ENGINEERING SENSITIVITIES TO ORE CHARACTERISTICS FOR WATER RESOURCES ON MARS AND IMPLICATIONS FOR RESOURCE EXPLORATION APPROACHES:

THE M-WIP STUDY, PART 3

Space Resources Roundtable, Golden, CO

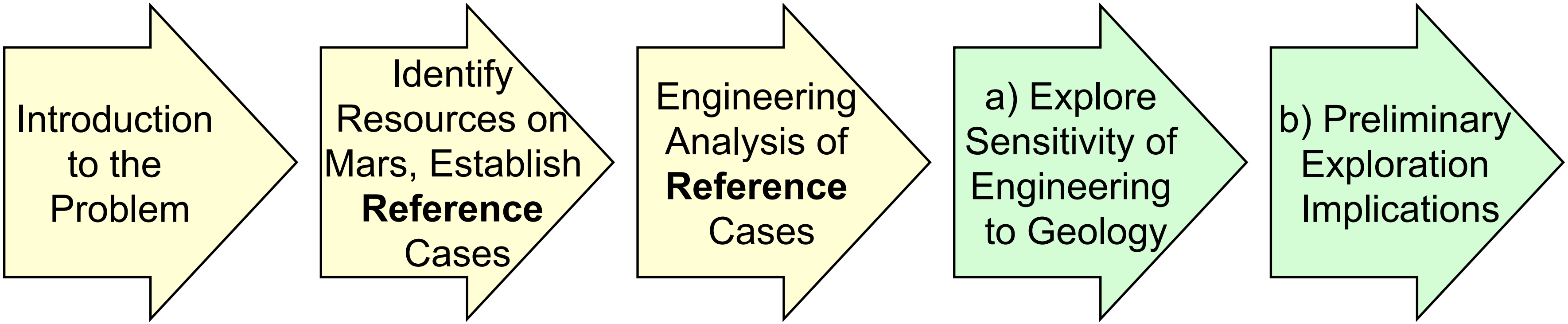
June 7, 2016

Charles Whetsel, Angel Abbud-Madrid, David Beaty, Dale Boucher, Ben Bussey, Richard Davis, Leslie Gertsch, Lindsay Hays, Julie Kleinhenz, Michael Meyer, Michael Moats, Robert Mueller, Aaron Paz, Nantel Suzuki, Paul van Susante, and Elizabeth Zbinden

For further information, see the full M-WIP report: http://mepag.nasa.gov/reports.cfm.

Introduction - Part 3

a) Prepare a sensitivity analysis of the major dependencies between the engineered systems and known or potential geological variation



b) Delineate some key preliminary implications for future implications

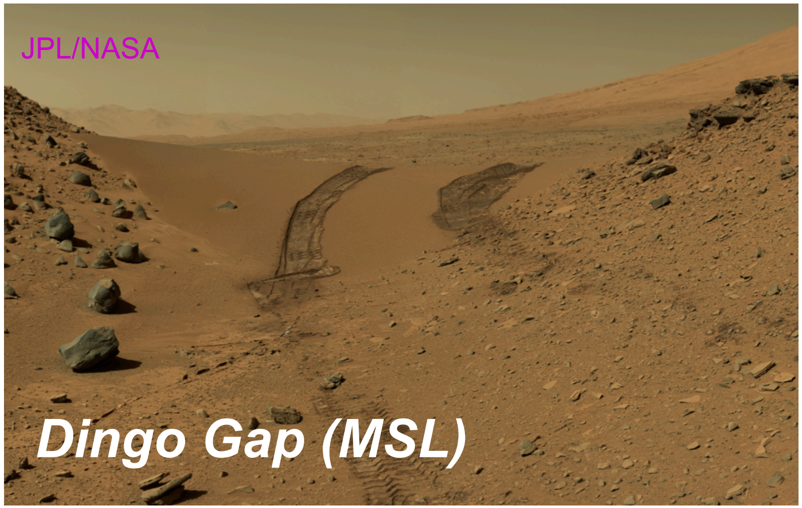
Dependencies of Engineering on Natural Geological Variation

- Several attributes of the natural geological variation of the deposits represented by the reference cases have the potential to exert a significant influence on the engineering architecture. Choosing and optimizing a specific engineering design is therefore dependent on knowledge of these properties. The following appear to be of greatest importance:
  1. Geometry, size, location, accessibility of the ore deposit
  2. Chemical properties ("processability") of the ore deposit
  3. Nature and scale of ore heterogeneity: mechanical consistency
  4. Nature and scale of ore heterogeneity: water concentration
  5. Thickness of overburden
  6. Mechanical properties of overburden
  7. Distance between the deposit and the processing plant
- Evaluating these dependencies in more than a qualitative way is deferred to future studies.

Nature and Scale of Ore Heterogeneity—Mechanical Consistency (1 of 2)

Given the kinds of mining and processing systems described in Task #2, several aspects related to the mechanical consistency of the ore have the potential to cause difficulties that would reduce the efficiency of the water production system:

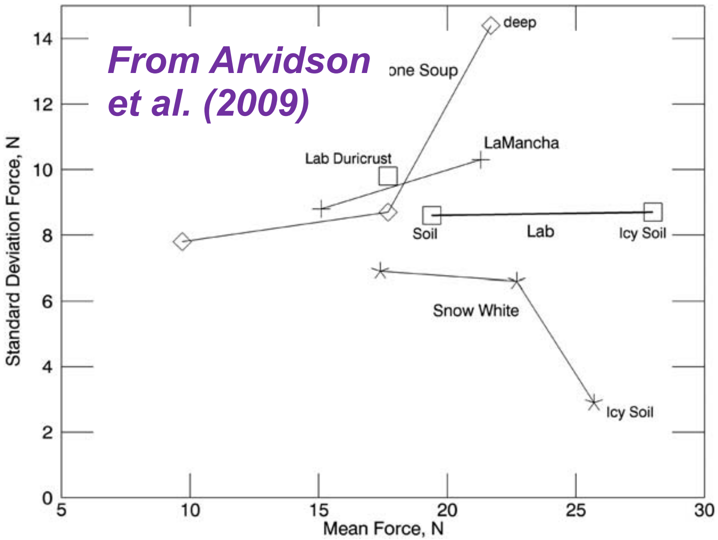
- Cases B-C-D: Many kinds of granular material deposits consist of uneven particle size distributions that include significant amounts of smaller and larger sizes than the process-optimum.
  - The abundance, and variation in size, of rocks is an issue that can be dealt with by the choice/ development of mining method. The presence of even a few very large boulders would sanitize a portion of the deposit, but a well-designed excavation sequence in space and time would minimize this impact.
  - Over-sized material (rocks) wedging in hardware and clogging the process flow would reduce water production rate and shorten equipment life.
  - Under-sized material (fines) lost during excavation and transport could reduce water production rate to a degree depending on the process used.



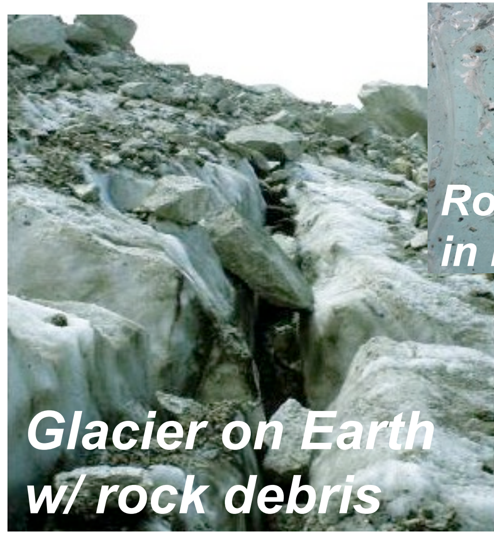
Note significant variation in mechanical properties of the regolith across this image.

Nature and Scale of Ore Heterogeneity—Mechanical Consistency (2 of 2)

- Case A: Glaciers are well-known for having entrained rocks/gravel/sand. In our definition of Case A, we assumed 90% ice, and 10% entrained other material. That proportion can vary widely in natural glaciers, as can the size of these rocks. The choice/development of mining method will determine the effect of entrained refractory material (rocks) on the process efficiency.



The ice at the PHX landing site was found to be very hard.



Dealing with glacial ice may require a strategy to deal with associated rocks.

Dependency of Engineering Conclusions on Variations in Geology

Relative Importance of Knowledge

Row #	Characteristic	A1: Ice (Open Pit)	A2: Ice (Subsurface)	B: Hydrated Sulfate	C: Clays	D: Regolith
1	Geometry, size of the minable ore deposit	L	L	M	M	L
2	Chemical properties (“processability”) of the ore deposit	L	L	M	M	H
3	Nature and scale of ore heterogeneity: mechanical consistency	H	H	H	H	H
4	Nature and scale of ore heterogeneity: water concentration	L	L	M	M	M
5	Thickness of overburden	H	M	n/a	n/a	n/a
6	Mechanical properties of overburden	H	M	n/a	n/a	n/a
7	Distance between the deposit and the processing plant	M	M	H	H	L

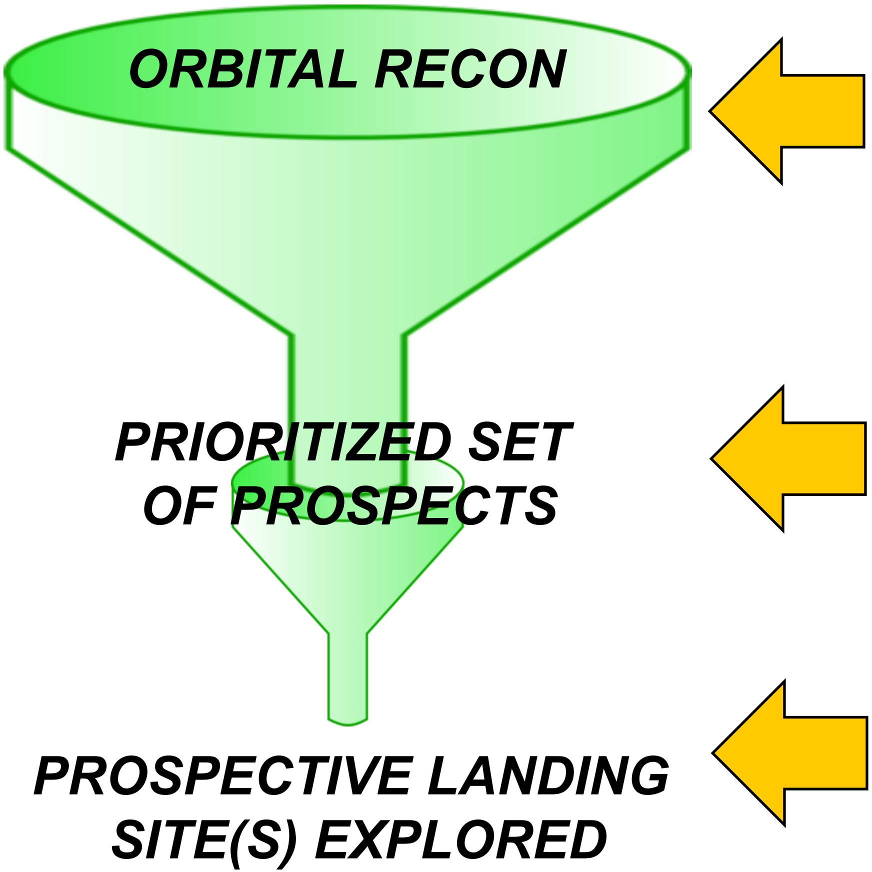
Information of Highest Priority to Engineering

The information of highest priority to determining engineering viability - proposed. Are these the parameters of greatest usefulness in exploration screening?

CASE	#1	#2	#3
A1 (Ice+open pit)	Thickness of overburden	Mechanical properties of overburden	Mechanical consistency of ore deposit
A2 (Ice+subsurface)	Mechanical consistency of ore deposit	*Thickness of overburden*	*Mechanical properties of overburden*
B (hydrated sulfate)	2D geometry/size of ore deposit	Mechanical consistency of ore deposit	Distance to processing plant
C (clay)	2D geometry/size of ore deposit	Mechanical consistency of ore deposit	Distance to processing plant
D (regolith)	Water concentration of ore deposit	Mechanical consistency of ore deposit	Chemical properties of ore deposit

Information in cells shaded in blue are those for which preliminary assessments can be made from orbit, those in green require data collected in situ. For Case A2 only parameter #1 was ranked high priority, parameters #2 and #3 (in italics) were ranked medium priority.

The Importance of Decisional Support



Which data sets would provide the most effective screening to define discrete, evaluatable, prospects?

Which data sets would be most useful in prioritizing prospective landing sites identified?

How could we maximize the probability that the prospective landing site(s) we explore on the ground will be able to meet remaining requirements?

<u>Note</u>: Creating a list of possible or proposed steps or missions to accomplish each step is an important piece of follow-up work.

This is a 2-step (at least) Exploration Problem

<u>FINDING #6.</u> Using orbital data alone it is not possible to collect the data necessary to achieve "proven reserves" for any of Cases A-B-C. Some of the required data are not observable at all from an orbiter, and others cannot be observed at an appropriate spatial scale.

- The best we will be able to do from orbit is to identify places of enhanced potential, or maybe "possible reserves".

<u>FINDING #7.</u> All of the parameters previously listed on <u>can</u> be measured from a properly-equipped rover, <u>as long as it is sent to the right place</u>.

- There is a time factor that matters. When is the earliest that we can get data from the second mission and when is it needed in order to influence mission architecture?

The 2016 Mars Water In-Situ Resource Utilization (ISRU) Planning (M-WIP) Study

Summary

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The M-WIP Study: Summary

BIG CONCLUSION #1

Mars has widespread potential for water resources that could almost certainly be upgraded to "proven reserves" with a sufficient exploration program.

BIG CONCLUSION #2

The currently known potential is based on four classes of geology (shallow ice, 3 categories of granular materials), however, we do not have enough information at present to down-select to a single, highest-priority deposit type—we need to keep all of them alive for now.

BIG CONCLUSION #3

The engineered systems needed to mine the raw materials, transport them, and extract/purify the water need significant development. Constraints/priorities from engineering need to be integrated with constraints originating in what Mars has to offer.

The M-WIP Study: Looking Ahead

The M-WIP study has showed that in order for water-based ISRU on Mars to be viable, significant advancements need to be made by a number of communities of technical people who don't always talk to each other. (This is a perfect role for the SRR!!)

- Technology developers, who can invent the necessary mining/processing equipment
- Advance mission planners (robotic), who can design the exploration missions needed.
- Advance mission planners (human), who can design an effective architecture of the human missions.
- Scientists expert in analyzing existing Mars data, to see how far we can advance prospect identification/prioritization using what we already have
- Other?

Appendix

Affiliations

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Acronyms & Definitions

- CheMin – Chemistry and Mineralogy Instrument (instrument on the 2011 MSL rover)
- CRISM - Compact Reconnaissance Imaging Spectrometer for Mars (instrument on the 2005 MRO orbiter)
- DAN – Dynamic Albedo of Neutrons (instrument on the 2011 MSL rover)
- DRA – Design Reference Architecture
- EDL – Entry, Descent and Landing
- EMC – Evolvable Mars Campaign
- FREND - Fine Resolution Epithermal Neutron Detector (instrument on the 2016 ExoMars-TGO orbiter)
- HAT – Human Architecture Team
- HLS^2 – Human Landing Site Selection
- ISRU – In Situ Resource Utilization
- LCH_4 – Liquid Methane
- LOX – Liquid Oxygen
- MARSIS - Mars Advanced Radar for Subsurface and Ionosphere Sounding (instrument on the 2003 Mars Express orbiter)
- MAV – Mars Ascent Vehicle
- MRO – Mars Reconnaissance Orbiter
- MSL – Mars Science Laboratory
- NEX-SAG – Next Orbiter Science Analysis Group
- PP – Planetary Protection
- RASSOR – Regolith Advanced Surface Systems Operations Robot
- ROI – Region of Interest
- RSL – Recurring Slope Lineae
- SAM – Sample Analysis at Mars (instrument on the 2011 MSL rover)
- SHARAD – Shallow Subsurface Radar (instrument on the 2005 MRO orbiter)
- TGO – ExoMars Trace Gas Orbiter
- TRL – Technology Readiness Level
- WEH – Water Equivalent Hydrogen

Definitions (terms as used in the context of this study)

- Exploration: As applied to resource deposits, the set of activities that result in the discovery and delineation of reserves.
- Feedstock: The output of one industrial process that is input to another.
- Mining method: The spatial (layout) and temporal (scheduling) sequence of mining activities.
- Resource: (1) Any useful raw material (2) A natural concentration or enrichment of water-bearing material that has the potential to become a proven reserve.
- Processing: Activities related to extracting, refining, and purifying the water from mined ore.
- Production: The combined activities of mining + processing for which the output is a commodity.

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