Notes from the Third Mars Science Laboratory Landing Site Workshop

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Monday, September 15th

Welcome/Introductory Presentations

John Grant

Overview of Process and Goals

- MSL site selection milestones
- We are here to discuss/evaluate the science, engineering constraints will not factored into discussion for site selection
- Each site will be evaluated on the following criteria: diversity, context, habitability and preservation

Mike Meyer

- Thanks for participating in the workshop and thanks to the orbiter teams for making data collection for proposed sites a priority
- Focus on rover's ability to determine/asses the habitability
- This workshop is not a competition; we want to focus on best site to accomplish the goals of the MSL mission

Mike Watkins (MSL Mission Manager)

Site Selection Process and Schedule

- Overview of project status - images of rover assembly, heat shield, payload (most will be delivered to JPL in the next few months), ground system and training
- UHF link analysis improved into a single target spec covering 30N-30S
    - All proposed landing sites are reachable with in-flight retarget beginning at TCM-1 from central launch vehicle target
- Orbiter and atmospheric model data sets ongoing; processing of data sets ongoing
- All sites are landable with > 95% success rate based on current data

Matthew Golombek

Surface Characteristics Supporting Safety Evaluations

- All of the landing sites are viable at this stage based on landing site criteria (including atmospheric properties, radar reflectivity, roughness, topography and slopes, thermal inertia, rock abundance, etc.)
- "Safe havens" for each site have been eliminated

Habitability and Preservation on Earth and Mars Presentations

Moderated by John Grotzinger

- Assuming life occurred on Mars, which of these habitable environments have the best chance of preservation? We want to stack the deck in our favor and pick the best set of circumstances to give us the best chance of finding life on Mars, keeping in mind that it's incredibly difficult to find evidence of early life on Earth.

Roger Buick (Terrestrial field geologist and biologist)
Earth's Earliest Record of Life

- Mars might be a better place to find life signs of early life compared to Earth
- What types of fossil evidence are there? Geologic settings? How can they be preserved or destroyed?
- Types of evidence
    - Microfossils
        - Not diagnostic of biological relationships
        - most are small, simple and typically preserved by rapid entombment
        - On Earth, very susceptible to contamination (although not so much a problem on Mars)
    - Trace Fossils (Stromatolites, oncolites, MISS)
        - Layered sedimentary mounds accreted by microbial growth, movement or metabolism
        - Many abiotic mimics (such as stalagmites) so hard to identify
        - Oncolites – like stromatolites but concentric microbial lamination around a lithic nucleus
    - Biomarker Molecules
        - Hydrocarbon molecules from photosynthetic pigments and membrane rigidifiers (found in oil and kerogen), just (complex) carbon skeleton, destroyed in high temperature environments, easily contaminated
    - Molecular fossils
    - Isotopes (Atomic Fossils)
        - Most robust, not easily altered by high temperature and high pressure (e.g. Methanogenesis (evidence of C-isotope))
        - On Mars, look for sulfate and sulfide minerals
        - Microbial metabolism fractionates are stable isotopes of carbon, sulfur and nitrogen. Much larger than abiotic at low temperature and pressure; survives trauma well
        - Different metabolisms fractionate differently; fractionation range varies according to ecological conditions
    - Bioalteration
        - Occurs mostly in carbonates, also basaltic glass and sedimentary sulfide minerals; occurs where microbes etch or dissolve minerals

        - Need very low metamorphic grade or else destroyed by recrystallization
        - Preserves organics but easily destroyed by metamorphism
        - Only known from aqueous settings (marine, lakes) but not rivers, ephemeral water bodies
        - Largely preserved in reducing environments
    - Biominerals (preserved remains of microbial mineralization), bioalteration (alteration of rocks/minerals that occurs as a result of microbial activity)
        - No record of it from early Earth
- Geological settings on Mars to look for life:
    - Sedimentary rocks (or water-lain tuff, but *not* generally volcanic)
    - Fine-grained sediments, not conglomerates
    - Rapid lithification (evaporates)
    - Carbonates, Sulfate evaporates
    - Long-lived aqueous sediments
    - Reducing environments (oxidation and acidic alteration are bad)
    - Stable tectonic environments
    - Stable tectonic distal settings far from heat and pressure
    - Far from areas of active erosion and ideally want recent exposures
    - Basic geology is well-understood

Questions:
(?) What is the resolution of microscopy?
(Roger Buick) Optical (1/2 micron) microscopy.

(?) What is the difference between biological vs. non-biological alteration?
(Roger Buick) Simple forms of bio-alteration are mimicked by non-bio alteration, which is complicating. Complex burrows that are sinuous and exhibit preferred orientations are indicative of biological alteration, whereas burrows that radiate linearly from a single fracture (e.g. Alan Hills meteorite) are less indicative of biological alteration.

Roger Summons, Organic Geochemist, expert on biomarkers on early Earth
Preservation of Organic Biomarkers on Earth

- What is a biomarker
- Organic rich rocks
    - Organic material can be ephemeral (often eaten, oxidized→ recycled)
    - Organics are often at low concentrations where it's being formed
    - Can be massively concentrated by surface processes
    - Organic material is best preserved when isolated, concentrated and a "tight" association with sedimentary minerals (clays, carbonates, evaporates)
- Organic matter in ancient sediments
    - Poor preservation of rocks presents greatest difficulty on Earth in search for organic matter
    - Destructive processes include geology, ionizing radiation
- Non-biogenic organic matter
    - Ideal reference point is organic matter in meteorites

    - Characterized by simple, “random” chemical structures
- Biogenic Organic Matter
    - Complex structures with very specific patterns (DNA, proteins, cellulose, membrane lipids)
    - Made from simpler building blocks
    - Patterns can be isotopic, chemical, or stereo chemical
        - Patterns in spatial arrangement of C-atoms
        - Patterning is a generic ‘biomarker’
- Abundant oxygen suggests organic matter preservation in continental hydrothermal systems problematic
- If organic matter is preserved on Mars, expect tight association with low temperature, sedimentary minerals – phyllosilicates, evaporates, silica
- On Earth, organic matter is largely concentrated in sediments deposited in aquatic environments

Questions:
(Dave) Patterns can be caused by chemical, not biological activity.
(Roger Summons) Molecular compounds in general often show spatial distributions and relationships that you see can which can tell you what processes are involved. On Mars, if we find diverse molecules, we may not know what type of organisms produced them, but we can look for patterns.

(Jack Mustard) What if there were no photosynthetic processes on Mars?

Nick Tosca
Habitability in Saline Environments on Mars
- Controls on life limitations: temperature, radiation, acidity, temporal availability of water, salinity (water activity)
- Define habitability in an evolutionary context
    - Pre-biotic chemistry and the origin of life
    - Evolution and/or adaptation to changing surface chemistry
- Water is a thermodynamic measure of salinity, the saltier things get, the busier molecules are in organic processes, and less is available to mediate other organic activities (increased salinity means decreased water activity)
- Water activity is a sharp limitation on biologic activity
    - Decreased water activity means decreased organism growth
- Microbial strategies for low aH_20 conditions
- For Martian water, calculate aH_20 at the point of saline mineral precipitation
- Compare water activity on Mars versus seawater: chlorites are bad (at significant low water activity), sulfate vs. chloride are insensitive to So_4/Cl ration of initial water, gypsum & carbonates are insoluble (reflect high H_20)
- Distinction between origination in and adapting to low aH_20; life would have to adapt to salty conditions → window of habitability on Mars was short and happened early, likely between 4.5 and 3.5 billion years ago (high tolerance is evolutionary)

- On local/regional scale: Need favorable pre-biotic chemistry: reducing conditions, mild pH, highest possible aH_20
- Focus on proposed sites that have phyllosilicate and sulfate-rich strata and capture phyllosilicate/sulfate transitions (Gale, S. Meridiani, Miyamoto) for diverse preservation potential

Lisa Pratt, Terrestrial geologist/geochemist – modern, ancient, range of environments
Preservation of Organic Matter in Phyllosilicates

- Clays on Earth
  - In place alteration of parent material
    - Alteration materials: biotic soils, persistent hydrothermal systems, fault gouge
  - Transported sediments
    - Transported sediment: hemi-pelagic and pelagic marine environments, lake, fluvial overband, glacial till, fan-outwash playa, wind blown clay dunes (rare)
- Clay enrichment on Mars
  - Alteration of parent rock: abiotic soils, persistent hydrothermal systems, fault and impact gauge
  - Transported sediment: lake, glacial till, permafrost expulsion (questionable process), fan-outwash playa, wind blown clay dunes (questionable abundance), wind blown fine grained dust (questionable composition)
- Anticipate 120,000 year cycle deposition of organic matter based on obliquity
- Consider orbital and rotational periodicities
  - Obliquity appears to have largest influence on Martian climate
- Shallow-water environments are better for occurrence and preservation of organics
- Very little preserved in open marine settings, more in restricted marine environments (limited amount of oxygen in water), and even more in lacustrine environments
- New target: very low organic contents
- Need to spend more time drilling and investigating

Questions:

(Max) Could you comment on how much is known about preservation regarding specific clay content?
(Lisa Pratt) Even in deeply weathered, tropical soils there's a fair amount of organic matter preserved if we expand analytical methods. Need to flush out relationships between iron-oxides and iron-hydroxides in soils in regards to preservation.

(Bethany Ehlmann) What is the role of minerals in deep-surface environments?
(Lisa Pratt) Look for kind of materials in fault/fracture fluid flow pathways. On earth, where life occurs in the deep subsurface, it's related to water. Very little work has been done on locating organic matter in vein-fills in the deep subsurface.

Alan Howard, Geomorphologist

Geomorphic Criteria for Defining Depositional Setting

- Lacustrine and marine environments are most favorable for hosting and preserving life
- Define Source to Sink: Origin → transport → deposition → diagenesis→ exposure
- The most attractive sites are where we can better constrain the source-to-sink scenario
- Gale, Holden, Eberswalde are basin environments, similar to the Great Basin on Earth, which is well-studied and understood
- Morphology of the Great basin is diverse: lake beds, beach shingles, tuff deposits, alluvial fans, fluvial-dominated fans, debris flows, etc.
- The context of “basin-sites” (Holden, Eberswalde, Holden, Gale) are more well-constrained than the other sites
- Production:
    - What process produced transportable debris?
        - Physical weathering, chemical weathering, impact cratering, volcanics, landslide
- Transport:
    - Fluvial transport, aeolian transport, glaciers, landslides and debris flow, turbidity currents (deep water environment), crater ejecta, volcanism, waves and tides
- Deposition:
    - From fluid traction on bed, suspension, bulk flow (unsorted generally), precipitation from solution
- Diagenesis:
    - Weathering, compaction and cementation, recrystallization, ox and rx reactions
- Exposure:
    - Unmodified, diff. aeolian erosion, faulting/uplift, landslides, cratering, fluid erosion
- Complications:
    - Significant temporal intervals in source to sink steps
    - Steps not mutually exclusive
    - Same geomorphic agent can be involved in more than one step
    - Multiple cycles of transport and deposition
- Caveats:
    - Landing at a site may not provide larger geomorphic context or well-defined age constraints (Meridiani)
    - May be surprised about what we discover about formative environment (Gusev)
- Sites here have differing degrees of interpretability of source to sink context
- Sites with best constraints in relatively closed basin (Holden, Gale, Eberswalde)
    - Greatest diversity of geomorphic environments

- Bonus of enclosed basin sites are fringing alluvial fans (including samples of ancient highlands crust)
    - Informative of hydrologic conditions
    - Fluvially dominated fans have more distinct bedding (vs. debris flow dominated fans)
    - Differing atmospheric chemistry on Mars implies differences in mineral stability and weathering potential

Questions:
(?) Why would channels be raised on the fans?
(Alan Howard) Aeolian erosion stripped finer-grained material that was overlying channels consisting of coarser-grained materials, which are more resistant to erosion.

John Grotzinger
MSL Science Goals and Site Evaluation Criteria

- Habitability: inventory chemical building blocks of life. Investigate chemical, isotopic, mineralogic composition of Martian surface and near-surface geological materials
    - Studies of terrestrial microbes increasingly show the viability of finding habitable environments on Mars (microbes on Earth can live anywhere - varying/extreme temperature, pressure, pH, toxins, saline environments, UV exposure, varying O_2 concentration, deep surface, etc.)
- Diversity: greatest number of possible science objectives
    - Want multiple science targets and styles of stratigraphic expression
    - Want site with both morphologic and mineralogic evidence for past water
    - Diverse hydrated minerals
    - Multiple styles of stratigraphic expression
- Regional context is important to characterize site
- Habitability – want an environment that can support microbial life
    - Presence of H_2O, energy source, carbon (for life as we know it on Earth)
    - Identify a particular geologic environment (or set of environments) that would support microbial life
- Preservation (taphonomy) – applies to organics, trace elements, etc.
    - Some processes are more favorable to biomarkers or fossil preservation (taphonomic window)
    - Taphonomic window is dominated by biogeochemical and thermal processes for microbes
    - Early diagenetic history of clays is critical to their ability to sequester organic substances
    - Even if life is not preserved at specific site, want to at least identify the habitable environment or taphonomic window
- Criteria and examples for defining the diversity, habitability, geologic context and preservation of fossils in rock record

Questions:

(Eldar Noe Dobrea) We might learn something from studying the boundary between wet, ancient Mars and dry, younger Mars (e.g. along the Noachian/Hesperian transition).

(?) We need to remember what the payload can and cannot do.

(Hugh) What is the extent climate change or other processes on Mars might have degraded the preservation on Mars that we don't think about on Earth?
(Dawn Sumner) Mars has better preservation potential compared to Earth because lack of tectonics and dry conditions.

Jeff Bada
Preservation of Organic Matter in Sulfates

- Factors in biomarker preservation on Mars
    - Current environmental conditions are harsh
    - Mineralogical concerns
    - Past environmental conditions
        - Hypersaline water bodies on Mars
        - Evaluation of stability issues with respect to preservation
    - Use amino acids as measure of preservation of Earth
        - Amino acids are ubiquitous in all forms of life
        - Racemize, decarbonxylate and deaminate (these pathways offer age info)
    - General classes of minerals detected on Mars: sulfates, halite, phyllosilicates
- Sulfate and halite are good candidates for preservation
- Phyllosilicates are good for preservation only if they were deposited and preserved in anoxic depositional environment
- Go to a site with more than just phyllosilicates to further preservation potential

Questions:
(?) What about amorphous silica?
(Jeff Bada) Ground-up quartz deposits are the cleanest stuff you can find.

(?) When you converted from Earth temperatures to Mars temperatures, did you use the average temperature or the average effect over Martian temperature ranges?
(Jeff Bada) We used the average temp weighted toward the highest temperature (average exponential temperature). If you argue for higher temperatures, the half-lives would be shorter.

General Discussion of Preservation and Habitability

(John Grotzinger) The most important medium to preserve traces of life are sedimentary rocks. Is the taphonomic window the same for Earth and Mars?

(Max): When we talk about phyllosilicates, we are referring to clay minerals rather than grain size, right?

(Linda) Keep in mind concentration; that's why sedimentary rocks are favorable. The idea of source to sink is important to think about.

(Jen) When looking for organic matter on Mars, we are talking about trace amounts; SAM is designed to look for trace amounts of organics and has multiple capabilities to detect carbon. Are we making a mistake asserting that the terrestrial environments are good analogs for Mars?

(Lisa) In lakes and playas on Mars, we assume that life is photosynthetic. Are we targeting photosynthetic life or non-photosynthetic life (i.e. deep biosphere)? Both are different parts of the system but require investigation. If we assume life on Mars was always in deep subsurface, water on Mars is less of a concern and we would look at fracture/fault dominated environment. Would we be able to see a signal on Mars that's not photosynthetic?

(Jack Mustard to Lisa) What about shallow crustal organic matter? Should we expand the types of environments we are searching for to incorporate non-photosynthetic life?

(John Grotzinger) The profound difference between Earth and Mars is that Mars never developed a photosynthetic system. Which environments would be best if we were only dealing with chemolithoautotrophs or alike?

(Dave) Preservation is important but you have to determine the concentration mechanism.

(John Grotzinger) How well would a deep fracture system be preserved?

(Lisa) At each site, we have to determine the process to sustain metabolism and promote simultaneous mineralization (in regards to life in deep biosphere). Sites with different strata gives multiple chances to examine different depositional environments. Diversity is important. We should favor sites with multiple layers, diverse mineralogy and multiple textures (i.e. edges of alluvial fans).

(Ross Iwrin) Has anyone studied impact craters as depositional environments and hydrothermal systems (with apparent heat source and interaction with groundwater)?

(Dave) Ultramafic rocks in area with sediments (serpentinzation).

(Dave) If a mineral is forming at same time organic matter is produced, preservation is increased. Weathering clays in a wet environment is ideal. We want chemical association between minerals and organics. Cellular preservation occurs because material is entombed by mineral while organic matter is still viable, isolating it from degradation. What is the range of environments that are possible for this scenario?

(Matt Golombek) We don't know whether the phyllosilicates formed in the basin where they are now or whether they were transported there.

(Dave) Source region might offer better preservation than environment where they are transported.

(John) If there were no photoautotrophs on Mars, would lake environments be less favorable for preservation?
(Dave) A lake basin might still be okay if you have reducing power to support organic matter.
(Livio Tornabene) Many of the lakes are in impact basins which might be fed by heat source and groundwater.
(Bethany Ehlmann) Jezero crater is a good preservation environment because it has smectite clays, which were coming from a huge source region where you had phyllosilicates forming in situ.

(Bethany Ehlmann) How come isotopic signatures maintain signatures of organic matter?
(Roger Buick) Isotopic signatures are more robust to high temperature and pressure but this may not apply to Mars. You can use a range of different isotopes that are preserved in range of sedimentary environments and minerals that represent chemo-, hetero-, and autotrophs. So, isotope signatures are powerful if you're just looking for organics. To find something specific, you need to have more specific conditions.

Miyamoto Crater Presentations

Horton Newsom
Overview of the Miyamoto Crater Floor Landing Site

- Well-established geologic history and context
- ~150 km diameter crater
- Stratigraphy and lithology similar to major units seen at Mawrth and Isidis basin margin
- Diversity of Materials
    - Phyllosilicates (sometimes in association with layers), chloride
- Organic preservation potential
    - Cemented inverted channel deposits (silica and other cements) and basal unit sediments with phyllosilicates
- Evidence of habitable environments
    - Analogous to Green River channels in Utah
    - Early fluvial episode; alteration of basal unit by aqueous processes
    - Major fluvial erosion episode forming regional valley networks
- Crater and valley networks early to mid-Noachian
- Deposits in ellipse probably late Noachian
- Variations in thermal inertia are consistent with geologic units and mineralogical diversity (not just grain size)
- Not significant dust cover
- At least two major units in landing site
- Mafic/silica/anhydrous-sulfate phases

- Stratigraphy:
    - Hematite bearing plains unit
    - Basin interior fill
    - Early basin fill (phyllosilicates)
    - Basement
- Landing site is classic truncated basin margin exposure
- Preservation potential:
    - Cementation of channel deposits that form capping unit
    - Phyllosilicate basal layer
    - Silica and other cements have high organic preservation potential

Questions:
(?) Could you expand on the mineralogy of the cementation/capping material?
(Horton) In the Utah channels, the cementing agent was silica, and we think that's a reasonable analogue for the cementing agent in Miyamoto based on orbital spectral data.

Josh Banfield
THEMIS and TES analysis of Miyamoto crater

- Data products
    - THEMIS spectral unit maps, TES and THEMIS surface emissivity maps and other data products here: http://faculty.washington.edu/joshband/cdp
- THEMIS and TES are sensitive to bulk minerals whereas NIR is more sensitive to significant components.
- Miyamoto
    - All surfaces have significant plagioclase and pyroxene (~20-40%)
    - Olivine and sulfates/high Silica phases are inversely correlated
        - Consistent with variable aqueous alteration
        - Sulfate detection is questionable, but not unreasonable
        - Ellipse is similar to olivine basalt 1 (plagioclase, pyroxene, olivine, sulfates, high silica phases)
    - Significant hematite concentrations 20-30 km east of landing ellipse
    - Dust is not significant throughout the region
    - Slope spectral unit has similar spectral, morphological and thermophysical properties as putative chlorides of *Osterloo et al.,* 2008 (located ~40 km to the west of the ellipse)

Sandra Wiseman
CRISM Analysis of Miyamoto Crater

- Phyllosilicates (Fe/Mg smectites) are present and appear to be the oldest exposed material and have good preservation potential
- No distinct signals for hydrated sulfates

Questions:

(?) What was interpreted at fluvial deposits is different than the clay signature. Don't know anything about deposition environment of clay material.

(Sandra Wiseman) Phyllosilicate signature does not correspond to the layers within the inverted channels.

(?) Do you see evidence of sulfates in the ellipse?
(Sandra Wiseman) No.

(?) How many other locations in index map yield that quality of phyllosilicate spectra? How much of the exposure has that degree of the robustness within the spectra?
(Sandra Wiseman) Almost everything in the D2300 index is a hydrated mineral.

Livio Tornabene
Impact origin for hydrous silicates on Mars

- Multiple geologic settings/mechanisms for phyllosilicate-bearing minerals
- Phyllosilicates are abundant in terrestrial impact sites and mineral assemblages match what we see on Mars, making origin of these minerals by impact a viable solution, especially given that we are dealing with the Noachian and the period of heavy bombardment
    - Do phyllosilicates mean abundant long term water?
    - It is possible to form such hydrous phases under transient water conditions?
- Impact structure hydrothermal alteration – devitrification may account for more than 50% of the clays on Mars (mostly smectites clays)
    - Clays are very common (particularly Fe-Mg smectites) in impactites recovered from terrestrial impact structures and especially within melt-bearing impactites (interior and exterior)
- Terrestrial impactite phyllosilicates formed predominantly by:
    - Hydrothermal (post impact fluids and heat)
    - Devitrification (direct, solid-state transformation; unstable hydrous melt/glass transformed by their composition and water content)
    - Does not require post-impact water-rock interaction to form clays
- Hydrothermal clays can be distinguished from devitrified clays:
    - In veins and has open space-filling textures
    - Clays more homogeneous in composition
- Devitrification could be more prevalent than hydrothermal as a clay-forming mechanism with respect to large impacts into volatile-rich targets
- Hydrous silicate impact melts on Mars?
    - Large and numerous impacts + volatile-rich crust = hydrated silicates
- Melt-rich ejecta associated with large-scale impact basins (e.g., Hellas, Isidis)
- Habitability:
    - Hydrothermal oasis, up to 10^5 years for large craters
    - Impacts also increase rock porosity and fracturing for cryptoendolithic habitats
    - Preservation and transfer of organic signatures to impactite
- *Martian hydrated silicates do not necessarily require long term water*

Questions:

(Scott) How important is the process relative to other processes where you get phyllosilicates? What about the northern hemisphere/polar? How do you explain intricate layering (e.g. Mawrth) where you have Iron/Magnesium silicates?
(Livio Tornabene) Dust, surface deposits and lack of outcrops in northern hemisphere are limiting. Erosion and transport of ejecta into layers. Most ejecta on Mars is layered; ejecta is not as chaotic as you think.

Discussion of Miyamoto Crater

(Jim) Please summarize units in the ellipse and their origins.
(Horton) There are two units within the ellipse. The basal, phyllosilicate bearing unit with polygonal fracturing and some layering and an overlying complex capping unit wht inverted channel deposits. The hypothesis for the basal unit is sedimentary basin fill, perhaps deposited by large river systems that flowed through crater. The hypothesis for the capping unit is cemented channel deposits. Cannot readily distinguish the depositional setting/origin of the basal unit.

(John Grant) What can you say about the deposition of the layered material? Can you say anything about the nature of the material (sedimentary, volcanic, etc.)?
(Horton)The location on the floor of a large crater which is part of this large channel system. The nature of the material is uncertain, but it is layered, phyllosilicate-bearing.

(John Grant) In terms of the material on top of the basal unit, how do you know if they are inverted channels rather than ridges that could form by another process? Why do you favor fluvial origin? Do channels flow across gradient?
(Horton) The aspect ratio of the ridges/channels is indicative of fluvial origin. No evidence of lobate forms that would be indicative of lava channels/volcanic origin. Channels generally flow down to crater center. If channels are cemented, organics could be trapped in there (question about ability for channel to preserve habitable environment because coarse grained material is generally associated with channel floors).We only have MOLA data at this point so topography is not well constrained (waiting for HiRISE DEM).

(?) What did you mean by aspect ratio? Can you access ridges with the rover? Did you imply that ridges were good for habitability and preservation; channel fills tend to be coarse materials.
(Horton) Aspect ratio is channel width/length. Organic matter can be trapped within cementing agents that form these resistant channels. There should be plenty of places where the rover can assess the channels; access shouldn’t be a problem because capping material is throughout the ellipse.

(Eldar Noe Dobrea) How unique is sulfate in the TES detections? Can you use a different mineral and still get similar results?
(Josh Banfield) You can use other minerals and they are not equally good, but still pretty good. Dark soils come up with ~10% sulfates but there isn’t a unique spot with increased sulfate minerals.

(Eldar Noe Dobrea) Is the only thing we are seeing unambiguously the Iron/Magnesium smectite clays?
(Sandra Wiseman) Yes, I would agree with that.

(Linda Kah) If you have a network of inverted channels, what can you say about the preservation of organic matter in the underlying phyllosilicate layers assuming that water would likely percolate through the cap unit? Could the phyllosilicates be entirely diagenetic?
(Horton) Yes, it is possible that the phyllosilicates are diagenetic.

(Alfred McEwen) Have you thought about a rover traverse?
(Horton) Not really, because everything of interest is spread throughout the ellipse, so there are lots of different scenarios depending on the length of the mission.

(?) Grain size analysis of sandstone?
(Horton) Lots more to do to look into this.

(John Grant) Can you say anything diagnostic about the setting responsible for the phyllosilicates and the ridge systems?
(Horton) No, we need HiRISE digital elevation models before we can do that.

(Alan Howard) The broadly meandering aspect of the ridges appears fluvial. Look for branching indicative of tributaries.
(Ken Tanaka) There are other ways to get ridges/channels. Debris flows or aeolian fill could have been deposited in pre-existing fluvial forms but the fill is much younger.

(Horton) The deposits are located on the flat crater floor so water forming these channels is consistent with fluvial. The other issue is relative uniformity of capping materials.

(Steve) In the site evaluation process, do we consider go-to versus non go-to as a selling point or not?
(Matt Golombek) Don't know how to evaluate that from an engineering stand point so we don't have a cost-benefit analysis.
(Mike Watkins) A good day would be several hundreds of meters in flat terrain if we have good MRO data in front of us; a bad day would be tens of meters. Still a cost-benefit analysis to ask whether it is worth giving up 20 days of science for the go-to sites.

(Michelle) There's no way to know whether minerals in channel deposits trapped active organic matter.
(Horton) Evidence for location of fluvial deposit would suggest that this is a reasonable possibility.

(Dawn Sumner) Keep in mind that we are biased by the preservation of organic matter is fluvial channels by having an anoxic environment.

(Joe Michalski) If we had HiRISE data prior to the MER mission, how would that have impacted mobility and mission operations?
(Matt Golombek) If we had HiRISE coverage, Opportunity likely wouldn't have gotten stuck in purgatory dune; we were navigating from MOC NA images so we didn't know exactly where we were at any given time. With HiRISE coverage, we would have been able to tell exactly which ripple or trough we were in. We would have been more efficient but would not have gone wildly father in traverses.

(Linda Kah) What is the observable stratigraphic thickness of the layered phyllosilicates?
(Horton) Minimum thickness of 20-30 meters

(Robin) Two of seven sites are close to Meridiani. What's more important? How are we supposed to weigh the pros and cons of understanding one location well or investigating different places on Mars?
(Golombek) Yes!

(Dave) Do the phyllosilicates post-date Miyamoto? What ways do you think Miyamoto can constrain phyllosilicates we see elsewhere on the planet? Also, if the phyllosilicates fill the crater, you can constrain the thickness of the deposit.
(Horton) We are pretty certain it's younger than ancient crust and older than the Meridiani plains units in terms of geological story. Consistent with huge fluvial event.

(John Grotzinger) Do we know if the materials on the western edge are overlain by the materials to the east?
(Horton) We see overlapping edge of basin fill materials extending out. Also, trough that runs to east is the extension of a huge fluvial system that drains toward Meridiani chaos. We don't know how far west the Meridiani material extends, but we see an eroded edge of the material.

(Michelle) How well do you know age range of units in this area?
(Bryan Hynek) Valley networks to the south are late Noachian and possibly reactivated at Noachian/Hesperian boundary. Hematite stack came after that. Maximum age is late Noachian for most materials. Phyllosilicates are coeval with these materials.

(Ken Edgett) I'm concerned about missing story stratigraphically. Also, no one has mentioned the lava flows? Don't see a geomorphic connection between channel going into and out of Miyamoto.
(Horton) The fluvial system that drained this area is very old. And I've never seen a lava flow.
(Ken Edgett) I emailed you months ago with images of the lava flows.

South Meridiani Presentations

Sandra Wiseman and Ray Arvidson

South Meridiani: Phyllosilicate / Sulfate-Hematite Contact

- Ellipse within same geologic unit as area explored by Opportunity rover (which is ~75 km to north)
- In place Noachian phyllosilicates exposures
- Middle to late Noachian fluvial dissection
- Noachian/Hesperian contact
- Ellipse has ~200 m elevation difference, with regional tilt down to north (allowing more basal unit explored here than where Opportunity landed)
- THEMIS analysis: olivine basalt unit extensive through the area (though more variation and strength), higher concentration within crater. Lower concentration of basalt = higher concentration of hematite
- TES analysis: shows similar data to THEMIS; olivine, sulfates, high-silica phases are present at lower levels, spectrally similar to what Opportunity investigated at Meridiani
- CRISM: spectra is dominated by Fe 3+, landing ellipse from CRISM perspective is poor. Meanwhile outside the ellipse shows aluminum phyllosilicates, iron/magnesium phyllosilicates and some other hydrated phases
- Geological context
    - Noachian: phyllosilicate alteration and deposition from unknown origin (alteration of Noachian crust, sedimentary deposits, impact related?)
    - Unconformity
    - Middle to late Noachian: period of fluvial erosion, dissects phyllosilicates
    - Late Noachian to Early Hesperian: accumulation of sulfate-rich sediments
- Benefits: Intact Noachian/Hesperian contact, older Noachian basement and younger sedimentary, sulfate-rich rocks
    - Only one direction to traverse (south)
- 3 phase mission
    - (1) Plains unit, more basal strata near unit margin, evaporitic environment - potentially a good preservation potential
    - (2) Noachian/Hesperian contact
        - Traverse south to fluvial dissection
    - (3) Noachian phyllosilicates (Diverse: Kaolinite, Montmorillonite, Iron/Magnesium smectites, Al-rich phyllosilicates)
        - Compositional stratification
        - Test formation hypotheses
        - Preservation potential is good

Questions:

(Ken Edgett) What are the chances that rocks are part of ejecta from Miyamoto rather than something deposited above/below deposits given its proximity to Miyamoto?

(Sandra Wiseman) Don’t see positive evidence for ejecta but it cannot be ruled out.

(Ken Edgett) Somewhere in the fluvial dissection, you would imagine you would see ejecta from Miyamoto unless it was entirely removed before the dissection.
(Sandra Wiseman) Not all light-toned layers exhibit evidence of phyllosilicates.
(Livio Tornabene) Ejecta from Miyamoto might still be in the subsurface. Preservation is complicated by other impacts so there's a very good chance that Miyamoto ejecta is preserved.
(Horton) You would expect hydrothermal alteration of materials around Miyamoto rim. Association of formation of Miyamoto crater would be interesting. Need CRISM data of Miyamoto rim for comparison.
(Sandra Wiseman) Looked at all CRISM data in a large area around this site and this is the first Al-rich phyllosilicate signature with the exception of one deposit 20 km away. Most are Iron/Magnesium smectites.

(Linda Kah) You showed mounds with different phyllosilicates signatures but you said something about concentration of signatures in different stratigraphic layers.
(Sandra Wiseman) That's a difficult question. Upper layer may have been draped on pre-existing topography. Red material (in CRISM spectra) is associated with the upper layer and is always stratigraphically above green material. In HiRISE, green material (in CRISM) might also be at distinct horizon. Not sure about other materials. The differences could be related to different mineral assemblages or differences in water chemistry through horizons.

(Horton) Materials you see could be associated with the formation of Miyamoto (which would be expected for a 150 km diameter). You should expect massive melting and hydrothermal processes affecting rim of crater. Also, might expect hot-spring type deposits, but most likely large valley network post-dated formation of Miyamoto.

(Linda Kah) Is there morphological evidence for hot springs?
(Horton) No, it's heavily eroded, so mineralogical signatures would be the only evidence preserved.

D. Fernández Remolar
Chances of Finding Preserved Biological Information at South Meridiani

- Early and late Noachian to Hesperian
- South Meridiani good for preservation of organic matter based on mineral assemblage: phyllosilicates, chlorides and other evaporates
- Phyllosilicates in early materials, acidic sulfates in aeolian-derived deposits and Fe-oxides
- Records at least one major paleoenvironmental event:
    - Mildly acidic to neutral
    - Strongly acidic
    - Formation of ferric oxides?
- Potentially records Mars biosphere from very early ages and going through a late Noachian acidic event
    - Boundary between phyllosilicates and acidic units
    - May record different preservation stages

- Phyllosilicates good for preservation, but likely affected by acidic event → could have been exposed to acid leaching which would have destroyed organics at surface
- Acidic sulfates:
  - Maintain structures and organics (gypsum and jarosite resistant to late stage dissolution events and preserve organics over time, respectively)
  - Salts can trap dormant microbes
  - Some can form under microbial mediation
- Iron oxides:
  - Highly resistant to physical and chemical weathering
  - Preserves structures well
  - Can preserve organics <u>but</u>: thermodynamically unstable and microbes can madurate/destroy organics
- Carbonates normally occur as precipitate mediated by microbes

Discussion of South Meridiani

(Horton) Sandra Wiseman, can you comment more on the diversity and nature of layering within the plains? In MOC images, I interpreted them as shorelines. Do you have evidence that those are exposed stratigraphically?
(Sandra Wiseman) Geomorphically, they look like discrete layers but it's not obvious in CRISM. The CRISM signature is dominated by bedrock and sand sheets.

(Horton) What do you see with CRISM at the contact between the basement materials?
(Sandra Wiseman) There is lots of dark mantling material which makes it difficult to see anything in CRISM. All the HiRISE coverage is in actual ellipse, not outside of ellipse along this contact.

(Michelle) Is there an assumption that this is a transition between the Noachian to the Hesperian?
(Sandra Wiseman) The phyllosilicate-bearing terrain pre-dates the fluvial dissection. The Late Noachian/early Hesperian unit is younger than the fluvial dissection.

(Ashwin Vasavada) What are the chances of understanding the environmental change along the boundary as opposed to observing the before and after?
(Ken Edgett) There's no guarantee that the plains that the Opportunity rover has investigated are Hesperian due to burial and exhumation. The rock that forms the Meridiani plains embays phyllosilicate-bearing rock, making the phyllosilicate-bearing rock older. This represents an unconformity, which is also covered by a mantle, so the transition might not be observable.

(Ashwin Vasavada So, what does that tell you about the value of stating that it's a scientific goal for this site?
(Ken Edgett) The benefit of this site is that you go to a different stratigraphic layer within a sequence we've already studied with the Opportunity rover with a different payload and a pre-existing set of questions.

(Roger Buick) There can still be weathering that records the history of the upper part of the lower unit in an unconformity. So, there's a possibility of getting into that gap; even though it's an unconformity, the history is not all missing. If it's sub-aerial you're titrating the rock with the atmosphere. Sub-aqueous, titrating dissolved gases. So either way you record something interesting and possibly biologically significant.

(?) Is it possible to record some lithological terminology in these rocks? "Phyllosilicate-bearing" is such an opaque term that I can't make out what it really is.
(Sandra Wiseman) With CRISM, we can detect iron, bound water, sulfates. If you have quartz and phyllosilicates, you can only detect phyllosilicates. Neutral components contribute to the spectrum but don't change it much. We can't say anything about the *abundance* of minerals. Phyllosilicate-bearing is the term used because there might be materials in there that we are not detecting. Unless it's hydrated, hydroxillated or contains iron, we can't be more specific.

(Alan Howard) This site is a type example where we have an intriguing spectral signature but no "source to sink" context. We run the risk of not learning much because the context is lacking.
(Eldar) This site clearly has great diversity but there's no context for phyllosilicates. If the stratigraphy isn't obvious, it will be based on assumptions/interpretations and we'll be in the same situation as the Spirit rover in Columbia Hills.
(Sandra Wiseman) The diversity is on a small scale relative to size of a CRISM pixel. It's difficult to assign specific unit in HiRISE to CRISM observation due to differences in resolution.

(?) If you found a specific pattern of textural features in the HiRISE data that correlates to a phyllosilicate signature, we would navigate that once on the ground.
(Horton) We would know within 20 m where the phyllosilicate signature is.
(Sandra Wiseman) There are materials that do not exhibit phyllosilicate signature in CRISM. The material that erodes to form the knobs, from a CRISM perspective, is dominated by a ferric signature. Most of the polygonal fracturing in general correlates with phyllosilicate detections.

(Ross Irwin) South Meridiani lacks depositional and geomorphic context, making this site less favorable.

(David?) Maybe best site for phyllosilicates is the one that offers the most vertical relief to begin to understand context.

(Matt Golombek) This site has both phyllosilicates and sulfates, which makes it incredibly attractive, but the context and origin are uncertain.

(John Grotzinger) How much stratigraphy could you do if you landed here? How much vertical section of sulfates would you have access to here?

(Sandra Wiseman) Don't know pre-existing topography that the Meridiani plains are overlying. As you get to the margin of the unit it's hard to tell the thickness of the deposits.

(John Grant) In one spot you might get 20-30 m of section from the largest impact crater south of the landing ellipse.

(John Grant) Going beyond payload with MER, how is this the best site for MSL?
(David) You could argue that the sulfates were deposited in situ, and the phyllosilicates were likely altered there. Maybe that's the best way to distinguish between sites, whether the minerals formed in situ or were transported to their current location.

(Jack Mustard) Exposure is good. How would Meridiani as an aeolian and groundwater system rank in terms of preservation?
(John Grotzinger) Sulfates can be good for preservation, but the concentration of the brine might not be good for habitability. If we get into complex terrains that are interesting (trace-element enrichment) but you find something different as you drive from rock to rock, it's hard to make sense of everything until you're done collecting data.

(Matt Golombek) Rovers are not good at regionally mapping out a unit. Haven't been able to do that with MER and doubt it's possible with MSL.

Tuesday, September 16th

Nili Fossae Trough Presentations

J. Mustard
Introduction to the Nili Trough Landing Site

- Persistently wet for a long period of time, preserved by geomorphic and mineralogic evidence
- Need to consider whether Mars never developed photosynthetic organic matter
- Regional Geology and Fluvial/Alluvial Events
- Habitability and potential for preservation

N. Mangold
Geologic Setting, Context

- Three units: Clay-rich basement (strongly altered), Olivine-rich unit (partial alteration), Nili Fossae lava flows at top (no alteration)
- Crater ejecta (inside ellipse) and some sapping-like valleys and fans (outside ellipse) are younger than the Nili Fossae lava flows
- Fans inside crater with hydrated ejecta
    - Sapping-like valley inside Nili floor (fan)
        - Late stage, more recent landforms
        - Slight hydration compared to bedrock of fan at outlet of sapping-like valley

        - Valleys cut olivine-rich layer
- Also sinuous valleys with fans (Jezero)
    - Jezero fan <100 m thick (average)
        - At least 10 times less than what valley should output
        - Jezero fan can't remove all the material from the valley
        - Last stage of activity (Jezero fan)
- Late fans uncertain to be related to any alteration but they suggest episodes of stable liquid water at surface
- Upper valleys and fan are possible relics from a climactic optimum (long history related to alteration of bedrock?)
- Sinuous valley system to the east (>300 m deep) and Jezero fans to southeast of landing ellipse formed after Olivine-rich unit and Nili Fossae lava flows

Bethany Ehlmann

Mineralogy of Nili Fossae Region

- At least three periods of sustained water-rock interactions
- Trough cuts through low calcium pyroxene (LCP) lava but is partially filled by high calcium pyroxene (HCP) dominated lava
    - LCP around trough and northern part
    - HCP covers southern area
- Very large concentration of olivine in this region
    - Pre-date the Fossae
- Secondary mineralogy: Fe/Mg smectites
- Also have kaolinite, illite/muscovite, chlorite, carbonate in region
    - 3 provinces of alteration
- Small occurrences of Mg-rich carbonate (altered under neutral to high pH conditions)
    - Requires lots of olivine and extensive interaction with water
- Cap unit is spectrally bland, likely mafic with small amounts of pyroxene
- Kaolinite-smectite on top of Iron/Magnesium smectite in Nili Fossae wall, light-toned layers, likely sedimentary (?)
    - Fe/Mg smectites→hydrated unit→kaolinite
        - Smectites have great layering in central peak of large crater to the north of the landing sites
    - Kaolinite layer caps both in-situ and transported smectites
- Two potential geologic histories - subsurface (hydrothermal or serpentization) vs. surface alteration
- For MSL:
    - In-situ smectites and kaolinite
    - Breccia blocks
    - Context: stratigraphy is distinguishable
    - Habitability: persistently wet and well exposed, neutral to high pH aqueous environment

Josh Banfield

TES and THEMIS Mineralogical perspective on Nili Trough Region and Landing Site

- Two units with compositions similar to basalt identified in TES/TEHMIS data (significant plagioclase, pyroxene, less high-silica phases)
- Olivine and pyroxene are inversely correlated with high silica phases (variable alteration?)
- Upper limit of phyllosilicate abundance is 10-20% (can be much higher if present as lose, fine particles)
- Ratio spectrum has strong 465 cm-1 feature but smectites doublet is absent
    - Only one "detection" using rations and indices leads to false positive due to CO_2
- Similar to Mawrth Vallis

J. Mustard
Mineralogic and Morphologic Diversity in Nili Trough

- Multiple, distinct habitable environments
    - Noachian phyllosilicates
    - Hydrothermal
    - Sedimentary units (alluvial/fluvial, infill of trough through sapping units, regionally layered units)
    - Subsurface groundwater or shallow crustal environment (habitability, abundant chemical energy sources for non-photosynthetic planet)
- Impact processes: superbly exposed ejecta from 65 km Hargraves crater
- Composition and character of ancient, unaltered crust
- Isidis basin and Syrtis lavas are major time-stratigraphy markers
    - Significant gradation between Isidis basin formation and Syrtis lava emplacement
    - Clearly defined wet periods
- Geologic context for understanding the interaction of water is well preserved and exposed
- Widespread gradation by alluvial and fluvial processes has filled topographic lows
- Go back in time when looking at breccia blocks
- Examine fractures, conduits for flow, mineralization
- Nili Fossae trough presents a diverse suite of goals and multiple scientific targets that mitigates risk
- Science in the landing ellipse: predominantly phyllosilicate rich ejecta from Hargraves crater (about 200 m thick on trough floor), Hesperian lava flows, diverse lithologies (including kaolinite), ridges (mineralized fracture zones or dikes?)

David Des Marais
Potential Habitability and Biosignature Preservation at the Nili Trough Site

- Need energy and water to find life; organic matter on earth found in subsurface environments
- Oxidation/reduction reactions can sustain life, even without photosynthesis (and without O_2)

- Nili Fossae has mafic source rock and altered product (energy source?)
- Near surface deposits consistent with widespread evidence of persistent near-subsurface aqueous environments
    - Consistent with confluence of long-term regional drainage
- Protection from destructive agents is critical
    - Organisms, thermal, oxidation, etc.
- Preservation enhancers:
    - Reducing conditions
    - Sequestration in phyllosilicates, silica, evaporites, carbonates, etc.
    - Burial (in near-subsurface to start with)
- Duration of habitable conditions – fluvio/alluvial and near subsurface alteration
- At Nili: Mafic source rock and altered product (great potential for preservation of organic matter), diversity of minerals, fractures give potential of mineralization, relatively unaltered by weathering, sustained water-rock interactions, accessible terrain, exhumed subsurface deposits

Nili Fossae Discussion

(?) The mineralogy and interesting relationships seem to be far from landing ellipse. How can we test the things within 1-2 landing ellipse when it's mostly ejecta which isn't as compelling as the in situ observations?
(Jack Mustard) It is ~10 km from center of ellipse to edge. The Hargraves ejecta is diverse, and may allow access to potential impact melts that contain aspects of environments in which they were emplaced. Preservation of organic matter in impact melt is a possibility. It's not until you get to the edge of the ellipse that you access other geology, but the additional science is just at the edge of the ellipse.

(Livio Tornabene) I wouldn't consider ejecta as "float," because we know exactly where it comes from.

(?) The point is that you're sampling ejecta rather than outcrop.

(Dawn Sumner) You can tell the source of impact breccia. On early earth, we are not sure when photosynthesis evolved, but prior to that, chemolithoautotrophs were also likely at the surface due to local gradients. In the deep surface, where the gradients are between water and rock, it's more difficult to identify. Organic matter in basalt is very small and independent of photosynthesis. Very high resolution images are necessary to confirm whether they are growing or not. An example of mixing subsurface and surface environments would be where bacteria is growing into pillow basalts. This also occurs on a micron scale and would be unobservable with the MSL payload. I'm worried about testing subsurface biosphere on Mars with the MSL payload.

(Jack Mustard) We don't understand a lot of the parts of the system.

(Dave D) This site offers a spectrum of access from the subsurface to the surface.

(?) Could you speculate on how much organic matter you might expect to find? How much total organic carbon (TOC)? Is that accessible by MSL?
(Dave D) Energy source rate and rate of sequestration. In terrestrial surface environments, it's about the rate of sequestration? In a fracture fill populated at margin, you could have high, local concentrations.
(?) The concentration of total organic carbon in fracture fills in a glacial environment is high.
(Jack Mustard) If you average the total organic carbon, the concentration will be small, but in local environments the TOC is higher.

(John Grotzinger) Which environments where the organic matter is trivially present do you have the best potential of preservation?

(Linda Kah) Alteration fronts are favorable but the brecciated bedrock doesn't offer a contextual relationship; you're missing the geochemical pathway that you would take. Hard to say what fluid pathways may have been due to missing sequential relationships. There is good evidence for sustained water activity but that might also hurt preservation potential. How can you distinguish clays that are with the package? Are we going to be able to recognize that or are we not going to be able to say anything about the chemistry?

(Dave D.) If you want high temperature processes down to ambient, this is the place to go.

(Jack Mustard) With the array of morphologic features and mineralogic context you have a site that offers strategic decisions on how to employ the MSL assets.

(?) The assemblage plays an important role. From the CheMin point of view, the bland cap rock seems like olivine plus volcanic glass.

(Livio Tornabene) CRISM can't see plagioclase but you see pyroxene, olivine.

(Dave) Just getting the full mineralogy of the sample will give you a lot.

(Ross Irwin) There is clear evidence of wetness but no convincing evidence of "sustained" wetness (e.g. flooding). Fluvial landforms are poorly developed relative to other places on Mars. The phyllosilicate-bearing unit is old, predating the Isidis basin impact, and what is the potential diagenesis?
(Jack Mustard) That's true for every site but we can connect the dots from source to sink.
(Livio Tornabene) If the phyllosilicate-bearing materials are basin ejecta…
(Jack Mustard) We are outside the transient crater of Isidis. Therefore you're in the zone of ejecta accumulation, likely a kilometer. The megabreccias that we see there is likely from Isidis. This is a very well-exposed example of the Noachian crust. To get at the origin of the phyllosilicates, the phyllosilicates were formed during the early period and the crust is deeply weathered. Great opportunity to figure out the process of

phyllosilicate formation. Where we see phyllosilicates and stratigraphy, we can figure out the transport.

(Bethany Ehlmann) In response to the wetness question, the mineralogy is evidence of sustained wetness. The fact that we have well-developed clays implies 10^4 years of water interacting with these materials. Also episodes of fluvial transport resulting in channel development and the excavation of material. Lastly, kaolinite is evidence for third period of alteration.

(Dawn Sumner) All the proposed sites have evidence of water, and water plus rock yields a chemical gradient. What specific things can we see that MSL can test? When you have a transport system of materials, you end up with a sequence of events through time that refine your time scale than something like the alteration of clays of old rocks. On earth, we don't know when alteration occurred, how quickly it formed, or number of episodes, even if you have an altered unit under a capping basalt - we argue all the time about role of groundwater versus surface alteration. With this site, besides getting the mineralogical context, it's unclear how to assess habitability. I'm not seeing the connection between what MSL can observe and refining habitability. What observations can you make on the old, clay-bearing crust that can tell you about habitability? At Miyamoto, I'm not sure; I haven't looked at the data enough. At Eberswalde, MSL can look at sedimentary structures (aeolian, volcanic sediments), mineralogy, variation of different environments. We want features in the rock beyond mineralogy that can tell you something about habitability. The crystallinity in the clays can tell you something about temperature.

(Jack Mustard) The fractures - look for morphology and alteration fronts. In the Nili Trough, there are also fluvially transported environments. There are multiple habitats for investigation.
(Dawn Sumner) We need to know the spatial scale.

(Roger Buick) How do you know the "mineralized fracture zones" aren't dikes (which are uninhabitable) or Neptunian dikes (remobilized and filled from above) rather than evidence for a hydrothermal system which would be indicative of subsurface environment?

(Jack Mustard) I don't know the origin of the fractures, these are hypotheses. There area lot of unanswered questions at all the proposed sites.

(John Grotzinger) Can you point to mineralized dikes? Other sites point to a delta.
(Livio Tornabene) HiRISE can't do it.
(Alfred) You can put together a story but lots of work needs to be done.
(Livio Tornabene) But given the geologic setting, you would expect an array of these features.
(Bethany) The fractures don't cut through many of the units; they are restricted to the lower unit. That doesn't rule out the possibility that they could have been dikes that were intruded prior to the emplacement of the upper units.

(Linda Kah) I've looked at carbonate weathering in basaltic caps and fractures and you don't see anything that hints at organic carbon within fractures of weathering profiles. If you move into the bake zone, you lose all signatures.

(?) When I hear the term "sustained water," I think of aqueous environments. What we don't have at this site is evidence of lacustrine or marine environments, which is where we get preservation of fossils and rapid burial. That's a problem with using fluvial/alluvial environment when looking for habitability.

(Jack Mustard) This is not a lacustrine site. There hasn't been enough conversation or experts to discuss the possibility of preservation in habitable environments that weren't lacustrine. We need perspective in a crustal biosphere; what was the potential for habitability there?

(Livio Tornabene) We don't know how long a lacustrine environment on Mars lasts.

(Pan Conrad) On Earth, when you have organic matter living in cracks, they have to get there and survive from somewhere else. Even at lost city, when you're in the submarine and looking for the hydrothermal vent, you can't see it until you're almost on top of it. The robust bioshere around the vent is *at* the vent. The surface of Mars is like a nuclear reactor. You can't help but think that you need standing water and slow depositional regime, protected from the radiation environment so that you can egress from the old to new environment and preserve those signatures. Need to keep balance of preservation and radiation in mind when assessing sites.

Holden Crater Presentations

John Grant
The Depositional Setting in Holden Crater

- Holden is a Noachian crater, and cuts Uzboi-Ladon-Moravo (ULM) system
- Uzboi breach that exposed deposits is late Noachian
- Formation of crater excavated materials underneath in basin
- 154 km diameter crater
- Layered and fan deposits
- Uzboi discharge eroded pre-existing deposits, emplaced fans/layers
- Deposits attributed to water, ice, wind, alluvial/lacustrine
- Some structural deformation of beds after emplacement (fractures in crater floor)
- Distal alluvial and lacustrine depositional setting
- Diverse units: light-toned layered deposits, dark capping material, mega-breccia (basement)
    - Megabreccia observed in crater walls, occur as distinct 'clasts', some stand in positive relief, locally associate with 'veins', diverse, some light-toned clasts
- Ancient aqueous settings
    - Bajada surface in landing ellipse; includes low-relief, inverted channels

- Three members of lower unit, all bedded with phyllosilicate signature, consistent with long-lived lacustrine or distal alluvial deposition in Noachian
    - Beds are at relatively constant elevation and are laterally continuous
    - ~5 to 10 meter relief over length scales of kilometers (not completely flat)
    - No truncations in bedding
    - Although not totally flat, could be draped or affected by fractures to the southeast (doesn't preclude lacustrine environment)
- Lower units exposed by discharge from Uzboi Valles that eroded materials
    - Multiple Uzboi breaches erode and bury lower unit. Fan deposits radiate from rim breach
- Upper unit – brecciated, giant current ripples (aqueous discharge), alluvial/lacustrine in Noachian, shorter lived, high-energy
    - Forms cliffs
    - Retains craters, but buried by aeolian ripples
    - Displays horizontal/inclined bedding
    - Entrains blocks of underlying deposits
    - Upper unit proximal beds truncate and low angles and grade to parallel beds distally and up-section
    - No large scale aeolian cross beds
    - Implies short-lived, smaller secondary lake phase

(?) Do you see gravel in the mega ripples?
(John Grant) We do see meter-scale blocks in megaripples at HiRISE scale, suggesting coarse-grained material was incorporated.

(Oded) There are errors in DEM that may affect horizontality of layers.

Ross Irwin
Notional Traverses and Science Targets in Holden Crater

- Targets:
    - Alluvial fans (closest) – priority 2
    - Light-toned layered deposits (11.5 km away) – priority 1
    - Uzboi flood deposits (18 km) – priority 3
    - Bedrock outcrop (26 km) – priority 4
- Clear context:
    - Examine lithology of alluvial sand, gravel and boulders
    - Pre-erosional and post-depositional weathering environment
    - Fluvial transport processes and environmental implications
    - Detailed sedimentary sequences and structures and relative timing of major stratigraphic units
    - Bedrock outcrop, impact hydrothermal setting
    - Implications of above observations for paleoenvironment and habitability

- Targets can be put into a regional geologic framework and are at the Noachian/Hesperian transition
- Habitability: lacustrine/playa environment, low-energy deposit
- MSL investigation of light-toned layered deposits would look at:
    - Composition of sedimentary deposits freshly exposed by wind
    - Sedimentary structures
    - Habitability

Question:

(?) Flat-lying layers doesn't necessarily mean lake deposits.
(Ross) The layers are thinly bedded and continuous and are confined within the crater floor. Could be looking at playa-like environment where you don't have a very deep lake but might have repeated episodes of flooding.

Kelin Whipple
The Holden Bajada: A Target-Rich Landing Site

- Bajada: Apron of coalescing alluvial fans
    - Bathtub ring of light-toned layered deposits
    - Strong context of bajada and light-toned layered deposits
- Traverse:
    - Source area (crater wall) materials
    - Context for light-toned layered deposits (depositional environment, paleoclimatic conditions)
    - Depositional process
        - Mudflow/debris flow
        - Other mass flow?
        - Fluvial (gravel-boulder)
        - Fluvial (sand-granule)
        - Intermittency?
    - Layers exposed in every fresh crater and channel ridge
    - Contact/transition exposed in cliffs?
- Morphology, raised channels, radiating from point source areas, coalescing nature, cross sectional morphology consistent with alluvial fans. Morphology consistent with some amount of water for some period of time.
- Full drainage basins are the source of the fans
- Provides context for light-toned layered deposits, typical of other alluvial fans in latitude belt on Mars

(?) ?
(Kelin Whipple) Expect to have a sequence in stratigraphic layers that will give us a chance to discover sedimentary structures and address the nature of the material (mudflows, etc). They do appear to be conformable with slope of the fan. Given limited exposure, however, it's hard to determine from orbit how tabular they are.

(Bill Dietrich) Why are the fans concentrated on only one side of the crater?

(Alan Howard) That's where the walls are the highest and the most relief to drive material.

Josh Banfield

TES and THEMIS for Holden Crater

- Two units with compositions similar to olivine basalts are present within Holden
- Bulk of all surfaces at all sites thus far are basalt. In Holden, mostly olivine basalt 1 (relatively unaltered) with smaller, isolated occurrences of olivine basalt 2 (enriched in mafics - higher olivine and pyroxene).
- Surface is dust-free

Ralph Milliken

CRISM Results for Holden Crater

- Noise in CRISM data makes it hard to determine whether there are clay units in the landing ellipse, but clays are widespread throughout Holden and we would expect a weak clay signature based on similar morphologic units elsewhere
- Direct relationship between clays and concentrations of olivine-rich units on rim; some of the clays in Holden are detrital (transported from rim)
- More hydration in crater rim than floor
- Clays throughout lower unit and upper unit, but strongest signature in the lower member of lower unit (Magnesium-rich clays, similar to Nili Fossae)
    - Spectral signatures most consistent with iron/magnesium smectites, although could be a mixed smectite-chlorite layer
    - Upper member of lower unit has polygonal fracturing and is clay-bearing
    - Alteration of olivine and pyroxene consistent with iron/magnesium smectites
    - Some of the clays may have formed in sedimentary environment in older Holden basin before crater formed
- Spectral differences between concentration of clays at front of alluvial fan; strongest signatures in middle groups of layers
- Fluvial features in upper unit suggest high energy flooding event associated with Uzboi breach
- Thick sequences of stratigraphy that record history of alluvial, fluvial and possible lacustrine environments

Discussion of Holden Crater

(Bill Dietrich) Is there anything here besides clays?

(Ralph) We are looking for sulfates, evaporates, etc. but haven't found them yet. That doesn't mean that they aren't there.

(?) The strength of spectral signature seems quite weak, especially compared to other sites.

(Ralph Milliken) There is not a 1-1 correlation between strength of signature and abundance. Yes, the strength of the spectral signature is weaker here but that doesn't mean that they are significantly less abundant.

(Jack Mustard) Assuming we are evaluating these sites in a consistent way, what would the implications be of a weaker signature in terms of preservation and habitability? If the abundance is truly less, what does that mean?

(John Grotzinger) Based on this data, does the spectroscopy community claim you found clays on Mars?
(Jack Mustard) Yes, absolutely. There are phyllosilicate signatures at this site.

(Golombek) Can you clarify the distribution of clays in Holden?
(Ralph) The signature is consistent with smectities. In certain sites, the smectite signatures look different than other sites. Some band asymmetry might be result of mixing. Holden smectites are different than what you see in Mawrth and Gale, which might reflect mixing.

(Jack Mustard) From a habitability standpoint, what are the implications for having a rock with 40% clay compared to the likelihood of preservation in a rock where you have 5% clay?
(Dawn Sumner) Exposure to organic matter, the depositional environment, and the post-diagenetic history are predictive measures of organic preservation rather than the percent of clay in a rock.
(?) A rock with a higher percentage of clay will increase preservation potential by clogging pore space and preventing water to percolate through.

(Ralph Milliken) The strongest clay signatures are associated with the lowest member in the lower unit.

(?) You might have mixed a lot of different rocks in CRISM pixels. When you're driving MSL, how are you going to find what you're looking for?
(Ralph Milliken) There's ChemCam, but overall, on a large scale, it's quite homogenous and you would have a fairly representative view of the materials as a whole.

(Ralph Milliken) We just don't know enough from well-controlled lab experiments to correct for abundances of actual rocks.

(?) Can you infer concentration from other means?
(J.P. Bibring) Quantitative assessments are available and we will show you how to do that in the presentation by Francios Poulet. High abundances occur where the phyllosilicates formed in situ. Transport decreases the phyllosilicate abundances. Lack of diversity limits conditions for habitability and precludes the possibility of investigating habitability.

(John Grant) The presence of clays supports evidence for a quiescent depositional environment.

(John Grotzinger) Habitability model is a tracer for where sedimentation concentration occurs.

(?) If the MSL rover is on a solid, sloped surface, can you sample on a slope?
(?) The rover has problems on sand rather than bedrock.
(Ken Edgett) Engineering requirement for the rover was to traverse up to 30 degree slopes.
(John Grant) The slopes that Ross Irwin sited were average slopes and many of the stratigraphic section is stair-stepped which gives us more options for maneuvering.

(Bill Dietrich) How were clays generated? Is the source of light-toned layered deposits associated with Uzboi breach?
(John Grant) The light-toned layered deposits predate the breach and were deposited in an enclosed basin where material was derived from the west and south alcoves along the crater wall. There are clays in the crater wall, some or all are likely detrital. Some of the clays may represent in situ weathering.

(Ralph Milliken) Holden is part of much larger system that has been infilled with clay bearing units, so they might be recycled sedimentary rocks.

(John Grant) The light-toned deposits are overlain by the upper member that is related to the Uzboi breach.

(?) Where is the polygonally fractured layer?
(John Grant) Going from lacustrine, inter-fingering with alluvial, to playa history. There's no breach in the crater wall, so the water is coming from groundwater or precipitation. Fans were sourced from the crater wall.

(?) The lack of phyllosilicate diversity is speaking to available energy at this site; there are no gradients. If we're speaking of chemolithoautotrophs, that would knock this site down.
(Ralph Milliken) In terms of chemical composition, Holden is not that diverse.
(?) There is not clear evidence for energy flow in Holden. But you can generate chemical gradients in other ways, like in a standing water body. This process might not be reflected readily in the mineralogy.

(Livio Tornabene) We cannot rule out hydrothermal products deposited into Holden. Phyllosilicates in the crater walls might be hot-spring deposits related to the formation of Holden. Also, mega breccia is exposed on the surface which would be good to assess.
(Ralph Milliken) I wouldn't say hot spring, but maybe hydrothermal. These clays are comparable to clays all around Mars. There are many ways to get clays on both Earth and Mars.

(?) Could you interpret the lower member to be a dune deposit and the chaotic middle member to be an alluvial fan?
(John Grant) No. They appear that way because of the way they are weathering along this slope. If you trace the middle member around you will see that it is well-bedded.
(Ralph) The lower member appears to weather along bedding planes.

(Tim Parker) The strongest selling point for Holden is the regional geologic context, geology and time stratigraphy. The Uzboi-Ladon-Movara system predates the Holden impact. The source of discharge for Uzboi is Nirgal Valles, which dates to Late Noachian/Early Hesperian. The lake deposits in Holden are late Noachian; the hiatus was followed by catastrophic discharge in the Early Hesperian. We potentially have a huge piece of geologic time that ties to the regional geology. We need to stress the importance of ties to regional geology.
(John Grant) You can probably tie in the discharge from Nirgal Valles.

(Roger) There is evidence of a long-lived lake at this site but are there alternative hypothesis for the origin of the light-toned layered deposits? Why not hydro-volcanic base surge tuffs that can be deposited over vast areas, etc?
(John Grant) The light-toned layers are topographically confined within crater. No volcanic constructs in area to link volcanics and deposition of these materials. There is a relatively lack of variability across the entire crater floor, and their distribution is not confined to one location (spans over 150 km).

Eberswalde Crater Presentations

Jim Rice

Context, Diversity, Habitability and Preservation Potential at Eberswalde

- Noachian delta formed in an enclosed, long-lived lacustrine environment
  - Water flowed in and not out
  - Preserved delta 10x25 km, volume 30 km^3
- Closed basin with inflowing channels and thick stack of layered rocks
- Deltas have sub-aerial and sub-aqueous components
  - Rapid burial (increases preservation potential)
  - Sequester organics
  - Lacustrine sediments are low energy aqueous deposits
- Indicates sustained ponded water environment, ideal for habitability and preservation of biogenic materials based on terrestrial experience
- Distributary, multi-lobate fan
- Meanders, distributive behavior indicate water flow
- 6 stages for Eberswalde (proposed)
  - channel sinuosity ranges from 1.17 to 1.77 (up to 2.8 in some reaches)
  - most channels under 200 meters wide
  - leaf shaped lobes suggest more aggradational process
  - tongue shaped lobes suggest progradational process
- Cross-cutting distributary relationships indicative of persistent flow

- Landing ellipse in proposed lake floor (access to lacustrine sediments)
- Diverse lithologies

Juergen Schieber

The Depositional Setting at Eberswalde Crater

- Well-known regional context and origin of material
    - Preserved source-to-sink continuity
- Delta developed between 150,000 years to several million years
- Crater is older than Holden and is partial filled by Holden ejecta
- Diversity: megabreccia, layers, delta, channels
- Habitability – water environment, numerous, extensive, and thick layers
- Preservation – lacustrine basin, limited circulation, phyllosilicate-rich, exposed by aeolian erosion allowing access to unaltered material
    - Deposited by standing water
    - Deposition of distal fines
    - Extensive and diverse phyllosilicates
- Targets:
    - Inverted sinuous channels and depositional lobes
    - Light toned rocks with phyllosilicates
    - Exhumed multi-thread channels (fluvial, on hill-slope)
    - Escarpments of lacustrine deposits
    - Exhumed from lacustrine blanket deposits (delta bottomset)
    - Mesas of flat-lying deposits
    - Megabreccia
        - Debate as to whether it can be interpreted as Holden ejecta
        - Near central uplift
- Bottom of delta (just west of landing ellipse) has strongest clay signatures
- Ellipse has numerous fluvial features (anastomosing, sinuous, branching channels)
- Clay minerals widespread
- Access to deeper crustal lithologies (megabreccia)
- Already well studied so now addressing next generation of questions

Questions:

(Steve Ruff) Do we know anything about the height of the water in the sink?

Kevin Lewis

Geomorphic Aspects of Eberswalde Delta and Potential MSL Traverse

- Clear geologic context and set of scientific questions
- While delta is to the west, other fluvial deposits are in the ellipse
- Channels are topographic highs and can be traced across delta surface
- Multiple lobes indicate several stages of construction
    - Base level drops between lobes
    - NOT consistent with alluvial fans

- Strata exposed in meander bend dip outward, as expected for a point bar deposit (not simply erosional)
- Deltaic geometry:
  - Downlap relationship observed on northern margin
  - Consistent with deltaic foresets prograding over bottomset/lacustrine beds
- Geologic contacts:
  - Truncated layers
  - Non-planar contacts with underlying material
  - Every location would expose slightly different stratigraphy
- Morphologic diversity:
  - Main delta (several facies)
  - Isolated channels in ellipse
  - Light-toned material on crater floor
  - Basement material
- Traversability:
  - Generally low slopes along delta front at 2 meter scale
- Can predict where fines and organics should be in delta
- Morphologic arguments for deltaic vs. alluvial origin using HiRISE digital elevation models
- Good qualities for a landing site:
  - Diverse sedimentary rocks
  - Long-lived body of water
  - Lithification
  - Fine grained material
  - Minimal oxidation/acidic alteration (exposed phyllosilicates)
  - Little subsequent disturbance
  - Recently exposed
  - Well understood basic geology

Questions:
(?) What is the composition of the coarse grained material?
(Kevin Lewis) Ralph Milliken will discuss composition.

Jeff Moore
Depositional Setting and Sedimentary Materials at the Eberswalde Crater Site
- Fluvial environment in region during Noachian/Hesperian transition
  - Suggest boulder deposits are likely primary depositional features for channels
  - Possible origins of boulders:
    - Coarse end of grain size distribution
    - Some boulders clearly released from weathering of consolidated layers in deltaic deposit
    - Generally source beds
  - Boulders on delta surface are different than boulders from weathering
    - Occur as stringers and lenses associated with sinuous channels
- Channels of delta are 50 to 100 meters wide

- Estimates from channel dimensions (width, meander wavelength) suggest discharge rate 296-580 m^3/s for bimodal; unimodal distribution yields discharge rate of 61,820 m^3/s
  - Can such discharges carry boulders across such a low gradient? → probably
- Discussion of Parana Basin discharge
- Multi-decade deluge erosion:
  - If rained like mad for 1,000 years, don't get geomorphology expected
  - If only rained once every two weeks or so but for much longer, get patterns we see now → implies long lived wet environment (but not catastrophic)
- Global View: Landform evolution model of Mars shows that Noachian-Hesperian aged, late-stage valley network formation require numerous repeated moderate flood events rather than one or a few continuous, multi-year, deluge-style flows

Josh Banfield
TES and THEMIS perspective
- Classic dark region, basaltic soil, unremarkable
- Plagioclase, pyroxene, high silica phases and a bit of olivine
- Similar to TES surface type 1

Ralph Milliken
CRISM Results for Eberswalde Crater
- Clays in landing ellipse, south of ellipse (although not contiguous with delta) and in the delta
  - Edges of delta show iron-rich clays, increases in pyroxene
- Three units in Eberswalde: clay-bearing unit with pyroxene, pyroxene unit with clays, Fe-rich clay unit (possibly ejecta from Holden, indicative of reducing conditions) – very iron-rich, not magnesium-rich
  - Nontronite (Fe-rich) implies reducing conditions
- Moderate pH and reducing conditions are preferable for habitability and preservation of organics
- Mineralogy and geomorphology are very consistent
- All units exhibit fracturing to some degree
  - Clay-rich units are more variable in their degree of fracturing
- CRISM results most consisten with Fe smectites, but chlorite may also be present
- Mineralogy is consistent with the morphology; deltaic environments with clays are excellent places to assess habitability

Discussion of Eberswalde Crater

(?) How much are we supposed to weigh a target outside of the ellipse?
(John Grant) You have to individually weigh targets outside the ellipse in your own mind and determine what the relative risk and science potential is.

(David Des Marais) What is the source region for the delta?

(Ralph Milliken) There are fan deposits in source region with light-toned material. CRISM data is very noisy in that area, limiting our interpretation.

(John Grotzinger) Josh Banfield said that THEMIS calls it "unaltered." Is there a chance that the clays in Eberswalde formed in situ?
(Ralph Milliken) The region is covered with a veneer of dark material. At a higher spatial scale, you start to see information in the delta. The spectral signatures of the delta units are similar to Holden materials. Clay material of what might be the Holden ejecta has a unique spectral signature and may have formed in situ, but there is no way to prove that from orbit.

(Jack Mustard) Bottom-set beds are spectrally weak, texturally they doesn't seem different than other places on Mars. Does a weak signature translate to a modest abundance? Can you use THEMIS to assess dust?
(Ralph Milliken) If they are intact mudstones or shales, all you're going to see is a flat line in the CRISM spectra; the clay minerals are not going to be visible. It's possible that the abundances are low or that some of the layers in the sequence have clays and are diluted at the pixel scale of CRISM. I believe dust is higher in the delta front.

(Bethany Ehlmann) Fe-rich clays are not so unique…see Nili and Mawrth
(Ralph Milliken) If you plot spectra of smectites, there are differences in band position. In Gale and Eberswalde and in some cases in Mawrth, they are shifted toward the shorter band wavelengths. Others are shifted toward the Magnesium-rich side. It's not unique to Holden, but there is variability in the band positions.

(Mike Carr) Is there any evidence for evaporitic minerals in Holden or Eberswalde?
(Ralph Milliken) We have looked for carbonates, hydrated salts, etc., but have not detected them in these areas. If takes lots of silica to form smectites and you would expect a huge excess of cations that would have to go somewhere, so you would expect salts or something else there. This is a scenario that you would expect at these sites and everywhere.

(?) The sediment to water ratio would indicate 250-1000 cubic km. The duration of the lake is limited by the time it takes to evaporate that amount of water (1-4 km of lost water). It would be interesting to calculate how long it would take to get rid of that amount of water.
(Jeff Moore) It would be more complicated if the lake were ice-covered.

(?) In cases where you might have a carbonate-type rock, would you expect differences in spectral signatures?
(Ralph Milliken) We don't know whether sulfates are occurring as gypsum or as pore-filling cement. It depends on porosity of material and CRISM can't detect quartz.

(Juergen) You don't have to have evaporates in a lake along with clays; the water might be somewhere else with the solutes.

(Jeff Moore) If the delta is entirely composed of fine-grained material, then it's equally susceptible to erosion.

(J. P. Bibring) For phyllosilicates to form in situ, you need water, mafic material and an energy source. Without an energy source you won't make clays. What is the energy source to warm the water?
(Ralph Milliken) Not sure I understand your question…

(?) What are the depths of the lake?
(Kevin Lewis) About 100 m, but channels might occur at varying elevations. Delta didn't stay at the same level.
(Jeff Moore) And if the lake were ice-covered, you would expect plastic deformation.
(Oded) We think we can identify base level changes. What sets Eberswalde apart from other landing sites is a very specific sequence. Therefore the terrestrial model can be used to help us find specific types of material and where we can expect to find organic material. The models of deltaic deposition are well-defined.

(Steve Ruff) Would we go to a place where we found a lake bed but it's been removed? The delta is a positive- relief feature, how much material has been removed? There's no smoking phyllosilicate signature?
(Oded) The bed architecture is diagnostic of deltaic deposits, which wasn't the case for Gusev.

(?)Can you comment on the oxidation of the organic matter and the state of preservation?

(Eileen) Are clays a required part of the argument for habitability and preservation?
(Linda Kah) Fine-grained sediment trap organic matter more efficiently than coarse-grained sediment. Rapid burial would also aid in the preservation of organic matter. Because this is an intriguing site, many studies have already been done.

(Bethany Ehlmann) The abundance of clays *is* important in the preservation of organic matter.

(John Grotzinger) What does abundance mean and what does clay diversity means? Abundance is not critical for a lacustrine model, but we use it as a beacon based on terrestrial experience. Clays are a proxy for the settling velocity of fine-grained material, and that's possibly where the organics would be; look where the fines are, not the sandstones or breccia. If you land in this area, you can quickly assess where the fine-grained material should be based on the familiar structure of a delta deposit.

(Dawn Sumner) Returning to the issue of energy sources…Mafic minerals plus water are just as active, although temperature is lower, but they are still driven the same way and life can take advantage of thermodynamic gradients. Chemical gradients are steepest at the surface because you have different processes. The surface of the lake might serve as layer of protection.

Mawrth Vallis Presentations

J.-P. Bibring
The Mawrth Vallis Landing Sites

- Recommend landing ellipse 2 and 4
- If Mars was habitable, it was when phyllosilicates formed
    - Only happened during part of Noachian
    - Bombardment erased evidence of most of previous aqueous alteration
- Must assess the best preserved site with respect to this sequential evolution (in place alteration)
- Uniqueness of Mawrth Vallis:
    - It's extension
    - Compositional diversity (Fe/Mg to Al-rich phyllosilicates) coupled with clear stratifications (preserves aqueous era and can study environmental conditions and climate)
    - Phyllosilicate abundance (above 50%)
- Diversity: phyllosilicate-rich signatures (high abundances) correlates to well-understood geomorphic stratigraphy
- MSL can address diversity and search for preserved habitability footprints with its current payload

Francios Poulet
Mineralogy model of phyllosilicate-rich deposits

- Laboratory experiments using varying mineral assemblages to model spectra observed from OMEGA spectra in Mawrth Vallis
    - For Mawrth 2, model fits with a mix of nontronite, ferrihydrite, plagioclase and dust
    - Hydrated minerals (Iron and Aluminum phyllosilicates plus iron hydroxide) > 60% by volume
    - Anhydrous component (plagioclase) <25%
    - Some pyroxene
- Modal mineralogy of deposits indicates a larger and/or differing degree of alteration + phyllosilicates-rich layers deposited above a less altered surface
    - Anhydrous minerals make up most of the percentage

Josh Banfield
THEMIS

- THEMIS observes full range of type 1 and type 2 surfaces as well as the contacts between them
- Can see contacts of surface type 1 and 2
- Lot of type 2

Steve Ruff
TES

- Ellipses 2 and 3 relatively high albedo occurrences (above 0.2)
    - Usually over 0.2 means dust covered, yet not here

  - Not dust, but also not fine particulate sediments of any kind
- TES type 2 material is probably a fine silicate glass

Joe Michalski
- Silica, feldspar and/or small abundances of zeolites
- Silica phases are necessary to model light toned data (phyllosilicates and basalts are not required)
- Texture affects result
  - OMEGA-TES disconnect: grain size surface textures

N. Mangold
Geologic Context
- 4 sub units (total 200 m thickness), conformable with pre-existing topography
- Regional stratigraphy:
  - First contact: top-lying mantling (HCP rich mantle)
  - Basal contact: has filled craters
  - Two unconformities
  - Internal layering
  - Minimum 4 sub-units 50 to 100 meters each (total 200 m thickness), conformable with pre-existing topography

J. Bishop, N. McKeown and M. Parente
Kaolinite Deposits, Aqueous chemistry, and Habitability at Mawrth - CRISM
- Diversity of phyllosilicates (nontronite, montmorilinite, kaolinite) in layered stratigraphy
- Kaolinite implies stable water at or near the surface, slightly acidic environment and moderate pH, which are habitable
- Expansive body of water
- Redox chemistry
- Advanced alteration at top of phyllosilicates profile
  - Hydrated silica
  - Kaolinite
- Phyllosilicates provide surfaces for binding/trapping organics
- Silica enables preservation of fossils
- Evidence for hundreds of km of phyllosilicates implies widespread aqueous event
- Fe/Mg smectites, Fe^{2+} material, hydrated silica, montmorillonite, kaolinite
- Ferrous slope observed at transition from nontronite to Al-clay/hydrated silica layers
  - Likely to be mica (could also be carbonate, sulfate, olivine)
  - Implies aqueous activity
- MSL more likely to find various phases of Fe than CRISM

James Wray
Compositional Stratigraphy and Evidence for a Drape deposit
- Mawrth has diverse mineralogy and geomorphology

- Focus on polygons, compositional layering, fracture fluid flow, possible folded layers, filled craters
- Abundant polygons in Ellipse 2
    - Variations in size and scale over even small area
    - How did the polygons form? Dessication? Mineral dehydration? Weathering? Periglacial at high obliquity?
    - How recent/old are they?
    - Could measure composition, depth, layer thickness, etc. with MSL
    - Iron/Magnesium clays have 'less-ordered' fracture patterns than Al-clays
- Aluminum-bearing unit (polygons) is different morphologically than Iron-bearing unit (rubbly)
- Halo bounded fractures
    - Fluid flowing through fracture likely changed materials, either chemically or physically
- Possible folds in nontronite-bearing layers
    - Consistent with (but not diagnostic of) soft sediment deformation
- Filled craters in nontronite-bearing unit
    - Quasi-circular color/albedo features of varied size
    - Unique to nontronite-bearing materials
- Compositional layering:
    - Al to Fe/Mg-clay transition exposed in wall of crater near center of Ellipse 2
    - Some exposures of both clays in ellipse 4 (even though it's a "go-to" site) exposed in crater wall and ejecta
- Al-clays always overly Fe/Mg clay unit
    - Is Al-unit pyroclastic/sedimentary deposit draped over Mawrth Vallis that was subsequently altered in place? Or did the alteration occur elsewhere?
    - This rules out deposition into a closed basin or that the unit is Chryse impact ejecta
- Fe/Mg unit cannot be similarly constrained because can't see bottom of that unit (can't see the unaltered stuff)

Eldar Noe Dobrea

The Mawrth Vallis Phyllosilicates Within a Regional Context

- The geomorphology, mineralogy and stratigraphy at Mawrth Vallis are common and consistent on a regional scale
- Multiple formation processes that are testable by MSL but evidence suggests prolonged water alteration
- Hydrated minerals are identified everywhere that surface unit has been eroded to deeper layers
    - Mineralogic stratigraphy is same throughout region implying a regional process
- Phyllosilicates are finely layered, weak, have unknown thickness
    - Is it deposition in a lacustrine system? Diagenesis?

Discussion of Mawrth Vallis

(John Grotzinger) What argument can you make that the entire section was not transported there?
(Eldar Noe Dobrea) You need a large basin and there is no evidence for that. The other option is that you have aeolian processes that brought material there and alteration occurs in situ. There is no fluvial evidence.

(John Grant) If you have material occurring as a drape deposit over large (thousands of kilometers) spatial scales and there isn't any evidence for a confining basin, isn't an airfall deposit a reasonable origin?
(N. Mangold) The deposit could be ashfall or aeolian in origin. There is varying chemical composition associated with layers.
(Joe Michalski) One geomorphic argument is that we have a diverse and thick sequence of rocks. Bedding is expressed because of erosional and lithologic differences. Some of them have to be sandstones or aeolian rocks of some sort.
(J. Bishop) It could make sense that the nontronite layer was followed by an aqueous event that altered the material in situ.

(Ralph Milliken) What is unique about the spectra that makes you think it is ferrous mica?
(J. Bishop) Most likely a ferrous mica but could be other things.
(Ralph Milliken) There are no clear absorptions that were indicative of ferrous mica?
(J. Bishop) That's correct.

(John Grant) In the absence of a confined basin at that scale of stratigraphy, are you left with airfall as the most viable origin?
(Tim Parker) The northern plains *is* a basin.

(Eldar Noe Dobrea) What appears to be a draping unit of aluminum phyllosilicates over iron phyllosilicates may not be a draping unit, it might be a front that leached material from the top down, alteration from some source. The point is that it might not be a morphologically draping layer. We don't know the origin of the layered deposits. An airfall deposit is viable. What's important is that they were turned into iron smectites.

(John Grotzinger) Do we really lose if these deposits turn out to be transported and removed from their source area? Once you go into layered stuff, it could be a volcanic layer altered in place, but it could be a lot of other things. At this point, your sites have layered terrain with phyllosilicates. How can you know with certainty that these layers were not transported?

(N. McKeown) It is possible that the material was transported there. Then we could be looking at an oceanic basin.

(J. P. Bibring) We have no idea what happened on early Mars, but Mawrth is the best place to look for life. Therefore we're forced to go to a place that we don't understand to answer these questions. The processes by which you add the material and how you cement it doesn't make a difference.

(Horton) In landing ellipse 2, we have seen a lot of different kinds of materials, including phyllosilicates and crater-fill that is different from the stratigraphy. Can you restate what is inside and outside of landing ellipse 2?
(N. Mangold) You have access to two types of materials in landing ellipse 2: aluminum-rich and iron-rich layers.
(James Wrey) In landing ellipse 2, there are good exposures of the two main units – the aluminum and the iron-bearing unit, as well as the contact between them. You also have access to the fractures with halos and polygonal textures within landing ellipse.

(Linda Kah) How is a story going to come out of this? There is a widespread occurrence of clays covered by aluminum-rich clays and this pattern exists over a broad region. The units are finely layered. There are morphological features such as folds, although I don't agree that they are truly folds, an array of possible origins for the material including impact, sedimentary (and within sedimentary you have aeolian, lacustrine or fluvial), a variety of hypotheses for the origin of the mineralogy alteration including lacustrine environment, diagenetic phase, circulation beneath of a volcanic cap. How can MSL possibly distinguish between any of these and determine what is going on at this site??
(Joe Michalski) We have an issue of scale but we have many testable hypotheses. It is complicated but MSL can test these hypotheses by driving up to the outcrop and examining the mineralogy and bedding structures.

(?) How thick is this package of stratigraphy?
(N. Mangold) About 150-200 m thick.

(J. P. Bibring) We don't know what happened, that's why we have to go there to understand.

(Brad) Uncertainty in the interpretation doesn't equal diversity.

(James Wrey) One of the main things that would be useful to look at would be grain size and structure that would help discern the mode of deposition. With MSL, we would be able to see all these things more definitely than with orbital modeling and HiRISE images. The Mawrth Valles presenters have been conservative about mode of deposition because there are many hypotheses and interpretations that could fit with the data. We strongly believe these hypotheses are testable with MSL payload.

(Ross Irwin) There are layered deposits over a wide range in topography and aerial extent, and this unit does have a regional context. Arabia Terry airfall is a viable origin and if that is a first order hypothesis, we have to very careful.

(Nick Tosca) Working under the assumption that life had difficulty starting we need to start with good conditions. There is fascinating mineral diversity at this site but want to believe that the clay here formed in situ.

(J. P. Bibring) The mineralogy here tells you about habitability and water stability at the surface. It is key for us to understand this mineralogy and whether it formed *in situ* is not important. It may have formed too late in the process when the atmosphere has already changed. Either way you can learn something about the environment.

(Bishop) We are seeing many phases in the sequence, not just aluminum and iron phases - it is much more complicated than that. It has to have been altered in place to explain what we see in the CRISM data. It's likely that multiple units that have been mixed, probably chemically. We can't tell the whole story through pedogenic processes alone.

(Alan Howard) Landing site 2 is the only place where we can analyze the stratigraphy. The other sites are very far from the valley. If this is primarily a weathering layer phenomenon, will that preserve biological material?
(?) There is limited metabolism (delta g). What metabolic processes would weathering processes support? I can't see many of them.
(*David Des Marais*) To weather rocks, you redox and release energy. Weathering process could support biota, but this process does not have as great of potential as other mechanisms.

(John Grant) If this is a leaching process, one of the first things to go is the organics. Is that right?
(?) If you have weathering reactions, organisms can tap and utilize that energy. That's not to say that actually happened, but geochemical reactions tend to support metabolic reactions. In a pedogenic process, you tend to get organics on the surface layer but in the long run, very few organics are preserved in the rocks, which has to do with the early and late pedogenesis. That includes all soils. Maybe there are other chemical ways of observing that.

(N. McKeown) We clearly see layers, so it is likely not intense pedogenesis because we have parent-rock structures.

(Dawn Sumner) We can look at iron redox state to indicate whether it is likely to get organics observed.

(?) And we do see that ferrous layer.

(Lisa Pratt) Pedogenic processes are driven by organic matter derived from above, resulting from photosynthesis. If we have life on Mars occurring in the subsurface, then we can imagine a different kind of "soil," a biotic weathering front, that moves downward in search of mafic constituents as an energy source, then we might look for profile that would be upside down, and the weathering might do interesting things if the organic processes were leaching upward rather than downward. We have to think on our heads – maybe the optimization here was to stay away from the surface and work downward.

(N. McKeown) The fact that Mawrth Valles is typical of a large area will provide context for a large region on the planet. If we land at one place on Mawrth Valles, we might be able to say something about that entire region.

(?) There are lots of different hypothesis at this site, and I think that's a huge benefit. We have a wide range of possibilities that don't focus on preconceived notions about what we'll find.

(F. Poulet) In Mawrth Valles, there is a huge amount of diverse clays that we don't see in other places on Mars.

(John Grotzinger) It doesn't matter to me whether they were transported or not, it's interesting either way.

(J. P. Bibring) Mawrth provides access to the crust and above and we can follow the evolution of Mars.

(Kelin Whipple) I'm confused about the constraint on the age. You keep stressing early Mars…if these units, where observed, are conformable to the modern topography that implies huge levels of stripping. Why are these units not considered younger?

(Bibring) That is too difficult to explain right now but I will explain it to you later if you want. The phyllosilicates formed early in the history of Mars and the sulfates formed subsequently.

Wednesday, September 17th

Gale Crater Presentations

Dawn Sumner

- Notional traverses presented
- 5 km thick layered mound in center of crater, erosional unconformity
- Provide a type section for early Mars
- Diverse mineral signatures that correlate to bedding and are easily accessible
    - Iron
    - Sulfates in upper stratigraphy
    - Clays in lower stratigraphy
- Unique location to test questions about sediment (origin of fill, composition, mode of deposition, depositional environments, timing), mineralogy and role of water
- Processes studied in Gale applicable to Mars on global scale
- Fluvial sediments present, but uncertain about crater lake

Questions:

(Horton Newsom) Is there any spectroscopic evidence for hydrothermal activity? Do you have any images of the clasts?
(Dawn Sumner) Ralph Milliken will show CRISM data and there are images of clasts in supplemental slides.

(Tim Parker) The localized unconformity doesn't appear to go entire way around the layered mound. The layered stack has craters in it where the "plastered on" unit does not appear to have craters.
(Ken Edgett) There's a lot more to this mound and its story that we can present in 30 minutes. We focused on the work that MSL can do in the first couple Mars years.

(Livio Tornabene) Of all the sites, Gale has a considerable amount of dust. Can the instruments on MSL deal with that?
(Dawn Sumner) The dust index is lower on the bottom part of the mound. The reason to go to Gale is the combined stratigraphy and spectral signatures. There is so much to do at the bottom of the stack where it's relatively dust-free compared to the top; it will be a miracle if we make it to the top of the stack!

Josh Banfield
TES and THEMIS

- Surface type 1 and dust
- Top of mound covered with dust; some dust in landing ellipse

Questions:
(Jim Rice) Did you do any atmospheric correction for the low elevation of the ellipse?
(Josh Banfield) We concentrated on just the floor outside of the mound.

Ralph Milliken
CRISM view in Gale

- Mineral Diversity: iron-rich smectites, Fe/Mg smectites, aluminum in octahedral sites of smectites, potential mixtures of aluminum and iron smectites, mono and polyhydrated sulfates (most likely magnesium), mixtures of smectites and sulfates, iron oxides, olivine
- Correlation of mineralogy to stratigraphic layers/beds
- Mineral assemblages vary through stratigraphic section and thus through time
- No evidence for Fe sulfates which implies lack of evidence for acidic conditions
- Can traverse up-section with access to large variety of minerals
- Nontronite unit is stratigraphically and topographically lower than olivine and clay unit
    - Fe-smectites require initially reducing conditions
    - Olivine and clay unit dips away from mound to north rim
- Layers being stripped and eroded; dipping toward center of crater
- "Grand Canyon" – clays, sulfates and mixtures of both
    - Finely stratified deposits
    - Could be inter-bedded, could be in distinct layers

- Some parts of mound are very similar to interior layered deposits in Valles Marineris
- Are finely stratified deposits linked to climate or orbital variations?
- Clear stratigraphic relationships, microcosm for similar processes on Mars, understand temporal relationships of clays and sulfates on Mars

Questions:
(F. Poulet) Your spectra for sulfate is very controversial.
(Ralph Milliken) I agree that it's not as clear, but if you do the continual removal you get the true band center. You get the drop in reflectance that is common for sulfates. The spectra clearly maps out as sulfates in the tectracolor. You have the water feature and the drop off in reflectance.

(Jack Mustard) What is the band at 2.2 microns? I agree that the 1.4 and 2.9 absorptions are right, but what is the odd concave feature between these absorptions?
(Ralph Milliken) Perhaps this feature is mixed (possibly with dust). But when we do know, they have much clearer sulfate signatures.

(?) The presence of calcium interbedded with smectites gives you massive amorphous beds instead of thin, well-crystallized presentation.

(?) There is no evidence of calcium.

(Ralph Milliken) We have diverse mineralogy and mixtures of clays and sulfates, and you're likely sampling diverse environments.

(?) Could the calcium still be there? That would affect preservation.
(Ralph Milliken) We don't see calcium, but that doesn't mean that they aren't there.

(Jack Mustard) The mineral signatures appear to be weaker compared to signatures from other sites.
(Ralph Milliken) The signatures are definitely there, but I agree, they are weaker than other sites. Even in Meridiani, we know from Opportunity that there is 35% sulfate in the rocks but we don't see that signature from orbit. The abundances can be very high, very low or anywhere in between.
(Jack Mustard) Well, that about covers it.

Brad Thompson
Stratigraphy at the Gale Crater Landing Site

- Positive relief fracture systems
- Lower mound layers 10 to 30 meters thick
    - Apparent slope about 2 degrees
- Upper mound layers about 3 to 7 meters thick
    - Apparent slopes of 5 to 10 degrees
- Geometry of upper unit contact not consistent with lacustrine deposit (some aeolian influence)

- Morphologically diverse – presented differences of upper and lower mound
- Gale formed in the late Noachian
- Low-energy sedimentary depositional environment
- Closed depositional basin
- Representative of numerous exposures of layered deposits on Mars, non-uniform in space and time.
- Long sedimentary record captures environmental changes during deposition
- Age context:
    - Continuing erosion
    - Onlapping valley network deposits on crater floor
    - Interior channel deposits
    - Deposition of upper mound layers
    - Deposition hiatus/erosional episode
    - Deposition of lower mound layers
    - Gale impact (late Noachian)
- Formation mechanism:
    - Unlikely: impact ejecta, effusive volcanism, pedagenesis, volcaniclastics (lack of regular repetition)
    - Possible: lacustrine deposition, aeolian deposition
    - Low-energy deposition of particles deposited via suspension from fluid (wind or water)
        - Even if aeolian, water played a significant role
- Upper mound about 3 km thick (much thicker than lower mound)
- Water alteration could have happened before deposited
    - Are they in place or were they transported?
    - Evidence of cementation of rocks before channels cut, so we have that constraint
- What's the water source? A few small inflows, no outflow. Was it groundwater?

Discussion of Gale Crater:

(Tim Parker) How extensive is the upper mound unit?
(?) It is large; it occupies a significant portion of mound.
(Ken Edgett) The stratigraphic section of the upper mound is 3 km thick. It is thicker than the lower section but has a smaller aerial extent.

(Tim Parker) The yardang unit is on top of the upper mound units.

(Jack Mustard) We can't determine whether aeolian or fluvial processes were dominant here. Even if it is aeolian, are fluvial processes are still significant?
(?) Aqueous processes; channels are sourced from the mound and are associated with the alteration of minerals.

(Jack Mustard) What can you say about the timing of the mineral alteration? Could the alteration have been prior to deposition?

(Brad Thompson) If this sediment was transported from somewhere else, it could be erosion of Noachian basement. All we can constrain is the formation of the crater and the formation of the valley networks.

(Dawn Sumner) There is evidence for cementation of the rocks, so we know that water flowed at the surface at time of the unconformity.

(Bethany Ehlmann) The rim of Gale is well-preserved. Are there any inflow or ouflow channels? Is it reasonable to say that the source of alteration was ground water and delivery of sediments the result of aeolian processes?
(Brad Thompson) There are many small inflow valleys (on the rim?). We have not done a mass balance calculation so I can't determine the role of ground water.
(Ken Edgett) In response to Bethany's question, I don't know whether there was a lake there. You have to keep in mind that the valleys that delivered material to the mound might also be eroded. This is a common story all over the planet.

(Bethany Ehlmann) We also see many craters with inflow and outflow channels.
(?) The issue with Gale is to prove whether it's lacustrine. There is no direct connection to a depositional environment here.

(Jack Mustard) There is a clear source-to-sink situation in Eberswalde, for example, but in Gale there is no clear connection between the channels and the sediment.

(Dawn Sumner) The advantage here is that Gale has a huge stratigraphic section. But it is impossible to identify lake deposits within the stratigraphy from orbit. We have an opposite problem here; we can test this from the rover by looking at sedimentary structures, distribution of minerals, etc. For example, if there was a playa lake, we would see mud cracks. If it were a deeper lake environment, we would look for turbidites. We can't develop a facies model from orbit. It is a large Noachian crater, if there was surface or ground water (Gale is 5 km deep) you might guess that there could have been a lake.

(Linda Kah) If you have a hole filled entirely by aeolian processes, the same process will take things out. The only way to trap sediment without a lake is to wick up groundwater. You must be looking at the interface of the groundwater table with the crater bottom or newly developed land surface. All are showing the influence of cementation.

(James Wrey) The mineralogic diversity in Gale is a strong selling point. What is the direct evidence that the sedimentary stack here is connected to global/regional processes?
(Dawn Sumner) This site will allow us to test whether it is a local change or a regional/global change. That is the first step in test that will tell us something about what to look for.

(J. P. Bibring) First you alter, then you deposit and erode the sediments.
(Dawn Sumner) You can't prove that from orbit.

(F. Poulet) The signature is very weak which supports transport rather than alteration of the material in situ.

(Ken Edgett) Think about the Grand Canyon for a minute. Could you infer the tale of the Grand Canyon based on orbital data? You can't tell the tale of the mound in Gale just by looking at it from orbit. But there is a 5 km-thick stack of layers that represents a large portion of the geologic history of Mars.

(Jim Rice) Is there a fan associated with the "grand canyon" in Gale?
(Ken Edgett) No, it's gone.
(Brad Thompson) It is likely covered by later crater fill.

(Jim Rice) You aren't proposing a traverse of the "grand canyon" in Gale, right?
(Ken Edgett) No. But maybe in the extended, extended mission!

(Brad Thompson) The fluvial system could have exploited a fault system, but there is an inverted channel at the bottom.

(John Grant) The geomorphic evidence for water is the valleys and the small fans, right?
(Brad Thompson) Yes, in addition to the cementation along with fractures zones.

(John Grant) The valleys and the fans on the floor post-date the layered mound?
(Ken Edgett) The canyons cut into mound, which requires that the lower layers were lithified before they were cut by the canyons. There are various channels that come into the crater, but their age is less certain.
(Ross Irwin) There is a narrow breach that deposited a fan west of central mound. It's uncertain whether there was alluvial deposition after mound was deposited. Material contributions from crater wall are very small. Gale may not have been as wet as other places.

(Ken Edgett) Whatever the processes were, that was what was happening on early Mars. We don't know the processes, but we do know that they were active on a global scale.

(Dawn Sumner) Gale allows us to test the timing of alteration by looking at sedimentary structures.

(?) I think this *is* testable, but I'm not sure we will get a definitive answer.

(Ken Tanaka) Gale is located along highland/lowland boundary. Degradation process may have been driven by the groundwater system, which may have been well above the floor of Gale. May have had ground water in the bottom of Gale and the material could have accumulated through aeolian activity, which would be consistent with the geologic setting.

(?) You may have had a change in the redox conditions during the time smectites were formed? That would speak to habitability and might give us a good story. How good are the instruments at testing differences in smectites?

(Ralph Milliken) You can differentiate between aluminum and iron-rich smectites.
(Dave) We are limited and it's less than perfect. We can tell a lot, especially if we can find a smectites in the assemblage. We can't tell whether they are bi or tri-octahedral but we can tell differences between major classes and other phyllosilicates like kaolinite.
(Ralph Milliken) You have different smectites with different cations (Mg, Fe, Al) in octahedral sites.

(Steve Ruff) What are the ellipse science possibilities? This is the dustiest site. Why was it chosen? And if the rover never leaves the ellipse, what compelling science are we going to get?

(Ken Edgett) The landing ellipse was positioned there because it's the only place to put an ellipse that gives you access to mound and it's free of sand sheets. The point of landing in Gale is to get to the mound. It's a new risk to have a 'go to' site.

(?) In terms of "go to" versus "non-go to" sites, I consider it an advantage to move away from landing site to get away from the plume associated with landing. It is part of the requirement of the mission to do traverses, so in weighing the risk and benefit, it's worth the risk.
(John Grant) You need to get about 100 m away to distance the rover from the landing plume.

(Bryan Hynek) What is the consensus on the age of the mound?
(Ralph Milliken) I did not mean to imply that the entire history of Mars is represented in Gale. We have those minerals in a stratigraphic section but don't know the ages.
(Ken Edgett) I doubt that there are distinct eras of chemical alteration. Hesperia Planum didn't undergo that much erosion, so it has to be older. What does it mean when you go up-section and have mineral changes? The mound is set up to answer these types of questions; you have access to the transitions.

(Matt Golombek) Gale crater itself is Noachian in age.

(Bryan Hynek) How can you prove that the layered deposits in Gale are not similar to the Medusae Fossae Formation (MFF)?
(Ken Edgett) That's mythological. The MFF has inverted channels and fans of channels. In the upper part of the Gale mound, you might have something similar to southern Amazonis.
(Ken Tanaka) The MFF is 300 km away from Gale. There are rare (Amazonian) channels that pass through MFF. Because it is located on the highland-lowland boundary, it's difficult to age-date the channels, it is difficult to constrain stratigraphy and the geological inferences are weak.

(Kaleb Fosset) It is hard to believe that we have a good age constraint in the MFF. Not having context for the stratigraphy is a risk. We prefer sites that have direct link to the source.
(Ken Edgett) Besides Eberswalde, what other sites provide a convincing source?
(Kaleb Fosset) Holden crater.

(Michelle) Do some sites have a better age constraint?
(Matt Golombek) Yes, some sites have direct crater counts, like Mawrth. The mound in Gale doesn't provide constraints.
(Kaleb Fosset) Age constraints vary among all the proposed sites. The mound in Gale is completely up in the air. Holden has marker times because the Uzboi breach cuts a well-dated crater. Some sites have better constraints than others.

(Brad Thompson) The idea that the age of the deposits in Gale are Amazonian is ridiculous.

(Ralph Milliken) We want to tap into as many geochemical events as possible. Gale is chemically diverse and has a huge stack of materials.

(?) Is there any basement or megabreccia in Gale?
(Ralph Milliken) I have not seen any.
(Alfred McEwen) The central peak might be exposed in the south side of mound.
(Ken Edgett) There is a chance that the fan in ellipse incorporated and transported wall rock.

(Tim Parker) Keep in mind that Opportunity has gone twenty times longer than its design.

(Alfred McEwen) The amount of structural uplift for that crater that size might be more than 10 km but the uplift is draped by younger sediments.

Open Discussion of All Proposed Landing Sites

(?) Which sites can you drive up-section? How much of a stratigraphic section can we sample?
(Matt Golombek) For all "go-to" sites, it's possible to drive up the stratigraphic package.
(Jim Rice) 150 m in Eberswalde
(Eldar Noe Dobrea) In Mawrth, you have a couple hundred meters
(Horton Newsom) In Miyamoto, you have 100-200 m
(John Grant) In Holden there is >150 m, plus 10s of meters of stratigraphy in fan
(Matt Golombek) In South Meridiani, there are tens of meters of sulfates, the phyllosilicates are on order of a hundred meters.
(Jack Mustard) Nili Fossae -??
(?) Layered mound in Gale is 5 km thick.

(Ross Irwin) We shouldn't restrict to lacustrine environments but also consider sub-surface or hydrothermal environments. In Holden, you can access both and might be a good compromise between Gale and Eberswalde.

(Horton) You would expect to see hydrothermal effects around rims of these large craters. Gale, the rim of Gale, Holden, Holden's central uplift and Miyamoto. There isn't a lot of data coverage.
(Jim Rice) Eberswalde as well because it is 67 km in diameter.
(Livio Tornabene) Yes, you can make the same argument for Eberswalde.

(Jim Bell) People have done a great job on evaluating each site! Can you talk through the rationale for spectral detection? Can you comment on longer wavelengths where there are diagnostic bands?
(Bethany Ehlmann) Spectra have particular absorptions at particular places. The 2.5 micron absorption and its slope and the ferrous slope (a broad slope down to one micron). Explanation of ratioed and un-ratioed spectra. At the Nili site, I was resistant to call them carbonates because mixtures can subdue the bands and there are normal magnesites that tend to be darker. Subtle absorptions at longer wavelengths (3-4 micron range) are not as well calibrated in CRISM.
(Jim Bell): What does THEMIS see?
(Bethany): Hard to distinguish where you'd expect carbonate vs. olivine absorption (occurs at almost same band in THEMIS) so indeterminate. Disconnect in wavelengths occurs with certain minerals in VNIR vs. longer wavelengths. May be strong in VNIR but weak in longer wavelengths.
In THEMIS data, it's difficult to distinguish where to expect the carbonate absorption and the olivine absorption.

(Jack Mustard) There is a disconnect in the wavelengths of certain minerals. The abundances are a consideration.
(Livio Tornabene) I'm not convinced that it's not a mixture of minerals. In a hydrothermal site, you can have mixing of several hydrous stages.

(Bethany Ehlmann) The relative band strength is fairly constant and we don't see weak absorptions. There's definitely mixing going on, due to the size of the CRISM footprint.

(Murchie): I believe it is a convincing identification although it's weak. This went through stringent peer review within the CRISM team before we released this theory. Expect physical effect of textural materials here as well as other places on Mars (like Banfield discussed yesterday).

(?) There is nothing that has structure at that wavelength that would be due to instrument artifacts. We believe this is a convincing interpretation of carbonate even though it is weak.

(John Grant) Are there minerals accessible within the ellipse or in the rover traverse?

(Bethany Ehlmann) They were presented for regional context. These detections are on both sides of trough relative to landing site ellipse.

(Eldar Noe Dobrea) The nontronite spectra varies. I'm worried about instrumental effects and the use of denominator in ratioed spectra.
(Bethany) We are very confident that these mineral signatures are distinct. There is carbonate here because of the interaction of water with olivine.
(Comment): Not proposed as sedimentary carbonate package, but it's weathering of olivine.

Brief description of instruments in the MSL Payload

(John Grotzinger): If there's organic matter, can we detect it? Is payload capable of doing this in context of science?

(Paul): SAM has very sensitive ppb of methane (Nili may be hot spot). Two fundamental experiments with SAM are atmospheric science and ground releasing chemicals. Position of evolved gas helps us understand carbonates, hydrated minerals, etc. Highly refractory material may not release carbon efficiently. If efficiently released, can get 1 to 10 ppb detection. Sam also has combustion capability and the mass spectrometer can see sulfur isotopes.

(Dave) (CheMin): For almost all minerals, there's a 3% detection limit. CheMin gives us quantitative abundances of minerals. Around 12% or above gives us quantitative amount plus or minus 2% of the abundance. Able to detect smectite but can't tell what kind of smectite, but xray fluorescence data can help. Qualitative XRF data of Fe or Mg present could help determine type of smectite. For any mineral present with abundances greater than 12%, we can do refinements, and for olivine, we can see total Fe and Mg present in structure. For carbonates, we can see amount of calcium present. Amorphous materials will look like glass. Glassy materials can semi-quantitatively be detected.

(ChemCam): Small spot size less than 1 mm. Multiple laser spots can remove dust remotely. Other instrument can give context of small spot. Capability to see major elements, including C and N. Carbon line is 248 nm (in UV) and plan to see carbon from chemcam at several % level. Sensitive for minor and trace elements (lithium, strontium, etc).

(APXS): Expect same as MER but with higher precision.

(Ken) (cameras): Molly is being calibrated now and can get at close focus 2 cm from target, get 14 microns per pixel. Can change focus out to infinity. Double MI resolution. RGB full color. LEDs for night. MARDI has been delivered and on rover now. RGB. Image during descent at mm/pixel when just above surface. After touchdown, instrument not designed to operate during surface mission, but trying to change that so it can be operated at 1-2mm/pixel.

(Jim Bell) (MastCam): Lost zoom capability because of descope. Revised system has two cameras. One is 34mm focal length with slightly better than Pancam resolution. Other is higher mm fixed focal length zoom, with high power 2-3x Pancam resolution. Can work as stereo pair (use center of wide angle view). Both have RGB and contain narrow band filters so can get some mineralogic diversity for iron minerals. Each camera has 8 filters, one is solar, one is blind, others are narrow band filters. Both have huge buffer; you can take movies if you want. Limited remote sensing mineral discrimination capability.

RAD (Radiation assessment detector): Atmospheric instrument looking at radiation and solar energy particles. Measure albedo and hydrogen ratio deposits on surface.

(Ashwin) (DAN, a neutron spectrometer): Active neutron detector that can detect on the go but can do stationary measurements for 30 minutes and gets 1% water detection. Sample acquisition has powdering drill (1cm drill bit) and delivers to analytical lab instruments. Drill goes from 0-5cm depth. Sample collected from about 2-5cm depth (lose first 1cm). There is no rock abrasion tool on MSL, but we do have a brush. Can sieve sample to 1mm size fraction for SAM. Also have a scoop, and can sieve scooped samples. Both can be places on observation tray and use contact instruments to study.

(Hynek): What's the status of cache?
(Meyer): Don't know status of it.

(Horton): ChemCam can look at very thin weathering rinds.

Discussion of MSL Payload and Voting

(John Grotzinger) The *diversity* and *context* voting criteria are the most tangible questions. Habitability is gut instinct.

(Jeff) Are these equally weighted?

(John Grotzinger) We want a majority of people to feel that the sites that end up above the bar, anyone would be happy with going to any of those. Preservation is more quantitative. Weighting should be toward the diversity and context, less on habitability and preservation.

(Ashwin Vasavada) The result of the workshop is to get red/yellow/greens so none of the sites will be reduced to a single number.

(Jack Mustard) As MEPAG chair, thinking long term, we don't want to get into a blanking situation where preservation of bio-signatures is the number one requirement, because as we know, the preservation of bio-signatures on Mars is difficult. We don't want to walk out of this meeting thinking that MSL is going to detect carbon compounds that must surely be there. Be aware we don't want to get in Viking situation where excitement towards preservation leads that to be level 1 requirement. Detection of carbon compounds is not a level 1 requirement. Be cautious that we don't leave here thinking

MSL will go just to find these carbon compounds. Diversity and context should be topics that influence us most and then opportunity for habitability and preservation are added bonus.

(John Grotzinger) There is nothing that I want to prevent more than to say we are going to find bio-signature on Mars. The chance that this happens is really small because it doesn't work on Earth very often. On Mars, it's only harder. Our goal of the mission is to investigate habitable environments and the instruments will allow us to ask questions about taphonomic windows. After discussion and voting, want majority of people to feel happy with any of the sites above the bar. Issue of preservation is a little more accessible. Can make observations about minerals used to preserve things. Weighting should be more on context and diversity – most important for picking a good field area. [Go over questions for voting]. Is it really just an issue of abundance to characterize diversity? Space and time is important for relative chronology. When biomass is preserved on earth, minerals we see better be contemporaneous with time organics are there. If minerals come after organics, we have a post-depositional alteration event. Do we want that? If fluids in cracks, are minerals we see contemporaneous with organics? Taphonomic window is important here. Can timing be relatively established? We may not know that for any of these sites. Most people think about oxidizing issue, but did we think about high water/rock ration issue? Additional water after organics trapped is not a good thing.

(?): What does a green mean on last point? Is it detrimental or not?

(John Grant) In terms of the discussion of these sites and the guidelines for voting, the science community does not "pick" the landing site. The PSG and The Project take our input and recommends the site, and it's NASA headquarters that selects the site. This is our opportunity to participate. We need to be relevant to be included. Think about the kinds of questions that The Project and NASA headquarters put forward and evaluate those against each of the proposed sites. We are not trying to get to a magic number of sites at this meeting. Instead, what are the top three sites? What are the bottom three sites?

(Matt Golombek) We are not going to prioritize the sites at this point. This is a "quartile" evaluation.

(John Grant) That being said, the sites are not all equal, so need to evaluate them.

The Project Lunch Meeting

(John Grant) In general, people are not raising new issues. After lunch, we don't want to revisit the discussion of the sites. We will provide a summary of the sites then we will vote using paper ballots. The votes will be a straight average of the scores and we will also use a weighting function to say, "how green was it?" Something like green is 5 points, yellow is 3 points, and red is 1 point. Do you think that the sites were discussed fully given the constraints of the three-day workshop?

(?) Yes, I think we are reaching the limits of the discussion.

(Alfred McEwen) The discussions will spur people to look back at data.

(John Grant) We need to guide the discussion so the major points are out there for general consideration. We are not going to discuss sites again this afternoon. I am thinking ten minutes per site to get a basic overview, 1-1.5 hours total before we vote.

(David Des Marais) How long should the written summaries of the sites be? Should we focus on question and answers?
(John Grant) A half-page to one page maximum. Capture the major points.

(John Grotzinger) With a silent ballot you might expect less yellow votes.
(John Grant) I think it's going to harder to game the system with the paper ballot. There won't be obvious "block" voting.

(John Grotzinger) There will be green, yellow, red votes for each site?
(John Grant) Yes, I don't think it will take very long because most people have already made up their mind.

(John Grotzinger) Have you seen the "Is Eberswalde really a delta?" poster?
(Alfred McEwen) Yes, but I don't think it's a serious challenge to that site.

(Alfred McEwen) I think we need to define red, yellow and green.

(Jack Mustard) At the last workshop, we need to be strong in our use of red, like the lowest percentile. We should instruct people to polarize as much as possible.

(John Grotzinger) In your experience, how do these sites compare to previous missions?
(Ken Tanaka) There are pros and cons for each site but the amount of information we have far exceeds anything we had in prior missions.

(John Grant) What's your sense?
(Alfred McEwen) These are great sites. We (HiRISE) can't complain about the image requests. I am slightly concerned about the safety of all of them.

(John Grant) In general, do you think that the sites reflect the diversity?
(Jack Mustard) Places like Eberswalde weren't even on the global mineral map before CRISM. Do we have on the table some of the most intriguing sites? Yes, I think so, of the places where we can safely land. There are some stunning places with much better signatures than Eberswalde, for example, but we can't land there. So, we are well represented.

(Matt Golombek) Is there anything about this landing site selection process that needs improvement?

(Alfred McEwen) There are lots of flaws but like democracy, no one can come up with a better solution.

(John Grotzinger) I think the experts on each site should have to swap and promote different sites!

(Jack Mustard) I don't think that the effort put into these sites will be lost, but perhaps MRO resources should be directed toward future missions.

(Matt Golombek) NASA has already agreed to help the ExoMars mission with site selection.

(Jack Mustard) If we can get fifty places on the table now then we can start asking for data.

(John Grant) We need to advertise; give people incentive to work up results.
(?) There is a tremendous amount of data already out there to start with landing sites
(Alfred) Some of the interesting sites are in the shadows of the orbits for current landing sites so they are not getting imaged by HiRISE.

(?) How will the sites be tabulated?
(Matt Golombek) The most voted color for that item and an average red, yellow, green score. Between those two modes, you can tell pretty well. After the vote at the second landing site workshop, there were some sites that a few people felt should be considered more (e.g. Vernal), so discussion followed the voting results. There will be around 150 ballots so we'll break into seven teams of two people to count them.

(John Grant) We'll provide a cover sheet with groups and once you've done the votes for your site, you'll make the cover sheet.

(Matt Golombek) We will have two computer counters.

(John Grant) We will kick people out and have the counters spread around the room.

Summary of Landing Sites, Questions, Discussion and Voting

Matt Golombek and John Grant
Site Evaluations, Voting, and Ranking

- Overview of each site by John Grant and Matt Golombek
- Location of sites on a global topographic scale
- MOLA view of each site with landing ellipse

HOW TO VOTE
(John Grant) Vote red, yellow or green for each site.

Miyamoto crater (summarized by Golombek)

- Probable Noachian crust with phyllosilicate signatures
- Inverted channels on top of phyllosilicate deposits
- Diverse mineralogy to east (sulfates) and chlorites well to the west

Questions:

(?) Has anyone considered the uplink situation with Opportunity in the same place?
(Matt Golombek) I don't think so, but that shouldn't be an issue.

South Meridiani (summarized by John Grant)

- Hematite abundance and likely sulfates
- Incised upland surface characterized by phyllosilicate signatures

(Bryan Hynek) Are there rocks or layers within the landing ellipse or are they hematite plains?
(Matt Golombek) There are ripples with underlying light-toned materials that are likely sulfates. The hematite concentration is high on the plains, and is enhanced by the lag of spherules. Small craters within the landing ellipse offers tens of meters of exposed section. Outside the landing ellipse on the uplands, there is a series of phyllosilicates with uncertain stratigraphic correlation.

Nili Fossae Trough (summarized by Matt Golombek)

- Basal unit is sedimentary infill overlain by Hesperian volcanics, overlain by ejecta from Hargraves crater (phyllosilicate detections, on the order of tens to hundreds of meters in thickness)
- Science objectives are in re-entrant, varying mineralogy and morphology
- Erosion by fluvial activity

Questions:
(Jim rice) How far are you from the re-entrant?
(Matt Golombek) About 10 -12 km to re-entrant from the center of ellipse.

(Jim Bell) Is there evidence for sulfates at this site?
(Jack Mustard) No, there is no evidence for sulfates. There are diverse phyllosilicates and possible carbonates.

(?) Are the carbonates in the ellipse?
(Matt Golombek) No, they are not in the ellipse. The carbonates are within a kilometer or two from the edge of the ellipse. The carbonate detection occurs in blocks.

(Oded) Are all the phyllosilicates consistent with deep alteration or are any consistent with surface alteration?

(Jack Mustard) In the large stack, we think we are seeing Isidis basin ejecta. We also have surface processes creating the kaolinite and carbonate unit, which left behind a record of mineral alteration.

Holden crater (summarized by Matt Golombek)

- Noachian crater impacted on the Uzboi-Ladon-Movara system
- Well-exposed light-toned layered deposits that are flat-lying, finely bedded, and are associated with a phyllosilicate signature
- In the ellipse, you have access to alluvial fans and raised ridges
- Geologic context is strong; there is a good timeline on the drainage system and the impact of basin and rim breach
- Phyllosilicates are positively identified in the light-toned layered deposits south of the ellipse; there are possible phyllosilicates in the fans
- Megabreccia bearing wall-rock unit another 5 km outside ellipse

Questions;
(?) How far is Eberswalde from Holden?
(John Grant) [Points to the MOLA topographic map]

Eberswalde crater (summarized by John Grant)

- Delta to the north of Holden, fed by valley
- Ellipse on crater floor
- Proposed crater lake
- At least one outcrop that might be related to Holden ejecta
- Phyllosilicates signature within delta and scattered in materials along crater floor
- Well defined source-to-sink
- Pre-existing knowledge of where to look for fine-grained versus course-grained material based on terrestrial studies of deltas

Questions:

(Steve Ruff) East of the delta there were inverted channels. How do those factor into the nature of the floor? Can you elaborate on the inverted channels?
(Kevin Lewis) The channels flow the opposite direction of the delta and they are also in the landing ellipse. There are other inverted deposits on the south rim. There is no clear stratigraphic relationship between the channels and the main delta. They aren't all at the same elevation.

(Dave D.) Why would you have such different depositional events in two craters (Holden and Eberswalde) that are so close in space and time?
(Oded) One of the main differences between Holden and Eberswalde and why the delta is far more extensive in Eberswalde is because its basin is significantly smaller than the discharge rates in Eberswalde. The discharge amounts for that drainage system is 20 times the volume of Eberswalde. When you compromise, you can have either the good parts of both or the bad parts of both. If you go to Holden, the certainty with which you can identify the targets of fluvial sedimentary deposits decreases.

(John Grant) While you can identify the environment, the beds in Eberswalde are much more eroded.
(Jim Rice) There's no delta in Holden crater.
(John Grant) An alluvial fan is a delta. There are certainly fan deltas related to a higher energy event (e.g. Uzboi discharge) in Holden.

Mawrth Valles (summarized by Matt Golombek)

- Noachian in age
- Large phyllosilicate exposure; at least 200m of phyllosilicate bearing materials with different chemistries between units
- Well-bedded and high correlation between layers, morphology of the beds and chemical differences in the phyllosilicate signature
- One of the only sites where the ellipse is located directly on top of the science you want to access

Questions:

(Tim Parker) You potentially have access hundreds of meters to kilometers of section in the Mawrth Valles trough.
(Matt Golombek) That would be important to determine the nature of the materials.

(John Grant) Sequence in Mawrth Valles was repeated up to 1000 km away, so this site is typical on a regional scale.

(Matt Golombek) James Wrey identified groundwater features leaching along fractures, which are also in the ellipse.

(James Wrey) The hydrated silicates are chemically diverse.

(Pan) Is there anything known about atmospheric effect on SAM?
(Matt Golombek) Albedo has a direct impact.
(?) We assume that the materials are well-vented.

Gale crater (summarized by John Grant)

- Alluvial materials in the ellipse
- Well bedded materials several kilometers in thickness
- Both phyllosilicates and sulfates
- Uncertain age of mound; but crater is Noachian in age
- Dustiest of the sites
- Objective to characterize a type-section for mars
- Unusually low elevation crater; hard to keep water out of a crater

Questions:
(F. Poulet) What kind of hematite?

(Ralph Milliken) There is an absorption at 0.86 microns. Not the fine-grained hematite, it is likely micron/crystalline hematite.

(Oded) The origin of the layered mound in Gale is suggested to be aqueous but aeolian processes can't be ruled out. Aeolian processes here might even be more likely due to lack of morphological evidence such as valleys and rim dissection. This is a terrific site with mineral diversity with access to many materials, but the mineralogy might not be indicative of the environment.

(Ken Edgett) There are lots of crater on Mars that have been filled and exhumed. If any of these kinds of places were lakes, how would we ever know without going there? Only Eberswalde is a certain lake environment. When are we going to test this hypothesis?

(Hugh) With the timescales we have here, there's time to seal lateral permeability.

(John Grotzinger) I don't think it's profitable to worry about transport of altered material vs. alteration of material in situ. Rather, if you have those minerals, what hay could you make with the payload?

(?) I have not seen evidence of standing water at any of the proposed sites.

(Jack Mustard) Nili has diversity of environments that are represented by the crust and fill materials.

Final Votes

Top: Eberswalde crater (44.53), Holden crater (43.2), Gale crater (41.95)
Middle: Mawrth Valles (37.92), Nili Fossae (37.08)
Bottom: South Meridiani (28.30), Miyamoto crater (23.84)

Post-vote Discussion

(Diana) Is there time for further argument now?
(John Grant) Everyone had the same opportunity to make their case. What we've done here is identify two sites in the bottom, two in the middle and three at the top. Any of these sites are compelling and we will start to focus our efforts in data collection. We can't say here which are in the final three.

(?) Will we have the opportunity to give input into the format of the next workshop?
(Matt Golombek) We would love to have input, please email John Grant or me.
(John Grant) We circulated the eleven questions that were used to evaluate the sites in the steering committee and they were also posted on the marsoweb website before the workshop. We definitely want input into the next workshop.

(Matt Golombek) The next workshop will have far more information on the nitty gritty engineering aspects which were kept separate from this workshop to isolate the science vote.

(?) Thank you for putting up the PowerPoint presentations so rapidly on marsoweb.
(John Grant) Ginny Gulick and Trent Hare are responsible for that.

(Jack Mustard) Can we go back to the "fever chart" for a minute? The first seven questions are the ones that should make a significant difference, whereas the last 4 questions relate to habitability and preservation.
(Matt Golombek) Even if you only look at the first seven questions, the results on the fever chart are still the same as the overall trend.
(John Grant) The difference between #3 and #4 are small and might switch places. But the difference between #1 and #7 is real, as is the difference between #2 and #6.

(Steve Ruff) The voting process forces our views into the views expressed on the fever chart. Why didn't we rank these sites 1-7 in terms of our personal preference? You're forced to respond to each question that may not be germane to how you factor the vote.
(Matt Golombek) We wanted a more systematic vote based on the goals of the mission.

(Steve Ruff) What more did we learn and how will that ultimately affect the fever chart?
(John Grant) We can't give you an answer to that. That was the reason for posting these questions before the workshop.
(Matt Golombek) We are not interested in your favorite site. We are interested in how you think each site relates to the goals of the mission.

(Horton Newsom) We will focus on what additional work needs to be done on particular sites. Some top sites fell down a bit and we need to pay more attention to them before final decision is made. I think we collected useful data.
(John Grant) This is not the decision. This is something that factors into the decision.

(Pan) Are the sites that got reds and yellows off the table at this point?
(Matt Golombek) At the next landing site workshop in April, it will be of the down selected three based on the concatenation of the engineering constraints and the science.
(John Grant) Discussions will not include the bottom two sites relative to what we see for the other five.

(Pan) The point is to give you the scientific input.
(John Grant) My guess is that there will be a shoot-out between Eberswalde and Holden since both are at 30 degrees south.
(Matt Golombek) One site has all the science in the ellipse.
(John Grant) We're helping evaluate the science, and that information gets put into the "hopper." The scientific community voted among relative equals and this is the result. There are lots of situations that might lead to different sites being picked. Our job was to say how we felt about these different sites in different areas.

(John Grant) You have to weigh the compelling nature of the science in the ellipse vs. how far the compelling science is outside of the ellipse.

(Watkins) We don't know exactly how it's going to play out at this point. There will be more information and we'll take it as it comes.

(John Grant) Steve, you're right if it's literal. But we're not splitting hairs that finely at this point. I don't think that would have altered where these sites ended up.

(Charles) How can you differentiate between Holden and Eberswalde?
(John Grant) It's going to have to happen, but we are not having that conversation right now. It's not just the PSG input, they will put a layer over the top of this.

(Charles) With two sites at the same latitude, would you want to vote between them?
(John Grant) The community feels that both Eberswalde and Holden are compelling and whichever one goes forward will be okay.

(Michael) Were there any that were diverged in the vote? Bimodal votes?
(Matt Golombek) No.

(James Wrey) If we disagree with fever chart, can we debate it right now?
(John Grant) You can provide us input but we are not going to vote again.

(James Wrey) Should we talk about parts of the chart that should be re-evaluated?

(Hugh) If you have constructive feedback on the process, those should be expressed?

(John Grant) We appreciate that a lot of people are here on their own dime and we realize that it's hard to devote a lot of time besides in the landing site meetings themselves. In that way it is sometimes hard to get feedback.

Documentation of the Third MSL Landing Site Meeting
These meeting notes were compiled during the meeting by Sharon Wilson Purdy of the Smithsonian Institution (purdys@si.edu) and Jennifer Griffes of Cal Tech (griffes@gps.caltech.edu). This document captures the presentations and discussions throughout the workshop; nothing was purposely omitted and there was no intention to misrepresent any of the participant's comments.