the sequence. Oyama Crater contains dateable lava flows, a regional tectonic ridge, and fluvially transported clays.

Biosignature Preservation Potential: Paleosol sequences have two key characteristics that promote preservation of biosignatures and organics: rapid burial, which protects buried materials from erosion, oxidation, and degradation at the surface, as well as high smectite clay content, which significantly decreases the permeability of sediments and protects against later degradation due to diagenetic processes [11,16]. Other local processes and/or environments within the soils can help to further enhance organic preservation, including reducing paleosols (e.g., wetlands) and silica deposition, both of which are inferred based on spectra at Mawrth [18]. Some of the redox reactions inferred at Mawrth may also be catalyzed by microbes, and thus may retain isotopic or physical biosignatures [19]. Concentration of biosignatures and organics may be locally enhanced in aqueous environments, especially reducing ponds or wetlands – for example, organic-bearing lignite/tonstein/seatearth deposits are not uncommon in paleosol sequences [16]. Elsewhere in the EZ, silica or sulfates in fractures as well as sulfate sediments could also facilitate biosignature preservation.

Resource Potential: The Mawrth region may represent one of the most valuable sites for exploration-related resources on Mars. Mixing models based on both near-IR and thermal-IR spectra of the Mawrth plateau surfaces suggest clay mineral abundances in excess of 50 wt.% [20-22], which is the largest clay abundance detected on Mars. Terrestrial analog paleosols from semi-arid environments typically contain anywhere from 35-100 wt.% clay minerals. In the thicker and more widespread lower unit, most of the clays are smectites, which have high water content suitable for extraction (5-20 wt.% [23]). Spectral unmixing of the lower unit also indicates a possible ferrihydrite component at ~15 wt.%, which would probably contribute similar levels of water [23], for a total of ~75 wt.% water-bearing minerals [20,21]. Spectral models support a high water content in these rocks, 7-9 wt.% at the surface [24]. The clay units could also be a good resource for iron, as they likely contains ferric (Fe/Mg-smectites) and ferrous (celadonite/glacuonite) clays [11], and iron sulfides [11,18,25]. The upper unit is modeled as a combination of kaolins (10-30 wt.%), smectite (20-40 wt.%), silica (5-15 wt.%), and ferrihydrite (5-15 wt.%) [22]. While the upper unit might produce less water than the lower unit, it could also be a valuable resource for aluminum and silicon.

References: [1] Michalski & Noe Dobrea (2007), *Geol.* 35, 10. [2] Loizeau *et al*. (2007) *JGR* 112, E08S08. [3] Bishop *et al*. (2008) *Science* 321, 830. [4] Noe Dobrea *et al*. (2010) *JGR* 115, E00D19. [5] Bishop *et al*. (2013) *LPSC 44*. [6] Poulet *et al*. (2005), *Nature 438*, 623–627. [7] Loizeau *et al*. (2010) *Icarus* 205, 396-418. [8] Farrand *et al*. (2009) *Icarus* 204, 478-488. [9] Wray *et al*. (2010) *Icarus* 209, 416-421. [10] Bishop & Rampe (2012) *LPSC 43*, #2277. [11] Bishop *et al*. (2013) PSS 86, 130-149. [12] Michalski *et al*. (2013) *Icarus* 226, 816-840. [13] Michalski *et al*. (2010) *Astrobio*. 10, 687-703. [14] Horgan *et al.* (2013) *EPSC* #511. [15] Carter et al (2015) *Icarus* 248, 373-382. [16] Retallack *et al*. (2000) *GSA Sp. Pap.* 344. [17] Loizeau *et al.* (2015) 2nd Mars2020 LSW. [18] Horgan *et al.* (2015) *AbSciCon* #7463. [19] Williams *et al*. (2015) *Astrobio.* 15, 537-668. [20] Poulet et al. (2008) A&A 487, L41-L44. [21] Viviano & Moersch (2013) *Icarus* 222, 497. [22] Poulet *et al*. (2014) *Icarus 231*, 65-76 [23] Bishop (2005) in *Water on Mars & Life*, doi:10.1007/b12040. [24] Milliken *et al*. (2007) *JGR* 112, E08S07. [25] Farrand *et al*. (2014) *GRL* 241, 346-357.

REFINING THE SEARCH FOR WATER ON MARS USING BALLOON-BORNE NEUTRON SPECTROMETERS. S. Johnstone[1], S. Montano[1], W.C. Feldman[1,2], L. Stonehill[1], [1]Los Alamos National Laboratory, Los Alamos, NM, [2]Planetary Science Institute, Tucson, AZ sej@lanl.gov.

Introduction: The search for water on Mars is critical for planning future human missions to the Red Planet. Having a substantial source of acceable water at an intended landing site will provide life support consumables (atmospheric O2 and crew water) and mission propellant. These two elements (crew water and propellant) represent a substantial mass for any Mars mission and leveraging this in-situ resource can be considered an enabling resource for any human mission to the Red Planet. Locating surface and near-subsurface water remotely on Mars can be accomplished using neutron spectrometers as was done on the Mars Odyssey Mission. Mars Odyssey orbited at an altitude of 400km and provide a global data set of water-equivalent hydrogen (WEH) abundance with a special resolutions on the order of 300km. Orbit-based neutron spectrometers are limited to this resolution range therefore in order to identify high-water content candidate landing sites for a future human Mars mission a higher resolution WEH survey is needed. The use of an air-borne neutron spectrometer flying over the martian surface at an altitude of 2-6km would provide km scale spatial resolutions of WEH. A survey of WEH even in a limited area of the planet would aid both a localized search for Martian water and allow for an educated extrapolation of regional martian water abundance estimates across a region.

Mission Concept: The most straightforward approach to increasing the spatial resolution of a remote sensing neutron spectrometer is to fly it close to the planetary surface. On a planet like Mars, this is best accomplished using a balloon with a tethered instrument package. Initial design estimates of mass, power, and mission duration of a martian balloon-borne neutron spectrometer indicate that the payload (spectrometer, framing camera, instrument electronics, solar panels) would be 100-150kg and would consume 5 to 10 watt-hour and have a mission lifetime of 45-60 sols. Deploying two or more of these payloads simultaneously would be preferred to increase mapping coverage of the target region and to increase maximum mission success.

Conclusion: A Mars balloon-borne neutron spectrometer as described here is a mission that can be accomplished with Technology Readiness Level (TRL) hardware of TRL6+. This type of mission would be well-suited as a secondary payload on a future mission such as Mars 2020. Assuming deployment on such a mission would place the balloon-borne neutron spectrometer in a region of considered human landing site locations (+/- 30 degrees latitude). Initial estimates of cost and development timelines are in the 10-15M range with hardware delivery possible within 2-3 years.

A HUMAN LANDING SITE AT APOLLINARIS SULCI: LIFE INSIDE A YARDANG.

L. Kerber[1], R.P.Mueller[2], L. Sibille[2], A. Abbud-Madrid[3], T. Bertrand[4], K.M. Stack[1], A.K. Nicholas[1], C.E. Parcheta[1], S. Piqueux[1], I. J. Daubar[1], M.J. Malaska[1], J.W. Ashley[1], S. Diniega[1] J.L. Dickson[5], C.I., Fassett[6], [1]Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Dr., Pasadena, CA 91109 (kerber@jpl.nasa.gov), [2]Swamp Works, Exploration Research and Technology Programs, NASA, Kennedy Space Center, FL 32899 [3]Center for Space Resources, Colorado School of Mines Golden, CO 80401 [4]Laboratoire de Météologie Dynamique, 4 Place Jussieu, Paris, France [5]Brown University, 324 Brook St., Providence RI 02912. [6]Department of Astronomy, Mount Holyoke College, South Hadley, MA.

Introduction: Human explorers on Mars will conduct investigations and collect samples that will have enormous and enduring scientific value. For this reason, any human landing site must provide access to a variety of geologic terrains of different ages and origins, ensuring continuous scientific return over many years. In addition, the site must offer resources that will allow future astronauts to reduce their logistical reliance on Earth and establish a stable and sustainable presence on Mars.

Apollinaris Sulci is a region located on the dichotomy boundary of Mars between the 4-km-tall volcano Apollinaris Mons and the ~150 km diameter Gusev Crater (**Fig. 1**). Its position at low latitudes, on the boundaries of diverse terrain types, and adjacent to a unique combination of useful resources, makes it an ideal candidate for a future human landing site.

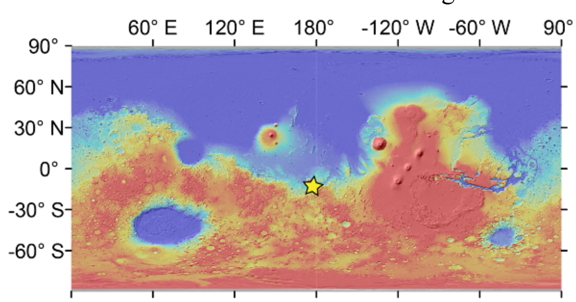


Figure 1. Location of the candidate human landing site at Apollinaris Sulci (12˚40' S, 176˚40' E). Global Mars Orbiting Laser Altimeter (MOLA) data and hillshade.

Science Targets: A 100-km radius exploration zone (EZ) centered on the flat, open plains of southern Apollinaris Sulci contains numerous scientific regions of interest that span across several periods of Martian history (**Fig. 2**). To the south, the landing site is bordered by Noachian highlands with two types of valley networks (**Fig. 2b**). To the southwest is Gusev crater, host to a vast Hesperian basaltic plain useful for calibrating crater counting ages. This region also has numerous kipukas that are similar to the Columbia Hills explored by the Spirit rover futher south and good conditions for observing dust devils. Towards the northwestern part of the EZ is a region of "chaos", a type of terrain which is hypothesized to be related to catastrophic water release [1-3]. In the northern part of the exploration zone is the terminus of the giant volcanic fan of Apollinaris Mons, a volcano that was last active near the boundary between the Hesperian and Amazonian periods [4]. Apollinaris Mons is thought to have formed through explosive volcanic eruptions with significant volcano-ice interactions [5]. Apollinaris Mons is also associated with a gravity anomaly, a magnetic anomaly [6], and unexplained hydrogen and chlorine anomalies [7]. Directly to the north of the landing site are yardangs (wind-eroded ridges) of the Medusae Fossae Formation (**Fig. 2b**), a voluminous fine-grained deposit stretching for thousands of kilometers along the Martian equator [8-9].

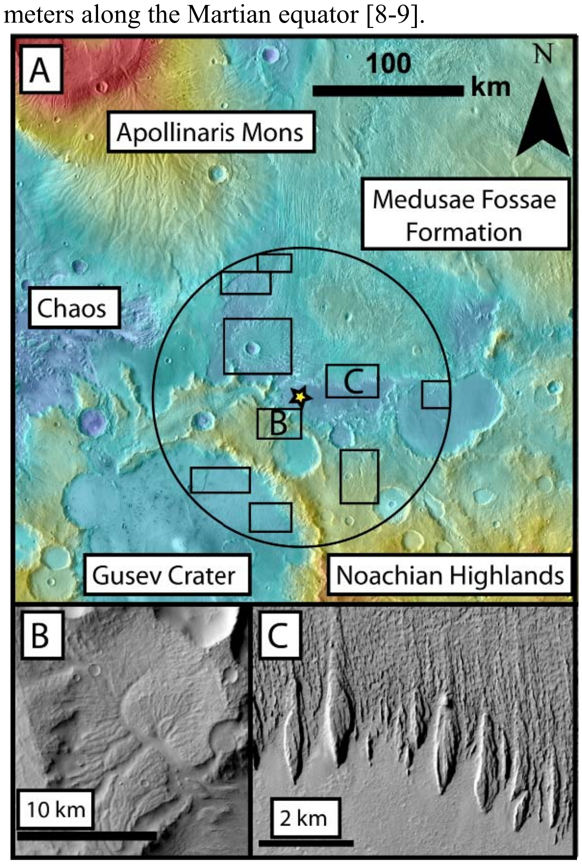


Figure 2. A) The location of the proposed Exploration Zone and scientific regions of interest. B) Dendritic valley network. C) Yardangs of the Medusae Fossae Formation. A from MOLA data, B and C from global CTX mosaic accessed via Google Mars.

This deposit is thought to be an ignimbrite (formed from volcanic ash flow deposits [8]), or a tuff (formed from volcanic ash fall deposits [9]). In most places the Medusae Fossae Formation is characterized by a gentle emplacement that preserves underlying geological features [10]. Later erosion exposes these buried strata in a nearly pristine state. Where it is exposed in Apollinaris Sulci, the Medusae Fossae Formation has fine-scale, non-uniform, and discontinuous layering. The presence of yardangs provides natural roadcuts into the Medusae Fossae Formation, allowing ready access to its depositional history and those of underlying units.

Possibilities for In-Situ Resource Utilization: While water ice appears to be common at high Martian latitudes, the Martian low latitudes are markedly depleted in hydrogen [7]. The region surrounding Apollinaris Mons and Lucus Planum is a notable exception to this trend: here gamma ray data reveal up to 7.5 wt% water-equivalent hydrogen within the first tens of centimeters [7]. This enhancement has been attributed to the phreatomagmatic nature of the Apollinaris eruptions [7], but the idea that water could still remain close to the surface at low latitudes for several billion years remains speculative.

A major advantage to landing a human mission near the Medusae Fossae is the potential to use the formation itself as a source of feedstock for civil engineering projects. The Medusae Fossae represents a vast source of fine-grained, easily mineable material that could be used to build landing pads, berms, roads, habitations, emergency shelters, equipment shelters, etc. [11]. In addition, dwellings could be dug directly into the side of yardangs, providing natural protection from temperature extremes, radiation, and small meteors. Volcanic tuff deposits have served as building material for human beings for milennia [11]. Cities such as Rome and Naples sit above extensive tuff quarries and underground tunnels, cisterns, storerooms. In the Cappadocia region of modern Turkey, early Christians built and enlarged underground cities, some of which were capable of housing more than 20,000 people and their livestock during times of war [12] (**Fig 3**). Some of these cave houses are still in use today as residences, storerooms, stables, and hotels.

The geography of Apollinaris Sulci is conducive to extended human habitation, as it includes a flat plain (for landing spacecraft, transporting materials, and eventual farming) coupled with the yardang cliffs of the Medusae Fossae Formation, which would provide raw construction material and a place to dig protective habitations. In-situ additive construction using basalt-based materials and sulfur compounds as binders would also be possible [13]. The exploration zone is close to the Spirit rover, which could eventually be retrieved and studied. At 12 S, the landing site is close enough to the equator to take advantage of solar power and the increased equatorial velocity of Mars for Mars Ascent Vehicles. In summary, the Apollinaris Sulci region provides a compelling target for scientific exploration, resource utilization, and human habitation.

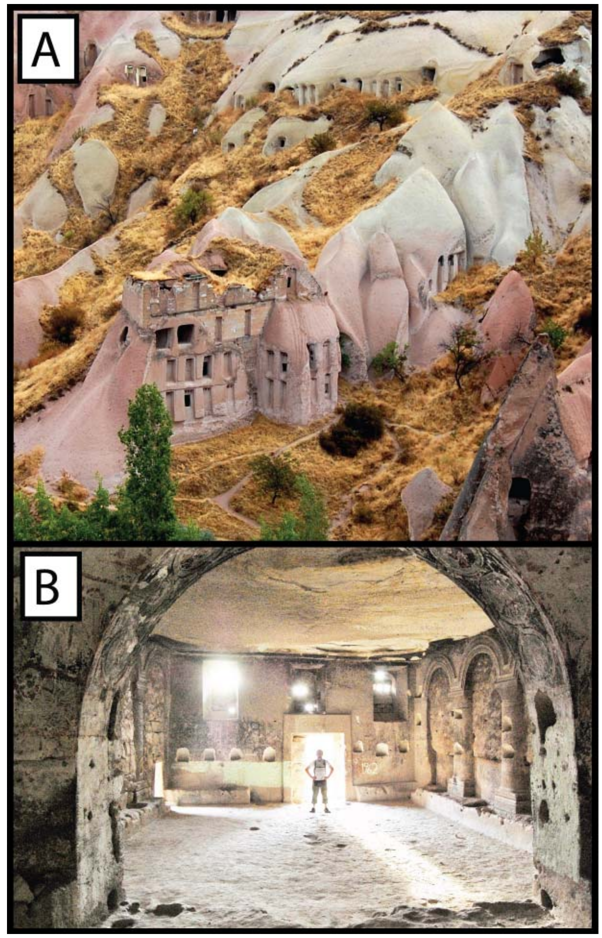


Figure 3. Ancient tuff dwellings in Cappadocia, Turkey from the outside (A) and inside (B). Photos by author.

References: [1] Sharp, R.P. (1973) *J. Geophys. Res. 78*, 4073–4083. [2] Chapman, M.G., Tanaka, K.L. (2002) *Icarus 155,* 324–339. [3] Meresse, S., et al. (2008) *Icarus 194*, 487–500. *JGR 90,* 1151–1154. [4] Greeley, R., Guest, J., 1987. *USGS Misc. Inv. Series Map I-1802*-B [5] Robinson, M.S. (1993) *Icarus 194*, 487–500. [6] Hood, L.L., et al. (2010) Icarus 208, 118-131. [7] Boynton, W.V. et al. (2007) *JGR 112*, E12S99. [8] Scott, D.H., Tanaka, K.L. (1982) *JGR 87*, B2, 1179–1190. [9] Kerber, L. et al. (2011) *Icarus 216*, 212–220. [10] Kerber, L., Head, J.W. (2010) *Icarus 206*, 669–684. [11] Funiciello, R. et al. (2006) GSA Special Papers 408, 119–126. [12] http://www.cappadociaturkey.net/derinkuyu_undergrouun_city.htm. [13] Mueller, R.P., et al. (2014) *Proc. of ASCE Earth and Space 2014*: pp. 394-403.

VALLIS MARINERIS MOUTH AS THE BEST LOCATION FOR EXPLORATION ZONE (EZ). G.G. Kochemasov, IGEM of the Russian Academy of Sciences, 35 Staromonetny, 119017 Moscow, kochem.36@mail.ru.

"Stream sediment sampling" was proposed in 1979 as a rational tool for collecting and studying various rock fragments on the martian surface (9th Gagarin reading on aeronautics and aviation) and was again discussed in 1988 (18th Gagarin reading) [1]. This idea was based on the author's experience in stream sediments, heavy fraction, and rock fragment sampling as a geological prospecting tool in various African and Asian environments. A particular parallel was drawn between the martian environment and that of mountain deserts of northern Africa (Anti-Atlas) where eolian contamination is rather pronounced and which has to be borne in mind during the martian rock sampling mission. Experiments in the Anti-Atlas have shown that significant eolian contamination exists in fine (<0.5 mm) dry mountain alluvial fractions. Hence, relatively large rock and mineral fragments are more safe for "on-the-spot" study of a catchment area and preparin[illegible]

VALLIS MARINERIS MOUTH AS THE BEST LOCATION FOR EXPLORATION ZONE (EZ). G.G.

Alkaline rocks, syenites, albitites, granites we[illegible] of "Pathfinder" and "Spirit" [2]. They were considered as the best candidates for the martian hig[illegible] the highlands (the southern hemisphere) standing much higher –on an average 6 km over a of diffe[illegible]here two different lelowlands (the northern hemisphere) must be significantly lighter than the lowla[illegible]ep angular momentvel segments – hemispheres) in one rotating body more or less equal. Higher diffe[illegible]dii – higher density difference of composing them lithologies. Thus, very dense lowland Fe-basalts m[illegible]t rocks, lighter than the Earth's andesites (an average composition of the Earth's continents). That is [illegible]red as the best candidates [2]. The martian gravity, more or less even over the whole surface, confirmed that this purely mechanical requirement of rotating body is fulfilled. Found andesites (directly) and dacites (remote sensing) showed that rocks of the lower density than basalts really exist. Now, Spirit found an outlier of layered highland rocks (Columbia Hills) enriched in Al, alkalies, P, S, Cl, Br, Ti [3-4]. This is already a direct evidence of existence of the alkaline family rocks. Rocks of "Algonquin" class fall on a petrological diagram directly into field of alkaline foidite and tephrite rocks. This forced Dr. McSween to declare existence on Mars of "an alkaline igneous province"(Internet, 23 Aug. 2006). The layered rocks of Columbia Hills fall into several petrologic classes,
some are Fe-rich, some Fe-poor, quantities of K, Na, P, S, Cl vary. All this is typical for layered syenite massifs.

Proposed EZ in the southern Acidalia Planitia has coordinates: 40˚W and 20˚N (Fig. 1-2). It is located between Viking 1 and Pathfinder landing sites. The first probe discovered Fe-basalts of lowlands, the second andesites of probable transition zone between lowlands and highlands. Thus, proposed FZ have solid chances to discover and study a wide variety of rocks of both planetary wide lithological provinces of Mars. This possibility is enhanced by location of EZ at the mouth of the longest and deepest Vallis crossing large expanses of the southern continents with presumably wide varieties of continental rocks. It is necessary for deciphering geologic history of Mars. Moreover, crossing the transition zone the Vallis Marineris can bring down specific rocks developed at "enigmatic" chaotic terrains very characteristic for the transition zone. This comparatively permeable zone can be enriched with volatile components coming from the mantle and among them water (in form of ice or mineral components) so needed for human activity at the martian surface.

Very sharply manifested hemispheric dichotomy of Mars [5] is not unique but is one of the best examples of the fundamental universal planetological characteristics [6, 7].

References: **[1]** Kochemasov G.G. (1989) Gagarin Reading on Aeronautics and Aviation, 1988, Moscow, Nauka, 275 (in Russian); **[2]** . Kochemasov G.G. (1995) Possibility of highly contrasting rock types at martian highland/lowland contact // Golombek M.P., Edgett K.S., Rice J.W.Jr. (eds) Mars Pathfinder Landing Site Workshop II: Characteristics of the Ares Vallis Region and Field Trips to the Channeled Scabland, Washington. LPI Tech. Rpt. 95-01. Pt. 1. Lunar and Planetary Inst., Houston, 1995. (63 p.), P. 18-19; **[3]** Gellert R., Brückner J., Clark B.C., Dreibus G. et al. (2006) Chemical diversity along the traverse of the rover Spirit at Gusev crater // LPSC-37, Houston, 2006, Abstract 2176, CD-ROM; **[4]** Dreibus G., Brückner J., Gellert R. et al. (2006) Chemical composition of rocks in the Columbia Hills at Gusev Crater, Mars // EUROPLANET-2006 Sci. Conf., Berlin, Germany, Sept. 22-26, 2006, Abstr. EPSC2006-A-00399; **[5]** Kochemasov G.G. (2007) Martian dichotomy expressed in relief, crustal chemistry, polar caps, atmosphere // Seventh International Conference on Mars, Abstract # 3033; **[6]** Kochemasov G.G. (1999) On a successful prediction of martian crust fractionation based on comparative wave planetology // The Fifth International Conference on Mars, July 18-23, 1999, Pasadena, California, Abstract # 6034, (CD-ROM); **[7]** Kochemasov G.G.(2004) Mars and Earth: two dichotomies – one cause // In Workshop on "Hemispheres apart: the origin and modification of the martian crustal dichotomy", LPI Contribution # 1203, LPI, Houston, 2004, pp. 37-38

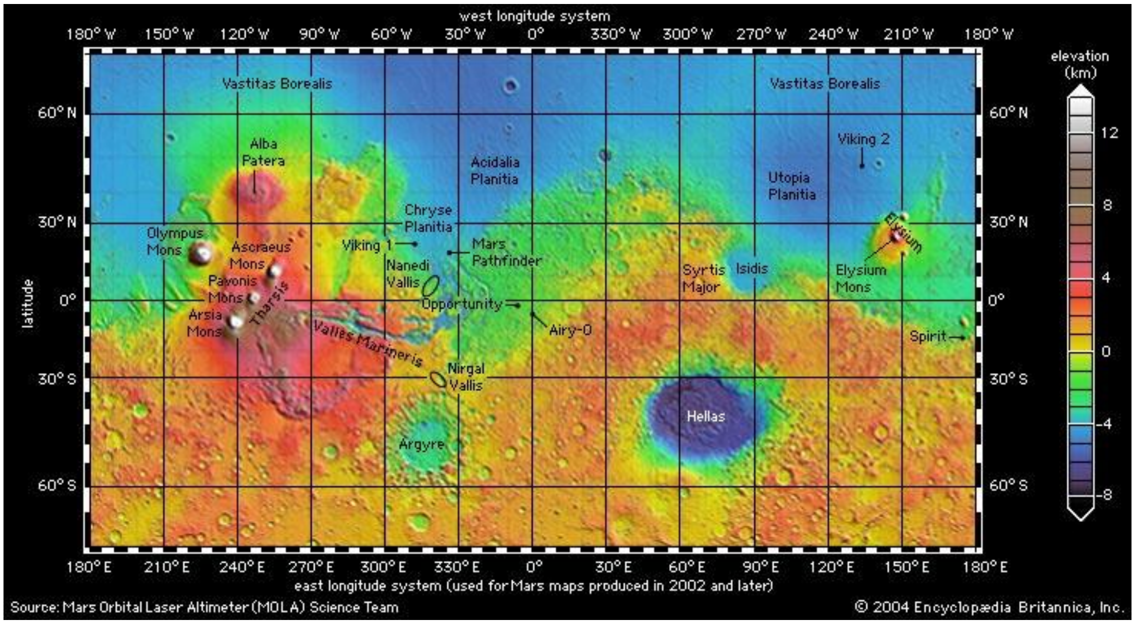


Fig. 1. Topography of Mars

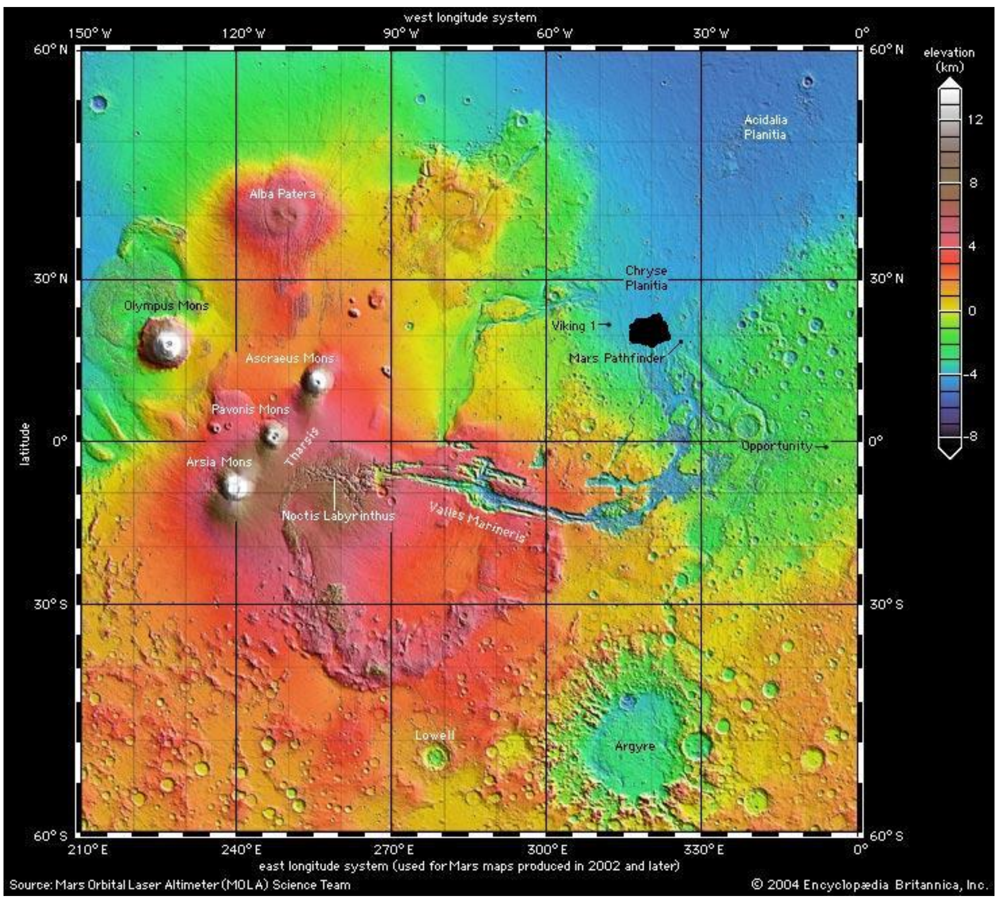


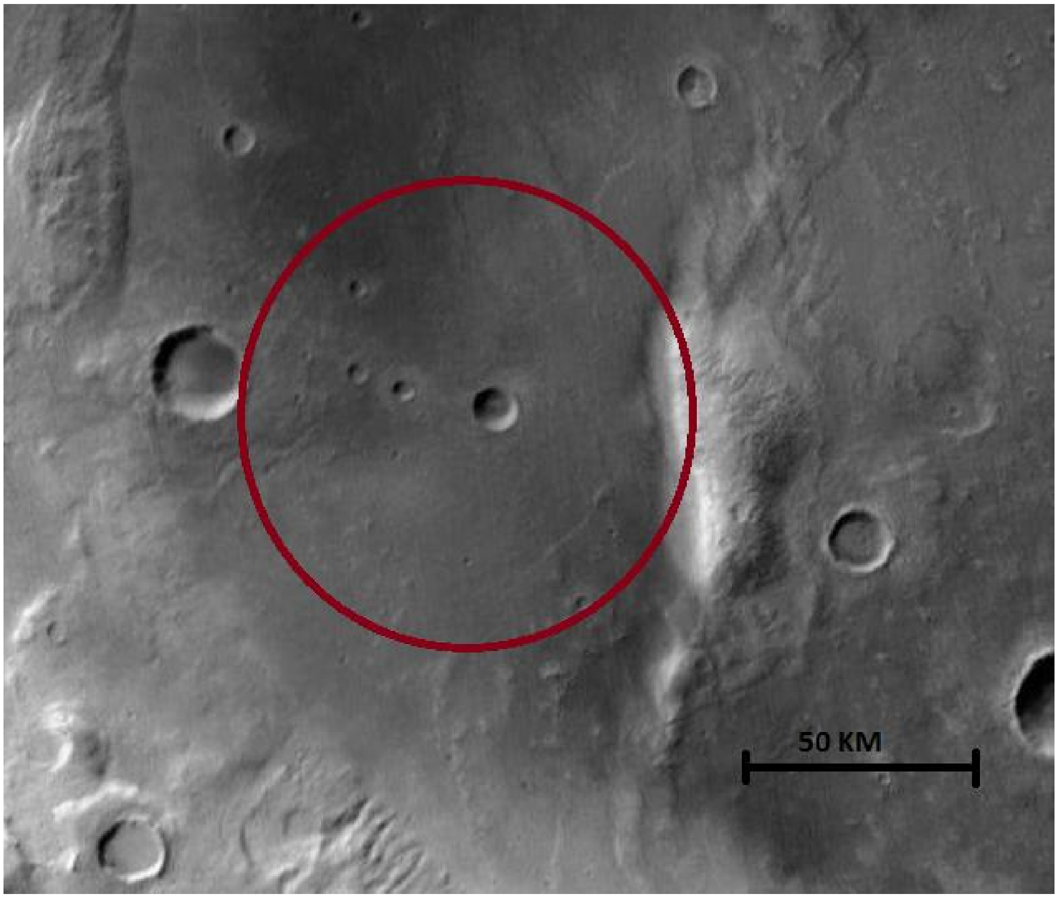
Fig. 2. EZ on Mars (black area)

Exploration Zone in Newton Crater

Pauli E. Laine

University of Jyvaskyla, Finland

Latitude and longitude of the proposed EZ: 40.6^{O} S / 200^{O} E



Rationale for proposed EZ: Newton is a large crater (300 km) located in Terra Sirenum in the Phaetholis quadrangle. This region is heavily cratered, preserves crustal magnetism, and has ground ice present. This region has been suggested target site for drilling to find the frozen remains of possible ancient Martian life (McKay 2010, Smith & McKay 2005). Within this EZ there are many potential science and resource ROIs, e.g. gully formations that are presumed to be indicative of past liquid water flows. There are also some observations about recent changes, probably formed from dry ice. This crater provides one of the few possible landing sites that are located in less than -2km altitude regions in the highlands of Terra Sirenum.

McKay, C.P. (2010). An Origin of Life on Mars. Cold Spring Harb Perspect Biol 2010;2:a003509.
Smith H.D., McKay C.P. (2005). Drilling in ancient permafrost on Mars for evidence of a second genesis of life. Planet Space Sci 53: 1302 – 1308.

NOCTIS LANDING: A Proposed Landing Site/Exploration Zone for Human Missions to the Surface of Mars

Pascal Lee[1,2,3], Shannen Acedillo[1,2], Stephen Braham[1], Adrian Brown[2], Richard Elphic[3], Terry Fong[3], Brian Glass[3], Christopher Hoftun[1], Brage W. Johansen[1], Kira Lorber[1], David Mittlefehldt[4], Yuta Tagaki[1,2], Peter Thomas[5], Michael West[1], Stephen West[1], Michael Zolensky[4]. [1]Mars Institute, NASA Research Park, Moffett Field, CA 94035, USA, pascal.lee@marsinstitute.net. [2]SETI Institute, [3]NASA Ames Research Center, [4]NASAJohnson Space Center, [5]Cornell University.

Exploration Zone Name: Noctis Landing
Landing Site Coordinates: 6° 29' 38.33" S, 92° 27' 12.34" W.

The proposed *Noctis Landing* Landing Site/Exploration Zone (LS/EZ) is shown in Figure 1. Our preliminary study suggests that the proposed site meets all key Science and Resources (incl. Civil Engineering) requirements. The site is of significant interest, as the EZ not only offers a large number and wide range of regions of interest (ROIs) for short-term exploration, it is also located strategically at the crossroads between Tharsis and Valles Marineris, which are key for long-term exploration.

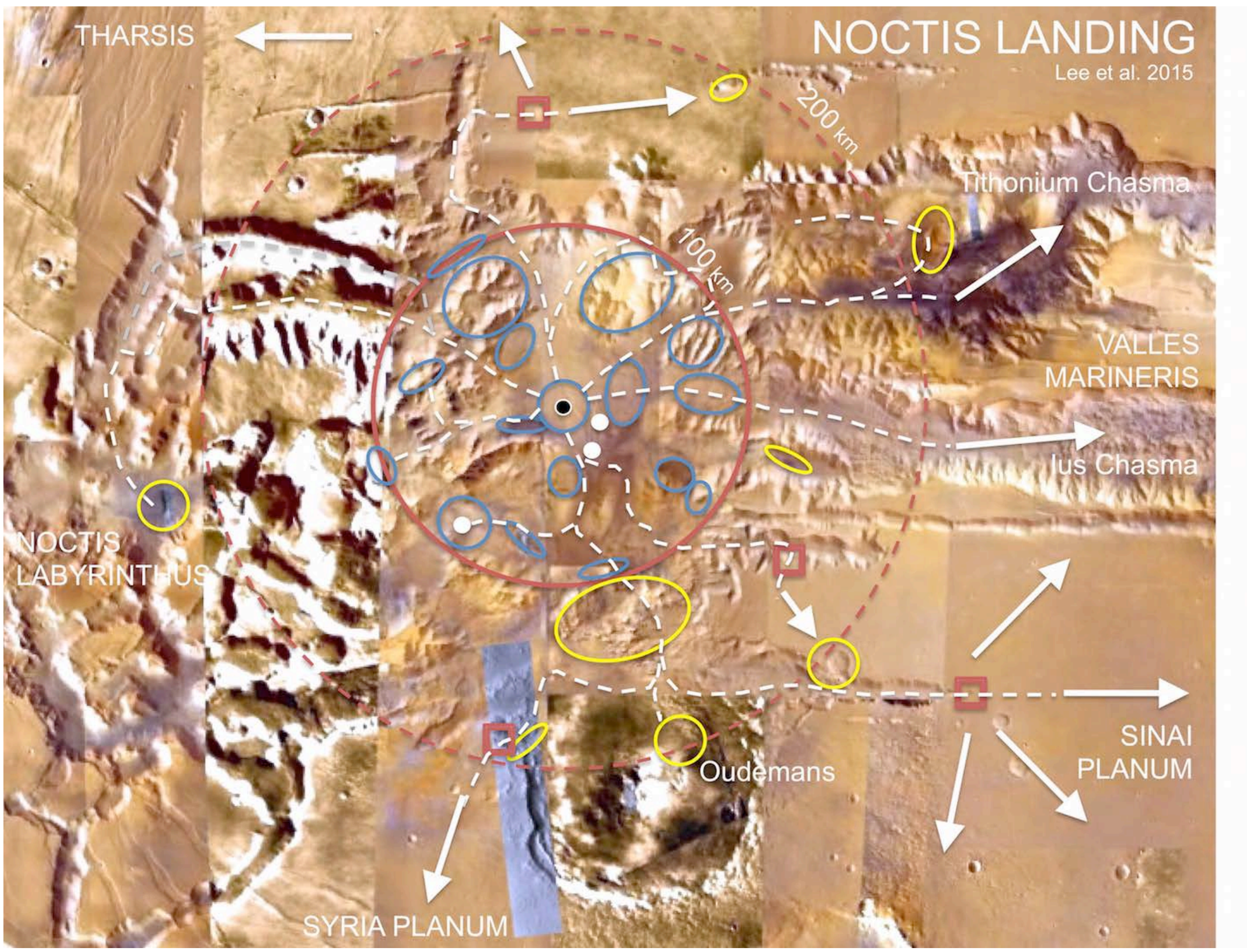


Figure 1: Map of the *Noctis Landing* LS/EZ. The solid red circle marks the distance of 100 km radial range from the Landing Site (LS), defining the primary Exploration Zone (EZ). The dotted red circle marks 200 km radial range from the LS. Areas circled (or ellipsed) in blue are high value science targets located within the primary EZ. Areas outlined in yellow are high-value science targets located outside the EZ, but within 200 km radial range from the LS. White dotted lines represent potential paths for pressurized rover traverses. White solid circles mark locations offering potential resources (hydrated minerals, iron and sulfur-bearing minerals, loose regolith). Red square boxes mark potentially trafficable access points to sourrounding plateau tops. White arrows point to general directions for further regional exploration beyond 200 km radial range form the LS. (Background images form NASA and ESA).

The proposed site contains Regions of Interest (ROIs) that meet the following Science requirements:

- Access to (1) deposits with a high preservation potential for evidence of past habitability and fossil biosignatures and (2) sites that are promising for present habitability. The site presents a wide variety of ROIs qith likely aqueous features and deposits, including sinous channels and valleys, slope gullies, lobate debris aprons, impact craters with lobate ejecta flows, and "bathtub ring" deposits. Neutron spectrometry also suggests hydrogen is present within the topmost 0.3 m or so of 4 to 10 wt% WEH (Water Equivalent Hydrogen).
- Noachian and/or Hesperian rocks in a stratigraphic context that have a high likelihood of containing trapped atmospheric gases. Collapsed canyon rim material with preserved stratigraphy is abundantly present and accessible.
- Exposures of at least two crustal units that have regional or global extents, that are suitable for radiometric dating, and that have relative ages that sample a significant range of martian geological time. Canyons floors in Ius Chasma, Tithonium Chasma, and plateau tops on Tharsis and in Sinai Planum offer access to distinct crustal units of regional extent.
- Access to outcrops with linked morphological and/or geochemical signatures indicative of aqueous or groundwater/mineral interactions. Iron and sulfur-bearing deposits on canyon floors in Noctis Labyrinthus, and in Ius Chasma (IC) and Tithonium Chasma (TC) offer many such outcrop options.
- Identifiable stratigraphic contacts and cross-cutting relationships from which relative ages can be determined. In place and collapsed canyon walls in NL, TC, and IC offer such opportunities.
- Other types of ROIs include access points to surrounding plateau top areas for longer term regional exploration.

  A key attribute of the proposed Noctic Landing site is its strategic location to allow the shortest possible surface excusions to Tharsis and Valles Marineris (VM). VM is the feature and region on Mars that exposes the longest record of Mars' geology and evolution through time. Tharsis is the region of Mars that has experienced the longest and most extensive volcanic history, and might still be volcanically active. Some of the youngest lava flows on Mars have been identified on the western flanks of the Tharsis Bulge, i.e., within driving range of future long-range (500 – 1000 km) pressurized rover traverses (See Lee et al. 2015, this conf.).

The proposed site also contains ROIs that offer the following Resources (incl. Civil Engineering) characteristics:

- Access to raw material that exhibits the potential to (1) be used as feedstock for water-generating in situ resource utilization (ISRU) processes and (2) yield significant quantities (>100 MT) of water. The raw material is likely in the form of hydrated minerals, and possibly ice/regolith mix. The top of the raw material deposit is at the surface.
- Access to a region where infrastructure can be emplaced or constructed. This region is less than 5 km from the LS and contains flat, stable terrain. The region exhibits evidence for an abundant source of loose regolith. Several deep pits in the area combined with the availability of sand suggests that some natural terrain features can be adapted for construction purposes.
- Access to raw material that exhibits the potential to be used as metal feedstock for ISRU and construction purposes. Iron and sulfur-rich mineral surface deposits have been identified in CRISM data in many locations in this area.

Noctis Landing is the lowest-altitude location on Mars that straddles both the Tharsis region (above average geothermal gradients) and Valles Marineris (minimal crustal thickness from surface (valley floor) to a subsurface liquid water table. Noctis Landing has the potential for being an ideal site for eventual deep drilling on Mars to access deep subsurface liquid water and potentially encountering extant life.

Available data remains insufficient to fully qualify the Noctis Landing site. Additional remote sensing data (visible, Near and Mid-IR, and radar) and surface reconnaissance via a high-mobility robotic rover are recommended. In particular, it will be important to assess the trafficability of the site, and its potential for yielding water and metals as a resource. Access to plateau tops from the Noctis Landing site on the canyon floor should be demonstrated. Future exploration of the site would also be enhanced significantly by the availability of robotic (tele-operatable) surveying and sample-collecting drones. Testing of the use of such collaborative science and exploration technologies should be conducted at terrestrial sites such as the Haughton-Mars Project site on Devon Island, High Arctic, among others.

Note: *Noctis Landing* is not an official Mars nomenclature name for this location. Because the area of the proposed LS/EZ had no name, and because it is close to *Noctis Labyrinthus* to the West while being distinct from it, the provisional name *Noctis Landing* is proposed. *Noctis* means night in Latin.

HAUGHTON-MARS PROJECT: Lessons for the Selection of a Landing Site/Exploration Zone for Human Missions to the Surface of Mars. Pascal Lee[1,2,3], Stephen Braham[1], Terry Fong[3], Brian Glass[3], Stephen J. Hoffman[4], Christopher Hoftun[1], Sarah Huffman[1], Brage W. Johansen[1], Kira Lorber[1], Christopher P. McKay[3], Robert Mueller, John W. Schutt[1], Karen Schwartz[1], Jesse T. Weaver[1], Kris Zacny[6]. [1]Mars Institute, NASA Research Park, Moffett Field, CA 94035, USA, pascal.lee@marsinstitute.net. [2]SETI Institute, [3]NASA Ames Research Center, [4]NASAJohnson Space Center, [5]NASA Kennedy Space Center, [6]Honeybee Robotics.

Exploration Zone Name: Haughton-Mars Project, Devon Islamd
Habitat Site Coordinates: 75° 26' N, 89° 52' W

The Haughton-Mars Project (HMP) is an international multidisciplinary field research project focused on Mars analog studies at the Haughton impact crater site on Devon Island, High Arctic. HMP analog studies include both science and exploration investigations. The project began in 1997, and has been hosting NASA-supported research each year since. Haughton Crater is approximately 20 km in diameter and 23 million years old. The crater is remarkably well preserved. Field operations at HMP are based out of a permanent field camp, the HMP Research Station (HMPRS), established in the northwestern rim area of Haughton Crater.

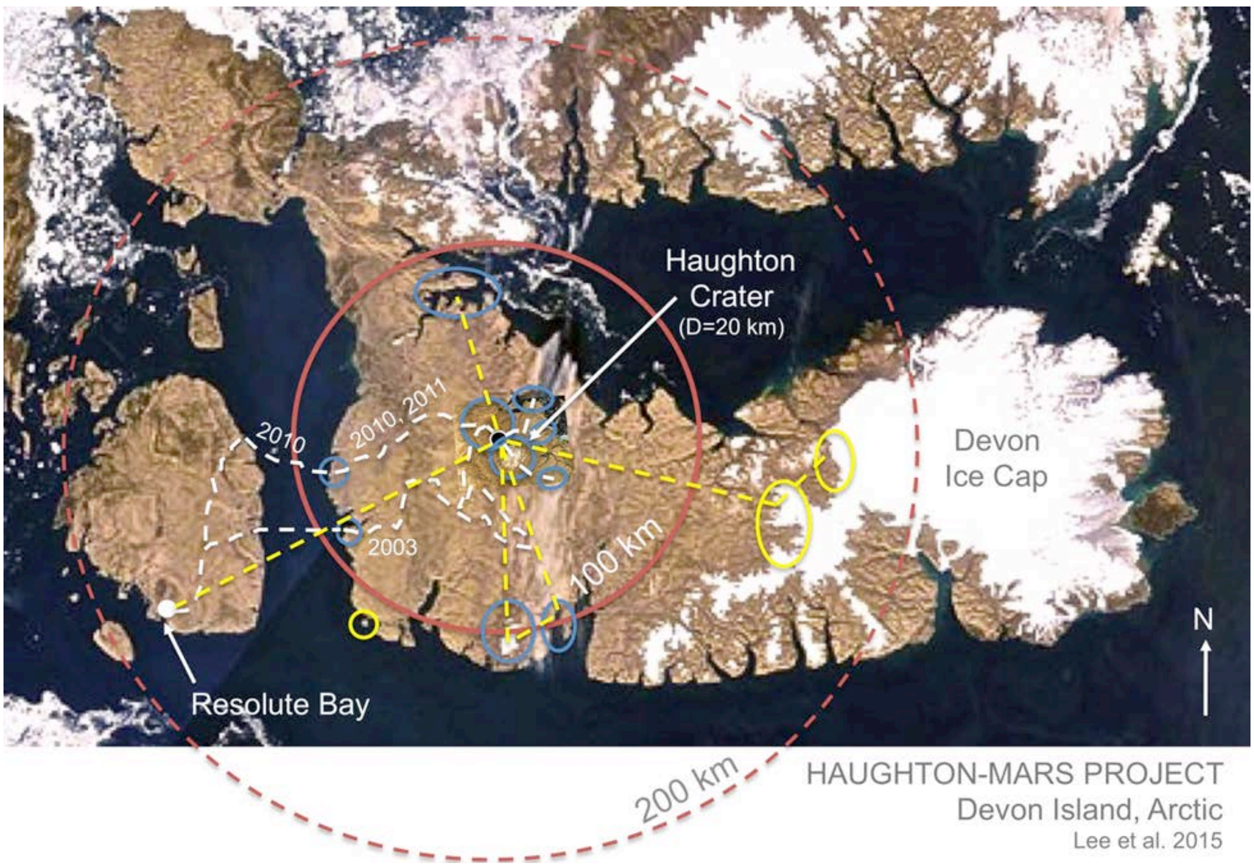


Figure 1: Map of the Haughton-Mars Project (HMP) "Exploration Zone". This map illustrates, in the same smanner as a Landing Site/Exploration Zone (LS/EZ) proposed for Mars, the main regions of interet (ROIs) within an EZ extending out to 100 km. The solid red circle marks the distance of 100 km radial range from the HMP Research Station (HMPRS) or "LS", and defines tthe primary HMP "EZ". The dotted red circle marks 200 km radial range from the "LS". Areas circled (or ellipsed) in blue are high value science targets located within the primary HMP EZ. Areas outlined in yellow are high-value science targets located outside the EZ, but within 200 km radial range from the LS. White dotted lines indicate the paths of crewed rover traverses, with their date (year). Yellow dotted lines indicate airplane or helicopter flights in support of science investigations. The white solid circle marks a site offering resources, in this case, Resolute Bay (a small town on Cornwallis Island, west of Devon Island), which is used for HMP logistics. (Background image: NASA).

Devon Island is the largest uninhabited island on Earth, and offers a wide expanse of vegetation-free terrain that is set in a polar desert. In addition to Haughton, a wide variety of geologic features that are morphologic analogs to geologic features on Mars are present on Devon Island, including canyons, valley networks, gullies, ground ice, patterned ground, debris flows and sprons, cold desert weathering crusts, and paleolake deposits. Astrobiology and planetary protection investigations are also conducted at the site.

Because of the close relevance to Mars of science investigations conducted at HMP, and because science and exploration operations there are conducted in a relatively extreme envionment (by terrestrial standards) and in a real field exploration setting, valuable lessons are learned at HMP that can inform the planning and optimization of future human science and exploration activities on Mars.

Figure 1 shows the range and extent of field science and exploration "regions of interest" (ROIs) at HMP. Since the begiining of the project in 1997, the field site is visited every summer by teams of geoscientists, biologists, and exploration engineers who iterate on advancing the scientific understanding of the site and of its implications for the evolution and future exploration of Mars. HMP-2015 marked the 19th summer field campaign of the project. In this time, approximately 97% of science and exploration investigations at HMP has taken place within a radial range of 20 km from the HMPRS "LS". Excursions for reconnaissance and/or brief sampling to areas beyond 20 km range were generally conducted by helicopter. About a dozen medium-range (5 to 10 km radial range from the "LS") crewed rover traverses have been conducted since 2003 (7th HMP field season onwards) using one of the HMP's two modified Humvees based at the HMPRS, including traverses from the west coast of Devon Island to camp.

Figure 2 shows the range and path of the 2009 field campaign of the HMP's Northwest Passage Drive Expedition (2009-2011), which involved driving a Humvee over a distance of 500 km on sea-ice from Kugluktuk on the North-American mainland, to Cambridge Bay on Victoria Island. The traverse encountered a number of challenges due to difficult weather, electrical problems on the vehicle, and the hummocky and unpredictable terrain (including leads in the sea-ice hidden under snow cover). The 500 km traverse traverse was eventually completed in 8 days. Similar long-range traverses should be possible and planned for Mars ro greatly expand the range amd productivity of future human exploration missions.

Long-range pressurized rover traverses on Mars from a "Landing Site" or a "Habitat Site" to a variety of ROIs will be a key aspect and requirement of human Mars science and exploration operations. In upcoming years, simulations at HMP of dual-pressurized rover traverses (involving two rovers working in tandem and able to lend assistance to one another in a contingency) are recommended. The will be key to informing the design, planning, implementation, and optimization of actual pressurized rover vehicles and traverses on Mars.

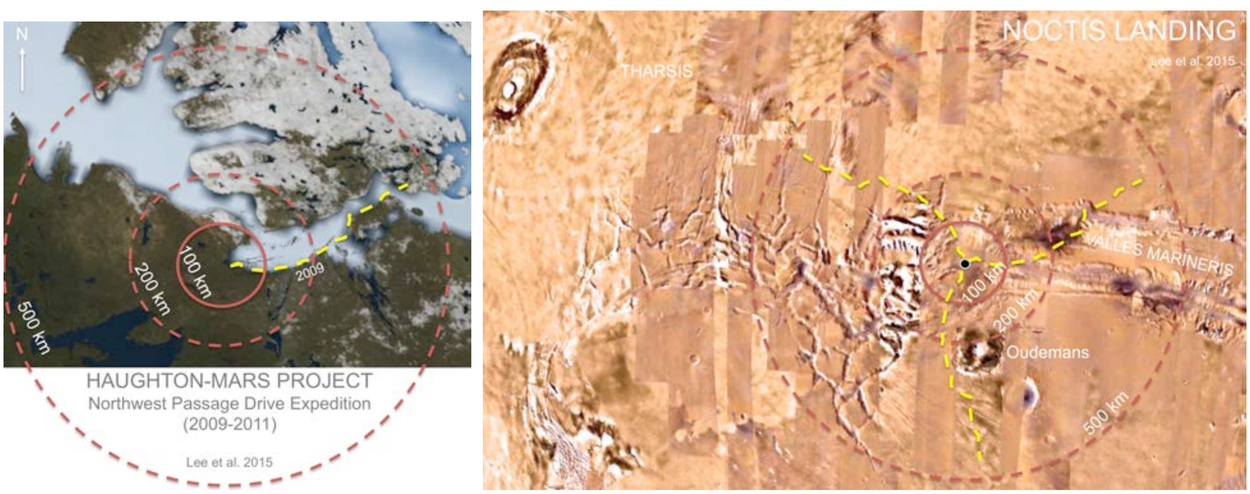
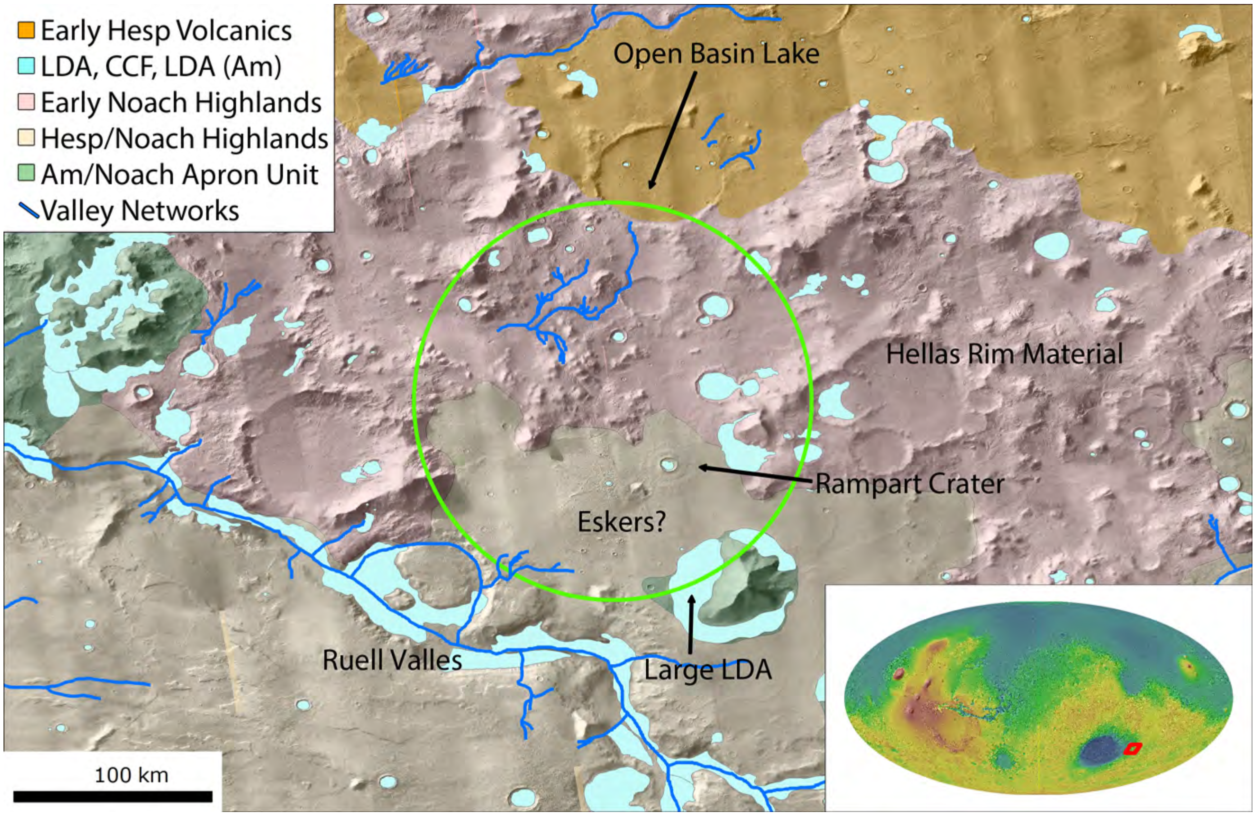


Figure 2: The HMP Northwest Passage Drive Expedition (NWPDX) & Pressurized Rover Traverses on Mars. Left: Map of the HMP NWPDX-2009 campaign of the Northwest Passage Drive Expedition (2009-2011). The NWPDX-2009 travese, which included science stops, represented a driven distance of 496 km over unprepared terrain (rough sea-ice) and was completed in 8 days. **Right:** The path of the HMP NWPDX-2009 traverse projected several times (in various orientations) onto a photomosaic map of Mars, with *Noctis Landing* as the hypothesized Mars Landing Site/Exploratiuon Zone (LS/EZ) (Lee et al. 2015, this conf.). This figure provides some sense of how far traverses equivalent in *radial range* to the NWPDX-2009 traverse would reach if carried out on Mars.

A HUMAN LANDING SITE ON THE HELLAS RIM: ANCIENT CRATERS, FLOWING WATER, AND ABUNDANT ICE. Joseph Levy and John W. Holt, University of Texas Institute for Geophysics, 10100 Burnet Rd., Austin, TX 78758. joe.levy@utexas.edu

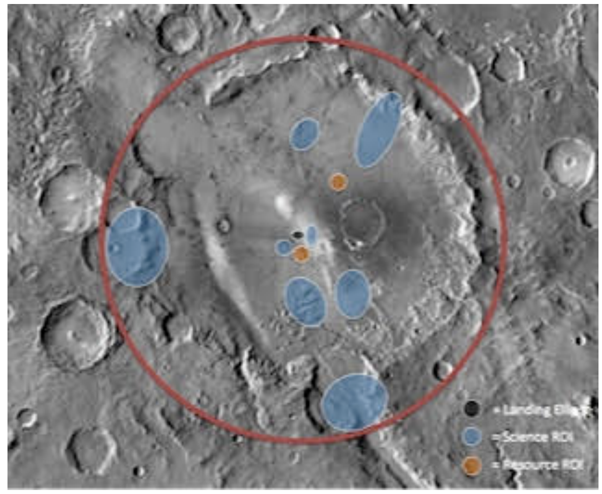


Located at 39.05˚ S, 101.91˚ E, the Hellas Rim EZ contains landforms that meet the astrobiology, geology, and climate requirements while providing abundant stores of near-surface water ice and usable ejecta and debris for raw materials. The EZ contains a lava-capped open-basin lake that has been exposed by several impact craters. It contains several large valley networks and provides access to the shores and headwaters of Ruell Valles. It provides access to Noachian highland materials associated with the Hellas impact, and supports two younger units (highlands and volcanics) with clear stratigraphic relationships and large surface areas. Water/rock interactions at the site are indicated by the presence of rampart craters, several valley networks, and possible eskers and supraglacial channels indicative of Amazonian-aged hydrological activity. The numerous LDA in the EZ have a combined mapped volume of >400 km^3, most of which is thought to be water ice on the basis of extensive SHARAD imaging of nearby LDA (e.g., Euripus Mons). High-slope LDA margins provide access to debris that has already been piled up, making excavation for transport easier. Together, these attributes constitute an EZ that has the rare combination of ancient volcanic deposits and early martian material with evidence for ~3-4 Ga of hydrological activity and abundant, proven stores of water ice.

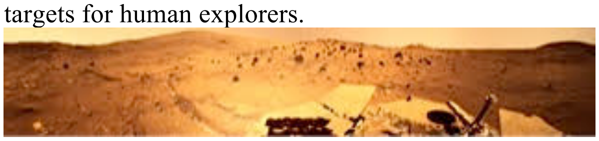
A Landing Site for Human Missions to Mars in Gusev Crater.
A. Z. Longo[1], [1]Cardinal Gibbons High School (417 Tharps Lane, Raleigh, NC 27614; azlmsr701@gmail.com).

Introduction: I propose Gusev Crater, the landing site for the Mars Exploration Rover (MER) Spirit, as the location for one of the first crewed missions to Mars in the 2030s. Gusev Crater is a 166-kilometer wide impact basin, named after Russian astronomer Matvey Gusev (1826-1866). The crater is located in the southern highlands of Mars, at 14.5° S, 175.4° E. Current analyses suggest that it formed approximately 4.0-3.8 billion years ago during the Noachian era of the planet's history. Many different mineral phases and landforms detected in orbital imagery suggest multiple episodes of past fluvial activity. Our current knowledge of the crater consists of data collected from orbital missions [1] since the 1970s and "ground truth" from the Spirit rover. Spirit landed on January 3, 2004 on the floor of the crater. After initial analysis discovered basaltic rocks, the rover drove to the Columbia Hills, a complex of ~200-foot-tall, heavily eroded kipukas where it spent the rest of the mission [2]. After discoveries of water-altered rocks dating from the Noachian through to the geologically recent past, Spirit succumbed to the cold of the Martian winter in 2011. Spirit's findings in the Columbia Hills region were intriguing, but its mobility restrictions left much to be explored.

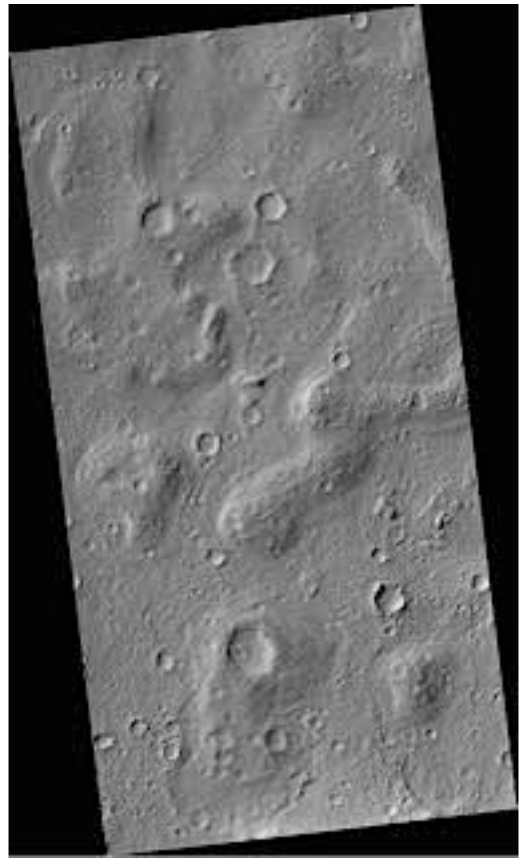
Landing Site and Exploration Zone: The 3 by 2-kilometer wide landing ellipse was determined using current Mars landing technologies and a very rough estimate of how far they will have been developed by the mid-2030s. The size of the landing ellipse will be dramatically reduced by the improvement of technologies and the presence of a human pilot capable of reacting to discrepancies in the landing system's performance. The ellipse, which will contain all of the outpost's major hardware, is located at the edge of the Columbia Hills and an unexplored region of etched terrain. The landing site is dominated by very flat topography with only small rocks and craters. No significant landing hazards exist. In the event of an off nominal landing, the vast majority of EZ (exploration zone) terrains are similar, allowing for a safe landing and a quick drive to the base camp. The EZ proposed is 200 kilometers in diameter and covers all parts of the impact basin. The surrounding terrain will provide information related to multiple epochs in its history. There are a total of 8 science ROIs as well as many interesting areas not included as part of an ROI that could be explored. The EZ contains 2 resource ROIs, one located adjacent to the landing ellipse and one about 30 kilometers away.



Science Targets: The ellipse contains a land-on, datable volcanic surface, which is a Hesperian ridged plain [3]. The Columbia Hills are located only 2.5 kilometers from the center of the landing ellipse. The Columbia Hills science targets are located in a remarkably compact, 3 by 5 kilometer region of interest and contain a dramatic geologic diversity [4]. Just a few examples of these are at least two igneous units, rare carbonate outcrops formed in a Noachian ephemeral lake, orbitally-detected phyllosilicates (Fe-rich clays, kaolinite, and possibly others) in polygonal terrain, sulfates, and opaline silica outcrops bearing a resemblance to biogenic structures found on Earth [5]. The Columbia Hills also contain the final resting place of Spirit, permitting an Apollo 12/Surveyor 3-type investigation to take place on how mechanical components age in Mars' environment over a long period of time. If repaired by the astronaut crew, Spirit could also be used for additional exploration of the site after they depart. To the south of the landing site is a large exposure of etched terrain. The etched terrain has a similar thermal inertia to the Algonquin-class tephra deposits [6], and has been postulated to have an origin related to fluvial or glacial processes. Similar exposures of etched terrain are present farther to the south, west, and east. Wrinkle ridges on the floor of the crater are similar to those found on the surface of the moon, and could be formed by the contraction of the planet's crust. Other kipukas in the EZ, such as the Apollo 1 Hills, could be compared to the Columbia Hills, providing a window into the planet's distant past. Large groupings of pingos, or permafrost mounds, are 30 kilometers southeast of the landing site [7]. Besides being a potential resource, permafrost has extraordinary potential for preserving biosignatures. On earth, organisms ranging in size from microbial life to juvenile ice age mammoths have been found preserved in permafrost [8]. If microbes once lived on Mars, their remains could be preserved in the Gusev permafrost. The southern portion of the crater is rich in science targets. Mesas at the mouth of the Ma'adim Vallis channel bear resemblance to eroded river deltas, and may be associated with an ancient ocean in the crater. To the east of the mesas are widespread deposits of Fe and Al-rich phyllosilicates. Both the mesas and the walls of Ma'adim Vallis could expose layers of water-altered material. Valleys and craters intersecting the rim of Gusev could also provide geologic context to the area. The Gusev Crater region is rich in science targets for human explorers.



ISRU: In-situ resource utilization (ISRU) is a critical technology, used to create water and fuel from available resources. As indicated by the etched terrain and pingos, Gusev possibly played host to glacial processes in the past. One resource ROI is located at each type of terrain. While the etched terrain will generate some water, the pingos contain much larger quantities. However, they are relatively far away, so the etched terrain will provide a preliminary feedstock until a larger amount of infrastructure can be put in place. Other sites I considered were locales containing recurring slope lineae (RSL), flows of briny water on the surface of Mars. However, exploring these features raises significant concerns about planetary protection guidelines, as the human body contains thousands of microorganisms, which could invade and contaminate this habitable environment. In addition, RSL could contain pathogenic bacteria, which makes pingos and other permafrost locations a favorable water source. In the long term, explorers may intend to build their own habitation units. Structures could be constructed between some of the larger kipukas or mesas located close to each other, utilizing them as the habitat's walls.



Conclusion: Gusev Crater is the ideal location for a manned mission to Mars because of MER Spirit ground truth, a rich diversity of science targets for exploration, and sufficient resources to sustain a human presence on the surface of Mars without jeopardizing planetary protection concerns.

References: [1] Parker M. et al. (2010) *Earth and Planetary Science Letters,* 294.3, 411-423. [2] Arvidson R. E. et al. (2008) *JGR, 113.* [3] Greeley R. et al. (2005) *JGR, 110.* [4] Rice J. W. (2011) *AGU 2010* P33D-1789. [5] Ruff S. W. (2015) *LPSC XLVI* 1613. [6] Ruff S. W. (2014) *Geology,* 42.4, 359-362. [7] Cabrol N. A. et al. (2000) *Icarus,* 145, 91-107. [8] Gilichinsky D. A. (1992) *Advances in Space Research,* 12.4, 255-263.

EXPLORING HABITABILITY, HYDROLOGY, AND CLIMATE CHANGE ON MARS AT COLUMBUS CRATER.

K. L. Lynch[1], J. J. Wray[2], [1]Department of Civil and Environmental Engineering, Colorado School of Mines, Golden, CO (klynch@mymail.mines.edu), [2]School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA.

The Terra Sirenum region of the martian highlands contains some of the most diverse aqueous environments on the red planet [1,2]. As such it would be an ideal center of focus for human missions, and the Columbus crater is an excellent candidate Exploration Zone for the first human mission to Mars. Columbus crater is a groundwater-fed paleolake basin located in the northwest region of Terra Sirenum (29° S, 166° W), is 110 km in diameter and the basin floor has an average elevation of 920 ± 30m, which is within the elevation criteria for a crew lander. The northeastern section of the basin floor is relatively flat, contains materials of medium to high thermal inertia and would be a plausible location for the primary landing site and habitation zone (Figure 1a) [3].

Columbus crater is known for hosting a large diversity of aqueous deposits and therefore hosts a variety of science ROIs and potential resource ROIs. The first potential science ROI is located in the northeast corner of the basin rim, approximately 13 km northeast from the proposed LS/HZ center (Figure 1b). The largest diversity of hydrated minerals is located in this region of Columbus crater, including the only detection of jarosite and alunite, thus suggesting a diverse aqueous history and groundwater/mineral interaction at this location; this would also be a location that would have a comparatively high probability for biosignatures. The hills on the north central crater floor, located ~7-10 km from the center of the proposed EZ/LS, serve as a potential resource ROI as they contain numerous hydrated minerals, including aluminum and Fe/Mg bearing phyllosilicates and polyhydrated sulfates (Figure 1c). The characteristic bathtub ring and other stratigraphic deposits in the crater rim serve as an ROI for the study of not only groundwater/mineral interactions but also for global climate changes on Mars. Finally, the crater floor is largely covered by a darker rock unit interpreted as a lava flow, variably draped by fine-grained materials interpreted as regional aeolian loess. These have been dated to the Early and Late Hesperian (respectively), while Columbus crater itself and its aqueous mineral deposits respectively date to the Middle and Late Noachian periods, collectively sampling a significant range of martian geologic time in rock units datable via crater counting [3]. These are only a few key examples of relevant ROIs present in Columbus crater and more will be addressed in the presentation.

In summary, Columbus crater meets the basic criteria for an exploration zone, presents diverse science and basic resource ROIs, and should be considered as a viable candidate landing site for the first human mission to Mars.

References: [1] Glotch T. D. et al. (2010) *GRL, 37*(16), L16202. [2] Wray J. J. et al. (2009) *Geology, 37*(11), 1043–1046. [3] Wray J. J. et al. (2011) *JGR, 116*(E1), E01001.

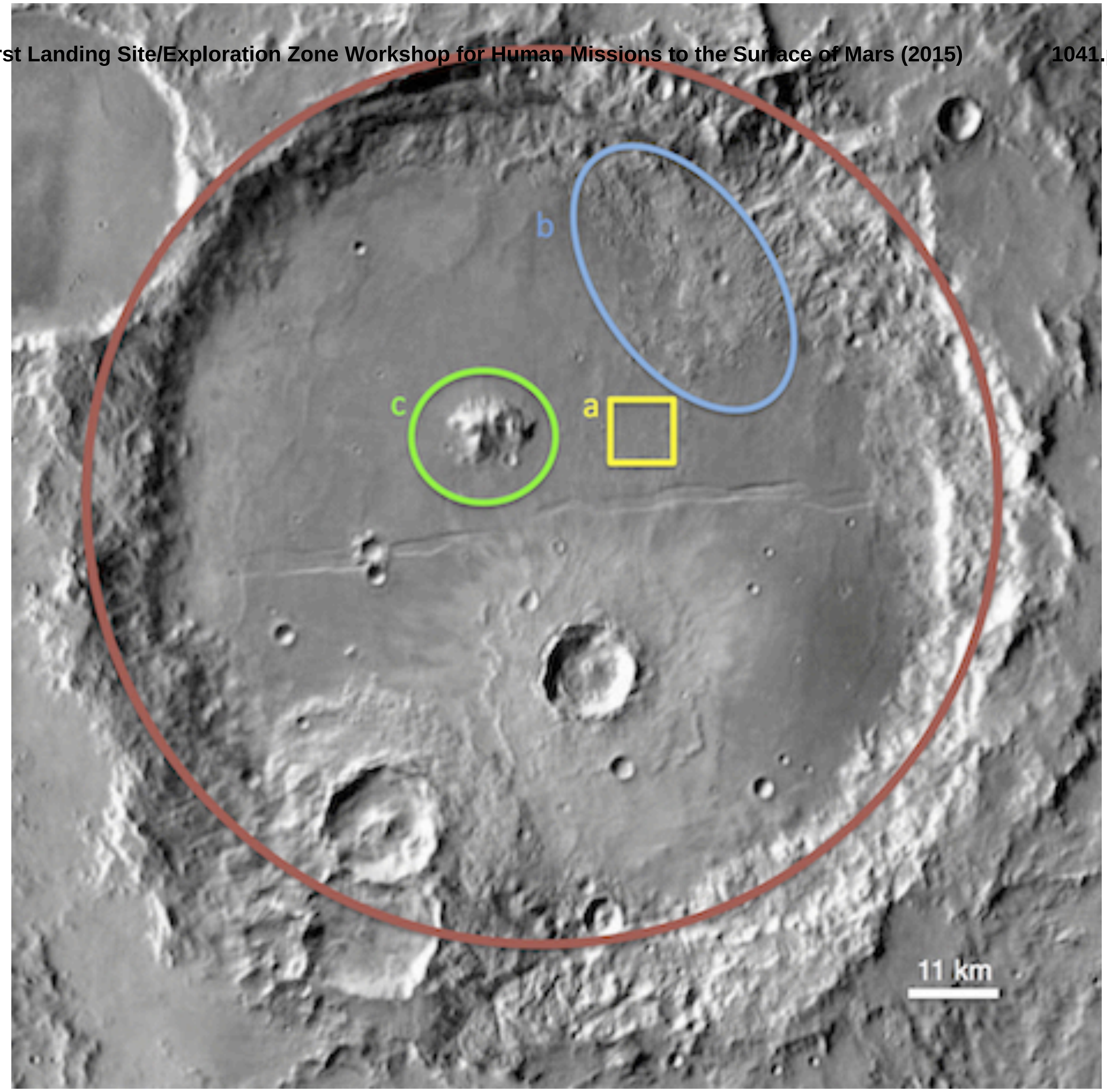


Figure 1. THEMIS daytime IR Mosaic of Columbus Crater . (a) Landing Site/Habitation zone 5 X 5 km. (b) Science ROI. (c) Potential Resource ROI

ISMENIUS CAVUS: ANCIENT LAKE DEPOSITS AND CLAY MINERALS SURROUNDED BY AMAZONIAN GLACIERS. N.Mangold[1] , E. Dehouck[2], F. Poulet[3], V. Ansan[1]. and S. Le Mouélic[1], [1]LPGNantes UMR6112 CNRS 44322 Université Nantes, France, [2]StonyBrook University, New York, USA, [3]IAS, Université Paris XI, 91405 Orsay Cedex, France (nicolas.mangold@univ-nantes.fr).

Introduction: Ismenius Cavus is a depression inside the Ismenius Lacus region located close to the Martian dichotomy, north of the Arabia region (Fig. 1) [1]. Geological data on this site (located 33°49'N, 17°10'E, elevation -3450 m, with Exploration zone of 60*70 km) include fluvial and deltaic landforms, clay-bearing sedimentary deposits and glacial landforms. This unique association of landforms of various ages (from Noachian to Amazonian) is of interest for human exploration because this site shares large water resources as ice or clay minerals and fundamental scientific interests for exobiology.

Fluvial landforms: Ismenius Cavus is a basin where six valley networks converge, including two from the east, two from the west, and two from the south, including the 1200 km long Mamers Vallis. One valley at the northern edge is an outlet that joins other troughs. Mamers Vallis may have been connected to the larger drainage basin associated with the Naktong-Scamander valleys to the south [2]. Three of the six valleys entering Ismenius Cavus have depositional fans interpreted as Gilbert-deltas [1,3,4]. Topographic profiles with slope breaks between a flat plain and a 10-15° front slope are typical of Gilbert deltas of fluvial deposits entering a lake. All fans have a flat-lying plain at elevation between -3100 and -3150 m also typical of deltaic deposits. The elevation difference between the delta plains and the deepest basin floor section implies that this lake was 600 m deep, providing a theoretical volume of liquid water of ~550 km^3.

Glacial landforms: Most valley floors, as well as part of the interior rims of Ismenius Cavus, are overlaid by lineated valley fills and lobate debris aprons [5] identified by their lobate shapes, lineations and pitted texture. These lobate landforms are usually thought to result from the viscous flow of ice-bearing material [5,6]. Recent orbital radar data have confirmed the presence of a high proportion of ice (up to 80%) north of the study region [7]. Glacial landforms cover more than one half of the Cavus hillslope as well as most valley floors. We expect ice to be present below a thin layer of debris or/and dust.

Mineralogical detections: Iron-rich smectites were detected in the layered unit by OMEGA [8]. CRISM data display spectra with 1.4, 1.9, and 2.3 μm absorption bands [1]. Possible minerals include Fe/Mg phyllosilicates, such as nontronite or saponite. Phyllosilicates are found in meters-scale thick layers present at elevations between –3400 m and –3600 m (Fig. 1). Layer dips extracted from topography are subhorizontal suggesting that this unit is ~200 m thick. Phyllosilicates are also observed on a series of layers with a V-shape in plan view. These layers have a sub-horizontal dip and correspond to an elevation of –3300 m. The whole layered unit forms a single unit ~300 m thick, and layering is only visible here because this area is currently under erosion. Lastly, the dark material on the Ismenius Cavus floor contains pyroxene, probably in dark sand giving its color to the low albedo area.

Region of interest 1 (Science and resources): Centered 33°42', 17°09'E. The clay-rich deposits extend over ca. 10 km*10 km immediately south of the proposed landing site. Sedimentary deposits are bottomsets of the paleolake, suggesting that clay minerals could be detrital or authigenic. This context (sediments inside deep lakes) is of topmost interest for the search of past life on Mars and past climate evolution. In addition, clay contains abundant interstitial water that could be used for resources at the landing site.

Regions of interest 2 (Science and Resources): Centered 33°46'N, 17°44'E (ROI 2a) and 33°44'N, 16°49'E (ROI 2b). The glacial landforms contain ice deposited during the Amazonian era, therefore enabling retracing the recent climate evolution. They content abundant water ice that can be used as resources for astronauts.

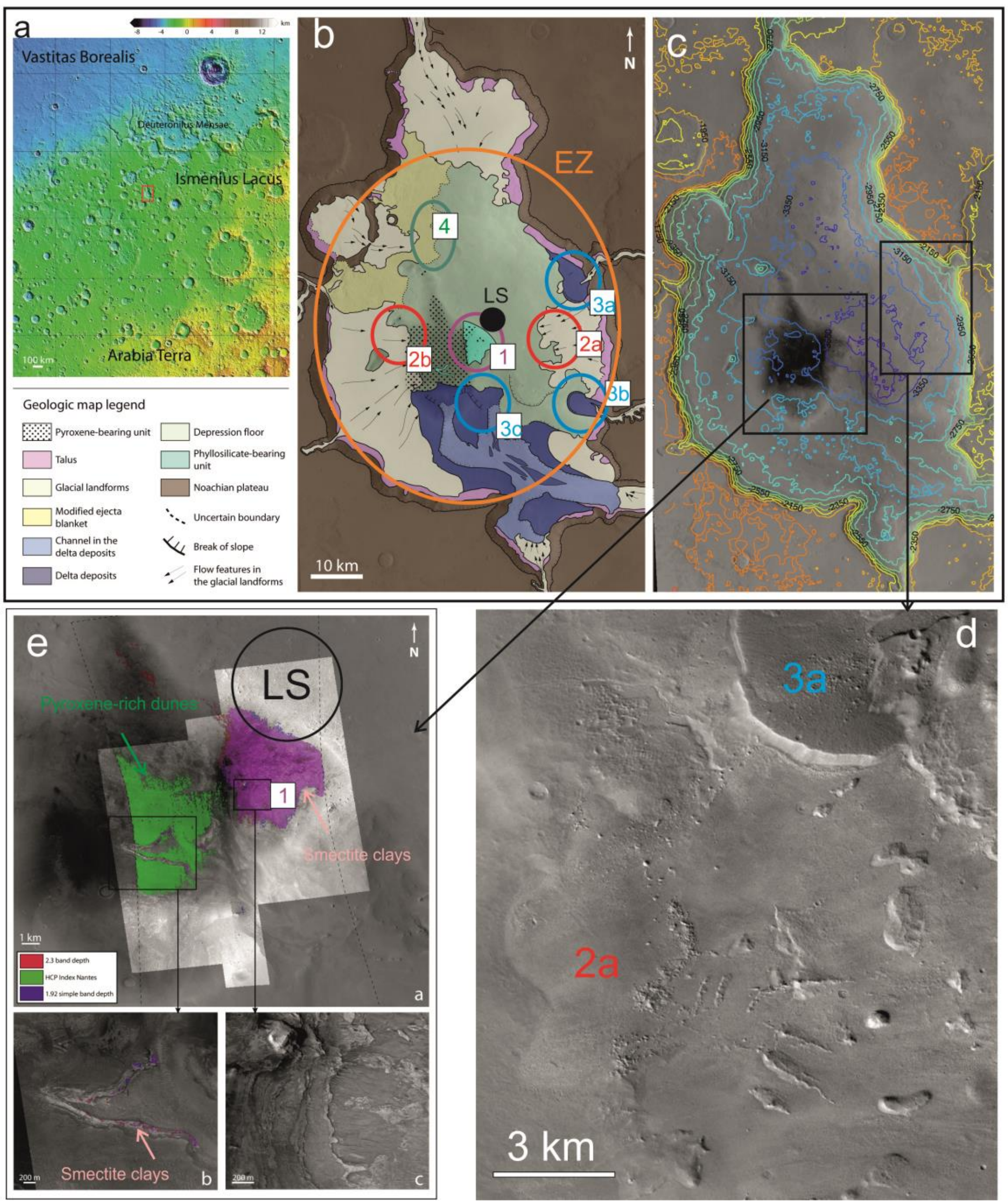
Regions of interest 3 (Science): Centered 33°55'N, 17°30'E (ROI 3a), 33°32'N, 17°30'E (ROI 2b), 33°34'N, 17°04'E (ROI 3c). The three deltaic landforms correspond to the deposits of fluvial valleys. They contain topsets and foresets of clastic sediments enabling to sample material from the Noachian source areas in Arabia Terra and will be complementary to the study of ROI 1 on bottomset deposits to understand duration and extend of the lacustrine activity.

Region of interest 4 (Science): Centered 34°12'N, 16°56'E (ROI 4). The ejecta from a large crater excavating Noachian crust would be of interest for sampling diversity of the crust.

Region of interest 5 (Resources): Dust-bearing areas are numerous on the edge of Ismenius Cavus. These areas should not be a problem on the landing site where themal inertia is intermediar, but dust present in the surroundings could be a third source of water as Arabia Terra dust is supposed to contain as much as 10% of water as observed by Mars Odyssey Neutron Spectrometer [9].

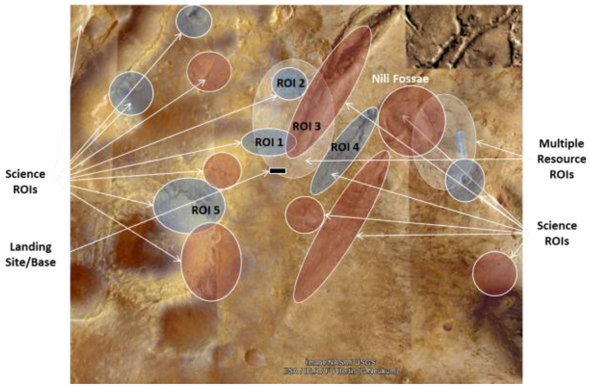
Figure 1: (a) Context topographic map with Ismenius Cavus on the top of Arabia Terra. (b) Geologic map from [1] with the ROI superimposed. Caption to the right. (c) HRSC mosaic with topographic contours. (d) CRISM data (smectite in purple, pyroxene in green) of ROI 1. (e) CTX image of convex, ice-rich lobate aprons (ROI 2a) and flat plain of the deltaic deposit (ROI 3a). LS=Landing site. EZ=Exploration zone.

References: [1] Dehouck et al., 2010, Planet. Space Sci., 58, 6, 941-946. [2] Irwin et al., 2005, JGR-Planets, 110, E12. [3] Cabrol and Grin, 1999, Icarus, 142, 160-172. [4] Ori et al., 2000, JGR-Planets, 105, E7, 17629-17641. [5] Squyres, 1978, Icarus, 34, 600-613. [6] Mangold 2003, JGR-Planets, 108, E4. [7] Plaut et al., 2009, GRL, 36, L02203. [8] Poulet et al., 2005, Nature, 438, 7068, 637-627. [9] Feldman et al., Science, 2002.



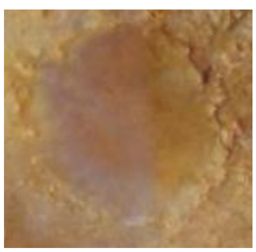
Nili Fossae Resource and Science ROIs. L. J. Markle.

Introduction: The Nili Fossae region is a very diverse region offering multiple opportunities for resource and science ROIs. The landing site, located approximately at 22.05°N, 76.95°E is centered in a crater at the southern end of a large valley. To the immediate east, north, and south, CRISM imagery indicates many key resources, most notably water ice.



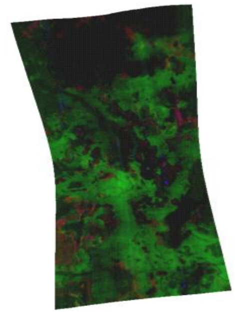
While this landing site is suggested, there are other nearby areas that could suffice for maximum ROI potential. Being located about 20° from the equator, this offers near maximum exposure to the sun for solar energy and food production. The Google Earth (GE) image below [1] indicates some of the many science and resource ROIs that are available in the area. One resource ROI is examined in more details below.

Landing Zone: This site [2] is a 9 mile wide crater with what appears to be a relatively smooth interior. The walls of the crater are no more than 600 feet at its highest peak and multiple passes provide easy exit to other ROIs.

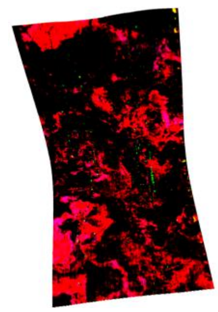


Alternate Landing Zone: This site [3] is an area about 9 mile wide also with what appears to be a relatively smooth interior. Located about 67 miles ENE of the primary LZ, this area is one where CRISM also indicates a wide area containing water ice. Another advantage of this site is that the Isidis region is much closer where that are could provide a science ROI to look for fossilized primordial live. Also located near here is a 5000' mountain which could operate as a communications repeater for long range communications.

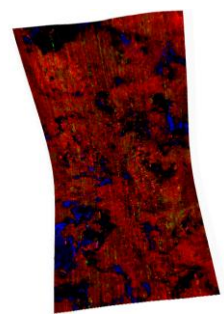
Resource ROI - Water Ice: This CRISM image [4] seems to indicate an abundance of water ice (green). Incidations of pockets of CO2 ice (blue) and water ice or hydrated sulphates, clays, or glass (red) are present in this image as well. Images south and east of this area show similar indications. Note, contrast and brightness were adjusted in this image to highlite the colors.



Resource ROI - Bound Water: This CRISM image [5] shows the presence of water containing minerals or water ice (red) and hydrated sulphates, clays, glass, or water ice (blue). Sporatic areas of monohydrated sulphates or water ice (green) can be seen in this image, but some of these may only be artifacts of the imagry.

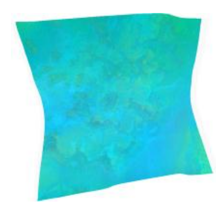


Resource ROI - Hydroxylated silicates: ThisCRISM image [6] shows indicates the presence of Fe/Mg phyllosilicates (red) in the area. There are some indications of hydrated sulfates (blue), clays, and/or glass in this image as well as small pockets of Al phyllosilicate or hydrated glass (green).



Resource ROI -Malfic Mineralogy: This CRISM image [7] shows the areas where olivine or iron phylosilicates may be found (red) and areas of low-Ca Pyroxene (green), and one possible area of high-Ca pyroxene (blue). It seems unclear in the image if the green areas are a combination of yellow and blue (high-CA) or actually green (low-Ca).

Resource ROI -Oxidized Iron Minerals: This CRISM image [8], located about 27 miles SSE of the previous image shows the areas of a varity of iron minerals (blue). Green indicates coatings (SH600 nm)



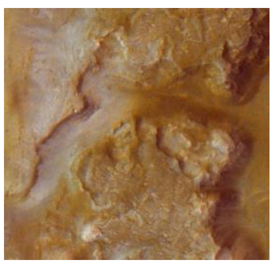
but further analysis would be needed to determine whether this is a viable source of minerals or simply scarce indicatations.

Astrobiology: As this area seems to indicate a large amount of water ice, this ice could contain the frozen/fossilized remains of Martian life. This would need to be considered if used for a source of water for drinking or growing crops. Also, approximately 150 miles east is the Isidis region which could offer interesting studies in possible fossilized remains of Martian life on the edges of what could have been a large Martian sea or ocean. While this is outside the current constaints of the EZ being proposed here, it does offer the possibility depending on where the base of operations is located or if extended explorations are realized.

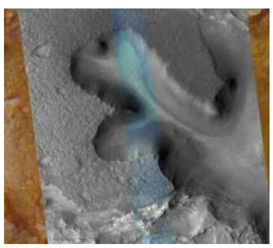
Geosciences: Craters, flows, crustal regions, and canyons (fossae) all offer multiple and diverse opportunities for geoscience. In surrounding craters, layered strata is exposed for geological analysis. In the fossae, studies can be done as to the origin, makeup, and age of these formations. While some of these are large, there do appear to be several locations for access into these canyons from the southern ends.

Atmospheric Studies: The proposed LZ is approximately 1700-1800 feet below mean elevation. Being this low, it offers an excellent opportunity for studies in an area of thicker atmosphere. This could also be beneficial for warmer temperatures because of the decreased elevation of the area.

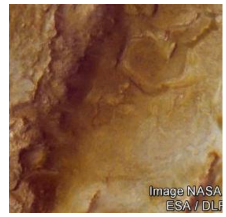
ROI 1 – Canyon 1: This canyon [9], located at 21 45'N, 77 02'E appears to have easy access from the SW end and may also provide access to the large fossae as well. GE imagry indicates possible layering throughout the canyon.



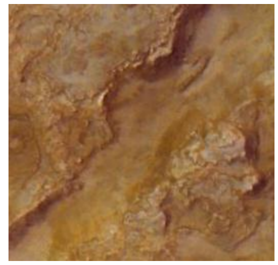
ROI 2 – Canyon 2: This canyon [10], located at 22.25°N, 77.07°E appears to be located in an ancient crater, with the SE portion opening into a large fossae. Dunes are present at the bottom of the canyon. The crater surface has a crust-like surface of some unknown material. Water ice appears abundant in the area as well. It appears to access the canyon from the SE portion of this image where other interesting geological features also appear.



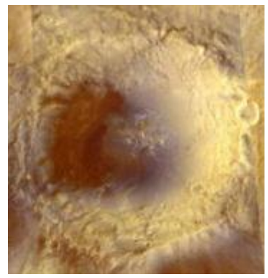
ROI 3 – Large Fossae: This canyon [11], begins at about 22.5°N, 77.0°E and extends approximately 200 miles to the NE. Beginning just outside the crater where the LZ is proposed, this appears to be an easy access point to the canyon to explore the cause, history, and geology of the canyon.



ROI 4 – Small Fossae: This canyon [12], begins just to the east of the large fossae, 21.1°N, 77.25°E While not as deep or long as the larger fossae, it could provide easier access and may be able to be traversed further into the interior for geological studies.



ROI 5 – Hargraves Crater: [13] Located about 32 miles SW of the proposed landing site, this large crater has multiple geological features. Expoxed layers on the rim as well as eroded features, flows, and subsequend impacts are some of the scientific interests in this area. About 37 miles in diameter, this crater provides an extensive area for exploration and research.



Additional ROIs: Many more scientific ROIs are available from either LZ. Only some are presented here.

References:

[1] Image from Google Earth, Nili Fossae region. [2] Google Earth image centered about 21.43°N 76.93°E [3] Google Earth image centered about 21.75°N 78.95°E [4] CRISM imagery HRL00011336_07_IF183L_ICE1.png
[5] CRISM, HRL00011336_07_IF183L_HYD1.png.
[6] CRISM, HRL00011336_07_IF183L_PHY1.png.
[7] CRISM. HRL00011336_07_IF183L_MAF1.png.
[8] CRISM. FRT0000871C_07_IF166S_FEM1.png.
[9] Google Earth image centered abt 21.75°N 77.05°E
[10] Google Earth image centered abt 22.25°N 77.07°E [11] Google Earth image centered abt 21.92°N 77.25°E [12] Google Earth image centered abt 21.53°N 77.53°E [13] Google Earth image centered abt 20.72°N 75.75°E

LANDING SITE AND EXPLORATION ZONE IN EASTERN MELAS CHASMA.
A. McEwen[1], M. Chojnacki[1], H. Miyamoto[2], R. Hemmi[2], C. Weitz[3], R. Williams[3], C. Quantin[4], J. Flahaut[4], J. Wray[5] , S. Turner[6], J. Bridges[6], S. Grebby[7], C. Leung[1], S. Rafkin[8] [1]LPL, University of Arizona, Tucson, AZ 85711; mcewen@lpl.arizona.edu), [2]University of Tokyo, [3]PSI, [4]Université Lyon, [5]Georgia Tech., [6]University of Leicester, [7]British Geological Survey, [8]SwRI-Boulder.

Introduction: A favorable Exploration Zone (EZ) for future human missions to the surface of Mars should have these characteristics: (1) resources needed to keep humans alive, especially H_2O; (2) important science targets; (3) diverse regions of interest (ROIs) that can be reached within ~100 km of a central landing site; (4) a central landing site or multiple sites of at least 5 x 5 km area that are favorable for landing (low slopes, few meter-scale hazards, not covered by thick dust); (5) equatorial location for thermal management and ease of ascent from Mars surface; and (6) low elevation for ease of EDL with large masses and protection from radiation. Eastern Melas Chasm may be the region that best meets all of these criteria [1].

Recurring Slope Lineae (RSL) and/or polyhydrated sulfates for water: RSL are seasonal flows or seeps on warm Martian slopes. Observed gradual or incremental growth, fading, and yearly recurrence can be explained by seasonal seeps of water, probably salty [2-3]. They are narrow (<5 m), relatively dark markings on steep (25°–40°), low-albedo slopes, which appear and incrementally extend during warm seasons, fade when inactive, and recur in the same approximate or exact location over multiple Mars years. RSL lack clear water absorption spectral bands in Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) spectra, but the fans on which they terminate have distinctive color and spectral properties [4], and hydrated salts have been detected at some locations [5]. The lineae commonly follow small gullies, but few topographic changes have been detected via 30 cm/pixel images from the Mars Reconnaissance Orbiter (MRO) High Resolution Imaging Science Experiment (HiRISE). RSL are found in mid-latitude and equatorial regions, but are by far most common in the central and eastern troughs of Valles Marineris [6]. The equatorial RSL are especially active on sun-facing slopes, moving from north- to south-facing slopes and back to track the peak insolation.

There are several key gaps in our understanding of RSL. Most importantly, the origin of water to drive RSL flow is unknown. The time of day of active flow is also unknown. Most RSL locations are steep, rocky, low-albedo slopes, with daily peak surface temperatures typically >250 K, and commonly >273 K, in the active season, but there must be additional factors, because many times and places with these properties lack detectable RSL [7]. Laboratory experiments show that even minor amounts of water (5 wt. % and no liquid film on surface) can darken basaltic soils while producing only weak spectral features [8, 9]. These spectral features may be undetectable in CRISM spectra obtained from MRO's midafternoon orbit, due to partial dehydration and evaporation, except in rare times and places [5].

RSL are presently not understood well enough to plan ISRU for human exploration. It is not known whether >100 MT of useable water could be produced from RSL. These may be dense eutectic brines filling pore spaces, so new technologies will be needed to extract usable H, O_2 and H_2O. The water may have an atmospheric origin [10], in which case the RSL may mark locations favorable for ISRU extractiuon of water directly from the near-surface air.

Fortunately, Hesperian-age kieserite and polyhydrated sulfates dominate the south-southwest half of this EZ [11], perhaps from upwelling of groundwater [12]. This 3-km thick deposit is dominated by polyhydrated sulfates, suggesting a significant amount of bound water (up to 50% by volume) for potential ISRU. The alternative is to go to a middle-latitude location with clean, shallow ice [13, 14] and plan for cold winters.

Discussion of East Melas EZ: This region (see figure; center ~11.7 S, 290.0 E) is one of the largest low-elevation equatorial regions on Mars, with some areas below -5 km. This low elevation minimizes the challenge of landing large masses on Mars, and also reduces the radiation exposure [15]. In addition to RSL and/or hydrated sulfates for water, the mafic bedrock, regolith, and aeolian materials likely provide ample Fe, Al, Si, Ti and Mg. Cobble-sized or smaller rocks and bulk, loose reglolith are likely to be available for construction. There are mesas with steep sides that might be adapted for construction purposes. Wind magnitude in the Valles Marineris might produce engineering concerns but the proposed region is far from the canyon rims and modeled as moderate [16].

There are important science targets for investigation of both ancient and modern habitability and potential life, and a broad range of geologic processes. This region includes a great diversity of landforms, including layered bedrock with diverse compositions, high massifs with landslides, volcanic dikes, possible glacial landforms, possible lake deposits, impact craters, sand dunes and other aeolian deposits. The deep bedrock exposed in numerous locations is largely Noachian (>3.6 Ga), while the interior layered deposits are Hesperian and aeolian materials are Amazonian.

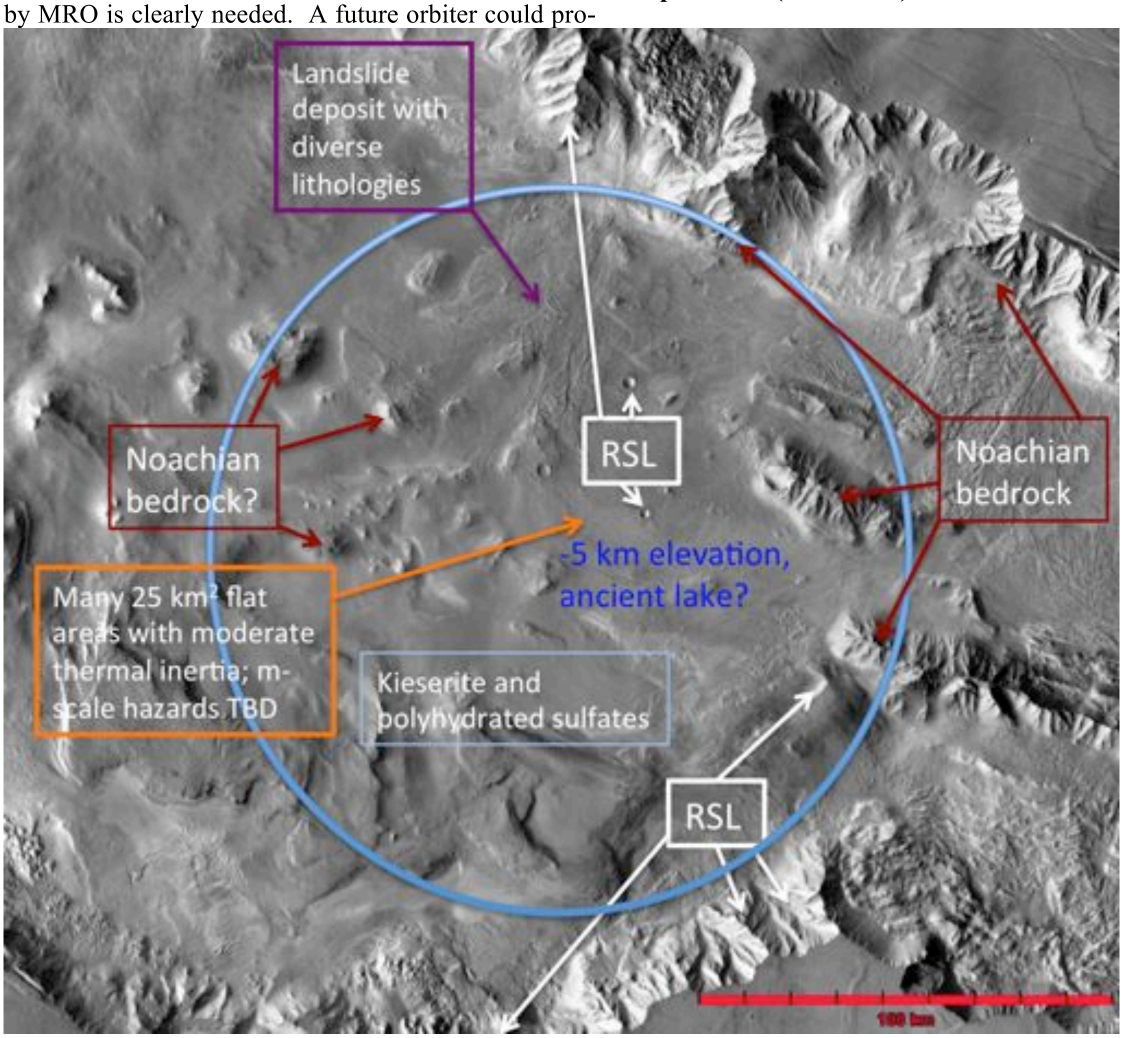
There have been many studies of minerlogy in Valles Marineris, including nearby Coprates Chasma and the SW Melas basin and surrounding [17] regions, with abundant phyllosilicates, sulfates, and other hydrated minerals. An unpublished CRISM analysis reveals a 2.21 μm absorption suggesting Al-rich phyllosilicate near the center of our EZ. CRISM full-resolution coverage of this EZ is only a few %.

The greatest engineering concern after water may be meter-scale EDL hazards. The available HiRISE image coverage is very sparse, a few % coverage, yet they show multiple 5x5 km flat areas with few boulders or scarps. Many of these flat areas are covered by small-scale aeolian bedforms, mostly <1 m high, and some appear indurated and eroded. Areas without aeolian bedforms tend to have more exposed boulders and slopes, but may be acceptable.

If East Melas is considered a promising region for a human EZ, then more CRISM and HIRISE coverage by MRO is clearly needed. A future orbiter could provide important new observations as well. JAXA is considering a future lander or rover to this region [18].

References: [1] Miyamoto, H. et al. (2014) http://marsnext.jpl.nasa.gov/workshops/2014_05/20_Valles Marineris_Miyamoto.pdf. [2] McEwen A. S. et al. (2011) *Science*, 333, 740-744. [3] McEwen A. S. et al. (2014) *Nat. Geosci.*, 7, 53-58. [4] Ojha, L. et al. (2013) *GRL* 40, 5621-5646. [5] Ojha, L. et al. (2105) *Nat. Geosci.*, in press. [6] Chojnacki, M. et al. (2014) LPSC 45, 2701. [7] Ojha L. et al. (2014) *Icarus*, 231, 365-376. [8] Masse, M. et al. (2014) PSS 92, 136-149. [9] Pommerol, A. et al. (2013) JGR Planets 118, 2045-2072. [10] McEwen, A. et al. (2015) EPSC abstract. [11] Roach, L.H. et al. (2010) *Icarus 207,* 659-674. [12] Andrews-Hanna, J. et al. (2007) *Nature 446*, 163-166. [13] Dundas, C. et al. (2014) *JGR-Planets* 119, 119-127. [14] Viola, D. et al., this workshop. [15] Guo, J. et al (2015) submitted to *Earth & Planetary Astrophysics.* [16] Spiga and Forget (2009) JGR Planets 114, E02009. [17] Weitz, C. et al. (2015) Icarus 251, 291-314. [18] http://mepag.jpl.nasa.gov/meeting/2015-02/08_MEPAG_Miyamoto_Final.pdf.

Figure: THEMIS daytime-IR mosaic with proposed EZ (blue circle) and features of interest.



McLAUGHLIN CRATER AS A CANDIDATE LANDING SITE FOR HUMANS ON MARS. J. R. Michalski[1,2], P. B. Niles[3], B. Sutter[3], and M. S. Bell[3]. [1]Planetary Science Institute, Tucson, AZ. [2]Natural History Museum, London, UK. [3]NASA Johnson Space Center, Clear Lake, TX, USA.

Introduction: McLaughlin Crater is an ancient (Noachian) Martian impact crater located at 337.6E, 21.9 N, just south of the dichotomy boundary. This site should be considered for future landed exploration because: a) it is located at the boundary of three types of scientifically important terrain that will yield key results about the geological evolution and habitability of Mars; b) it contains surfaces where radiometric dating can be related to age dates estimated from crater counting, c) it contains volatile-rich rocks that will not only yield interesting results regarding ancient atmospheric chemistry, but will also be high quality, accessible targets for ISRU, and d) the site within the crater provides a flat, low-risk and low-elevation landing zone, which will facilitate landing large payloads on Mars.

McLaughlin Crater is a Noachian impact crater that contained a deep (~500 m) lake >3.8 Ga [1]. Evidence for the existence of an ancient lake comes from the presence of channels in the east crater wall which terminate above the crater floor, the presence of what is likely a delta in the same location, and the observation of layered subhorizontal clay and carbonate rocks in the crater floor. The lake was almost certainly fed by crustal fluids, and therefore the deposits could provide insight into deep biosphere habitability.

The clays and carbonates on the floor of the crater are overlaid by a datable, dark airfall deposit that is likely volcanic ash. And, this airfall deposit is overlaid by ejecta from Keren Crater, on the southern wall of McLaughlin, as well as debris flows derived from the interior wall of McLaughlin Crater. The ash layer itself is a datable unit of regional extent. Also, radiometric dates of a large suite of igneous grains in the ejecta would give an indication of how much extremely ancient material in in the crust and to what degree thermal events have affected interpreted ages. Lastly, ridged plains outside McLaughlin, which are of regional extent of likely igneous in nature, provide another target of interest for radiometric dating.

The ejecta and debris flows within McLaughlin Crater are also interesting scientifically because they contain blocks of deep crustal materials with very strong spectral absorptions associated with carbonates and likely serpentine, which likely formed in habitable conditions in the Martian subsurface before behing exhumed by impact and collapse. Some of the debris flows within McLaughlin seem to have occurred suaqueously [1], which is interesting because it implies rapid burial – a favorable scenario for the preservation of biomarkers.

The McLaughlin site contains many potential advantages for ISRU. The *average regional* H_2O-content estimated from GRS data is ~5-6% from both GRS data [2] and infrared data [3]. There are at least two types of mineral resources detectable from orbit, and both of these targets display extremely strong infrared absorptions (which likely translates to relatively high abundance of these phases). One target is hydrated Mg-rich carbonates in the southern part of the crater floor. HiRISE images show that these materials are located within blocky ejecta and debris flows. Therefore, an advantage is that the rocks to not need to be "mined" – they can simply be loaded for transport because they are found in fragmented blocks. Phyllosilicates are also found in both the ejecta and layered deposits in the crater. These include several types: a) dioctahedral smectites (probably yielding more water at lower T), b) triocthaedral smectites (higher water yield of hydroxyl) and c) serpentine (less water content than smectite).

McLaughlin Crater is located at the boundary of three regional terrains: a) the ancient Noachian crust to the south, b) the northern plains to the west, and c) the Mawrth Vallis deposits to the east and north (Figure 1). An evaluation of slopes in and around the crater suggest that it should be possible to exit the crater via the north or northeast routes and therefore, a long-term presence at this site will allow for exploration of all three categories of terrain. However, the most important science and resource targets of interest are located within the crater. The Landing zone (LZ) could be located in any number of positions on the crater floor in order to provide closer access to resources or to science targets. In the proposed position, the 25 km^2 LZ is located on the ash deposit. On the western boarder of the LZ is a debris flow deposits of likely subaqueous origin. On the east and south sides of the LZ are the lacustrine, layered clay deposits. An excellent exposure of >50 m of clay-carbonate lacustrine deposits is located ~10-15 km from the proposed LZ.

References: [1] Michalski, J. R. et al. (2013). Nature Geoscience, 6. 133-138. [2] Feldman, W. C., et al. (2004), JGR 109, E09006. [3] Milliken, R. E. et al. (2007). JGR 112, E08S07

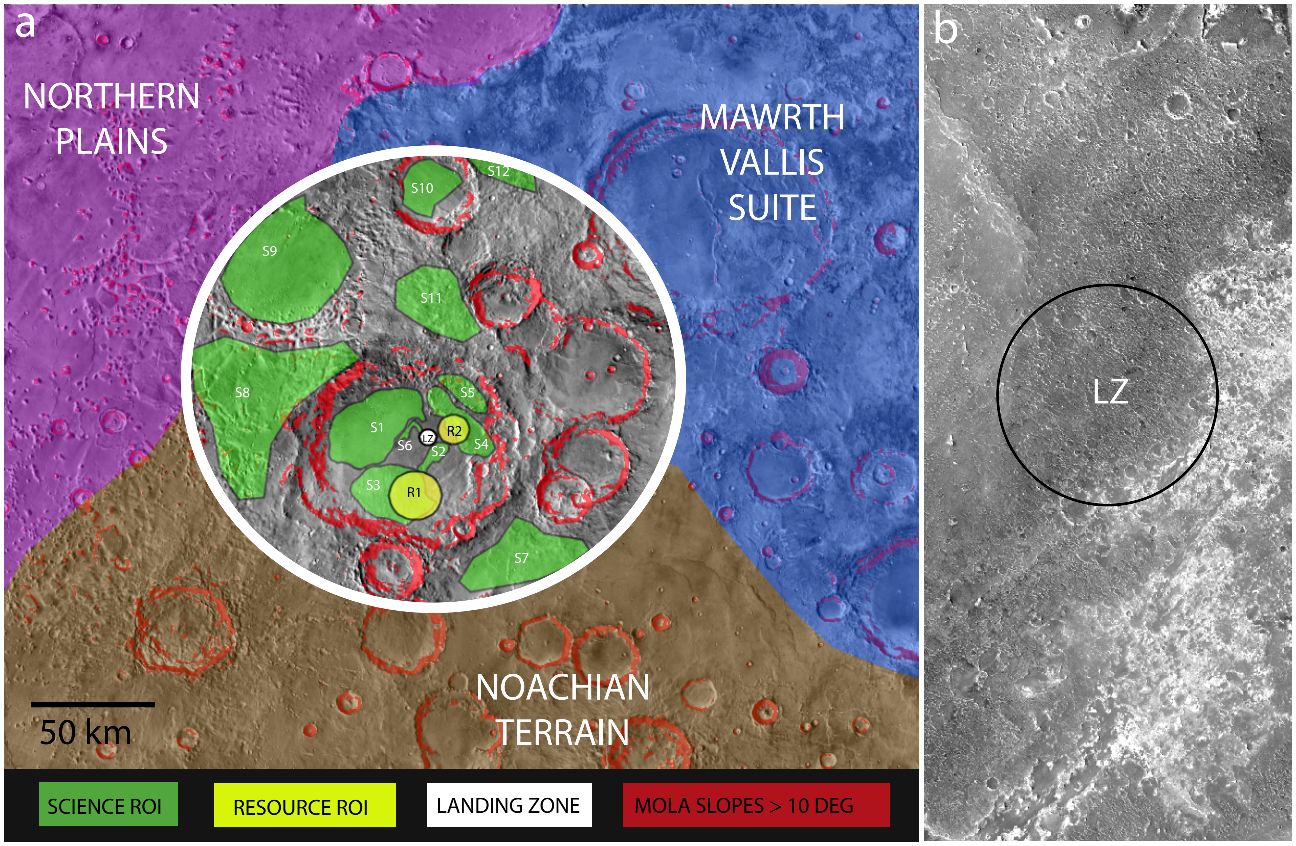


Figure 1: Exploration zone located within McLaughlin Crater, which was a ~500 m-deep lake in on Mars >3.8 Ga (a). Lacustrine deposits contain abundant clays and carbonates of interest for both science anc resource utilization. The elevation of the landing zone is -5.1 km. There are many possible locations of a landing zone (LZ) on the crater floor. CTX data (b) show a high resolution view of the proposed landing zone (image is 10 km wide).

Table 1: ROI characteristics for McLaughlin Crater site.

EXPLORATION ZONE: McLAUGHLIN CRATER AND SURROUNDING TERRAIN	
ROI	
R1	Blocks of hydrated carbonates (already fragmented)
R2	Smectitic clay minerals (both dioctahedral and trioctahedral clays)
S1	Datable airfall igneous unit with regional extent; same as in Mawrth
S2	Thick section of layered Noachian lacustrine carbonates and clays
S3	Ejecta and debris flow with large sampling of deep crustal igneous and hydrothermal materials. Key for both igneous petrology and deep biosphere. Igneous materials are likely datable.
S4	Delta deposits in ~500 m-deep Noachian lake
S5	Channels in crater wall
S6	Likely subaqueous debris flow deposits
S7	Datable igneous surface: ridged plains
S8	Pyroclastic deposits
S9	Northern plains deposits
S10	Datable surface, likely igneous
S11	Altered ejecta; deep crustal materials
S12	Mawrth Vallis clays

Equatorial Opportunities for Humans on Mars

Julie Mitchell & Philip Christensen
Arizona State University

Introduction. The goals of a human Mars mission are to establish a permanent presence in space and to study the evolution of the planet. Selection of an exploration zone suitable to both of these mission goals is therefore of paramount importance. The equatorial site presented here (-18.83°N, 310.79°E, Figure 1) fits the engineering and resource criteria while maximizing the science return of a human Mars mission.

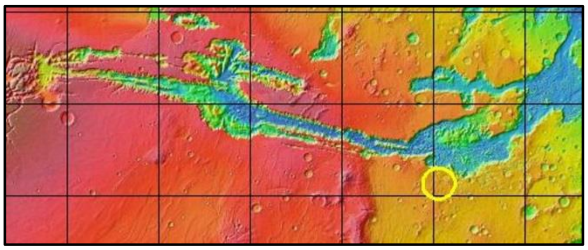


Figure 1. MOLA colorized elevation of Valles Marineris with exploration zone (yellow circle).

Scientific Relevance. Liquid water is both a prerequisite for Earth-like life and an in-situ resource. The proposed exploration zone (EZ) is in proximity to recurring slope lineae (RSL), which likely contain liquid water [1]. In addition, five sites containing hydrated minerals [2] and seven sites containing chlorides [3] – possible evaporative products – are contained in the EZ.

The major geologic processes that have dominated Mars' surface are represented in this EZ. Numerous impact craters are accessible by crew, including unique morphologies such as rampart craters which may have formed via impact into a water-rich substrate [4]. The formation of Valles Marineris – the largest canyon in the Solar System – is one of the biggest mysteries in Mars science; this EZ is ideal for studying the tectonics that formed it. Volcanic activity likely occurred in this region as indicated by morphologies resembling terrestrial maar volcanoes and the general abundance of basalt. In addition, a transition in Mars' remnant magnetic field lines is present in this EZ, potentially providing insights into the earliest part of Mars' geologic history [5]. Finally, the contact between two of the largest geologic units on Mars – the mid- and late-Noachian highlands – provides a window into the period during which water was actively shaping the martian surface [6].

Engineering Constraints and Resources. The landing and habitation sites are smooth (slopes <10°) at Mars Orbiting Laser Altimeter (MOLA, 100m) scales [7]. The region is also low in dust as measured by the Thermal Emission Spectrometer (TES) [8]. Early missions will be in proximity to a chloride site and multiple small, accessible impact craters, allowing substantial science operations without the need to travel long distances. Science and resource regions of interest (ROIs) were selected to allow for a gradual branching-out within the EZ. Thermal inertia measurements identify small regions within the EZ comprised of sand-sized particles, providing raw materials for construction. In addition to the water outlined in the previous section, ample resources are available for human use, making this site ideal for sustained surface operations.

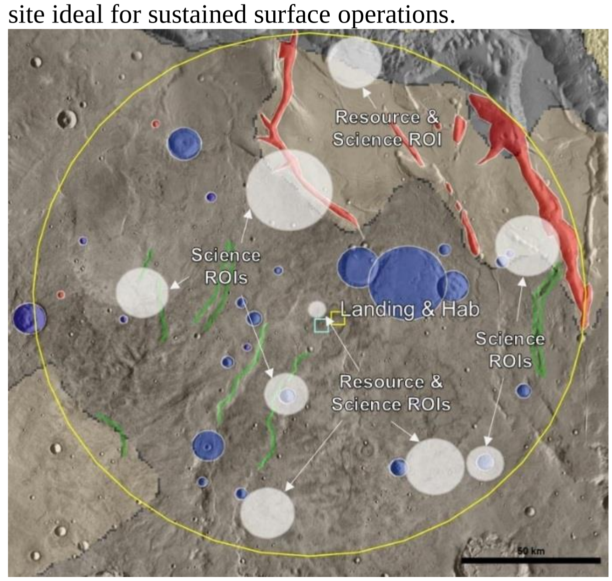


Figure 2. EZ (large circle) and Science/Resource ROIs (white circles). Major impact craters (blue), valleys (red), tectonic features (green). Landing/habitation sites at center (squares).

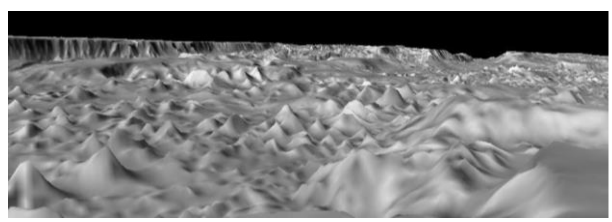


Figure 3. The view from south Valles Marineris, a source of excitement and engagement for the public (THEMIS Day IR on MOLA, 1.5x vert. exaggeration).

References: [1] McEwen, A., et al. (2014) *Nature Geoscience, Vol 7*. [2] Carter, J., et al. (2013) *JGR, 118*. [3] Osterloo, M. et al. (2008) *Science, 319*, 1651. [4] Head, J., and Roth, R. (1976) *The Lunar Science Institute Meeting, 50*. [5] – Connerney, J. E. P., et al. (2005) *Proceedings of the Nat'l Academy of Sciences*, Vol. 112. [6] Tanaka, K., et al. (2014) USGS Map SIM 3292. [7] Zuber, M., et al. (1992), *JGR, 97*. [8] Ruff, S. and Christensen, P. (2002) *JGR, 107*.

Human Exploration of Mars at Valles Marineris: The Past, Present, and Future of Life on Mars. A. Mojarro[1], G. Ruvkun[2], M. T. Zuber[1], and C. E. Carr[1-2,*], [1]MIT Department of Earth, Atmospheric and Planetary Sciences, Cambridge, MA, [2]MGH Department of Molecular Biology, Boston, MA. [*]Correspondence: chrisc@mit.edu

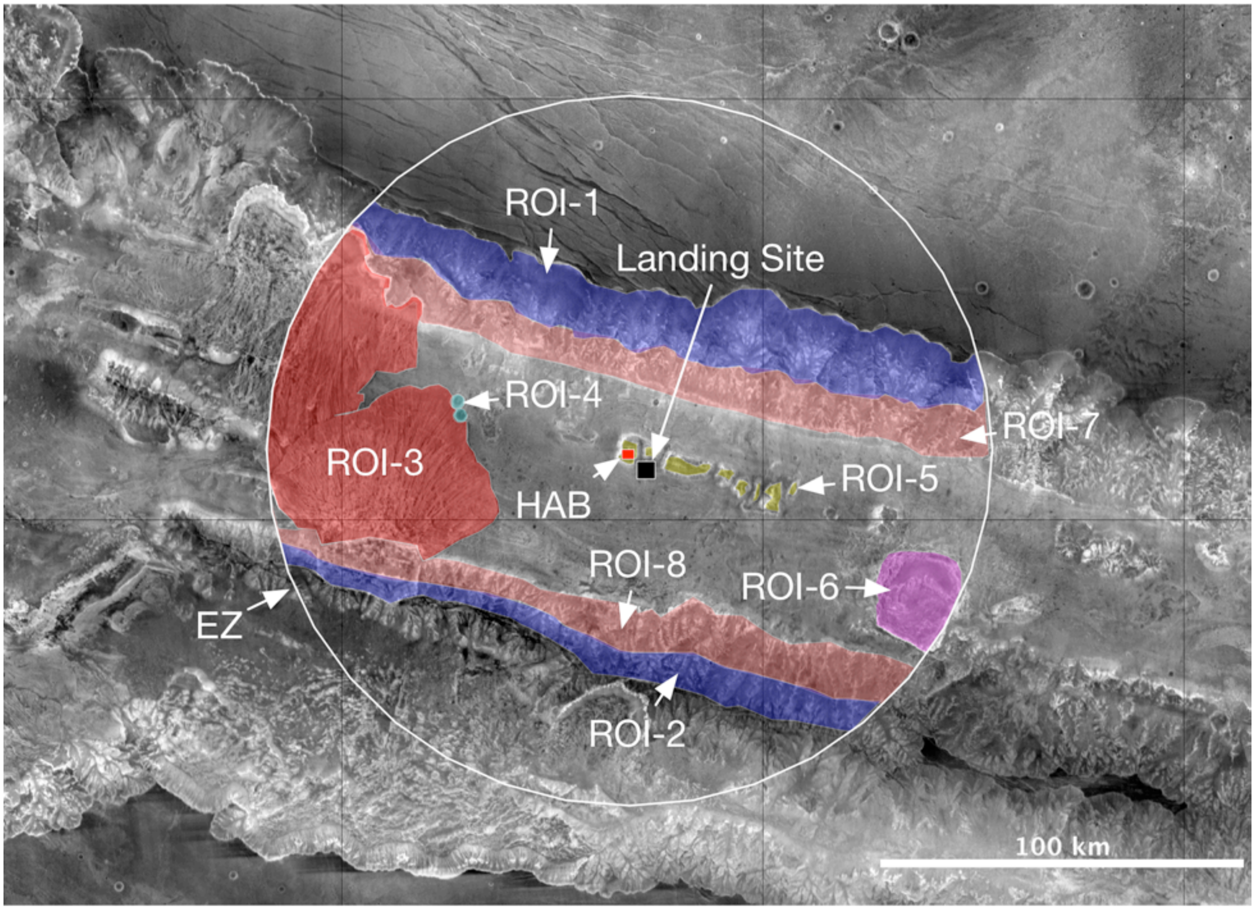


Figure 1. Our proposed exploration zone (EZ) in western Coprates Chasma, Valles Marineris, encompasses regions of interest (ROIs) relevant to the deep geologic history of Mars, the search for ancient or extant life, and a setting and resources that could support human habitation on Mars. Image data: JMars (ASU) with Night IR (NASA Mars Odyssey/THEMIS).

Introduction: Mars's grand canyon, Valles Marineris, is host to numerous preserved geologic features, modern atmospheric phenomena and potential subsurface aqueous activity favorable towards human habitation. Our proposed exploration zone is centered atop an inferred tilted fault block 1 km above the valley level in the western aspect of Coprates Chasma, 293.367°E -11.684°N. Within 100 km of our proposed landing site are several regions of scientific and engineering interest including: recurring slope lineae (RSL) [1], cross cutting alluvial fan deposits, tilted valley walls [2], impact craters, olivine deposits [3], clay mineral deposits [3] and exposed deep crustal lithologies [3]. Favorable environmental conditions include strong year-round solar insolation [1] and high atmospheric pressures [4].

Science: Key regions of interest (ROI) in the search for extant life on Mars are RSLs (ROI-1,2) [1], which may be fed by subsurface brine aquifers. The valley walls surrounding the habitable zone (HAB) contain a high concentration of RSLs which increases the likelihood for detection of an extant microbial ecosystem, if life ever took root on Mars and survived the Hesperian-Amazonian transition. Direct sampling of briny waters at RSL sites, combined with nucleic acid sequencing, along with corroborating evidence, could provide strong evidence of extant life on Mars [5-7]. RSLs are found on steep slopes, posing sampling challenges for existing robotic systems. However, humans, or Mars-adapted helicopters [8] or quadcopters [9] may be able to target these and other hard to reach ROIs.

Cross cutting alluvial fans (ROI-3) from opposite valley walls 42 km to the west of the habitable zone, Ophir Labes and younger Coprates Labes, are plausible regions for preserved organics and/or microfossils. The spreading geometry and flow distance of these alluvial fans indicate an aqueous origin [10] as opposed to dry granular flows [11]. Both fans appear to be a result of groundwater discharge which supports our subsurface aquifer theory. Organics or microfossils transported from the aquifer or valley walls could be preserved within the sediment and ideally buried deep enough to survive the harsh surface radiation environment [5, 12]. Futhermore, twin impact craters (ROI-4) at the north-east edge of Coprates labes could also harbor signs of ancient life. Recent literature has indentified impact glass formation as a potential preservation mechanism of biosignatures [13]. If the formation of Coprates labes and the twin impacts occurred within a timely geologic period, organics could be preserved beyond the surface limitations [12]. The proposed habitable zone and adjacent regions due east (ROI-5) are inferred to be tilted fault blocks [2] remnant from the rifting [14] or transextentional [15] event which initiated Valles Marineris. The vertical stratigraphy of Valles Mariners could easily be analyzed horizontally, spanning billions of years. Human explorers would walk along the depositional history during rifting/transextention and subsequent canyon incision and gaze into crustal lithologies and the corresponding thermal history. Lastly, another region of interest south west of the habitable zone (ROI-6) is an impact crater [2] with playa deposits from inferred groundwater discharges, possibly as a result of localized ground ice melting from the impact.

Resources: An easily exploitable water reservoir on Mars is critical to the success of a prolonged human exploration mission. RSL regions (ROI-1,2) are the obvious candidate sites for groundwater pumping assuming groundwater brine melts [1] and not deliquesence [16]. An alternative source is to directly harvest water from the atmosphere anywhere whitin the exploration zone (EZ). First observed by the Viking orbiters, morning ice fogs are a prevalent diurnal occurence [17] that could provide a reliable source of water directly from the atmosphere [18]. In addition, a dependable source of breathable oxygen is also required for a successful mission. A thick atmospheric column throughout the canyon floor [4] means higher outputs from an in-situ oxygen generator such as the Mars 2020 Rover's MOXIE instrument [19].

Renewable energies on Mars could supplement nuclear sources and provide energy security and independence for prolonged habitation. Although the winds at Valles Marineris have not been fully characterized, widespread migrating sand dunes in Melas Chasma [20] suggest strong winds may traverse the valley. Bio-inspired vertical-axis wind turbines could possibly provide high efficiency wind energy and provide wind dampening immediately downwind [21] for protection of strong gusts. Accessible olivine deposits (ROI-5,7,8) [3] can act as a precursor source of methane [22], carbon fuels, and promote greenhouse gas buildup in the atmosphere [23]. Lastly, exposed crustal lithologies (ROI-1,2,7,8) [3] and chemically altered altered clay deposits [3] provide a rich variety of minable metals and clay minerals for in-situ 3d printing [24] of materials and agriculture feedstock.

Summary: Human exploration of Mars will lead to grander scientific discoveries over the current fleet of Mars exploration rovers. Increased mobility will open regions once inaccessible. If there is extant life on Mars, it may be in regions that are not accessible to rovers but might be accessed by human explorers. We belive our proposed landing site hosts a careful balance for scientific and engineering success.

References: [1] McEwen A. S. et al. (2014) *Nature Geoscience*. 7, 53-58. [2] Witbeck N. W. et al (1991) *Mars,* 2010. [3] Murchie S. L. et al. (2009) *Journal of Geophysical Letters: Planets,* 114. [4] Zuber M. T. (1998) *Geophysical Research Letters,* 25, 4397-4400. [5] Lui C. et al. (2011) *Aerospace Conference IEEE,* 1-12. [6] Carr C. E. et al. (2013), *Astrobiology,* 13, 560-569. [7] Carr C. E. et al. (2013), *Astrobiology,* 13, 68-78. [8] Volpe R. (2014) *i-SAIRAS,* 17. [9] Ramsley K. R. and Head J. W. (2015) *LPSC*, Abstract #1185. [10] Blair T. C. and Mc Pherson J. G. (2009) *Geomorphology Desert Environment,* 413-467. [11] Senthil Kumar P. et al. (2013) *Journal of Geophysical Research: Planets,* 118, 206-223. [12] Bada J. L. and Mc Donald G. D. (1995) *Icarus*, 114, 139-143. [13] Cannon K. M. and Mustard J. F. (2015) *Geology,* 43, 635-638. [14] Banerdt W. B. (1992) *Mars*, 1, 249-297 [15] Yin A. (2012) *Lithosphere,* 4, 286-330. [16] Martin-Torres F. J. (2015) *Nature Geoscience,* 8, 357-361. [17] Möhlmann, D. T. et al. (2009) *Planetary and Space Sciences,* 57, 1987-1992. [18] Hilstad S. A. et al. (1998) *LPI, #955* [19] Hecht M. H. et. al. (2015) *LPSC,* Abstract # 2774. [20] Quantin C. et al. (2005) *Journal of Geophysical Research: Planets,* 110. [21] Dabiri J. O. (2014) *Physics Today*. 67, 66-67. [22] Oze C. and Sharma M. (2005) *Geophysical Research Letters,* 32(10). [23] McKay C. P. (1982) *Journal of the British Interplanetary Society,* 35, 427-433. [24] Cesaretti G. et al. (2014) *Acta Astronautica*, 93, 430-450.

GROUND TRUTH ASSESSMENT OF THE GALE CRATER REGION USING MARS SCIENCE LABORATORY DATA FOR CHARACTERIZATION OF POTENTIAL HUMAN MISSION LANDING SITE AND IN SITU RESOURCE UTILIZATION. S. Montaño[1], S. Johnstone[1], N. Lanza[1], and D. Delapp[1], [1]Los Alamos National Laboratory, Los Alamos, NM, sgordon@lanl.gov.

Introduction: Instruments and cameras on board the Mars Science Laboratory (MSL) rover give ground truth information on chemistry, terrain, and atmospheric characteristics of the rover's traverse to Mount Sharp in the center of Gale crater. Analysis of this unique and robust data set allows for a thought experiment to determine the ability of a future robotics-assisted human mission to survive diurnal temperature changes, navigate the terrain of the Curiosity rover's traverse, and find, access, and exploit materials for *in situ* resource utilization (ISRU). The MSL rover has been exploring Gale crater since August 2012 and has observed many different geologic regions along its traverse to Mount Sharp, including an alluvial fan, lake sediment deposits, dunes, and exposed outcrops [1]. In-depth characterization of chemistry, morphology, and environment in Gale gives this site an advantage over others, as we will be able to target resource locations on a smaller scale that would benefit a human mission. Gale crater has ground truth on the order of a 400-micron scale up to meters-long transects along the more than 10-km path of the rover. Although the rover's traverse is only 10 km long, with an analysis area spanning up to 5 m on each side of the traverse, comparison of the local-scale MSL data with orbital data from Odyssey and MRO gives a much better idea of what to expect throughout a 100 km-diameter Exploration Zone (EZ) at Gale. This crater meets the general criteria for a candidate landing site, with an elevation of less than 2 km and a near-equatorial latitude of 4° S. Specific examples of MSL results leading to candidate Regions of Interest (ROIs) and an ideal location for the Landing Site (LS) as outlined in [2] are discussed below. All locations are labeled in Figure 1.

Regions of Interest (ROIs). Gale has the advantage of hosting a current robotic mission that has confirmed past habitability [1]. The traverse of MSL, therefore, is the most obvious Science Region of Interest (ROI) to confirm and expand on the findings of the mission so far. Mount Sharp is the second most important Science ROI, as its layers hold evidence of past climate, chemical, and aqueous environmental conditions. Exploration of the MSL traverse and Mount Sharp will help answer the majority of the science objectives outlined in [2]. Examples of MSL findings that can be confirmed and expanded upon by further analysis during a human mission include confirmation of past habitability [1], methane detection [3], elemental geochemistry of surface sediments [4], and the absolute and relative ages of geologic events [5]. An extensive study of Gale crater using data from the Mars Reconnaissance Orbiter and Mars Odyssey orbital missions was completed by [6], and current MSL data agree well on a local scale with the regional analyses performed in 2010. In that study, the authors pointed out a dark-toned sheet of sand in the southwest area of the crater. This sand is a Resource ROI that can be explored (along its edges until the depth and mechanical properties are confirmed safe for astronauts and/or rovers to traverse) as a potential location of minimally-altered soils that can be used for farming.

ISRU and civil engineering objectives. ISRU-related results from the science instruments on board MSL indicate global hydrated soils [7] that could be used as a water source for astronauts. Images of unconsolidated material also showcase the availability of potential building materials and radiation shielding. A level, smooth, low thermal inertia, high albedo region has been chosen as a landing site with a site for infrastructure located less than 5 km to the northeast of the landing site. There are small craters near the infrastructure site that could be used as ready-made radiation shielding, and there is evidence of abundant, loose regolith on the crater floor that can be used for construction [8]. These soils have also been shown, along the MSL traverse, to contain about 2 wt % H_2O in soil minerals and 3 to 6 wt % H_2O in the soil's amorphous component [9]. Extrapolating this finding to the infrastructure site chosen in this study, there is more than enough hydrated soil to yield water for ISRU activities as outlined in [2]. MSL has also found evidence of cobble-sized rocks that were transported into the crater by a fluvial environment [10]. As [6] discussed, the entire crater shows evidence of fluvial environments and so it can be expected that cobble-sized rocks will also be available at the site chosen for infrastructure construction.

Mining in Gale crater may mimic terrestrial techniques to extract Si and Fe from materials. Both of these elements can be used as construction materials to build the infrastructure in the exploration zone, and both elements must be reduced from minerals using the carbon monoxide in the martian atmosphere [11]. There have been instances of extremely high silica in rocks in Gale crater [12] and the ubiquitous iron oxides give Mars its red color; therefore, Gale meets the requirement outlined in [2] for potential to mine these elements.

Engineering constraints. The landing site criteria outlined in [2] are met in the location labeled in Figure 1. This landing site is relatively level, smooth, and free from hazards. The infrastructure construction site is located far enough from the landing site that an acceptable "lander blast zone" will not be obstructed by building materials or ISRU facilities. With regard to traversing across the crater to get to the ROIs outlined above, the best small-scale data lie with the wheel wear seen at Gale with MSL. Orbital images give good indications of which terrain is navigable within a landing site but in situ experimentation has shown the limits of a large rover with aluminum wheels driving through sand, over rocks, and up inclines [13]. In particular, ventifacted rocks have been encountered at Gale that have damaged the rover's wheels much more quickly than expected. With this knowledge of the environment at Gale, proper precautions can be taken to reinforce any wheeled vehicles and avoid similar damage during a long-term human expedition.

References: [1] Grotzinger, J. et al. (2014) *Science, 343,* DOI: 10.1126/science.1242777. [2] Workshop Supplemental Background Information, http://www.hou.usra.edu/meetings/explorationzone2015/supplemental_background _information.pdf. [3] Webster, C. R. et al. (2014) *Science, 347*, 415-417. [4] McLennan, S. et al. (2014) [5] Grant, J. A. et al. (2014) *JGR,* DOI: 10.1002/2013GL058909 [6] Anderson, R. B. and Bell III, J. F. (2010) *Mars, 5,* 76-128. [7] Meslin, P.-Y. et al. (2013) *Science, 341,* DOI: 10.1126/science.1238670. [8] Anderson, R. C. et al (2015) *Icarus, 256*, 66-77. [9] Leshin, L. A. et al. (2013) *Science, 341*, DOI: 10.1126/science.1238937. [10] Williams, R. M. E. et al. (2013) *Science, 340*, 1068-1072. [11] Badescu, V. (Ed.) (2009), *Mars: Prospective Energy and Material Resources*, Springer. [12] Frydenvang, J. (2015) *AGU*, submitted. [13] White, C. et al. (2014) *Aerospace Conference, 2014 IEEE*, DOI: 10.1109/AERO.2014.6836407.

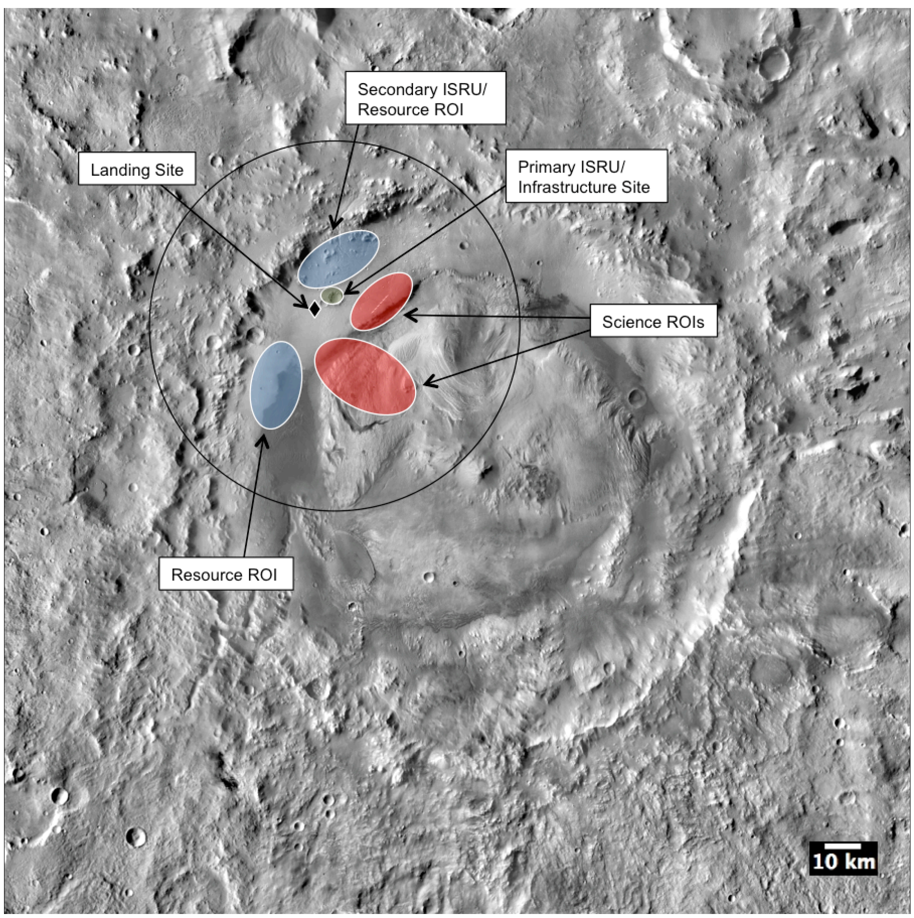


Figure 1. Gale crater Exploration Zone. Red Ovals= Science Regions of Interest (ROIs), Blue Ovals= Resource ROIs, Green Oval= Infrastructure Site, Black Diamond = Landing Site. MSL Traverse as of August 2015 shown as white line in upper Science ROI.

Jezero Crater Watershed, Isidis Basin, Sulfate Deposits and Syrtis Major: A Compelling Exploration Zone for Human Exploration J. F. Mustard[1], T. A. Goudge[2], M. S. Bramble[1], B. L. Ehlmann[3], J. W. Head[1], J. L. Dickson[1], C. I. Fassett[4] and K. M. Cannon[1] [1]Department of Earth, Environmental and Planetary Sciences, Brown University, Providence, RI 02912, [2]UT Austin, [3]Caltech/JPL, [4]Mt. Holyoke College, John_Mustard@brown.edu.

The Late Noachian/Early Hesperian watershed for the Jezero Crater open basin lake, and associated delta deposits, lies at the compelling stratigraphic contact between the Noachian-aged Isidis basin and the Hesperian-aged Syrtis Major volcanic flows and the Noachian-aged Isidis Basin. The center of the Exploration Zone is 17.747° N 77.037° E. This well-studied region has an extensive literature supporting an exceptional geologic diversity with astrobiological significance and with high potential for resource exploitation. We propose this region as an Exploraiton Zone for Human Missions to Mars. It is a target-rich environment that fulfills all five science regions of interest (ROIs) and provides an intriguing set of ROIs that are likely to fulfill the resources requirements outlined in the ROI documents (www.hou.usra.edu/meetings/explorationzone2015). The science ROIs include sedimentary rocks in the Jezero Crater delta that have exceptionally well-preserved bottomset beds ideal for biosignature preservation of organic compounds, extensive deposits of ancient olivine that are variably altered to carbonate and serpentine (important for understanding past habitability and for biosignature preservation), exposure of pre-Isidis basement rocks rich in water-bearing phyllosilicates, a 500 meter thick stack of hydrous Mg-sulfate-bearing layered strata, and rocks from the Syrtis Major volcanics (Hesperian age) and Isidis basin material (Noachian age) important for fundamental Mars science. The science merit for this EZ is summarized under four headings: diversity of rocks and minerals, regional geologic context, habitability potential defined largely by water and its history, and the biosignature preservation potential or taphonomy.

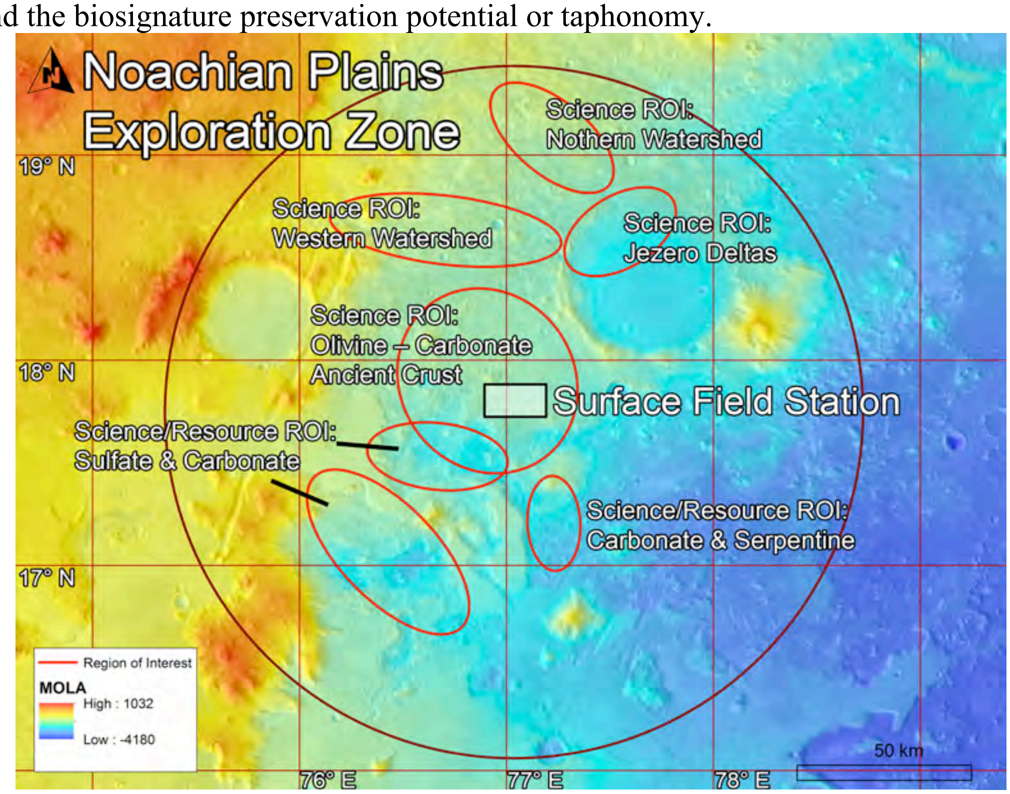


Figure 1. The exploration zone for the Jezero Crater delta watershed at the contact between the Isidis Basin the Syrtis Major volcanic region

SHALL WE SEND HUMANS TO HOLDEN CRATER? HOW A GEODESIC GIS APPROACH CAN AID THE LANDING SITE SELECTION FOR FUTURE MISSIONS TO MARS.

J.H.P. Oosthoek[1], P. Arriazu[2] and R. Marco Figuera[1], [1]Department of Physics and Earth Sciences, Jacobs University, Bremen, Germany (j.oosthoek@jacobs-university.de) [2]ETSIIT, University of the Basque Country, Bilbao, Spain.

Introduction: The stakes are high when it comes to sending humans to Mars. The scientific results of all past robotic missions need to be incorporated in to making the best selection of a landing site. It would therefore be helpful to encourage publishing data as open source. Geographical information system (GIS) software is a great tool to perform such spatial data analysis and can greatly reduce the number of potential landing sites [1].

Until recently, spatial analysis in a GIS was limited to 2D map projections. These projections are sufficient for local to regional scale studies. However, global scale spatial analyses, such as landing site selection, immediately show the limitations of 2D projections: -180°E equals 180°E. Therefore, a GIS is needed that projects the data on a sphere (or ellipsoid) and that can perform geodesic spatial analysis.

We present the first results of a geodesic-GIS approach to landing site selection for future missions to Mars. 10 types of potential regions of interest (ROIs) were selected as input [2-11] (Table 1). Holden crater (a Mars Science Laboratory (MSL) candidate landing site) proved to be the most promising [12] (Figure 1).

Methods and results: In general, landing site selection can be divided into 3 steps:

1. Define the areas where not to land.
2. Select a target outside of the excluded areas.
3. Investigate each target in high detail with respect to engineering constraints and science potential.

We discuss our approach to the second step and refer to the results of step one presented in [13]. Both steps have been performed using ESRI ArcGIS 10.2.

Step 2: As defined by the workshop conveners the various scientific and resource ROIs need to lie within 100 km of the landing site (e.g. the Exploration Zone (EZ)). All 10 ROIs we have used are based on scientific literature (Table 1).

Table 1. The 10 types of ROIs chosen for this study.

1. Deltas [2]	6. Dune fields [7]
2. Hydrous mineral sites [3]	7. Open-basin lakes [8]
3. Layered Megablocks [4]	8. Valley networks [9]
4. Infilled craters [5]	9. Tectonic & volcanic structures [10]
5. TES Exposed Bedrock [6]	10. OMEGA olivine [11]

For each ROI we created geodesic polygon buffers of 100 km. We used a 3396.19 km spherical representation of Mars. The buffer method only works with point data and lines, and polygons were converted to their vertex points [using: 14]. The olivine data [11] was provided as a raster dataset and was converted to a shapefile.

The 10 geodesic buffers were combined into one dataset using the Union ArcGIS tool [15]. For each ROI, the result contains a field that is set to either 0 (meaning that there is overlap) or -1 (meaning that there is no overlap). Figure 1 shows the color-coded results. Three areas were found to cover a maximum of 8 out of the 10 geodesic buffers. In other words, 8 of the ROIs are within 100 km distance to these areas (Figure 1). Of these three areas, Holden crater is the most promising. The other regions are mostly within the excluded areas determined in step 1.

Discussion and future work: Besides Holden crater also Eberswalde crater, 30 km north of Holden, falls within 100 km of our resulting area. Both craters contain deltaic deposits [2] and were in the top 4 of candidate landing sites for MSL [12]. Holden, Eberswalde and the surrounding region are relatively well covered by high resolution imagery (HiRISE [16]) and hyperspectral data (CRISM [17]) (Figure 2). These datasets have led to the detection of 3 [3,4,5] of the 10 ROIs. Potential targets, classified using our approach, are therefore expected to lie in the high density areas as seen in Figure 2.

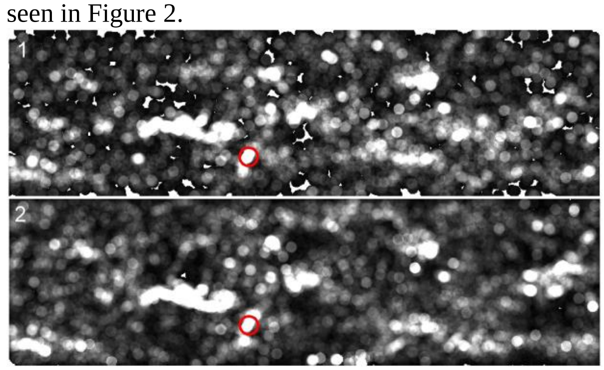


Figure 2. Density maps of HiRISE (1) and CRISM (2) data coverage, between -180°E, 180°E and within 50° N and S. White is high density. The red circle is the location of Holden.

Our approach is highly dependent on the quality of the input data. Although many datasets were available online [e.g. 18], some of the coordinate data had to be extracted from the respective publication. The approach would therefore greatly benefit from the open source publishing of scientific GIS data.

We currently weighted each ROI type as equally important. More elaborate evaluations than simple counting can be devised. Tools used for mineral exploration on Earth, such as the Spatial Data Modeller ArcGIS plugin [19], are of interest but would need to be redesigned to allow for geodesic spatial analysis.

Instead of buffers we could use an intersection method to count the number of ROIs within each EZ. We plan to use the Near tool [20] of ArcGIS 10.2, which supports geodesic distances. Alternatively, we may upgrade to version 10.3, which supports geodesic intersections [21].

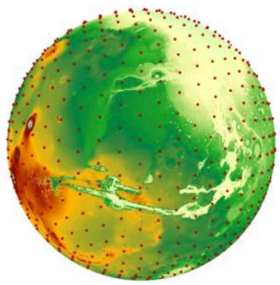


Figure 3. Example of a geodesic grid of points on the Martian globe (made using ESRI ArcGlobe and color coded MOLA data).

To classify each potential landing site, we will use a geodesic grid of points, created using the Delaunay triangulation method [22, 23] (Figure 3). Each point reflects a 25 km^2 circle (the area of the landing site as provided by the workshop conveners).

In conclusion, our ROI selection approach is a work in progress and needs to be further refined. We encourage scientists to share their data, especially global datasets of potential ROIs for a future human mission to Mars.

Acknowledgements: We have used the #Mars slack (www.hashtagmars.com) for online discussions.

References: [1] Koenders R. et al. (2007) http://www.rssd.esa.int/SYS/docs/ll_transfers/1118565.pdf [2] Di Achille G. and Hynek B.M. (2010) doi.org/bx7tbd [3] Carter J. et al. (2013) doi.org/7mh [4] Caudil C.M. et al. (2012) doi.org/7mg [5] Edwards C.S. et al. (2014) doi.org/pd2 [6] Edwards C.S. et al. (2009) doi.org/bsg47v [7] Hayward R.K. (2007) pubs.usgs.gov/of/2007/1158/ [8] Fassett C.I. and Head J.W. (2008) doi.org/cpdwxs [9] Hynek B.M. et al. (2010) doi.org/db5sr6 [10] Tanaka K.L. (2014) pubs.usgs.gov/sim/3292/ [11] Ody A. (2013) doi.org/7mj [12] Golombek M. (2012) doi.org/7mk [13] Oosthoek J.H.P. (2015), http://www.jelmeroosthoek.nl/2015/08/02/where-not-to-land-humans-on-mars/ [14] Jenness J. (2012) http://www.jennessent.com/arcgis/shapes_graphics.htm [15] ESRI (2014) *Union tool*, goo.gl/2LTsoj [16] McEwen et al. (2007) doi.org/dnd8j3 [17] Murchie et al. (2007) doi.org/bksb23 [18] Hare T.M. et al. (2003) *LPSC XXXIV*, Abstract #1974. [19] de Souza Filho C.R. (2012) www.ige.unicamp.br/sdm/ [20] ESRI (2014) *Near tool*, goo.gl/1lqZXS [21] ESRI (2015) *Select layer by location*, goo.gl/Fu22xE [22] Burkardt J. (2012) people.sc.fsu.edu/~jburkardt/m_src/sphere_delaunay/sphere_delaunay.html [23] Oosthoek J.H.P. et al. (2014) *44th LPSC*, Abstract #2565.

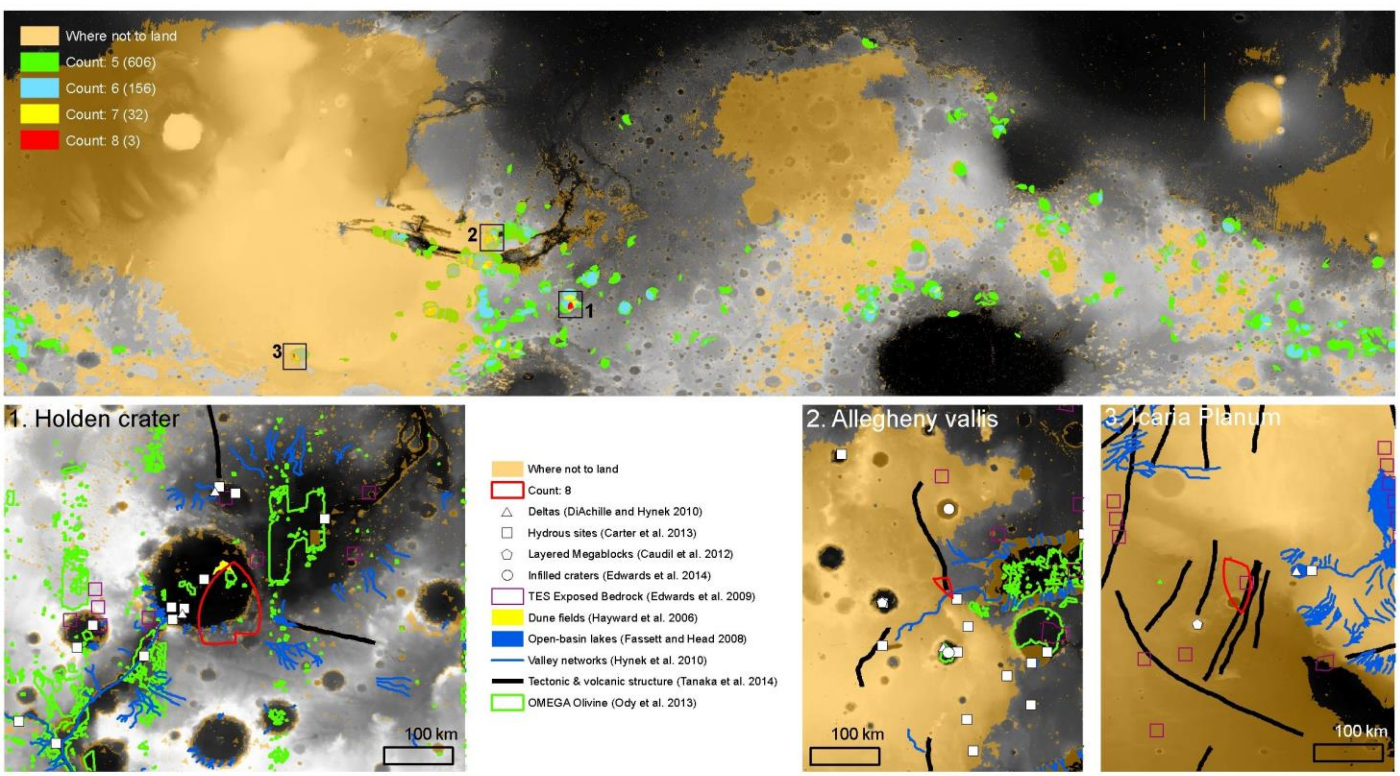


Figure 1. The preliminary results of the geodesic buffer approach. Only areas with 5 to 8 ROIs within a 100 km radius are shown. Areas within a 100km radius of 9 or 10 ROIs were not detected. For a further explanation see the text. The background is grayscale Mars Orbiter Laser Altimeter (MOLA) data.

Exploration Zone for Human mission to Mars: the area South of Firsoff Crater in Arabia Terra G. G. Ori [1 2], M. Pondrelli [1]. [1]IRSPS, Universita' d'Annunzio (Viale Pindaro 42, 65127 Pescara, Italy, ggori@irsps.unich.it), [2] Ibn Battuta Centre, Universte Cadi Ayyad, Marrakech, Morocco

Introduction: The entire Arabia Terra is a promising area for Martian Exploration, but the area around Cromelin and Firsoff craters bears a large number of targets that may be useful in understanding the geological history and the complexity of Mars. We are proposing an area South of Firsoff Crater centered at 0° 23' 28"N, 8° 21' 45" W (Fig. 1). The area is relatively flat (elevation range: min. -1900, max -1600) and dominated by an unnamed crater to the North. The procedure to define the name of this crater will be started if the EZ will be approved for further analysis. The area has been deeply mapped and investigated [1]. Engineering constraints will be analyzed after an assessment of the scientific requirement. The working team is involved (under contract ESA/Thales Alenia Space) with the analysis of the engineering constraints and certification of the ExoMars 2016 and 2018 missions. Therefore it shows a good background for this kind of analysis.

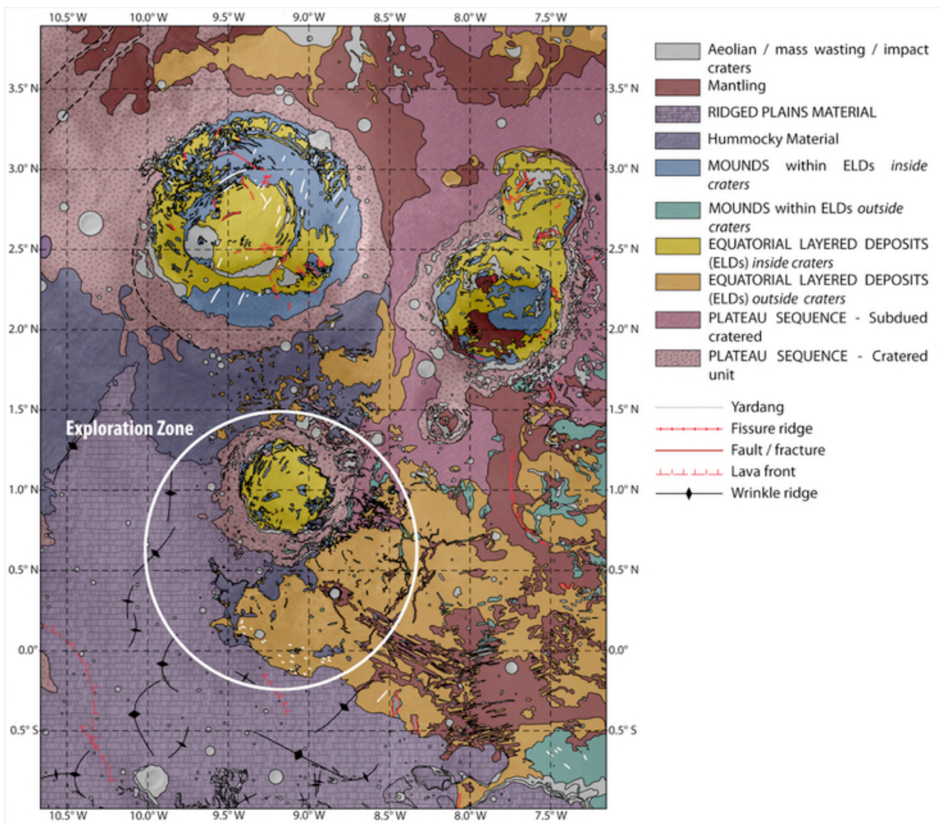


Fig. 1 - Geological map of Firsoff crater and the surrounding plateau [1]. The Exploration Zone is shown.

Science requirements: The area displays a wealth of different geological and astrobiological targets that can be investigated in several ROIs (Fig. 2):

- ROI1 (8°56'46.094"W 0°54'45.528"N), possible spring mounds and layers aligned along a fissure ridge in a terrain that consist of sulfate bearing light-toned layered deposits;
- ROI2 (9°1'44.735"W 1°11'3.785"N), possible spring, travertine-like, terraces made of sulfate bearing light-toned layered deposits;
- ROI3 (8°56'24.81"W 0°41'55.274"N), Middle Noachian highland unit [2], onlapped by the light-toned layered deposits;
- ROI4 (9°24'52.264"W 0°31'30.191"N), Middle Amazonian Ridged Plains Material [1];
- ROI5 (9°32'15.115"W 0°12'9.427"N), stratigraphic relation between light-toned layered deposits, Hummocky Material and Ridged Plains Deposits;

- ROI6 (9°11'29.523"W 0°9'10.552"N), aeolian cross bedding in light-toned layered deposits in the plateau;
- ROI7 (8°32'23.801"W 0°48'16.871"N), aligned mounds and possible playa deposits.

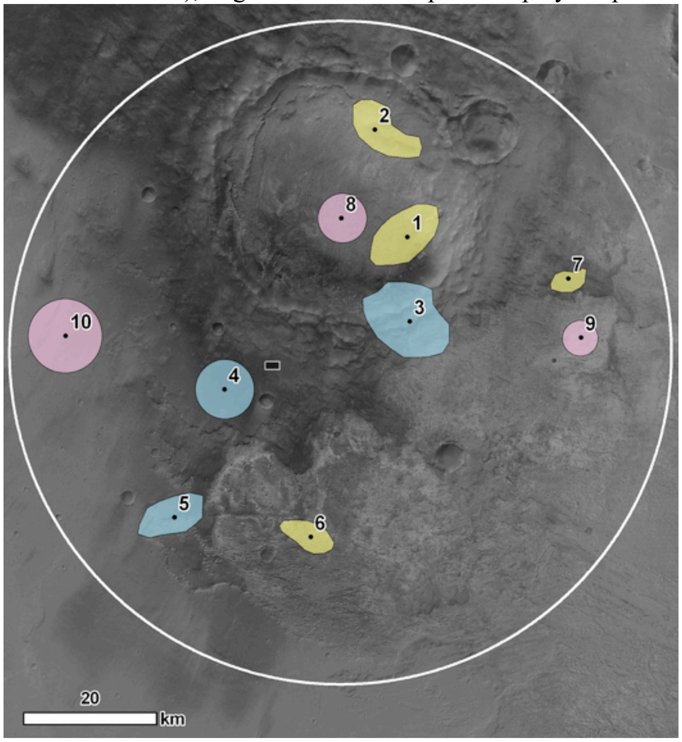


Fig. 2 - ROIs location. In yellow and blue science targets (yellow=light tone deposits, blue = stratigraphic reconstructions), in pink resources targets. The black square indicates the Mars Landing site and surface field station.

These first selected ROIs include a number of scientific themes that allow the reconstruction of the stratigraphy at global scale, including absolute dating of the Middle Noachian highland unit and the Middle Amazonian Ridged Plains Material, the identification of sedimentary environment and, consequently, the reconstruction of changes in environments and climates, and an assessment of the astrobiological context and eventually, the identification of past life.

- The presence of sulfate and possible presence of clay are suggestive of high habitability and good biosignature preservation
- The stratigraphic sequence cropping out in the area span from late Noachian to Amazonia providing a large slice of the Martian geological history [1]
- The Noachian Highlands and the Ridged Plains are datum that can globally constraint the local stratigraphy
- Capping lava flow provide also a datum plane (stratigraphic and radiometric) for the sedimentary sequence
- The possible playa deposits cropping out south of the unnamed crater is interpreted as sebkha deposits that provide a good environment for biological and plaeoclimatic investigation
- Mound features are the evidence of subsurface/surface communication with the transport of water, sediments and possible biological material from subsurface to surface
- The area is mapped in details and most of the unit boundaries and mapped and evaluated.

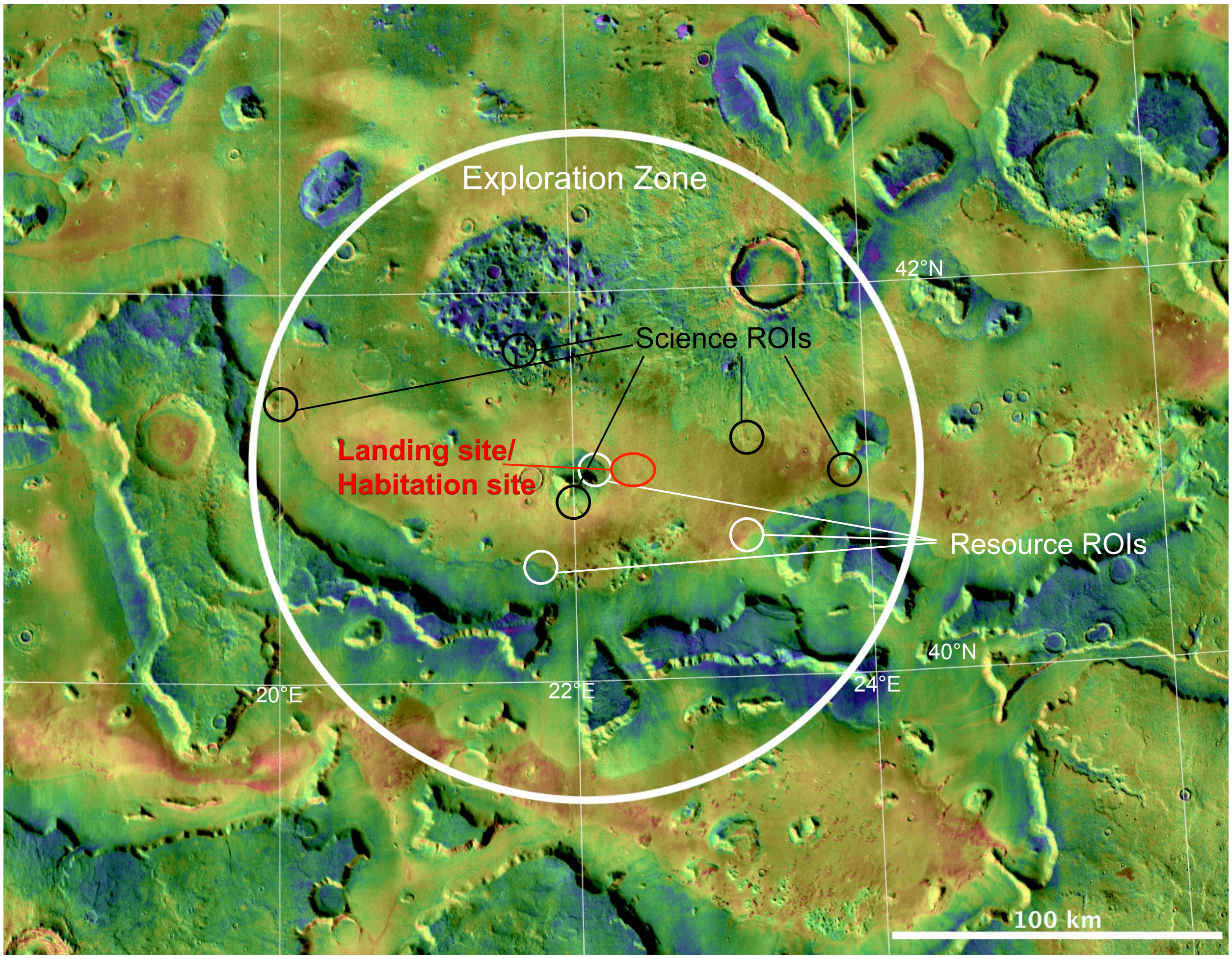
Resources and Engineering Constraints: These aspects will be analyzed in the near future however resources for construction and supplies are generically available. The engineering constraints, at first sight do not represent a major problem. Rock abundance does not seem to be extremely high and slopes, apart from the crater rim (that is however largely dissected) are within the rover operational constraints. Resources might consist of sulfate materials (ROIs 8 and 9) and basalts (ROI 10).

References [1] Pondrelli M et al. (2015) GSA Bulletin 127 (7-8):1064-1089. doi:10.1130/b31225.1, [2] Tanaka, K. L et al., 2014, USGS Scientific Investigations Map 3292..

A Resource-rich, Scientifically Compelling Exploration Zone for Human Missions at Deuteronilus Mensae, Mars

Jeffrey J. Plaut
Jet Propulsion Laboratory, California Institute of Technology
4800 Oak Grove Dr., Pasadena, CA 91109
plaut@jpl.nasa.gov

The Deuteronilus Mensae region of Mars is promising as a potential landing site for human exploration because it contains vast, readily accessible deposits of water ice in a setting of key scientific importance. The proposed Exploration Zone (EZ) is centered on a landing site adjacent to a small massif that is partially surrounded by a "lobate debris apron" deposit shown by orbital radar sounding to consist primarily of nearly pure water ice hundreds of meters thick [1].



Deuteronilus Mensae Exploration Zone on THEMIS infrared day time image colored by THEMIS night time temperature (red is warm, blue is cold). Resource regions of interest (ROIs) include a small ice-rich apron adjacent to the landing site, and several others at greater distances. Science ROIs include remnant Noachian highlands massifs, sequences of likely ice-rich deposits associated with a remnant impact central peak in Hesperian terrain, the edge of a multiple-lobed ejecta crater, and the lobate aprons themselves, interpreted to be remnant glaciers of Amazonian age.

The proposed EZ meets the provided engineering constraints: latitude 39-43 deg. N, longitude 20-24 deg. E; elevation -2 to -4 km wrt Mars mean planetary radius; moderate thermal inertia; relief < 100 m and slopes < 15 deg. along possible traverses; rock abundance to be investigated (no large boulders observed in HiRISE; thermal inertia consistent with low rock abundance).

Access to water ice for ISRU purposes requires removal of overburden, estimated to be between 0.5 and 10 m thick [1]. While the high end of this range is potentially challenging to remove, once the ice is exposed its expected purity and thickness mitigate processing complexity. Terrain between the landing site and the primary resource ROI appears flat and smooth in available data.

Science ROIs in the EZ contain materials from all three major martian geologic periods. Remnant glacial ice from the Amazonian can be sampled for geochemical indicators of climate conditions and for bio-signatures. Micro-environments associated with the remnant ice likely experienced periodic melting temperatures, providing targets for the search for extant or recent life. The landing site and much of the EZ sits on Hesperian age plains terrain, which while of uncertain origin, contains numerous indicators of periglacial processes. North of the landing site is a chaotic terrain that is interpreted to be a remnant of the central peak of a large impact crater. This terrain contains numerous exposures of collapsed layered terrain that likely contain a record of the environmental/climatic conditions of the Hesperian. The regional setting of the dichotomy boundary allows access to Science ROIs at remnant massifs and scarps of Noachian age highlands terrain. These outcrops contain a record not only of the origin of the Noachian lithology but also of the processes that created the dichotomy itself. Several of the Science ROIs contain contacts among 2 or 3 units of diverse ages and will provide insight into erosional and depositional histories. A moderately fresh impact with a large (50 km radius) multiple lobed ejecta blanket occupies the northeast sector of the EZ. This will provide a rare opportunity observe such a deposit in situ, to understand the dynamics of its formation and the role of volatiles.

Reference:

[1] Plaut, J.J., A. Safaeinili, J.W. Holt, R.J. Phillips, J.W. Head, R. Seu, N.E. Putzig, A. Frigeri, 2008a, Radar evidence for ice in lobate debris aprons in the mid-northern latitudes of Mars, Geophys. Res. Lett., doi:10.1029/ 2008GL036379.

MANNED MARS MISSION EXPLORATION ZONE: EASTERN RIM OF HELLAS IMPACT BASIN.

J. W. Rice, Jr.[1] (rice@psi.edu), D. A. Crown[1], W. C. Feldman[1], A. V. Pathare[1], A. J. Feustel[2], L. S. Gertsch[3]. [1]Planetary Science Institute, Tucson, AZ, [2]Johnson Space Center, Houston, TX, [3]Missouri Univ. of Science and Technology, Rolla, MO.

Introduction: The Hellas impact basin, located in the southern cratered highlands of Mars, formed during the Late Heavy Bombardment period of the Solar System (3.9 to 4.3 Ga). This corresponds to the earliest period of Martian history, the Noachian. Hellas is the largest and deepest impact crater in the Solar System (2,300 km diameter and over 9 km deep from rim to basin floor). The Hellas impact event played a major global role in the geologic evolution of the planet.

Science Rationale: Our proposed 200 km diameter Exploration Zone centered near 40°S; 104°E is located along the eastern rim of the Hellas basin which will allow astronauts to study and collect very ancient deep seated materials which were excavated in the impact event and subsequently deposited as ejecta forming the rim. These rocks will provide a unique window on the very early history and conditions (astrobiological, geological and climatological) on Mars.

Another key type of landform/material/resource found in this EZ are the numerous Lobate Debris Aprons (LDA). LDAs resemble glaciers on Earth and are thought to be dust/debris covered glaciers. MRO SHARAD data indicate that these features are indeed ice dominated deposit covered by a thin veneer of regolith. The LDAs likely formed during a recent climatic episode favorable to glacial processes at these latitudes. It appears that a large portion of the glacial ice is preserved underneath a thin layer of regolith. These ice deposits will be very important sites for astrobiologic, climatic, and geologic studies/sampling. Additonally, these ice deposits will be crucial for ISRU purposes. This EZ also contains a large channel system, Reull Vallis, and a multitude of valley networks which dissect the highlands and plains.

Science ROIs: *Noachian age* massifs/mountains and intermontane basin fill (fluvial deposits) located along the rim of Hellas. The massifs and mountains are ancient crustal blocks of material uplifted during the impact event. Noachian/Hesperian age valley networks and deposits.

Hesperian age fluvial plains formed by the overbank flow of Reull Vallis. The channel walls and floor deposits of Reull Vallis which are composed of materials eroded upstream from the cratered higlands.

Amazonian age lobate debris aprons (LDA) which are dust/debris mantled glaciers located at the base of numerous massifs and mountains as well as on the floors of craters in the EZ.

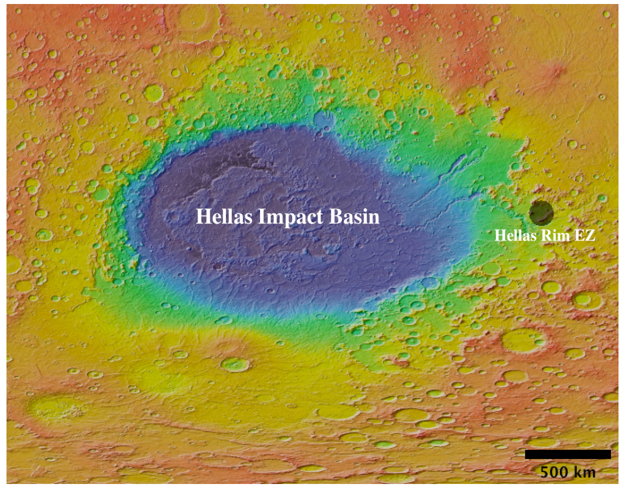


Figure 1. Regional view of the EZ located on the eastern rim of the Hellas impact basin in the Southern Highlands of Mars.

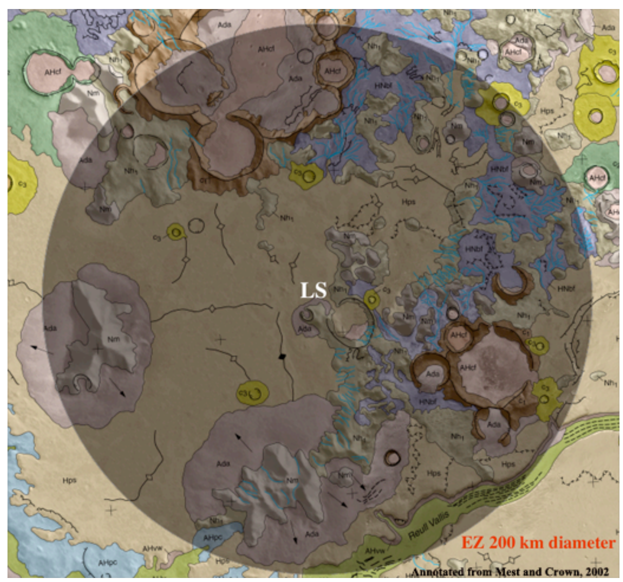


Figure 2. EZ placed on the geologic map of the area.

MANNED MARS MISSION EXPLORATION ZONE: GUSEV CRATER-APOLLINARIS SULCI.

J. W. Rice, Jr.[1] (rice@psi.edu), S. W. Ruff[2], A. Z. Longo[3]. [1]Planetary Science Institute, Tucson, AZ, [2]Arizona State University, Tempe, AZ [3]Cardinal Gibbons High School, Raleigh, NC.

Science Rationale: Our proposed 200 km diameter Exploration Zone centered near 13°S; 175°E is located along the floor and north eastern rim of Gusev crater and Apollinaris Sulci.

Science ROIs: *Noachian age* Gusev crater rim materials/massifs and ancient fluvially dissected cratered plains.

Hesperian age lava flows on the floor of Gusev and dissected fluvial plains located in the highlands outside of Gusev crater.

Hesperian-Amazonia age lava flows from Apollinaris Mons and fluvio-lacustrine deposits in east central Gusev crater as well as in the cratered highlands outside of Gusev crater.

Amazonian age Medussae Fossae Formation materials that are interpreted to be thick deposits of pyroclastic material and welded ash flow tuffs interbedded with aeolian deposits.

Extra Incentives: The Spirit Rover explored a small portion of our EZ, namely the Noachian age Columbia Hills as well as the Hesperian age basaltic plains. The Columbia Hills are most likely the upper remnants of a central peak or peak ring in Gusev Crater.

The two biggest discoveries made by Spirit were the silica–rich hydrothermal deposits and carbonates. The opaline silica deposits (as much as 91 weight percent SiO2) are interpreted to have formed in a hydrothermal environment because they are found in close association with volcanic materials such as Home Plate. Two types of environments could have been responsible for forming these materials: fumaroles or hydrothermal sinter deposits produced by hot springs. This discovery is of paramount importance for understanding the past habitability of Mars because terrestrial hydrothermal environments support thriving microbial ecosystems.

The discovery of carbonates (16 to 34 wt %) in the Comanche outcrops of Haskin Ridge implies extensive aqueous activity under near-neutral pH conditions that would be conducive to habitable environments on early Mars. Additionally, silica and carbonate precipitation are well known to promote biosignature preservation.

A final extra incentive for revisiting this site is that Spirit can be located and inspected (i.e., Apollo 12 and Surveyor III). Thereby making for an excellent long duration exposure experiment providing long-term data on the martian environment, including weathering, micrometeorites, and its effects on materials degradation and other systems (including power, propulsion, and optics). This data will aid in the design of surface systems, equipment and structures for the future robotic and manned exploration of the planet. Perhaps one day a crew will crate up Spirit and bring her back home to be on display and inspire the next generation of Martians.

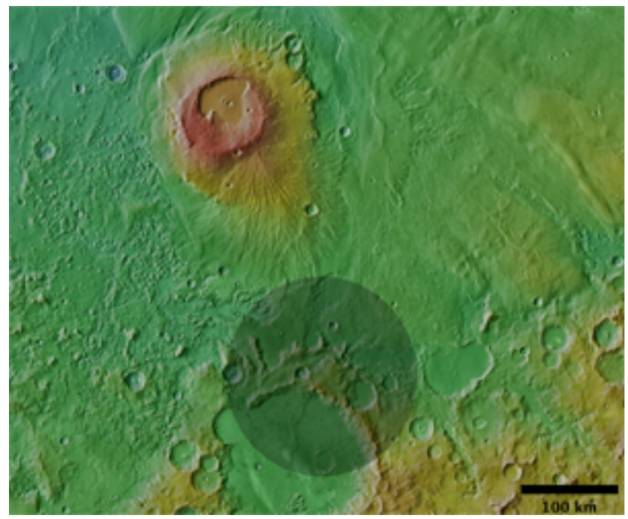


Figure 1. Regional view of the EZ located in the NE portion of Gusev crater and just south of the Apollinaris Mon volcano.

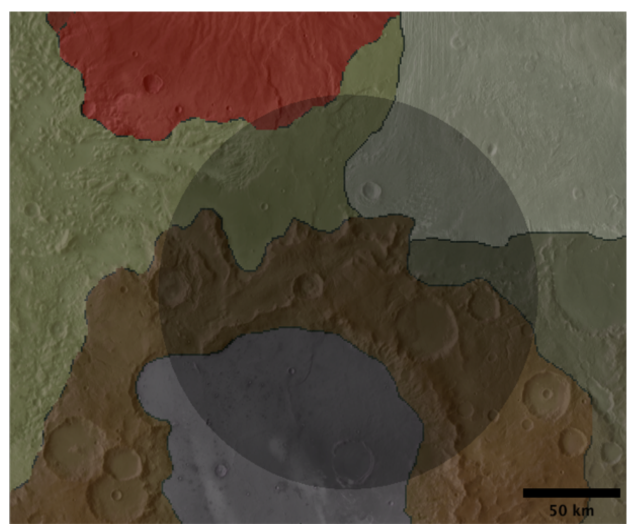


Figure 2. EZ placed on the geologic map of the area.

ARAM CHAOS: A LONG LIVED SUBSURFACE AQUEOUS ENVIRONMENT WITH STRONG WATER RESOURCE POTENTIAL FOR HUMAN MISSIONS ON MARS

L. Sibille[1], R. Mueller[2], P. B. Niles[3], T. Glotch[4], P. D. Archer[5], M.S. Bell[5]

[1]Swamp Works, ESC-5, NASA Kennedy Space Center, FL 32899 (Laurent.sibille-1@nasa.gov)
[2]Swamp Works, UB-R1, NASA Kennedy Space Center, FL 32899
[3]Astromaterials Research and Exploration Science, NASA Johnson Space Center, Houston, TX 77058; (*paul.b.niles@nasa.gov*)
[4]Department of Geosciences, SUNY Stony Brook University, NY 11794
[5]Jacobs, NASA Johnson Space Center, Houston, TX 77058

EZ coordinates: 2° 25' N, 20° 02' W

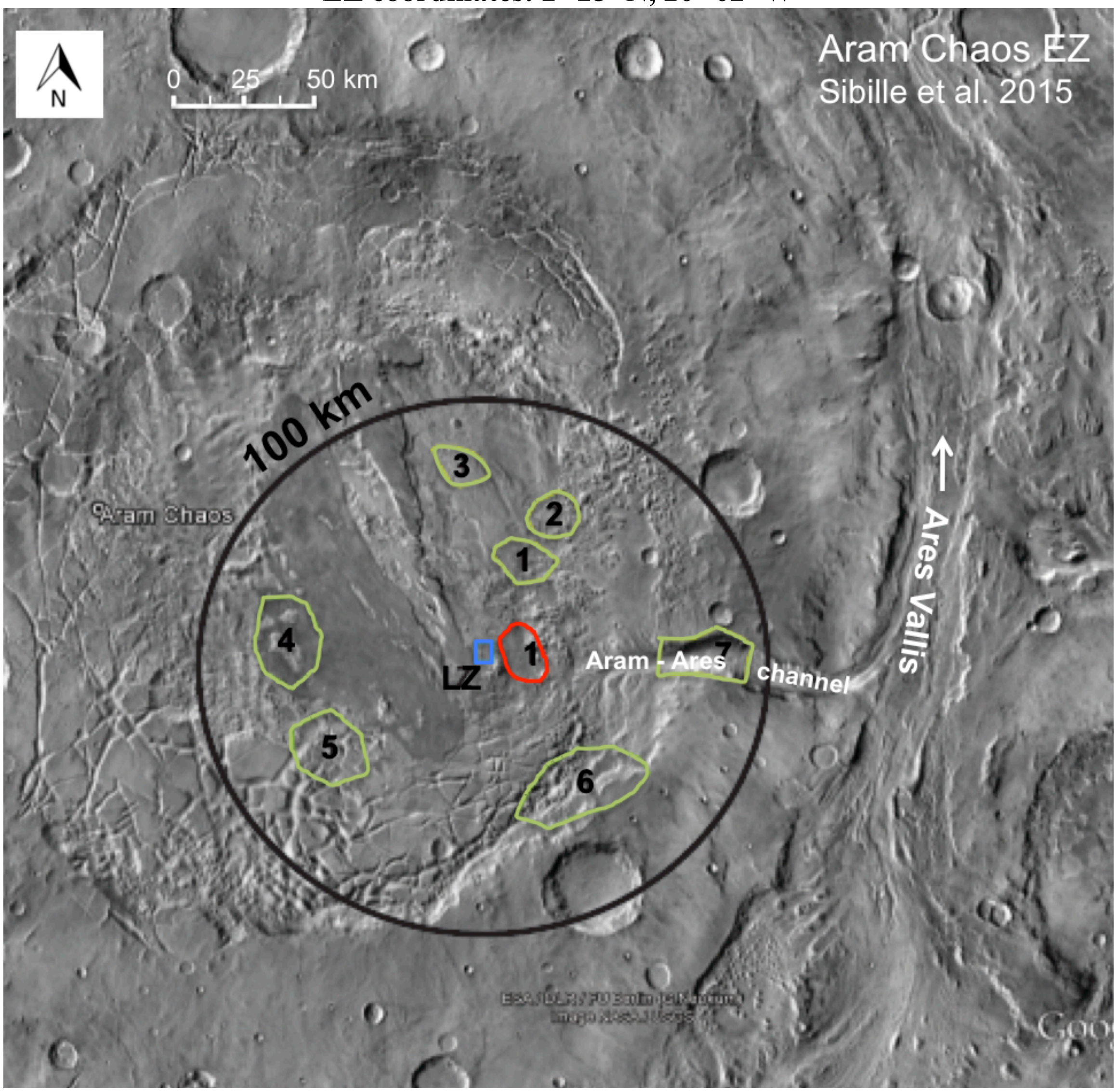


Figure 1. Aram Chaos Exploration Zone. Green circles indicate Science ROI's, red circles indicate Resource ROI's, and the blue square indicates a potential landing zone (LZ). ROI's #1-3 target hydrated minerals. ROI's #4-6 target different geologic units for understanding history of water and climate in the region. ROI #7 indicates potential exposure of Noachian terrain through incision of the Aram-Ares channel.

Aram Chaos, Mars is a crater 280 km in diameter with elevations ca. -2 to -3 km below datum that provides a compelling landing site for future human explorers as it features multiple scientific regions of interest (ROI) paired with a rich extensible Resource ROI that features poly-hydrated sulfates [1]. The geologic history of Aram Chaos suggests several past episodes of groundwater recharge and infilling by liquid water, ice, and other materials [1-3]. The creation of the fractured region with no known terrestrial equivalent may have been caused by melting of deep ice reservoirs that triggered the collapse of terrain followed by catastrophic water outflows over the region. Aram Chaos is of particular scientific interest because it is hypothesized that the chaotic terrain may be the source of water that contributed to the creation of nearby valleys such as Ares Vallis flowing toward Chryse Planitia. The liquid water was likely sourced as groundwater and therefore represents water derived from a protected subsurface environment making it a compelling astrobiological site [2]. The past history of water is also represented by high concentrations of hematite, Fe-oxyhydroxides, mono-hydrated and poly-hydrated sulfates [1, 2]. Poly-hydrated sulfates are likely to contain abundant water that evolves at temperatures below 500 C thus conferring Aram Chaos a potentially high value for early in-situ resource utilization ISRU [4]. The geologic history also calls for future prospecting of deep ice deposits and possibly liquid water via deep drilling.

The most recent stratigraphic units in the central part of Aram Chaos are not fractured, and are part of a dome-shaped formation that features bright, poorly consolidated material that contains both hydrated sulfates and ferric oxides according to OMEGA data [5]. These surface material characteristics are preliminary indications of their potential use in civil engineering activities that involve regolith moving and hauling, while further study is needed to assess traverse-ability challenges. The widespread distribution of sulfates is also of interest as a resource for the use of sulfur as a binding compound in regolith-based concrete for constructions. The terrain depressions caused by the rock fracturing events may challenge surface mobility but also suggest the possibility of using such natural features for additional shielding from space radiation and as emplacement of nuclear surface power reactors for the same reason. The high concentration of hematite (up to 16 %) in some of the smoother recent terrains of the central part of Aram Chaos [2] is a favorable attribute for metal extraction ISRU to create iron-based feedstock for in–situ fabrication of replacement parts or their repairs.

Preliminary data on Aram Chaos indicate that it offers a combination of many critical criteria for human missions to the surface of Mars: equatorial region at low MOLA, evidence of hydrated minerals over large areas and at high concentrations tied to historic evidence of liquid water over long periods.

1. Lichtenberg, K. A., Arvidson, R. E., Morris, R. V., Murchie, S. L., Bishop, J. L., Fernandez Remolar, D., ... & Roach, L. H. (2010). Stratigraphy of hydrated sulfates in the sedimentary deposits of Aram Chaos, Mars. *Journal of Geophysical Research: Planets (1991–2012)*, *115*(E6).

2. Glotch, T. D., & Christensen, P. R. (2005). Geologic and mineralogic mapping of Aram Chaos: Evidence for a water‐rich history. *Journal of Geophysical Research: Planets (1991–2012)*, *110*(E9).

3. Zegers, T. E., Oosthoek, J. H., Rossi, A. P., Blom, J. K., & Schumacher, S. (2010). Melt and collapse of buried water ice: An alternative hypothesis for the formation of chaotic terrains on Mars. *Earth and Planetary Science Letters*, *297*(3), 496-504.

4. Boynton, W. V., & Ming, D. W. (2006). Use of the Thermal and Evolved-Gas Analyzer (TEGA) on the Phoenix Lander to Detect Sulfates on Mars. *LPI Contributions*, *1331*, 18.

5. Massé, M., Le Mouélic, S., Bourgeois, O., Combe, J. P., Le Deit, L., Sotin, C., ... & Langevin, Y. (2008). Mineralogical composition, structure, morphology, and geological history of Aram Chaos crater fill on Mars derived from OMEGA Mars Express data. *Journal of Geophysical Research: Planets (1991–2012)*, *113*(E12).

CONSIDERATIONS FOR HUMAN EXPLORATION OF AN EXHUMED, INTERCRATER BASIN IN THE MARTIAN CRATERED HIGHLANDS: THE HADRIACUS PALUS AND CAVI EXAMPLE. J. A. Skinner, Jr.[1], T. M. Hare[1], C. M. Fortezzo[1], and D. L. Rickman[2], [1]U.S. Geological Survey, Astrogeology Science Center, 2255 N. Gemini Drive, Flagstaff, AZ 86001 (jskinner@usgs.gov), [1]Jacobs Technologies, Inc., Marshall Space Flight Center, Huntsville, AL 35812.

Introduction: On Earth, exposed sections of geologic strata within structural basins provide critical information about pre-, syn-, and post-basin forming tectonic processes, depositional environments, and interactions with regional to global climate [1]. The widespread occurrence, varied internal architecture, and common aqueous signatures of basin-related (principally non-crater) stratified rocks on Mars are critically important for an improved understanding of broadly-occurring geologic processes and their interaction with climate dynamics through time [1-2]. Though current and past orbital and landed assests have greatly improved our understanding of Mars' evolution [e.g., 2], human exploration is likely to result in a broader observational envelope than currently afforded by recent and upcoming rovers. Here, we describe Hadriacus Palus and Cavi – an exhumed, structural (principally non-crater) basin on Mars – as a highly relevant "type example" exploration zone wherein engineering contraints are satisfied and scientific objectives can not only be reasonably achieved but also broadly extrapolated to enable a more holistic understanding of Mars' evolution.

Regional Setting: Hadriacus Palus (77.30°E, -27.25°N) is a 160-km long by 80-km wide, locally low-lying, nearly horizontal plain located north-northeast of Hellas Planitia and southwest of Terra Tyrrhena in the eastern, mid-latitude region of Mars (**Fig. 1**). The palus surface has a mean elevation of -2640 m and is bounded by gently-sloping cratered terrains, interspersed topographic massifs, and variable diameter impact craters. Two channel systems enter into – and terminate within – Hadriacus Palus from the north (Napo Vallis) and east (Huallaga Vallis). These channels originate in southwestern Tyrrhena Terra and constitute drainage of a diverse section of highland-forming rock sequences, including volcanic and crustal massifs, deeply cratered plateaus, and volcaniclastic plains [2-3]. Hadriacus Palus is defined on its southern margin by the Hadriacus Cavi (78.05°E, -27.25°N), a 50-km long series of east-west-oriented depressions that are locally >800 m deep. These depressions expose diverse stratified rocks with morphologic and textural characteristics suggestive of volcanic (tuff and/or lava), fluvial (channel cross-section), aeolian (dark sand), and impact (breccia and faulting) origin [3].

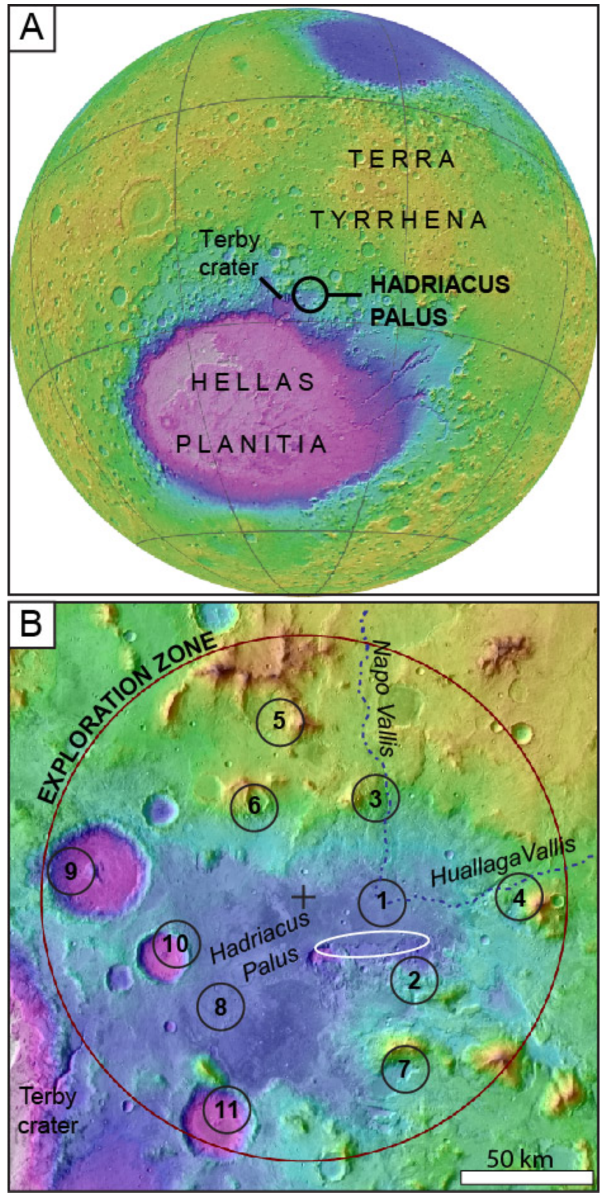


Figure 1. Physiographic characteristics and exploration potential of the Hadriacus Palus and Cavi. (A) Exploration zone (centered at 77.47E, -26.84N) is located NNE of Hellas Planitia, SW of Terra Tyrrhena, and E of Terby crater. (B) The Hadriacus Cavi – located on SE margin of Hadriacus Palus – expose >800 m of stratified sedimentary and volcanic rocks. The local exposed basin strata, bounding massifs, cratered terrains, and impact craters potentially enable observation of all aspects of the rock cycle from the Early Noachian to Early Amazonian.

Hadriacus Palus is part of the highland plateau unit sequence, as defined by [2]. These include the Early Noachian highland massif (eNhm), Early Noachian highland (eNh), Middle Noachian highland (mNh), and Late Noachian highland (lNh) units [2]. Local crater size-frequency assessments [3] provide model absolute ages for the palus surface of 3.38 ± 0.08 Ga (Late Hesperian), with subsequent resurfacing occurring in parts of the western palus at 1.57 ± 0.55 Ga (Early to Middle Amazonian). The surrounding (subjacent) cratered terrains have an model absolute age of 4.06 ± 0.10 Ga (Early Noachian), with subsequent resurfacing occurring at 3.39 ± 0.15 Ga (Late Hesperian). The model absolute age of resurfacing within the immediately adjacent cratered highland terrains closely correlates with the emplacement age of the palus surface.

Rationale: Though many of the detailed parameters required to establish potential landing, development, and exploration sites have yet to be fully determined, it is essential to ascertain the state of knowledge and the rationale for not only particular sites but also (and perhaps more importantly) for particular <u>types</u> of sites. The identification and evaluation of candidate locations for human exploration of Mars requires a clear understanding of the environmental context wherein that exploration will occur. Hadriacus Palus and Cavi is an excellent "type example" of a structural (principally non-crater) basin containing partly exhumed stratifed rocks that were emplaced through diverse, interacting processes. The rationale for considering Hadriacus Palus and Cavi specifically – and structural basins generally – for human exploration are as follows:

1) The region satisfies known baseline engineering constraints with regard to latitude (<50°), elevation (≤+2 km), landing radius, dust cover, slope, and infrastructure separation.
2) The region provides potential (though indeteremi-nate) access to subsurface water-ice (< 5m depth) and hydrated mineral phases (phyllosilicates) along the margin of Hadriacus Cavi.
3) The region affords access to multiple outrops of geologically and stratigraphically diverse units within a range of distances from the proposed landing site, including convergence of two discrete channel systems draining contrasting Noachian age terrains (#1 in **Fig. 1B**), uplifted crustal massifs abutted by breccias, lava and/or tuff, and fluvial sediments in stratigraphic section (#2 in **Fig. 1B**), a range of topographic massifs of crustal and/or volcanic origin (#3-7 in **Fig. 1B**), lobate ejecta ramparts (#8 in **Fig. 1B**), impact crater rim, wall, floor, and central peak assemblages (#9-11 in **Fig. 1B**), and intra-crater alluvial fan deposits (#9 in **Fig. 1B**).
4) The region represents a previously un-visited, though widely occurring, geologic setting that affords examination of rocks emplaced through processes that were active during the Early Noachian to Early Amazonian. Moreover, local outcrops are likley to provide details about tectonic processes that have yet to be observed *in situ*.
5) The region is pervasively horizontal and is fed by channel systems that terminate at a common elevation, implicating a potential ancient quiescent environment that potentially supported and preserved evidence of ancient life.

Considerations: Initial selection and evaluation of potential sites on Mars that can reasonably achieve both engineering and science priorities is a challenge on multiple fronts. Engineering constraints, including the identification, extraction, and processing potential of *in situ* resources necessary to sustain human exploration, are likely to be the primary driver for site selection. Scientific constraints, including environments that could have promoted, sustained, and preserved ancient life, are likely to be secondary factors in site selection. The community should ascertain the means by which these constraints can be dynamically integrated using existing and potential future observations to globally identify sites of high relevance for human exploration.

We contend that structural (principally non-crater) basins that have accumulated rocks and sediments from not only various geologic processes but also from various geologic terrains hold the highest potential for achieving both engineering and science objectives. From an engineering perspective, structural basins on Mars (as on Earth) tend to be expansively horizontal, promoting safe development and traversability by human explorers. From a scientific perspective, exhumed structural basins tend to provide access to sequences of rocks and sediments that record long-lived interactions between basin-forming tectonism and regional to global climate oscillations. Records of these processes and their interactions are key pieces of information that are currently missing from our understanding of the evolution of Mars, including the potential ascent and preservation of life on that planet.

References: [1] Busby, C. J. and Ingersoll, R. V., *Tectonics of Sedimentary Basins*, 1995. [2] Tanaka, K. L. et al., (2014), USGS SIM 3292, 1:20M scale. [3] Fortezzo, C. M., and Skinner, J. A., Jr., *LPSC 2013*, #2104.

HALE CRATER – ANCIENT WATER SCIENCE, CONTEMPORARY WATER RESOURCE. D. E. Stillman[1], R. E. Grimm[1], S. J. Robbins[1], T. I. Michaels[2], B. L. Enke[1], [1]Dept. of Space Studies, Southwest Research Institute, 1050 Walnut St. #300, Boulder, CO 80302 (dstillman@boulder.swri.edu), [2]SETI Institute, 189 Bernardo Ave Suite 100, Mountain View, CA 94043

Uniqueness: We chose Hale crater as a human landing site (LS)/exploration zone (EZ) primarily because of the ease with which liquid water can be extracted from Recurring Slope Lineae (RSL) found on the slopes of its central peak complex. Furthermore, the Hale EZ can address most or all of the astrobiology, atmospheric, geosciences, cross-cutting, and resource objectives.

Introduction: Hale crater is a complex impact crater (125 × 150 km located at 35.79°S, 323.68°E; **Fig 1**). Hale formed in the Amazonian (>1 Ga) and released ~10 km^3 of liquid water, fluvially modifying nearby channels [2]. The impact occurred on the Argyre basin periphery, and appears to be superposed on the long outflow system comprised of Uzboi, Ladon, & Morava Valles (ULM [3]; **Fig. 1**). ULM transported an estimated ~150,000–450,000 m^3/s of water during the late Noachian through the early Hesperian [3].

Hale's general mineralogy suggests deep mantle and primordial crustal material, while parts of the crater rim have been altered via impact-induced hydrothermal activity [4]. Minerals in the EZ may have recorded at least 3 impulses of activity: post-Argyre (~3.9 Ga [5]), post-Bond, and post-Hale (1-3 Ga [1,2]).

Within the last 10 Ma, hundreds of gullies were carved in the steep slopes of the central peaks and rim of Hale [6]. While gullies can be modified by the sublimation of CO_2 [7], it is generally accepted that gullies are a result of flowing water released during an epoch with a significantly different obliquity [8].

Currently, hundreds of RSL occur in the large uplifted mountains of the crater's central peak. These low albedo, narrow (<5 m) features incrementally lengthen down slopes (25–45°) from L_s 171±23° to 336±6° (270±50 sols from spring to summer), fade during the colder season, and recur the following year [9]. Water-based hypotheses best match observations that correlate incremental lengthening with higher surface temperatures [9-13]. Hale RSL begin flowing when surface maximum temperatures are significantly below 273 K. These flows are therefore briny, and likely originate from a confined aquifer [9].

Landing site: Many of the ~200 sites on Mars with RSL [9] present significant LS challenges. In contrast, Hale offers smooth, flat areas for landing and shallow slopes (<30°) for brine/water access. Our proposed LS (35.30°S, 323.14°E, elevation of −1621 m) is to the northwest of the central peak (**Fig. 2**).

Resource Regions of Interest (ROIs): We have located the LS and surface field station to allow access (<5 km) to the west- and southwest-facing slopes of the central peak. These slopes are covered in RSL during the spring and summer. While the spring-like sources that RSL emanate from are on steep slopes of 45°, most RSL extend onto smooth, shallower slopes (~25°). Modeling indicates that brine occupies the top 4-10 cm of these RSL. This brine could therefore be collected and sent downhill via a pipeline to a water treatment facility. Tapping a single RSL would likely provide 100 MT of water over the duration of the active RSL season.

Engineering material could be acquired from the lower scree slopes of the central peak or from the ponded and pitted material [2] in the center of the crater. The latter material may have a low rippability, allowing machinery to more easily move the material.

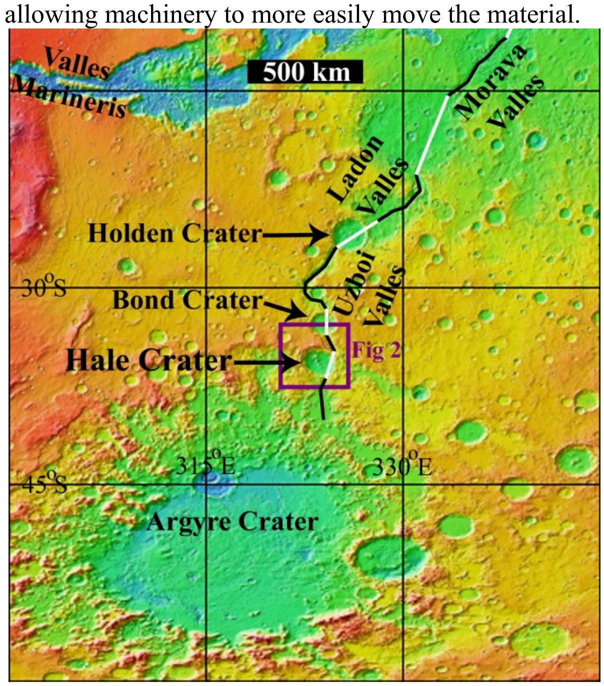


Figure 1. MOLA topography, showing Hale crater's location along the ULM outflow system and proximity to Argyre. Preserved ULM channels (black lines) and presumed lost morphology (white lines) trace the path that water took from Argyre or a lake on its rim to a basin within Margaritifer from ~3.8 to 3.5 Ga [3].

Scientific ROIs: While the nearby RSL-covered slopes would be used for resources, RSL-bearing slopes further to the southeast could be studied to better understand RSL and the dynamic local micro-environment(s) that they create. This would address the extant life and chemistry Astrobiology science objectives: A3, A4, A5, and A6.

The search for extant life within RSL should be a major priority. The RSL in Hale must be so briny (very low water activity values) that no known terrestrial life can respire there. This reduces the impact of cross-contamination by terrestrial life (i.e., reduced planetary protection). However, martian life may have either evolved a way to live in such an environment, or may be living within the depths of the RSL source regions.

Study of the gully science ROIs would address the diverse geologic processes Geoscience objective G3. Furthermore, Atmospheric science objective B5 (previous climate states) could be addressed by better understanding how/when the gullies were formed.

The ancient channel and hydrothermal mineralogy science ROIs would allow investigation into the formation of two pre-existing channels and hydrothermally-altered mineralogy. These channels may have been linked to a large outflow network (ULM; **Fig. 1**) and the hydrothermal environments may have once been habitable. Thus, these science ROIs could address the past life Astrobiology science objectives A1 and A2. Fluvial ejecta from Hale have partially filled these external channels. Subsurface imaging (using tools such as ground penetrating radar) could allow for a better estimate of the dimensions of these channels before Hale crater was emplaced, yielding better estimates of the amount of discharge needed to form these channels in the late Noachian to early Hesperian. Furthermore, understanding the impact-generated, fluvially-modified ejecta will improve our knowledge of surface conditions when Hale formed, as well as other similar craters such as Mojave, Tooting, and Sinton. Together, these science ROIs address the geologic and paleoenvironment evaluation Geoscience objective (G1) and additional questions about surface/ground water (Q8).

No well-constrained absolute ages of Mars' surface exist. Instead the lunar chronology (only marginally-constrained itself) is used along with dynamic arguments to estimate absolute ages on Mars. Argyre represents a significant stratigraphic event (modeled to ~3.9 Ga [14]) and significant structural work has been done to map its stratigraphy relative to major surrounding features [e.g., 4,14]. Additionally, since the formation of Hale postdates the likely end of major aqueous activity (the active channels), dating Hale would put a lower limit for this important epoch of Martian history. Radiometric age measurements of drill-collected impact melt material or in-place shocked minerals from the ROI could reveal two distinct ages, allowing us to anchor both of these events, significantly increasing our understanding of Mars' chronology and addressing the age Geoscience objective, G2.

Atmospheric stations at the field station and science ROIs would allow monitoring of the regional and intracrater water vapor, dust, and sediment transport, addressing Atmospheric science objectives B1 and B3.

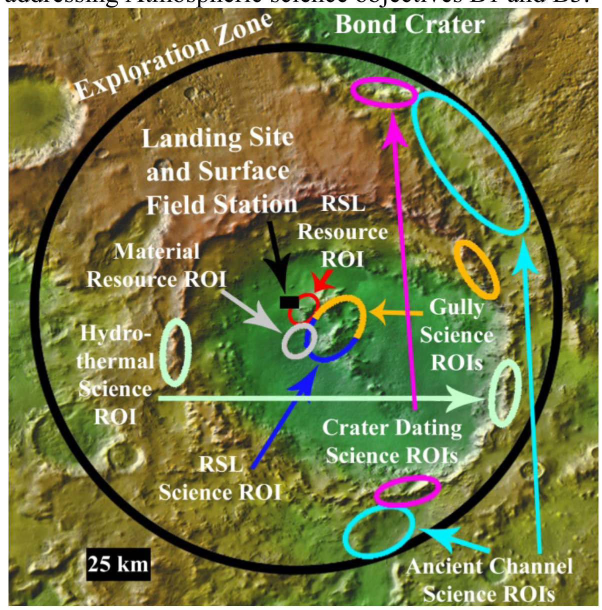


Figure 2. Proposed Hale LS/EZ.

Conclusions: The Hale EZ would allow easy access to liquid water via RSL. This EZ also exhibits a long history of water activity from the Noachian to today. The science ROIs meet the threshold criteria of allowing *access to deposits with a high preservation potential for evidence of past habitability and presence of sites that are promising for present habitability* via RSL, ULM channel, and hydrothermal exploration; *access to outcrops with morphological and/or geochemical signatures indicative of aqueous processes or groundwater/mineral interactions* via RSL, ULM channel and hydrothermal exploration; and *identifiable stratigraphic contacts and cross-cutting relationships from which relative ages can be determined* via dating, helping bound the ages of ULM system and Argyre.

References: [1] Cabrol et al. (2001) *Icarus*, 154, 98-112. [2] Jones et al. (2011) *Icarus*, 211, 259-272. [3] Grant and Parker (2002) *JGR*, 108, 8086. [4] Dohm et al. (2015) *Icarus,* 253, 66-98. [5] Robbins et al. (2013) *Icarus*, 225, 173-184. [6] Kolb et al. (2010) *Icarus*, 205, 113-137. [7] Dundas et al. (2012) *Icarus*, 220, 124-143. [8] Dickson et al. (2007) *Icarus*, 188, 315-323. [9] Stillman et al. (2015) *Icarus*, in review. [10] McEwen et al. (2011) *Science*, 333, 740-743. [11] McEwen et al. (2014) *Nature GeoSci*, 7, 53-58. [12] Stillman et al. (2014) *Icarus*, 233, 328-341. [13] Grimm et al. (2014) *Icarus*, 233, 316-327. [14] Irwin III et al. (2013) *JGR*, 278-291.

Midlatitude Ice-rich Ground on Mars: an Important Target for Science and In Situ Resource Utilization on Human Missions

Carol Stoker and Jennifer Heldmann, NASA Ames Research Center, Moffett Field, CA 94035

Location of ROI: 40-50 N, 160 -190 E ; Specific Landing Site proposed: 46.16N, 188.8 E

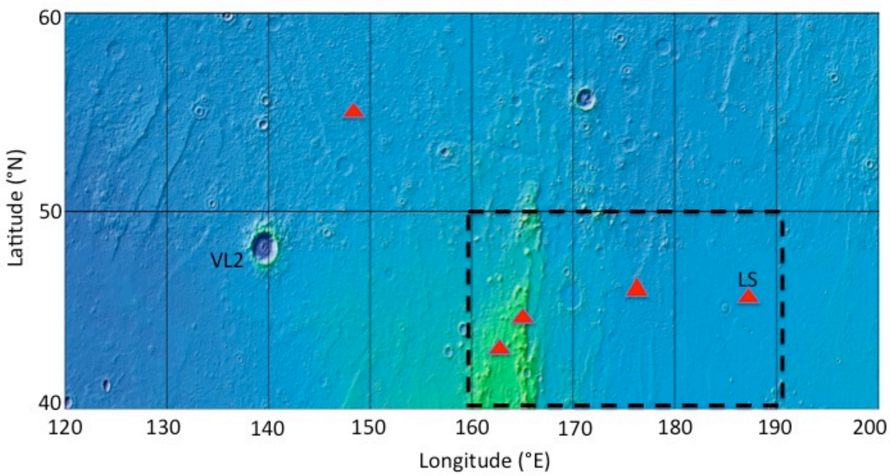


Figure: Dotted line shows ROI. LS is best landing site within the ROI. Red triangles are locations where fresh craters exposed near surface ice(Byrne et al, 2009). VL2 is Viking Lander 2 site. Base map is MOLA altimetry.

The region of ROI is characterized by proven presence of near surface ground ice and numerous periglacial features. Midlatitude ground ice on Mars is of significant scientific interest for understanding the history and evolution of ice stability on Mars, the impact that changes in insolation produced by variations in Mars' orbital parameters has on the regions climate, and could provide human exploration with a reliable and plentiful in situ resource. For both science and exploration, assessing the astrobiological potential of the ice is important in terms of (1) understanding the potential for life on Mars and (2) evaluating the presence of possible biohazards in advance of human exploration. Heldmann et al. (2014) studied locations on Mars in the Amazonis Planitia region where near surface ground ice was exposed by new impact craters (Byrne et al. 2009). The study examined whether sites in this region were suitable for human exploration including reviewing the evidence for midlatitude ground ice, discussing the possible explanations for its occurrence, assessing its potential habitability for modern life, and evaluating the resource potential. They systematically analyzed remote-sensing data sets to identify a viable landing site. Five sites where ground ice was exposed were examined with HiRise imaging and were classified according to (1) presence of polygons as a proxy for subsurface ice, (2) presence and abundance of rough topographic obstacles (e.g., large cracks, cliffs, uneven topography), (3) rock density, (4) presence and abundance of large boulders, and (5) presence of craters. A suitable landing site was found having ground ice at only 0.15m depth, and no landing site hazards within a 25 km landing ellipse. This paper presents results of that study and examines the relevance of this ROI to the workshop goals.

References: Byrne, S. et al. (2009) Distribution of mid-latitude ground ice on Mars from new impact craters. Science 325:1674–1676.; Heldmann, J. et al. (2014) Midlatitude Ice-rich ground on Mars as a target in the search for evidence of life and for in situ resource utilization on human missions, Astrobiology 14, 102–118.

MID-LATITUDE MARTIAN ICE AS A TARGET FOR HUMAN EXPLORATION, ASTROBIOLOGY, AND IN-SITU RESOURCE UTILIZATION.
D. Viola[1] (dviola@lpl.arizona.edu), A. S. McEwen[1], and C. M. Dundas[2]. [1]University of Arizona, Department of Planetary Sciences, [2]USGS, Astrogeology Science Center.

Introduction: Future human missions to Mars will need to rely on resources available near the Martian surface. Water is of primary importance, and is known to be abundant on Mars in multiple forms, including hydrated minerals [1] and pore-filling and excess ice deposits [2]. Of these sources, excess ice (or ice which exceeds the available regolith pore space) may be the most promising for in-situ resource utilization (ISRU). Since Martian excess ice is thought to contain a low fraction of dust and other contaminants (~<10% by volume, [3]) only a modest deposit of excess ice will be sufficient to support a human presence.

Subsurface water ice may also be of astrobiological interest as a potential current habitat or as a preservation medium for biosignatures. Permafrost on Earth is a known habitat for cryophilic terrestrial organisms [e.g. 4], and it is possible that the subsurface ice on Mars could contain extant or recently extinct Martian microorganisms at depth within the ice.

We propose two Exploration Zones (EZ) in the northern mid-latitudes of Mars in the vicinity of Arcadia and Amazonis Planitiae. These regions are thought to contain abundant subsurface excess ice within the uppermost meter of regolith that has been present for >20 Myr [5]. This ice can be considered both a science and ISRU region of interest (ROI) as described above, and is the primary motivation for proposing these sites. The uppermost surface at both of these locations is also fairly rich in iron and silicon (14 and 18-20 wt. % respectively, [6]), which are also of interest for ISRU. Additional science ROIs for each specific EZ are discussed below and can be found in Figures 1 and 2.

Erebus Montes: This proposed site is centered near 192.1°E, 39.0°N (Fig. 1). The central landing site is located within Amazonian lava flows, and provides access to two different exposures of Hesperian-Noachian transition terrain [7]. The region contains evidence for glacial and periglacial landforms such as ice-altered secondary craters [5] and ice-rich lobate debris aprons [8]. Furthermore, a recent ice-exposing impact was identified within this EZ [9]. These are all strong indications of accessible subsurface excess water ice and represent locations of interest for future study. The nearby exposures of Noachian-Hesperian transition unit are also of scientific interest, providing the opportunity to study ancient rocks within the context of the surrounding Amazonian lava flows.

Acheron Fossae: This proposed site is centered near 220.6°E, 39.8°N (Fig. 2). Acheron Fossae is a region of late Noachian highlands terrain, and is comprised of a series of grabens and ridges surrounded by later Hesperian/Amazonian lava flows from the Tharsis region [7]. The proposed landing site is within these lava flows (HAv), and provides access to a region of late Hesperian lowlands in the western region of the EZ. There is evidence for Amazonian glacial and periglacial activity [e.g., HiRISE images PSP_008671_2210 and ESP_017374_2210], and the Gamma Ray Spectrometer water map suggests that there is abundant subsurface ice in the uppermost meter within this region [10]. Meandering channel-like features have been identified in HiRISE images (e.g., PSP_003529_2195 in close proximity to apparent ice flow features), suggesting possible past sub-ice water flow. Material interpreted as rock glaciers has been observed on the floors of the grabens [11], which may also be of interest for future study since they are found throughout the northern and southern mid-latitudes.

Advantages as Landing Sites: Both of these sites are at low elevations (-3.98 and -3.15 km) to facilitate Entry, Descent, and Landing with large atmospheric masses and greater radiation shielding. The terrains are quite flat at the scale of both MOLA and HiRISE DTMs. There are few meter-scale hazards in most HiRISE images. Multiple 25 km^2 landing sites appear to be acceptable. They are at the lowest latitudes at which we currently know that shallow ice is present, minimizing thermal challenges. HiRISE images indicate that loose regolith is available for construction purposes.

Potential Challenges: Both of the regions proposed here are moderately dusty (typical thermal inertia values for Erebus Montes and Acheron Fossae are 120-130 and 60-90 $Jm^{-2}K^{-2}sec^{-1/2}$, respectively), which may prove to be a challenge for future human exploration. Dust also obscures the ability of spectroscopic instruments to determine the composition of underlying rocks, which makes it difficult to acquire mineralogic data in these terrains from orbit. However, we have hypothesized that this dust may serve to insulate the subsurface ice against sublimation loss, allowing it to remain stable in large quantities within the shallow subsurface of Arcadia Planitia [5]. The two sites proposed here attempt to minimize surface dust based on the TES Dust Cover Index while remaining within regions thought to contain abundant subsurface ice.

References: [1] Bibring J-P. et al. (2006), *Science, 312*, 400-404. [2] Mellon M. T. et al. (2009), *JGR, 114,* E00E07. [3] Dundas C.M. & Byrne S. (2010), *Icarus, 206,* 716-728. [4] Hoover R.B. & Gilichinsky D. (2001), *NATO Sci. Series, 76,* 553-579. [5] Viola D. et al. (2015), *Icarus, 248,* 190-204. [6] Boynton W.V. et al. (2001), *JGR, 112*, E12S99. [7] Tanaka K.L. et al. (2014), *USGS*, Map #3292. [8] van Gasselt S. et al. (2014), *EPSC,* Abstract #530. [9] Dundas C.M. et al. (2014), *JGR, 119,* 109-127. [10] Boynton W.V. et al. (2002), *Science, 297*, 81-85. [11] Kronberg P. et al. (2007), *JGR, 112*, E04005.

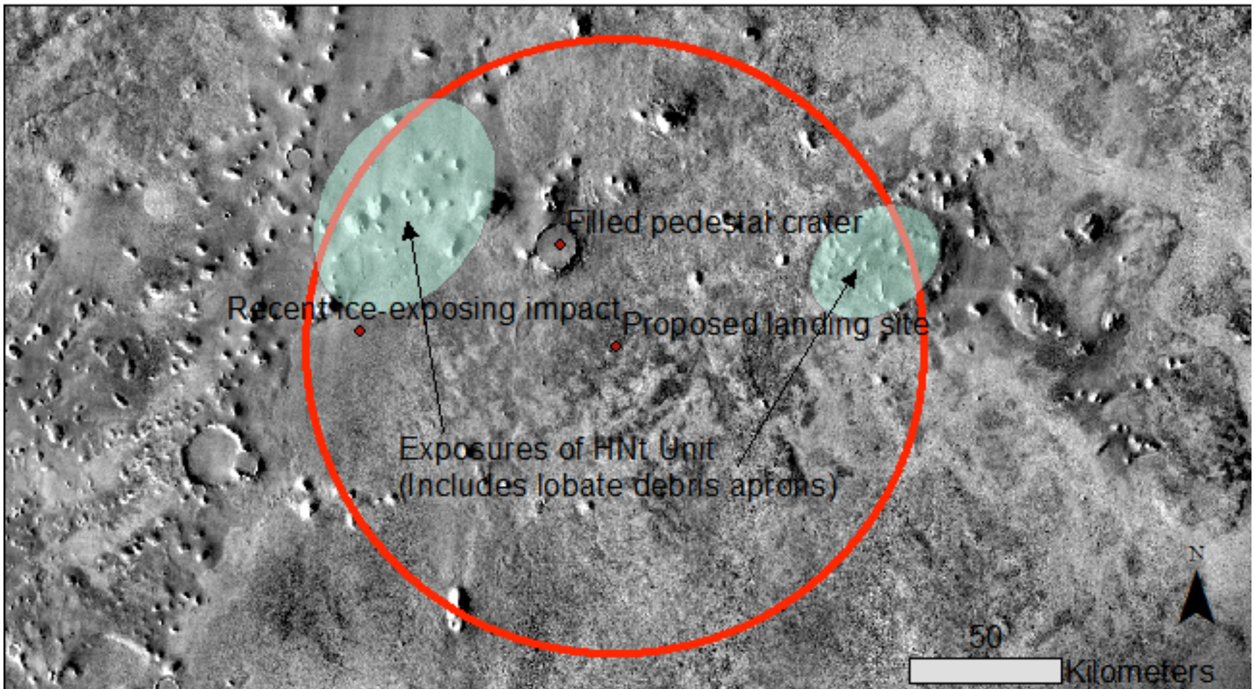


Figure 1: Erebus Montes EZ.

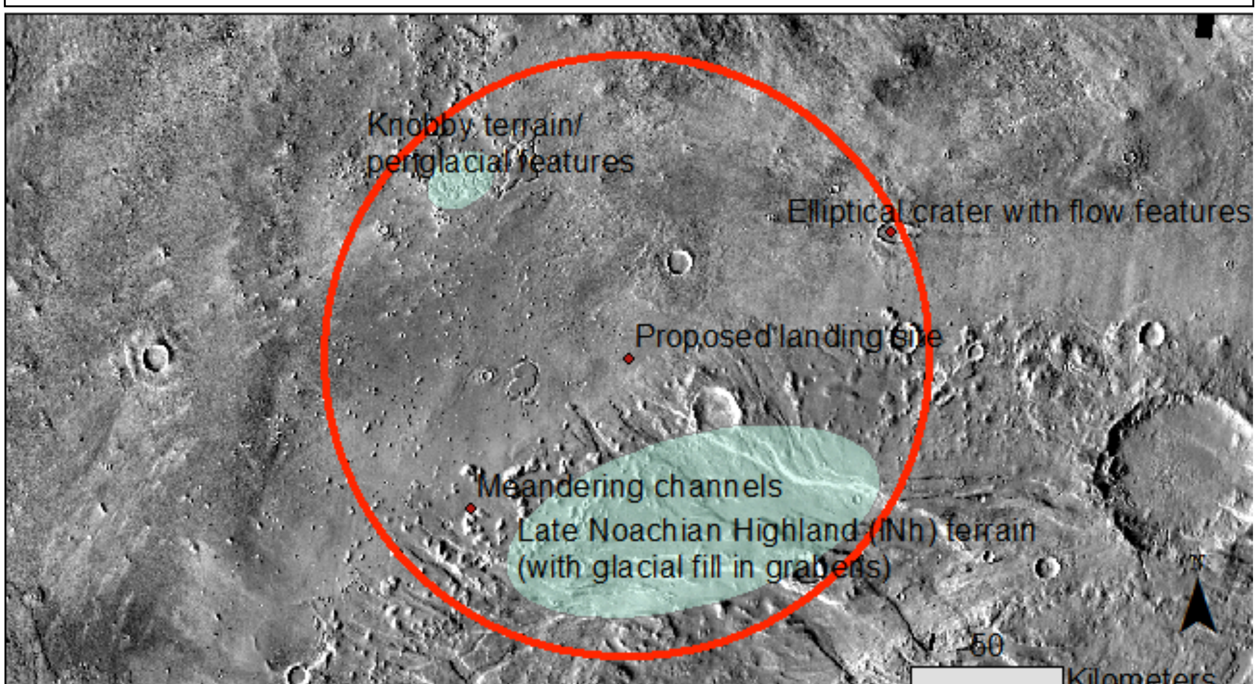


Figure 2: Acheron Fossae EZ.

THAT FIRST STEP SHOULD RESONATE FOR MILLENNIA TO COME

A.A. Westenberg, M.A.[1], R.A. Zucker, J.D.[2]
[1] Explore Mars, Inc., 100 Cummings Center, Suite 331K, Beverly, MA 01915, Artemis@ExploreMars.org ,
[2] Explore Mars, Inc., 100 Cummings Center, Suite 331K, Beverly, MA 01915, Zucker@ExploreMars.org

Introduction: The selection of the first human landing site on the planet Mars should be based not only on technological capabilities and the potential for scientific research, but also on its intrinsic historical significance. That first step will be history in the making, one that should not only be meaningful to those who witness it first-hand, but also to future generations. Moreover, the choice should serve to honor past generations of scientists, whose thirst for knowledge and passion for exploration formed the cornerstone of humanity's efforts to move off our home world and out into the solar system.

The ancient crust of Mars contains clues to a distant geological past. From a geological standpoint, areas containing ancient crust are very interesting, as this type of crust might not only reveal secrets about the geological history of Mars but also about the geological history of Earth. Furthermore, ancient crust of 3 to 3 ½ billion years old is a prime candidate for having retained remnants of Martian life.

For these reasons, Explore Mars, Inc. proposes Copernicus Crater.

Selecting a landing site that has scientifically interesting features is part of the selection process as a matter of course.
In addition, as indicated in the Abstract above, historical significance should also be considered.

In deciding where humans land on Mars for the first time, we have the opportunity to link this landing not only to the present, but also to the past and to the future: Those who came before us investigated the heavens from the confines of our home planet; we are building upon their work by taking the first small steps on a new world; and those who come after us, who will talk proudly about those 21st Century explorers who dared to go to Mars, will continue to develop and expand that beachhead so that humanity can truly become a multi-planet species.

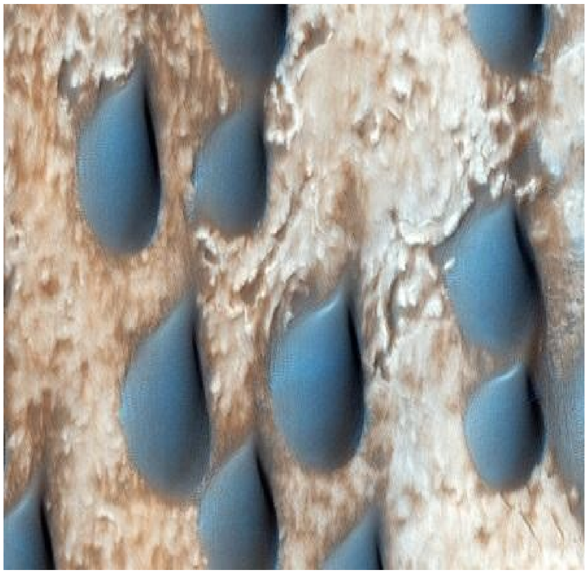
Copernicus Crater which by its very name provides a link between past, present, and future, appears to satisfy the above criteria. The name gives honor to an important astronomer.

The crater lies in the region of the 3 billion-year old ancient crust of Mars. Copernicus Crater has interesting gullies that might point to recent flows on Mars, now thought to be the product of dry ice, a feature that is not found on Earth. Also Copernicus Crater contains olivine dunes. These three geological features combined make this crater a good choice for landing as it contains several 'Regions of Interest' as set out by this workshop. Copernicus also has a diameter of almost 300 kilometers, which makes it large enough for the first landing as well as large enough as the exploration zone for several landings.

Copernicus Crater is located south of the planet's equator in the heavily cratered highlands of Terra Sirenum in the Phaethontis quadrangle at 49.2°S and 169.2°W.

It is respectfully submitted that further research should be conducted about other possible landing sites that fit the above criteria.

Olivine dunes in Copernicus Crater
PIA17879



Mars Reconnaissance Orbiter (MRO);
High Resolution Imaging Science Experiment (HiRISE)
Image credit: NASA/JPL-Caltech/Univ. of Arizona

Gullies on Two Different Levels in Crater Within Copernicus Crater
ESP_039621_1315

Mars Reconnaissance Orbiter (MRO)
High Resolution Imaging Science Experiment (HiRISE)
Image credit: NASA/JPL-Caltech/Univ. of Arizona

Context map of gullies on crater within Copernicus Crater

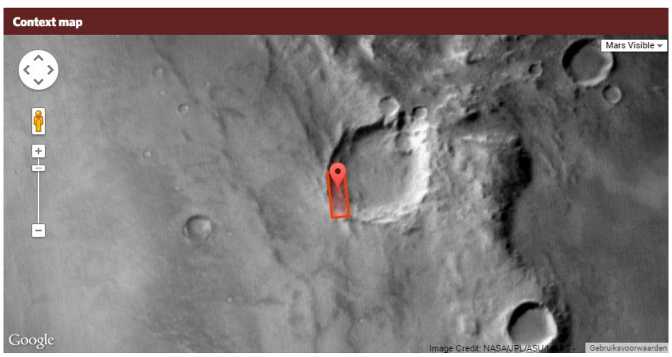


Image credit: Google Maps Mars

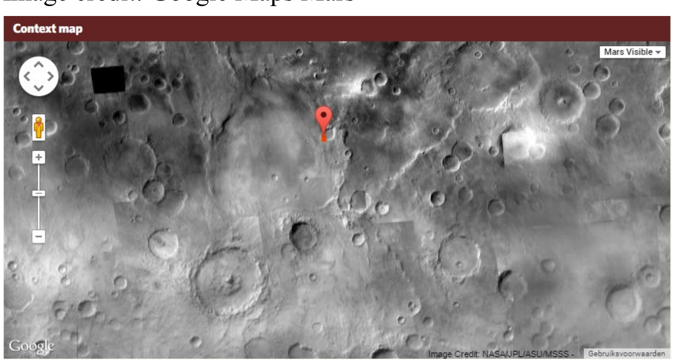


Image credit: Google Maps Mars

Sinus Meridiani Landing Site for Human Exploration—A Mesoscale Fluvial System

EZ: SW Sinus Meridiani, centered 6.4335degW 2.2526degS, Fig. 1 Regional stratigraphy, Miyamoto Crater, Opportunity Traverse, Hematite concentrations, raised ridges -- flat landing zone

Sinus Meridiani was selected as the *Opportunity* exploration region for many reasons, including its geological evidence of a relatively thick, sedimentary stack 800-900 m thick, with its surficial layer of hematite nodules. One of the competing theories underlying the choice of the Exploration Zone (EZ) below (Fig.1) is the fluvial theory of emplacement of the Meridiani units [1]. Fluvial depositional environments *at the mesoscale* ($2x10^4 – 10^5$ km^2) are still poorly understood on Earth [2]. The large fan model (or *fluvial fan, megafan*, or incorrectly, the *inland delta* model) of continental fluvial sedimentation appears to provide a coherent set of explanations at this scale, for several characteristics of the Sinus Meridiani rock suite. Large fans (>100 km) have been classed as alluvial fans, but their significantly larger area sets them apart from the well-known desert alluvial fan in terms of process [3]. More importantly, global mapping reveals the ubiquity of large fans (nearly 200 on all continents) and very large areas that they underlie (e.g., nested large fans cover 0.75 million km^2 in S America). Although still little recognized, the maps in turn reveal unexpected patterns and relationships [3] that appear to be particularly useful in understanding the Meridiani rock suite [1].

The mesoscale, fluvial-fan model specifically provides explanations for: (i) the layered character of the Meridiani sediments; (ii) the dense, network of curvilinear ridges of the ridged plains (cemented river channels cover entire surfaces of large fans on Earth); (iii) the concentration of hematite deposition nearest the dichotomy (relating to known high water tables in large fan zones near upland margins); and (iv) the widespread inundation by sediments of impact craters within the Meridiani rock mass [4] (partly by sediment from rivers flowing on neighboring intercrater plains).

The large fan model also applies to the Meridiani layered rocks at a wider scale (i.e., at the EZ scale): (v) the extent of the layered units (1200 km east-west along the southern boundary, 1000 km north from the boundary) is at the same scale as the large fan systems that emplace the sediment bodies of contiguous large fans; (vi) the close geographic connection between the southern highland fluvial systems and the layered units, assuming that some of the Meridiani sediments were delivered by north-flowing rivers of the valley networks immediately to the south; and (vii) the probable absence of a waterbody connected to the layered units (layered sediments of Meridiani dimensions are routinely laid down *subaerially* at the foot of terrestrial highlands by rivers sourced even in uplands of low topography—ninety megafans in Africa emanate from low uplands demonstrating that major mountains are not a prerequisite for the development of large fans).

Despite much scientific attention, including a rich data set supplied by the rover, several theories still compete to explain the origin of the Meridiani units. Several major science questions can be addressed by observations in the proposed ROIs, through the lens of the large fan model.
(a) *Detailed examination of the regional sedimentary stack*: to elucidate the materials, sedimentary structures and internal architectures of units and subunits (unit mNh is global, unit HNhu is regional/Meridiani-wide); and provide a window onto the cratered terrain rocks beneath (the best exposures in the zones as denoted were employed for measurement of the regional slope of the Meridiani layered strata [5]);
(b) *Miyamoto Crater sedimentary stack:* Meridiani layered units and phyllosilicate outcrops both occur within the confines of the crater.

(c) *Connection between, and comparison of, intercrater and crater sedimentary stacks*: Miyamoto and other craters display obvious or probable connections to external units on the intercrater plains. The phenomenon of crater inundation by sediment is more easily explained if at least some fluvial sediment is laid down as large fans across wide areas, as suggested by the fluvial model.
(d) *Hematite distribution over a wider geographic area*: extending findings from the rover traverse may yield answers to the origin of this intriguing unit. Highest hematite concentrations along the southern zone of the Meridiani units suggest connections to the southern highlands.
(e) *Enigmatic ridges of the ridged plains*: networks of light-toned ridges are widely displayed on exposed intercrater surfaces, but also some crater units: e.g., the Miyamoto raised ridges interpreted as probable relict stream channels and show CRISM phyllosilicate responses. With several terrestrial analogs now available, examination of the ridges is likely to provide a satisfactory explanation.
(f) *Connection between Meridiani units and rocks and channel systems of the southern highlands*: this is another debated issue: access to one of few locations where these landscapes almost meet.
(g) *Access to Opportunity's Traverse Path*: reasons may arise to re-examine some parts of the traverse path, and for further data collection.

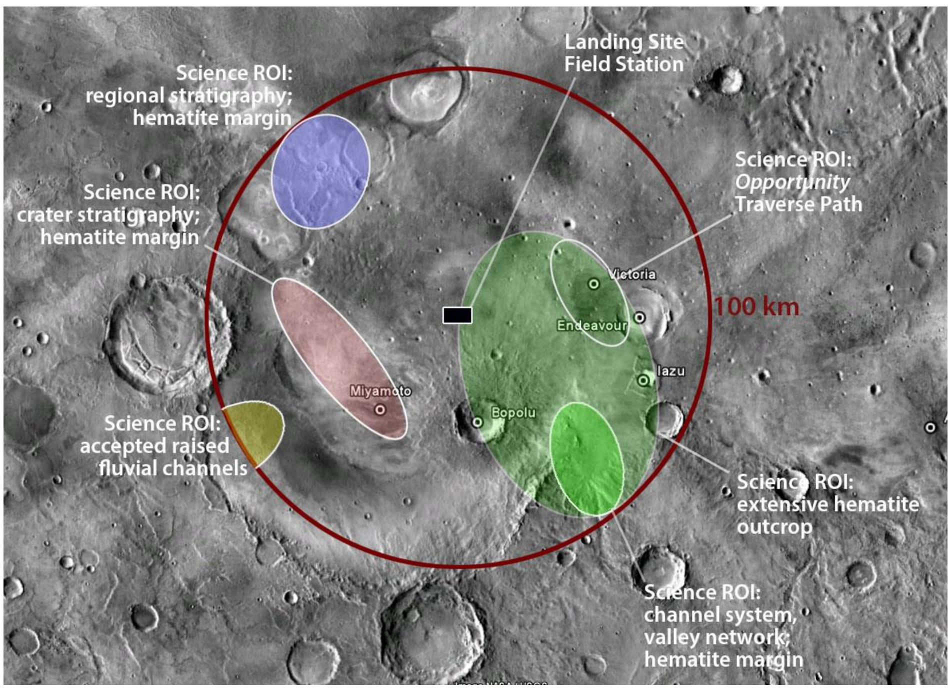


Figure. 1 EZ SW Sinus Meridiani: ROIs with main research elements

References: [1] Wilkinson MJ et al., 2007, *Eos Trans. AGU, 88(52), Fall Meet. Suppl.,* Abs #P12C-03; Wilkinson MJ et al., 2008, *LPS XXXIX,* Abs #1392; Wilkinson MJ et al., 2009, *Workshop on Modeling Martian Hydrous Environments (LPI),* Abs #4034*;* Wilkinson MJ, McGovern PJ, 2010, *LPS XLI,* Abs #2253; Wilkinson MJ, 2010, *First Intl. Conf. on Mars Sedimentology & Stratigraphy*, El Paso, TX, Abs #6065. [2] Wilkinson MJ et al., 2006, *J. South American Earth Sci.* 21: 151-172; Wilkinson MJ et al., 2010, In Hoorn & Wesselingh (ed.) *Amazonia, Landscape and Species Evolution*, Blackwell, Ch. 10. [3] Wilkinson MJ, 2015, *Large Fluvial Fans, AAPG-ACE Conf*., Denver CO. [4] Edgett KS, 2005, *Mars* 1: 5-58. [5] Hynek et al., 2008, Earth & Planetary Sci. Letters 274: 214–220.

An Exploration Zone in Cerberus Containing Young and Old Terrains, Including Fossae/Faults and Shergottite Distal Ejecta

S.P. Wright[1], P.B. Niles[2], M.S. Bell[3], C. Milbury[4], J.W. Rice, Jr.[1], A.S. Burton[2], E.B. Rampe[3], P.D. Archer, Jr.[3], S. Piqueux[5], [1]Planetary Science Institute, Tucson, AZ; [2]NASA Johnson Space Center, Houston, TX; [3]Jacobs, Houston, TX; [4]Purdue University, Lafayette, IN; [5]Jet Propulsion Laboratory, Pasadena, CA

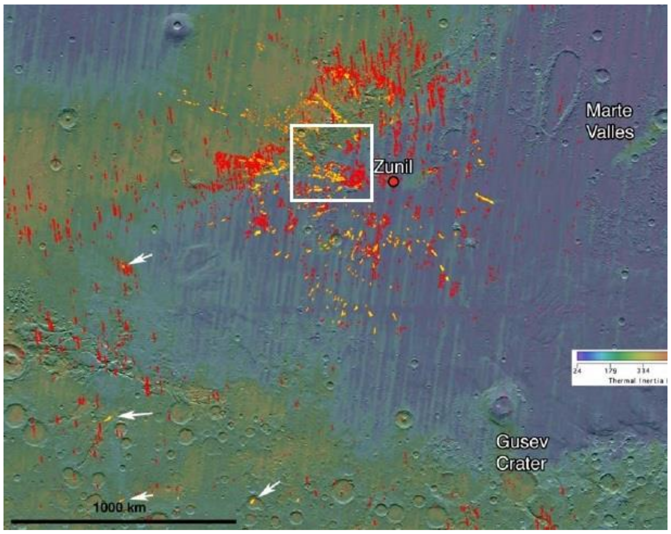
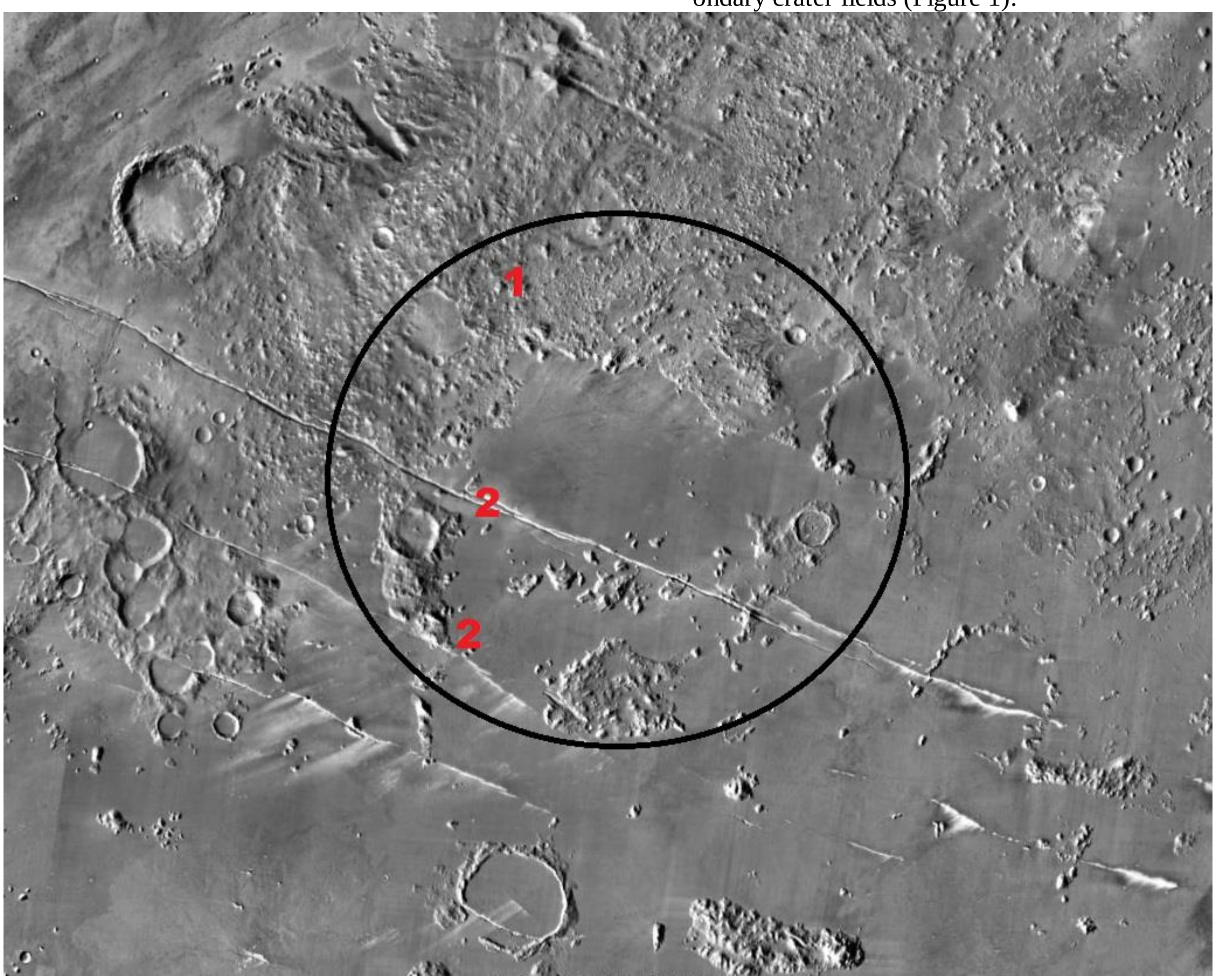


Figure 1. Regional (20° S to 34° N, 138° to 180° E) TES Thermal Inertia overlaid on a shaded relief map adapted from *Preblich et al*., 2007 and *Putzig et al*., 2005 showing the geologic context of the Exploration Zone (EZ) of Cerberus to the west of Zunil Crater in Figure 2. Ejecta rays from 10.1 km Zunil Crater are shown in yellow and secondary crater fields are shown in red. White arrows call attention to distal rays. White box is context of Figure 2.

Figure 2. Mosaic of daytime THEMIS TIR images showing 200 km diameter Exploration Zone with center landing site at 10° N, 162° E. Regions of Interest (ROIs) #1 (older, ridged and knobby terrain) and #2 (Fossae/faults) are labelled. Not labeled in Figure 2 are more ROI's: ancient crater rims, Amazonian lava flows, Zunil Crater ejecta rays and secondary crater fields (Figure 1).



Science ROI's:

- Older terrains that pre-date Cerberus lava flows are likely Hesperian or Noachian in age (ROI #1 in Figure 2). Knobby and ridged terrains generally suggest sedimentary rocks subjected to aeolian processes. These have implications for habitability and trapping ancient gases. Nearby photogeologic units that *might* be embayed in the EZ include the Medusa Fossae Formation and Southern Highlands' Cratered Terrain.
- Fossae (faults) (ROI #2 in Figure 2) can be put in a stratigraphic and geologic context, along with perhaps showing some groundwater/ground ice flow in Fossae (*e.g.*, HiRISE ESP_018708_1960). The nature of the Fossae could be explored (*e.g.*, tectonic rifting or subsidence).
- The center of the EZ are flat basaltic lava flows that can be dated and provide a regional geologic context as nearby, likely contemporaneous Elysium has been well-dated with crater counts.
- In agreement with E2E-iSAG, there will be a variety of lithologies and geologic materials to collect: igneous rocks, impactites, ejecta, embayed older terrains, aeolian sediments, regoliths/soils, dust, and perhaps aqueously altered (due to groundwater/ice) and/or hydrothermally altered samples (due to Amazonian volcanism). With complementary field data, these samples can be put into a geologic context for a better picture of the regional or perhaps global geologic history.
- Mars' dynamo was likely active until 3.6 Ga [*Milbury et al*., 2012], and would have shielded the atmosphere and atmospheric species (water) from loss due to solar wind erosion. The EZ is located within a region that is magnetized, so outcrops may have remnant magnetization and this may have allowed water to persist in this region past the demise of the dynamo. The localized magnetic field in the EZ could shield future explorers from solar radiation.
- Per the matrix template for EZ rubric, "primary and/or secondary crater ejecta" is a bonus ROI seen on Figure 1. HiRISE images suggest that ~1-2 Ma ejecta from 10.1 km Zunil Crater ~500 km to the east/southeast have covered the region with basaltic ejecta and secondary craters [*McEwen et al*., 2005; *Preblich et al*., 2007; *Tornabene et al*., 2006]. These distal ejecta may prove that Zunil Crater is the source region for the basaltic shergottites (2.9 Ma ejection event), olivine-phyric shergottites (1.1 Ma) or lherzolites (3.9 Ma) [Fritz et al., 2005]. With evidence for two periods of flood basalt volcanism in the nearby region, Zunil could be the source of ~175 Ma basaltic shergottites stratigraphically overlying ~330 Ma basaltic shergottites [*Wright*, 2007]. This potential ground-truthing of both shergottites and crater counts of the surface would benefit Mars science tremendously.

Resource ROI's:

- *Water or water ice as an in situ resource utilization (ISRU)* Cerberus region shows a high hydrogen abundance on GRS maps. Geomorphology of region (rootless cones, flood features) suggest flooding of water and near-surface ground ice/water either during or after the most recent volcanism. There is preliminary evidence that 2 or 3 Recurring Slope Lineae (RSLs) [*McEwen*, Mars 2020 Workshop, 2015] exist in the alluvial fans (or perhaps washes) exiting the older knobby and ridged terrain (ROI #1) into the younger lava flows (flat center of EZ).
- *Materials* Older knobs in ROI #1 (Figure 2) may be high in silica.
- *Infrastructure* Cobbles, pebbles, sands, and fines will be available. Volcanic and/or tectonic constructs from lava flows and Fossae may provide shelter in addition to potential present-day habitable environments (*e.g.*, amino acids found in a shergottite [*Callahan et al*., 2013]).

References: Boynton et al. (2002) *Science*, *297*, pp. 81-85, doi: 10.1126/science.1073722. Callahan et al. (2013) *Met. & Plan. Sci.48*, pp 786–795, doi: 10.1111/maps.12103. Fritz et al. (2005) *Met. & Plan. Sci.*, *40*, pp. 1393-1411. McEwen et al. (2005) *Icarus*, *176*, pp 351-381. Milbury et al. (2012) *JGR*, *117*, 2156-2202, doi: 10.1029/2012JE004099. Preblich et al. (2007) *JGR*, *112*, doi:10.1029/2006JE002817. Putzig et al. (2005) *Icarus*, *173*, pp. 325 – 341. Tornabene et al. (2006) *JGR*, *111*, doi:10.1029/2005JE002600. Wright (2007) *7th Mars Conf.*, #3399.

HILLS ZEPHYRIA PLANUM - A SOURCE OF DEEP RESOURCES

Valeriy Yakovlev. Laboratory of Water Quality«PLAYA»
61001, 38, Kirova str., Kharkiv, Ukraine. Yakovlev_val@mail.ru

We propose area in the equatorial region Zephyria Planum to be considered as landing site for the mission. The site is located in "Sea Urchins" (fig.1,2) having landing point coordinates 1˚22,3'S;157˚8,5'E

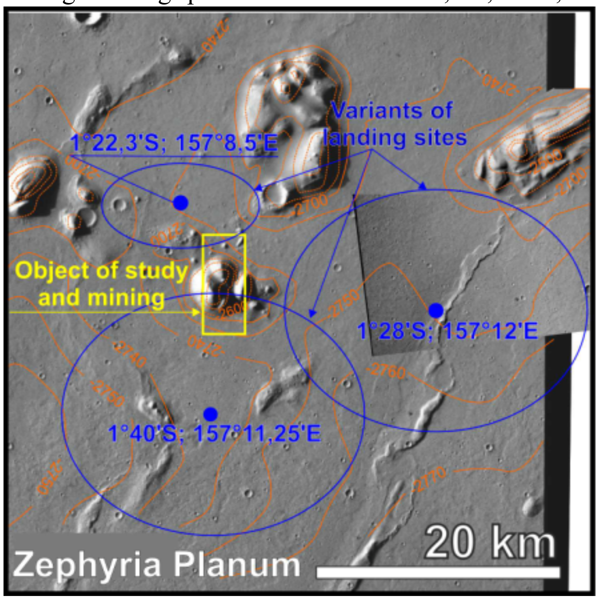


Figure 1. Location of intended landing, object of study and resource extraction in Zephyria Planum.

Background of choice of the site. The theoretical justification of the existence of large hydrolakkolits at low latitudes of Mars is based on existing notions of a subpermafrost hydrosphere [1] and is represented in the materials of conferences and publications [2-4]. Landing site for the scientific laboratory MSL2020 (Site 114) had been proposed by the author back in 2014. Extended version of the proposal was submitted in the beginning of 2015. There was no author's proposal presentation at the Second Landing Site Workshop because proposed area didn't meet technical constraints i.e. low thermal inertia, high albedo and planetary protection restrictions (cannot approach the water). What distinguishes current choice from others is that proposed site if focused on discovery of traces of modern and recent life in the substrate formed from subpermafrost waters.

Study space. Place of the first humanitarian mission is defined by the main purposes, which in the understanding of the author are to implement the landing on Mars and to test technology of survival.
The biggest challenges for the perspective landing place are: to ensure safe landing and to address mission's survival concern, where easy access to the verity of resources such as water, heat, metals, methane and other gases, building materials could be critical. Scientific goals of the first humanitarian mission will come mainly to the solving of technical tasks, except for the task of discovery traces of life. Proposed site for the first humanitarian mission takes into account the need to mitigate the adverse environmental conditions:

- location of the site is at the height of "-"2700 m, which determines the significant thickness of the atmosphere and an opportunity for effective deceleration landing modules;
- location near the equator is favorable for reasons of ballistics;
- predominance of large lowland areas also creates favorable conditions for landing, movement and review;
- the equatorial position (1,5˚ south latitude) defines the highest possible average temperature of the subsurface soil- about "-"40°C and a long season with day time temperatures around zero;
- low thermal inertia(90J m^{-2} $s^{-0.5}$ K^{-1}) and high albedo (0,3) of the surface in this area assume a loose cover of silt which can be used as a heat insulating material at building of hideouts;
- sand dunes is likely to contain a condensation (fresh) water, and the well-sorted dune granular substrate using a binder allows to produce blocks for building in automatic mode;
- hills on the plain Zephyria Planum typical, most likely are hydrolakkolits at geomorphological features and geological conditions, and show signs of recent activity [2,3]. This suggests existance of channels of brine in flow from interpermafrost or subpermafrost reservoirs to the surface of Mars, which increases the ability to attract water, mineral and thermal resource, sand expands the search capabilities of modern life to the deep reservoirs of liquid water. If injection nature of the hills on the plain Zephyria Planum confirmed they should become the main object of the scientific research and place to test the innovative technologies for resource excavation and data processing. Considering favorable climatic conditions and sand nature of the relief we can conclude that this site (and similar ones) can be very appealing for the first humanitarian mission. Summarizing above mentioned aspects we arrived at a decision that key factor in determining perspective anding site would be proving injection nature of the conical hills of Zephyria Planum.

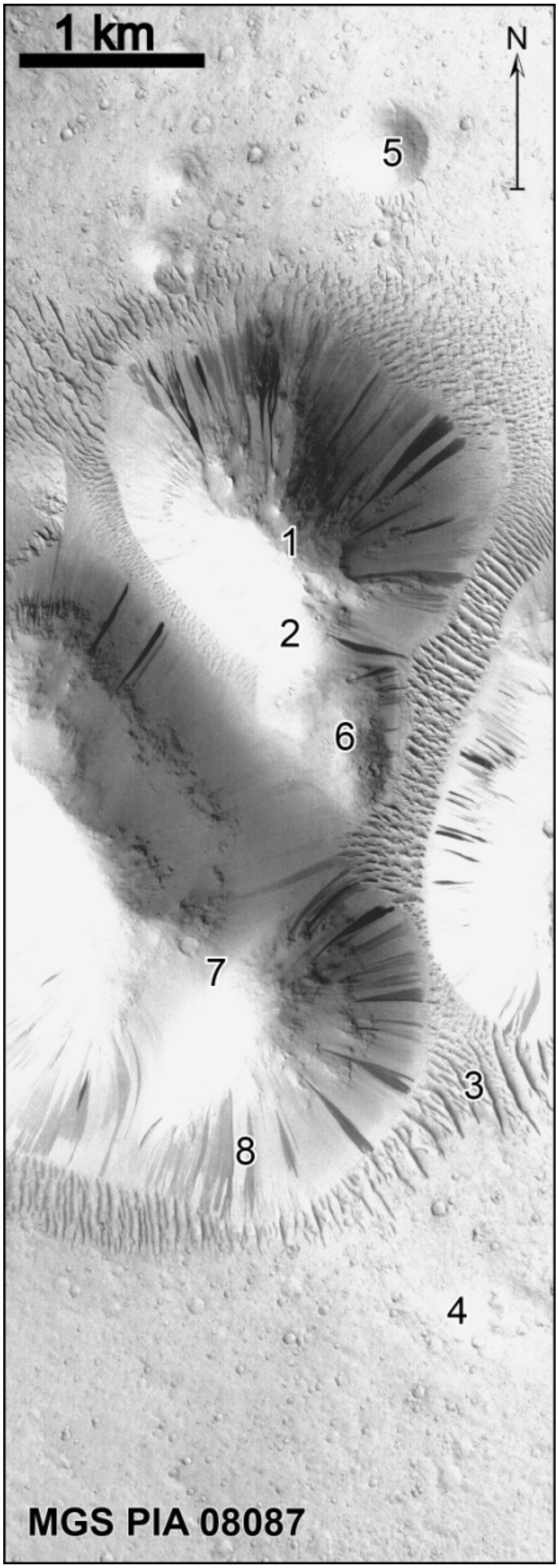


Figure 2. The object of study and resource extraction. Hills Sea Urchin. Numbers denote: a group of hills with convex caps (1) with jagged contours and gentle slopes (2). They are surrounded by dunes (3) on a flat plain (4). The height of hills above the plain is approximately 250-370 m. The indirect signs of hydrolakkolits are close grouping of large hills on the isometric site, the presence of small hills of the correct form in the upper part of the image (5), apparently having the same nature; the presence of clearly secondary form (6), presumably formed by the subsurface fluid flow from the top of the northern hill; the presence of a dense ring of dunes that resembles sand dunes of the terrestrial glaciers. The signs of the structures recent activity (modern subpermafrost water injection) include: the regular conical shaped hills; the correct form of the saddle (7) formed under the dominance of the active drift and accumulation of silt from the western larger hill; the large concentration of the slope streaks (8), having presumably aqueous nature and developing on the substrate of crystalline hydrates. The center of the image has the coordinates close to 1°28'S; 157°20'E

Reduced requirements for the magnitude of thermal inertia from 100 to 90 J m^{-2} $s^{-0.5}$ K^{-1} and lifting the ban on contact with water bodies (planetary protection) will allow the MSL2020 to carry out this mission in conjunction with the future first humanitarian mission. The author believes that one of the physical analogues is Mount Sharp in the crater Gale, which, as the author suggests, has the injection nature [4]. Morphological characteristics of the mountain, elemental, lithological composition and traces of relatively large recent floods at its foot are not contrary to the model of participation of deep injections into the formations of the central massif of the crater Gale. Thus the area of research of laboratory of Curiosity to a certain extent can be considered as a valid test range for studying the large Martian hydrolakkolits.

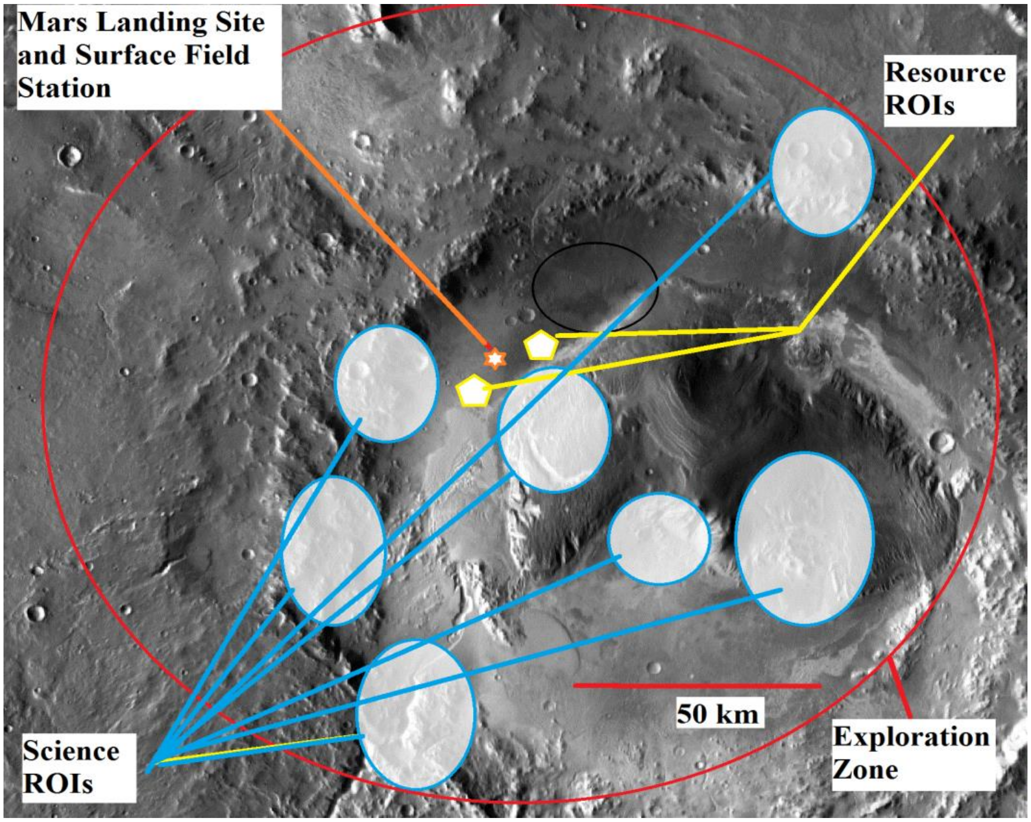
Author is ready to offer his extensive expertise in the field of Earth's hydrosphere science if chosen to participate in special studies related to the testing of active hydrolakkolits, evaluation of landing sites of alleged humanitarian mission sand the development of research programs of Martian hydrosphere.

References: 1.Clifford S. M., Lasue J., Heggy E., Boisson J., McGovern P., Max M.D. Depth of the Martian cryosphere: Revised estimates and implications for the existence and detection of subpermafrost groundwater. Jornal of Geophesical Research: Planets (1991-2021)115 (E7) 2010. 2.Yakovlev V.V. Large basins of water on Mars/ European Mars Science and Exploration Conference: Mars Express &ExoMars. European Space Agency ESTEC, Noordwijk, 2007. 3.Yakovlev V. Conditions and mechanism of Mars big hydrolakkolits formation/ Fifth Mars Polar Science Conference (2011) 6026. 4.YakovlevV.V. The nature of the central structure of the Martian crater Gale. Scientific publication UkrDGRI№3.K2012-S.102-113.

NASA Landing Site/Exploration Zone Proposal for Human Missions

Paul M. Yun
El Camino College
Torrance, California

Latitude and Longitude of the proposed EZ: 4.6°S 137°E



Rationale: Aeolis Palus in Gale Crater has been proven to meet Engineering Constraints through the successful landing of Curiosity. Also, Curiosity found that water is accessible (1.5 to 3 weight percent) in its soil sampling. The surrounding of Gale Crater has a great potential for past and present habitability, and its geological diversity meets science site criteria in astrobiology, atmospheric science, and geoscience. Since the site is close to equator, and it used be the bottom of lake, food production might be more plausible than many other sites. In addition, the crater's flatness will help astronauts move around easily among Regions of Interest. Lastly, Curiosity's findings in the region will better prepare human exploration than any other unexplored regions on Mars.