MINUTES OF THE 11th MARS CRATER CONSORTIUM
SEPTEMBER 29-30, 2008 USGS, FLAGSTAFF, AZ

Attending: Don Barker (NASA/Johnson Space Center), Nadine Barlow (Northern AZ Univ.), Dan Berman (PSI), Joe Boyce (Univ. HI), Veronica Bray (Univ. AZ), Trent Hare (USGS Flagstaff), Rose Hayward (USGS Flagstaff), Ken Herkenhoff (USGS Flagstaff), Andrea Philippoff (Univ. AZ), Audrey Rager (Univ. NV Las Vegas), Stuart Robbins (Univ. CO Boulder), Jim Skinner (USGS Flagstaff), Larry Soderblom (USGS Flagstaff), Tom Stepinski (Lunar Planetary Institute), Ken Tanaka (USGS Flagstaff), Livio Tornabene (Univ. AZ).

Minutes derived from N. Barlow's notes.

Monday, Sept. 29:

Barlow welcomed everyone and gave a brief history of the Mars Crater Consortium (MCC). Following introductions and a brief summary of each attendee's research projects, participants discussed recent meetings of relevance to the MCC. Barlow discussed the August Large Meteorite Impacts IV meeting in South Africa, which included a 2-day field trip to the Vredefort Structure. Vredefort has recently been declared a World Heritage Site and several ceremonies related to that designation were held in conjunction with the meeting, including the official opening of the Vredefort Interpretation Center and minting of a commemorative gold coin. Tornabene reported on the September 18 MEPAG meeting, which included discussions of the selection of MAVEN, an update on MSL, Phoenix results, and planning for Mars Sample Return. Tanaka attended the International Geological Congress in Oslo in August, which included a session on geologic time scales. A proceedings volume will be published by Cambridge University Press and includes a chapter on geologic time scales throughout the solar system by Tanaka and Bill Hartmann.

Software Tools, etc.

Hare updated the group on the latest GIS and on-line tools available for planetary studies.

- The latest edition of the GIS Handbook includes a chapter on Planetary GIS.
- The latest version of ArcMap (version 9.3) is now out. This latest version allows the user to generate GeoPDFs.
- By 2011, all geologic maps published by USGS must be submitted in GIS format.
- USGS is holding GIS workshops to help train planetary mappers on how to do their maps in GIS. A 1-day workshop was held in conjunction with the Planetary Mappers Meeting in June and a 2-day workshop will follow the MCC. The nice thing about putting everything in GIS is the ability to overlay various layers.
- Adobe Acrobat 9 can now open and manipulate GIS files. Users can now make a GeoPDF with any level of ArcMap.
- Google Earth is coming out with Google Planets which will show all the planets. However, Google Planets does not provide topographic data, whereas WorldWind does. But GoogleEarth runs on Macs. It is stilll very limited in terms of doing more than just zooming in, panning, etc.
- JPL has the following Mars (http://OnMars.jpl.nasa.gov/) and lunar (http://OnMoon.jpl.nasa.gov) online applications.
- PlanetaryGIS.org: new site which links to many Mars GIS datasets.

- WorldWind is developed by NASA and is open source. It works on all platforms. It has a Java form which has all the good plugins, etc.
- FWTools: GDALOGR subpackage is a library and set of utility applications for reading and writing a variety of geodatabases. Can transfer one vector file into another (i.e., converting shapefile to kml). Ogr2ogr command does this. User can then superimpose file onto Google. GDAL is for rasters; supports ISIS 2 and 3.

Science Presentations:

Stepinski: Completion of the first automatic survey of craters on Mars

- Machine survey of craters based on MOLA topography. Builds adaptive computer systems that are able to improve their competence and/or efficiency through learning from input data or from their own problem solving experience.
- There are some craters which the survey missed. Accuracy at different surfaces is different. False positives and false negatives are present.
- Measurements:
    - All measurements are approximate
    - Crater size is the diameter of a circle having area equal to the are of identified depression
    - Crater depth is the largest elevation difference within a depression
- Cannot be used in studies requiring great accuracy but can be used for statistical purposes.
- For global survey, divided planet into 300 overlapping equatorial tiles and 56 polar tiles. Included 75,919 craters. Each entry has center's coordinates, diameter, depth, underlying geologic unit, elevation. Complete down to ~3 km diameter.
- In general, has found more craters in 3-10 km diameter range, but Barlow catalog still has more in larger diameter ranges.
- Upcoming: surveying sub-km craters based on shadow identification.
- Open issues:
    - Machine Survey:
        - Further review and comparison with existing catalogs
        - Possible application to HRSC-derived DEMs
        - Adding more features and measurements.
    - Scientific results:
        - Global distribution of crater depths—what does it mean?
        - Why deepest craters are in the lowest regions?
        - What is the meaning of the shallow craters in the northern plains?

Robbins: MOLA Data may introduce significant artifacts in crater diameters

- Creating a new crater database. Interested in Arabia Terra and the adjacent S. Highlands. 32,310 craters in region of interest.
- Identification of the craters: THEMIS based—day IR mosaic overlaid over Viking MDIM mosaics.
- Uses ArcGIS.
    - Convert vertices into km from average lat and lon of each crater
    - Use a non-linear least-squares algorithm to fit a circle
    - Used enginvectors to fit an ellipse

    - Saved number of points ued.
- Step 2: Determine depth
    - Used MOLA MEGDR data at 1/128 deg per pixel
    - Used Igor Pro software, which showed region around each crater along with central latitude/longitude marked
- Avoided interpolation artifacts (i.e.,where gaps existed in MOLA data).
- Types of depths measured:
    - Rim to floor depth
    - Pre-impact surface estimate
    - Lowest positions on floors
- Igor recorded each polygon vertex in matrix index—needed to derive crater properties.
- Take mean elevation and standard deviation of each polygon.
- Saved derived data produces: rim height, rim-to-floor depth, floor depth below surface.
- ~25000 craters could be analyzed with MOLA.
- See offset between THEMIS and MOLA derived diameters, especially at lower D (where MOLA data is iffy). But also see offset at larger D.
- Comparison of Robbins' THEMIS data with Barlow catalog shows no major differences except at 5 km.
- Comparison of Robbins' MOLA data with Stepinski's catalog shows more offset. Generally Stuart's results were slightly smaller than Tom's.
- Possible explanation?
    - Wall just interior to crater rim has steepest gradient.
    - Steep gradients are the least likely to return a signal to MOLA
    - Woith a lack of return the data product would e interpolated.
    - Interpolation would shift the location of the rim "outward" by 1 px in radius
    - This could account for up to 2-px widening, which could account for most of our observed offset.

Hare comment: MOLA discrepancy could simply be due to fact that MOLA often misses the exact highest point of the rim. Take count data and use nearest neighbor analysis to determine how many pixels off from the actual rim.

Boyce comment: Must really understand what MOLA is measuring and the problems before conclusions can be drawn from such studies.

Rager: Proposed experiments on the effect of rapid decompression on the fragmentation of basalt with implications for the formation of Martian rampart craters (poster)

- Modeling layered ejecta formation. After ejecta curtain passes, material behaves like a pyroclastic flow, so use the physics of pyroclastic flows.
- Continuum of fluidized ejecta. Is including:
    - Role of volatiles
    - Fines
- Using lab facilities in Munich to test fracture strength of rocks. The equipment measures rock strength as well as the process of fragmentation.
- Currently looking at effect on rock fragmentation from the transition of CO_2 from gas to liquid phase. Want to later include water into the experiments on the fragmentation of materials.

Robbins: Depth/diameter ratios of 2.5+ km craters in Arabia Terra, Mars, and hints at refining the region's history

- Tested 2 ideas regarding the unique characteristics of Arabia Terra:
  - Region of massive erosion and deposition that occurred early in Mars history
  - Exposure of basement rock
- Massive erosion:
  - If this is true, it should be reflected in the old impact craters in 2 ways:
    - SFD plot should show a larger deficit of craters <~10-20 km
    - Craters should be ~1 km shallower than those in neighboring S. Highlands
- Basement Layer:
  - SFD plot should show "pristine" Noachian surface
  - Should be shallower due to them having been buried and not entirely exhumed
  - Thickness of crust should be same as the northern plains
- To test, need:
  - Craters in Arabia Terra and neighboring S. highlands
    - Crater diameter
    - Crater depth
  - Crustal thickness data.
- Results on incremental plot (3440 craters in Arabia; 7137 craters in southern hemisphere)
  - above 50 km:
    - Arabia: b = -1.76
    - Southern Highlands: b = -2.14
  - In 5-50 km range:
    - Arabia: b = -0.85
    - Southern Highlands: b = -0.33 below 20 km; b = -0.66 up to 50 km
  - For D <5 km:
    - Arabia: b = -1.15
    - SH: b = -1.21
- Results are opposite of that predicted by Massive erosion idea.
- For the southern highlands,
  - Deepest craters are deeper than the deepest craters in Arabia by ~100 m
  - There is a dichotomy between the deepest and the shallowest craters in southern highlands. It is not a continuum like in Arabia
- Crustal thickness is "middle ground"—not as thin as northern hemisphere and not as thick as southern highlands.
- Arabia Terra has more craters than the Southern Highlands per unit area for craters in the ~2-10 km.
- Proposal:
  - Arabia Terra and Southern Highlands form ~same time, resulting in formation of oldest craters.
  - Southern Highlands experience massive obliteration of crater <40 km in diameter at ~4GY while in Arabia they are buried and protected.
  - Arabia is exhumed ~3 GY ago.
  - Craters build up again on both terrain units.
- Density of craters >40 km is identical on the southern highlands and Arabia. But at lower diameters, Arabia has higher crater density.

<u>Berman: Degradation of mid-latitude craters on Mars</u>

- Previous work: survey of craters in 2-20 km diameter range with respect to gullies. North of 44°S latitude, most gullies were pole-facing. South of 44°S, gullies were equator facing. Craters with arcuate ridges followed this same trend. Typical trend: Rim with gullies/ridges was lower than other rim; floor sloped from high on rim with gullies/ridges downward toward opposite rim.
- What about larger craters? Often see tongue-shaped lobate flows in larger craters.
- Project consists of two study areas:
    - Eastern Hellas (30-60S, 110-150E)
    - Arabia Terra Region (30-50 N, 0-40 E)
- Features of interest:
    - Lobate flows
        - 24 craters in Hellas; 6 craters in Arabia
        - Raised ridges at lateral margins
        - Equator-facing gully walls found south of 45°S latitude
        - Most craters with lobes are in the 30-70 km diameter range
    - Channels
        - 21 craters in Hellas; 19 in Arabia
        - Erosional landforms
        - Often breach crater walls and extend outside craters
        - Sometimes infilled by mantling deposits
    - Valleys
        - 16 craters in Hellas; 23 in Arabia
        - Simple branching patterns, are flat floored, and sometimes are filled with rough-textured material
        - Widen downslope
    - Alcoves
        - 13 craters in Hellas; 43 in Arabia
        - Sometimes see alcoves without gullies
        - Gullies are not as common in larger craters
    - Debris flows
        - 9 craters in Hellas; 33 in Arabia
    - Gullies—previous study
    - Arcuate ridges—previous study
- Features are commonly found together. Suite of degradational morphologies consistent with flow of ice-rich materials.
- Latitude dependence for lobate flows, alcoves, and debris aprons
- No latitude dependence for channels or valleys
- Lobe measurements in E. Hellas:
    - 54 lobes in 22 craters
    - Lengths: 1-7 km; mean 4.5 km
    - Thicknesses: m to 10's m
- Rim height and floor slope trends seen in smaller craters are seen in larger craters, but are not as obvious. Hence, degradation model consistent but more complex in larger craters.

- Pole-facing orientations for lobate flows, gullies, and arcuate ridges are prevalent in 30°S-45°S latitude zone. Equator-facing orientations are more prevalent between 45°S and 60°S.
- In larger craters, sloping crater floors interior to walls with glacial and/or fluvial features are consistent with previously described model for crater degradation developed on basis of characteristics of small craters.
- Orientation dependence suggests direct relationship to difference in total solar insolation.
- Features may all stem from multiple cycles of deposition/erosion of ice-rich materials.

Boyce: Preliminary assessment of the morphometry of martian impact crater ejecta deposits and their implications

- Objective: providing deeper insights into the causes of ejecta fluidization on Mars.
- Approach:
    - Characterize the detailed morphology of ejecta deposits of fresh martian craters, particularly the small-scale flow related features and their patterns
    - Compare and contrast the morphology data with findings from published granular flow studies as analogs to test and develop models of ejecta fluidization that connect morphology to process
    - Go from process to environmental conditions
- Recent advances in granular flow research have provided new insights into the rapid flow of both wet and dry particulate materials that can be used as analogs for the study of ejecta flow.
- Flow features common to ejecta blankets:
    - Hollows and closed depressions
    - Ramparts
    - Secondary craters
    - Radial grooves
    - Transverse ridges and troughs
- Transverse troughs and ridges: straight, chevron, and wavy patterns. Both layered ejecta and terrestrial landslides show similar scale and type features.
- Radial features: troughs and ridges. Possible formation mechanisms:
    - Divergent flow: stretching and ripping apart
    - Erosion by supersonic flow in blast surge
    - Shearing from differential flow
    - Longitudinal vortices generated by granular equivalent of convection caused by high granular temperature.
- For Double Layer Ejecta morphology, suggest that grooves and ridges are very similar from those created by supersonic flow in blast surge.
- Distal ramparts: (seen on all large flow deposits)
    - Rampart development by particle segregation—requires a variation in grain size in material. Large grains forced to top. Top part of flow moves more rapidly (lower part slows due to friction with surface) so larger particles are moved to front. Helps to slow the flow because of angularity, plus circulation within "toe" of flow. Water in flow promotes circulation of large particles in the flow. Water tends to create lower ramparts which are broader. For double layer ejecta,

rampart of inner layer is broader and lower than rampart for outer layer, Single Layer Ejecta rampart, or Multiple Layer Ejecta rampart.

- Secondary craters:
  - Some cases where ejecta layers have overflowed secondaries.
  - But in high resolution, see features which could be secondaries, although they could also be pits. Some of these "proposed" secondaries lie atop the ejecta layers.
  - See alot of pits along ramparts. These are probably not secondaries

Tuesday, Sept. 30:

Barlow: Central pit craters on Mars: Characteristics, Distributions, and Implications for Formation Models

- Central pit craters contain a central depression, either on crater floor (floor pits) or on central uplift (summit pits). Common on Mars, Ganymede, and Callisto, suggesting that target volatiles play role in formation.
- ~1600 central pit craters have been identified in this study. 50% are symmetric floor pits, 41% are summit pits, and 9% are asymmetric floor pits.
- Seen on all terrains in ±70° latitude range. Hint of higher concentrations in Xanthe, Margaritifer, and Arabia Terrae and around Tharsis and Elysium. No variation in distribution of floor pit craters versus summit pit craters.
- Both floor pits and summit pits are found in craters in the 5 to 60 km diameter range. Frequency peak occurs near 15 km.
- Wide range of preservational states (from 2.0 (degraded) to 7.0 (pristine)) indicating that pit formation has occurred throughout Mars' history. Fresh pit craters typically also display a multiple layer ejecta morphology.
- Floor pits tend to be larger relative to their parent crater than summit pits. The ratio of pit diameter (D_p) to crater diameter (D_c) ranges between 0.7 and 0.28 (median = 0.15) for floor pits and between 0.05 and 0.19 (median = 0.11) for summit pits.
- Most central pit craters on Ganymede are floor pits, but occur on updomed floor due to rebound of ice-rich target. Using MOLA, looked at topographic profiles of Martian floor pit craters—no updoming, suggesting low concentrations of ice (as low as the 20% ice values estimated from layered ejecta studies) can still produce pits.
- Models of central pit formation:
  - Collapse of a central peak in weak target materials
    - can be rejected based on (a) presence of summit pit craters where the pit lies atop a central peak, and (b) both central peak and central pit craters are seen in the same diameter and preservational ranges in the same regions.
  - Excavation into subsurface liquid layer
    - Supported by high concentrations of central pit craters in regions with high density of channels and chaotic terrain (i.e., Arabia, Xanthe, and Margaritifer Terrae).
    - Fresh central pit craters typically associated with multiple layer ejecta morphology. One possible mechanism of multiple layer ejecta formation is excavation into subsurface liquid reservoirs.

    - But distribution of central pit craters across entire planet suggests that liquid layer must exist within 5 km depth everywhere on planet.
    - Currently investigating if there is a relationship between crater size (and hence depth of excavation) with preservational state.
  - Vaporization of subsurface volatiles during crater formation
    - Modeling by Pierazzo et al. and recently by Stewart and Senft provide mechanism for central pit formation by this process.
    - Consistent with current observations of central pit craters
    - However, why are central pit craters located adjacent to non-pit craters of similar size and age? And why do some craters have pits on the floor while others have pits atop central peaks?

Tornabene: Hydrous silicates in terrestrial impactites: Implications for the formation of phyllosilicates on Mars

- Phyllosicilate clays and hydrous silica glasses occur together in the ancient heavily cratered and dissected Noachian terrains. Could phyllosilicate formation be process-driven rather than climate-driven? Do phyllosilicates = abundant long term water?
- Mars may have been cold/dry throughout much of its history with water only sporadically (intensely) occurring at or near the surface. Is it possible to form such hydrous phases under transient water conditions? Yes.
- Clays (particularly Fe-Mg smectites) are very common in interplanetary dust particles, carbonaceous chondrites, and impactites recovered from terrestrial impact structures.
- Big picture thus far: Martian phyllosilictates are
  - Mainly exposed by craters or in ancient bedrock not covered by surface deposits (surbsurace orign?)
  - Found in some finely layered deposits (Mawrth Vallis), fans and depocenters (craters)
  - Restricted to Noachian terrains (Appear to be—a restricted orbital view)
    - Most voluminous in Noachian? Less voluminous, or simply more difficult to detect, in younger deposits?
- Impact damage of crustal materials (in order of increasing shock pressure):
  - Consequence of high energy shock: Fracturing, pulverization, shock metamorphism, melting, and vaporization of target
  - Fracturing: increased porosity and permeability
  - Pulverization: (brecciation) smaller grain sizes = greater surface areas = increased susceptibility to alteration
  - Diaplectic glass: crystallization structure $\rightarrow$highly disordered material
    - Glasses (especially hydrated) unstable and alter more reaily than xtralline materials
  - Melting $\rightarrow$ glasses
    - Same as above
    - Hydrated melts common
- Study of 62 impact structures (D ~1.8-250 km) and a detailed petrographic SEM analysis of impactites indicate:
  - Phyllosicilates are abundant in terrestrial impactities
    - Especially within melt-bearing impactites

    - Hydrous silica melt/glasses (volatile-rich target)
        - Typically rich in other common elements and w/ up to 24 wt% H_2O
    - Terrestrial impact phyllosilicates formed predominantly by
        - Hydrotherm
            - Post-impact fluids and heat circulating and interacting with impactities or surrounding country rocks
        - Devitrification (and autometamorphism)
            - Direct, solid-state transformation unstable hydrous melt/glasses transformed by their composition and water content (autometamorphism)
            - Does not require post-impact water rock interactions to form clays
- Devitrification/autometamorphism could be more prevalent than hydrothermal as a clay-forming mechanism with respect to large impacts into volatile-rich targets!
- Large and numerous impacts + volatile-rich crust = hydrous melts → hydrous silicates
- Larger impacts produce prodigious melts. Peak shock, hence melting, is dependent on total energy yield, whereas size of a crater becomes dependant on gravity-scaling. Melt-scaling may explain phyllosicilicate bias to Noachian. Excavation flow causes pressure contours: larger craters produce more prodigious impact melt than smaller craters.
- Basins can create meters-thick ejecta deposits.
- Large scale phyllosilicate bedrock and outcrops near basins make sense. Exposure and redistribution by smaller impacts important locally. Impact-melt-distribution from largest impacts could be global (e.g. Chicxulub).
- Megabreccias in Nili Fossae correlates with Fe-Mg smectite-rich units. Suggests a possible impact-origin for some Nili Fossae hydrated silicates is likely. Suggests basin ejecta (melt-rich) from nearby Isidis Basin is present.
- Conclusions:
    - Melting is fundamental consequence of impact cratering
        - Scales with D
        - Volumetrically important part of Noachian crust
        - Most promising hydrothermal sites? Lasting 10^5 yrs
    - Is an impact origin for Martian hydrous silicates feasible? Yes
        - Terrestrial experience indicates abundant hydrous glasses and phyllos are present strongly associated with melt-bearing impactities
        - Similar hydrous glasses and phyllos detected by OMEGA and CRISM
    - Is it possible to form such hydrous phases under transient water conditions? Yes
        - Long term availability of water NOT required, just volatile-rich target materials for the production of impact melts
        - Mars may have not experienced a long-term warmer and wetter Earth-like environment
    - Does not rule out some long term water activity on surface and within basins
    - BUT standing water may have been metastable over sporadic and brief geologic periods of time
    - Impact damaged crust would be particularly susceptible to alteration over fresher materials

<u>Burt: Mars and the Late Heavy Bombardment</u>

- Mars, like Moon and Mercury, is an impact-dominated planet. Unlike them, Mars had an atmosphere and subsurface volatiles, so that the effects of impact were somewhat distinctive
- Most of the impact craters that we see probably date form the Late Heavy Bombardment (LHB) dated at ~4.0-3.8 Ga
- The observed Noachian period may actually have been rather short, corresponding to the period of the LHB, especially its latter stages.
- Many features of Noachian Mars are probably more intimately related to the LHB than is commonly recognized—eg, climate, sedimentology, and geochemistry.
- Possible effects of LHB
    - Excavation of giant impact basins, smaller craters
    - Ice and brine vaporization, followed by temporary greenhouse warming, followed by torrential precipitation. Acid and salt formation.
    - Impact glasses altered to Noachian clays.
    - Drainage networks, temporary crater-filling lakes, deltas, alluvial fans, etc.
    - Erosion, transport, and deposition of layered sediments (ballistic, impact base surge, fallout, wind/water-reworked, etc.). Widespread spherules.
    - Erosion of atmosphere and hydrosphere; Mars dried up and froze. Crater preservation.
- Post-LHB processes:
    - Continued impact cratering at a reduced rate (whole planet). Distinctive rampart craters.
    - Wind erosion (abrasion), transport, and temporary deposition (difficult to make a real rock).
    - Locally dominant early basaltic volcanism especially in Tharsis (overlapped with the LHB)
    - Catastrophic flooding in brine outflow channels.
    - Local landslides and debris flows, terrain softening owing to ground ice, glaciers (including rock glaciers). Ice caps and seasons. "Young gullies"
    - Negligible chemical weathering.
- Climate and climate excursions:
    - Early (pre-LHB) martian climate probably difficult to deduce
    - Martian hydrosphere and atmosphere were probably more massive than today.
    - Distance from Sun and small size of Mars suggests atmosphere was relatively thin and the surface icy.
    - During LHB, extreme climate excursions. Direct and greenhouse (H_2O) warming, rain, snow, acid (SO_2) generation.
    - Early volcanism also released CO_2, H_2O, SO_2; could have added to temporary greenhouse.
    - Most post-LHB climate excursions appear to have been minor; caused by variations in obliquity and orbit.
- Spirit tracks reveal acid sulfates. How are these stable? Phoenix measured soil to be alkaline; basalts are alkaline. Probably acid sulfates are result of freezing.
- Acids and salts on Mars:
    - Suface of Mars is salty. Sulfates exceed chlorides. Some of the sulfates are acidic.

- Acid sulfates typically are attributed to volcanism and evaporation of acid seas and lakes.
- Problem: In the presence of liquid water, acids react rapidly and completely with basaltic regolith.
- Therefore, acid sulfates imply almost ***NO*** liquid water since the time they formed and very little when they formed. Ice is OK.
- Two possibilities:
  - Fumarolic condensation from steamy, oxidizing, Fe- and S-rich impact cloud, or
  - Post impact oxidation of comminuted Fe-sulfides
- Late frost leaching may explain paucity of Cl-salts.

- Impact reworking of salts:
  - Earliest Mars probably had salty seas, as did Earth—rapid neutralization of acids released during planetary differentiation and volcanism.
  - Evaporation, or freezing (and sublimation) would result in salt crystallization, especially in subsurface regolith (beneath ice and brine)
  - Impacts reworked salts
- Hematitic spherules inside Victoria Crater
  - Sedimentary concreations or accretionary lapilli related to impact (probably reworked by later impacts)? If concretions, why are they so rarely clumped together?
  - Better interpreted as disseminated accretionary lapilli.
  - Hematitic concretions in Navajo Sandstone south of Page, AZ. Sizes vary greatly; clumping is common.
  - Concretions cut bedding in Navajo Sandstone.
- Impact sedimentation:
  - Ballistic ejecta curtain of crudely layered breccias, commonly with inverted stratigraphy.
  - Impact glasses, including suevite (glassy breccias). Glass favored by soft target, large impactor. Glass hydrates easily to palagonite and clays.
  - Spherules, including tiny glass condensates, tektites, and, if steam is condensing, accretionary lapilli. Size-limited, largely unclumped, high temperature.
  - Finely layered base surge deposits with cross-bedding, etc. Ballistic cratering. Roll out 100’s of km from large impact. Require atmosphere.
  - Fallout deposits; reworked deposits.
- Cape Verde cliff, Victoria Crater:
  - Dunes or base surge? To Burt, this angular unconformity appears to have resulted from an energetic horizontal surge, such as that provided by a blast.
  - No fine-grained crossbedding in terrestrial sandstone (Navajo); only cross-bedding is course-bedded.
- Rosenthal (Expectation) effect:
  - In its simplest form, just states that scientists see what they expect to see and find what they expect to find—that scientific results can easily be biased inadvertently.
  - This is why medical and psychological testing must be done “double blind” in order to be valid.

    - This is a difficult protocol for any scientific study where you have to spell out in great detail what you expect to find in order to obtain funding.
    - Studies of Mars, dating back to Lowell, probably provide numerous examples of this phenomenon. People **expect** Mars to be Earth-like.
- Summary
    - Partly for historic reasons, people expect Mars to be Earth-like. It is not. It is an impact-dominated planet.
    - The present-day surface of Mars was dominated by the effects of the LHB, that probably occurred over a relatively short period and whose effects included the preservation of its cratering record.
    - In addition to craters, the LHB could account for climate variations, clays, palagonite, drainage networks, ephemeral lakes, the distribution of salts, and the dominant forms of sedimentation. Later impacts reworked earlier sediments.
    - The effects of later volcanism, wind, and ice appear to have been largely superficial, except locally.

Mission Updates:

Boyce: THEMIS Update

- Spacecraft and instrument are generally in good shape.
- Moving orbit to time when we can get good themophysical data (esp. thermal inertia) and composition. Downside to the change is that it effectively wipes out GRS observations.
- Taking requests for targeted opportunities with THEMIS.
- Plans for a 9-10 band global mosaic at 100 m resolution.

Tanaka: MSL Update

- Third MSL Landing Site workshop was held Sept. 15-17. Aim was to narrow down number of landing sites for focused studies.
- From engineering standpoint, all sites are good at 95% confidence level. A few issues still to be worked out. Hence no engineering constraints put onto landing site selection at this time.
- Concerned with higher latitude sites because of temperature and lubrication of actuator arm.
- Final 7 sites:
    - Nili Fossae Trough (21.00N, 74.45E)—Noachian phyllosilicates
        - In trough
        - Mostly covered by ejecta from nearby large craters
        - Mineralogic diversity
    - Holden Crater Fan (26.37S 325.10E)—Fluvial layers, phyllosilicates
        - Part of large drainage system from Argyre.
        - Site is within detritus from rim material
        - Some dissected deposits from channels just outside ellipse
    - 4 sites in Mawrth Vallis (24.65N, 340.09E, 24.01N 341.03E (primary), 23.19N 342.41E, 24.86N 339.42E)—Noachian layered phyllosilicates
        - Phyllosilicates
        - Most of emphasis is on site 2
    - Eberswalde Crater (23.86S 326.73E)—Delta

        - Part of large drainage system from Argyre
        - Only site where everyone agrees there was standing water
        - Long period of deposition of the deltaic deposits, hence standing water existed for a long time.
        - Some ejecta from Holden in this area—underlies delta
    - Miyamoto (3.34 S 352.26 E)
        - Diversity of phyllosilicates and sulfates
        - Could drive up to Meridiani sulfate deposits within crater
        - Channel systems come in from south
    - S. Meridiani (3.05S 354.61E)
        - Land on Meridiani sulfate-rich deposits; can drive up to diverse phyllosilicate deposits in nearby highlands.
        - Could have stratigraphic sequence, but not as clear as other sites
    - Gale Crater (4.49S 137.42E)
        - Land on plains between rim and central deposit
        - Could navigate into channel within deposit, which could take us up the stratigraphic sequence.
        - Two stratigraphic layers
            - Lower section is ~2 km thick
            - Upper section is ~3 km thick; could be eolian
- Some presentations included potential traverses.
- 3 tiered voting system (green, yellow, red).
    - Miyamoto and S Meridani basically taken out of running by this vote.
    - Eberwalde and Holden are strongest sites, followed by Gale, Mawrth, and Nili.
- Landing ellipses have radius of ~10 km.
- Launch expected Sept. 2009.

<u>Herkenhoff—MER Update</u>

- Update of activities in the past year (since last MCC)
- Status of rovers:
    - Pancam severely affected by dust; Mini-TES on Opportunity is so covered it is essentially useless. Some contamination of MI and Hazcam.
    - Shoulder actuator on Opportunity arm basically makes it unusable so not stored anymore.
    - Recent current spike in front wheel on Opportunity—led to exit from Victoria Crater ASAP.
- Spirit at Home Plate. Not too much of an update since just waiting out winter.
    - Spent last 3 years around Home Plate.
    - Low angle; cross-lamination—favored interpretation: volcaniclastic, perhaps base surge, but cannot rule out impact.
    - “Kenosha Comets”: APXS measured ~90% SiO_2; result of fumeralic leaching of basaltic clasts, or precipitation from hydrothermal fluids? Aqueous conditions implied in either case.
    - Spirit is filthy with dust, mostly from last year’s dust storm. Probably clumping due to electrostatic forces.

    - Right now power level is at 256 W-hrs; minimum to do anything is ~250 W-hrs. Can't drive or use arm yet, but energy is coming up.
- Opportunity:
    - Some dust got in under dust cover on MI.
    - Fins—fine-grained material; consistent with them being a fracture zone later filled with material.
    - Tried to get as close as possible to almost vertical outcrop on Cape Verde, but couldn't get too close. About same time was the current spike in the front wheel, so quickly headed out.
    - Measured rim height and ejecta of Victoria Crater(Grant).
        - Dark gray basaltic sand has been blown in and out of crater over long time, scouring out the region.
        - Depth/diameter ~ 0.1
        - Serrated low rim
        - Interior dune field
        - Eroded primary, not pristine secondary. How much erosion?
            - Compare to pristine craters 500-700 m across
            - 500 m crater produces rim of all ejecta
            - 700 m crater produces rim of all uplift
            - 600 m crater closest to observed rim, ejecta
            - Diameter elongated by ~50 m along direction of recent/current winds.
            - Bays display low gradients (average 19 degrees). Rounded bays are more uniform. Consistent with eolian erosion.
        - Eolian processes most important in erosion of Victoria Crater
            - Victoria enlarged ~150 m; ~50 m wider due to prevailing winds
            - Explicit structure in walls (tear faults—probably matching stratigraphy)
            - Wind streaks and dunes reflect transport of material into and out of crater
            - Infilling: Infilling from walls accounts for ~20% of interior material
    - Dark annulus:
        - Regional contact? Ejecta? Other?
        - Limited erosion produces resistant lag of big hematitite spherules, traps basaltic sand, slows further erosion
        - Extent suggests forms after ~1 m erosion or less
        - Asymmetry due to erosion or oblique impact? Aligned with prevailing wind.
    - Proposed crater degradation sequence
        - Initial mass wasting/gullies? Superceded by eolian activity
        - Rocks easily eroded by wind
        - Eolian exploitation of structure and relief creates bays, rim
        - Wind steaks and dunes reflect transport into, out of crater. Lags form on ejecta to form annulus
        - Deepest, smoothed, and rounded bays align with wind

        - Crater ~50 m wider in direction of prevailing wind
        - Infilling dominates (already more important at Victoria)
        - Rim planed, crater slowly fills over time
- Long-term goal is 22 km diameter Endeavour crater, ~12 km away. Image craters along the way. Probably take a couple years to get to Endeavour crater.
- As of today:
    - Both rovers have survived 18 times longer than their 90 day nominal mission lifetime.
    - Spirit's problems: right front drive motor failed, RAT teeth gone, dust
    - Opportunity's problems: right front steering motor failed, arm azimuth motor heater stuck on, RAT motor encoder failed, dust contamination
    - Yet end of mission is nowhere in sight…
- Funding for 2009 looks good enough to keep going.

<u>Tornabene—HiRISE Update</u>

- Imaged Phoenix during descent on parachute.
- 817 images taken related to impact processes; 1348 images have been suggested.
- Continue to image small dark spots.
- New cluster of small impacts (meters in diameter) formed between June and July of 2008 near 47°N latitude. Have small ice deposits inside—wondering why ice is still being maintained. Deposited ice or exposed ice? Will keep watching them. Probably from breakup of bolide in atmosphere, producing strewn field. Discussion of whether these are really of impact origin or related to ice process (appeared right after northern summer solstice).
- Examples of dark-spot craters.
- Dust avalanches triggered by impact blasts.
- Crater clusters.