9^{th} Mars Crater Consortium Meeting
October 16-17, 2006   USGS

Recorded by: Nadine Barlow

Attending: Nadine Barlow (NAU), Joe Boyce (U. HI), Jeff Byrnes (USGS), Robert Frampton (Boeing), Ron Greeley (ASU), Bill Hartmann (PSI), Trent Hare (USGS), Robbie Herrick (U. Ak), Audrey Hughes Rager (UNLV), Jim Skinner (USGS), Tom Stepinski (LPI), Ken Tanaka (USGS), Tim Titus (USGS), Shawn Wright (ASU)

Monday, Oct. 16: AM Session:

Announcements:

The Proceedings volume of the July 2005 Workshop on the Role of Volatiles and Atmospheres on Martian Impact Craters will be published in the October 2007 issue of *Meteoritics and Planetary Science*. Nadine Barlow, Sarah Stewart, and Olivier Barnouin-Jha were the guest editors for this issue.

Upcoming meetings:

7^{th} International Conference on Mars: Caltech, Pasadena, CA, July 9-13, 2007

Bridging the Gap 2—Effect of Target Properties on the Impact Cratering Process: Canadian Space Agency, Montreal, Sept. 22-26, 2007. Focus of the workshop will be on the details of how target properties affect the cratering processes. A field trip to the Charlevoix impact structure will be held the first 2 days.

Discussion of previous meetings:

Brown-Vernadsky Microsymposium (March 11-12, Houston, TX): Focus was on issues related to planetary chronology, particularly for Mars. Major discussion topics included the role of secondary craters, latest estimates of flux rates, and accuracy of SNC crystallization ages.

ESA 1^{st} International Conference on Impact Cratering in the Solar System (May 8-12, Noordwijk, the Netherlands): Covered all aspects of cratering in the entire solar system. Topics included the new dynamical models of outer planet migration and its influence on the inner solar system late heavy bombardment, cratering records on the Earth and other planets, crater formation as revealed by laboratory experiments and numerical modeling, and impact-induced extinctions.

Workshop on Surface Ages and Histories: Issues in Planetary Chronology (May 21-23, Houston, TX): Covered issues related to age dating using crater counts, radiometric sampling, and other techniques. Topics included dynamical models of outer planet migrations as a cause for a cataclysmic late heavy bombardment, geochemical evidence for the cataclysm, flux rates, the role of secondary craters, radiometric dating of samples, the possibility that fluid interactions have affected the crystallization ages obtained from shergottites, and crater degradation.

The influence of secondary craters on ages obtained from crater counts was a major topic at all three of these workshops. Hartmann led a discussion of the issues. There are three major camps: (1) Secondary craters can be separated from primaries and therefore do not influence the ages obtained from crater counts (Neukum), (2) Most small craters are secondaries and therefore ages based on small crater analysis are unreliable (McEwen), and (3) There is some contamination of the small crater population by distant secondaries but the secondary + primary production function over time approaches that of the primary crater production function so ages are reliable even with some secondaries included (Hartmann). Hartmann noted that crater counts done individually by himself and Neukum are similar, even though Hartmann looks at mix of primaries and distant secondaries while Neukum believes he can separate secondaries from primaries.

MER Update—Jeff Johnson and Trent Hare

Spirit is close to Sol 1000. Has discovered two possible nickel-iron meteorites on surface near its winter position. Spring is returning and the plan is to start moving again after solar conjunction (~Oct. 30).

Opportunity: Features in Beagle crater suggest that this crater possibly punched through to distal ejecta of Victoria crater. The big blocks in this area could be from ejecta. Within the walls of Beagle and Victoria we can see some bedding in rocks and indications of sulfate-rich materials.

The walls of Victoria crater (~800 m in diameter) display some interesting banding as well as signs of filling and exhumation. There is a small crater on the rim of Victoria—it was originally proposed to be a collapse pit, but HiRISE images suggest there is an ejecta deposit surrounding it so it could be impact. However, it is very deep compared to typical small craters on Mars. There are lots of large blocks along the rim of this feature.

With HiRISE image of Opportunity at Victoria, we have now bridged the gap between orbital observations and surface operations. HiRISE images show details not visible in MOC.

<u>Monday, Oct. 16, 2006: PM Session:</u>

Tom Stepinski: Machine Identification and Characterization of Martian Craters from Digital Topography

Team has developed an automated crater detection algorithm which utilizes MOLA digital elevation models (DEM). This differs from other automated crater detection algorithms because it uses topography, not imagery, to identify the craters.

Currently use MOLA 1/128° topography, which allows detection of craters down to ~3 km in diameter. Plan to use higher-resolution DEMs from Mars Express HRSC in future.

First step has machine identifying potential craters. Transform function smoothes out features smaller than some value r, resulting in smooth surface with craters of size r or larger forming obvious basins. Second step involves human interaction with results to “teach” machine which are craters and which are not.

Results give size and depth of each crater.

Team has applied this technique to six sites on Mars: 4 in Terra Cimmeria (mainly Noachian) and two in Hesperia and Sinai (mainly Hesperian). Results reveal more craters than listed in the Barlow Catalog—most of these are smaller craters not included in the latter database. Some degraded craters are missed. Estimated accuracy is 95%.

Bill Hartmann: New Measurement of Martian Impact Crater Production Function Size Distribution

Project is in response to two major questions raised by others:

1. Do observed size-frequency distributions (SFDs) fit the proposed production function SFD? (question raised by Plescia)
2. What is role of secondary craters on small crater SFDs and the ages derived from them? (question raised by McEwen and Bierhaus)

New crater counts conducted in an area in east Amazonis Planitia (~30°N, 100°W). Area characterized by overlapping late Amazonian lava flows. Used MOC, THEMIS, HRSC, and Viking to obtain crater counts—result is the SFD over 3 orders of magnitude resolution (from 16 m to 16 km).

Result: Very good fit in the 16 m to 1.4 km size range to 2004 isochron system, giving average crater retention age of ~100 Ma for this area.

HRSC images show that craters which don't fit isochrons well are often embayed by later deposits. Thus, on low resolution images they are counted as post-surface craters when in reality they are dating an older, buried surface.

The close fit to the isochron also indicates that the production function SFD (primaries + distant secondaries) is well determined. Distant secondaries are included, but their contribution is smoothed out over time as the production function of secondaries + primaries approaches that of primaries alone.

Robbie Herrick: Updates on Martian Oblique Impact Craters

Project compares oblique craters from experiment, Moon, Venus, and Mars.

Experiments conducted in low atmosphere produce oblique craters which are morphologically similar to those seen on Moon.

Low impact angles produce a forbidden zone in the uprange direction. As you go to smaller angles, you also get a forbidden zone in downrange direction. Crater becomes more elongated as impact angle decreases.

On Venus, oblique-related features start to occur at higher impact angles than what is seen under low atmosphere conditions. In an atmosphere, the projectile is generating downrange wind which helps to propel the ejecta downrange. Under Venusian conditions, you never get a downrange forbidden zone.

On Mars, oblique craters have both uprange and downrange forbidden zones, therefore they are more similar to what is seen on the Moon than on Venus. The impact angles where the transitions (uprange only versus uprange and downrange) occur are analogous to those occurring on the Moon.

From experiments, the uprange forbidden zone tended to be curved while the downrange forbidden zone tends to have straight edges resembling a V-shape. Therefore, from morphology alone we can determine the uprange and downrange directions.

Currently there is no good answer as to why you get uprange and downrange forbidden zones. This is something the team wants to investigate further.

Initial study of martian oblique craters used Viking data. THEMIS and MOLA data are now being used to investigate these craters in more detail. Results include:

- Not seeing strong variations in interior morphology until impact angles get quite low.
- Both inner and outer ejecta layers are offset by about same amount in low-angle craters.
- Some craters show ejecta off to sides but no well-developed forbidden zone in either uprange or downrange direction.
- At larger crater diameters, don't see forbidden zone extending all the way to the rim as one sometimes sees at smaller diameters.

- In a few cases, see a small elongated crater downrange from main oblique crater. Called ricochet craters. Interesting aspect of these ricochet craters: see ejecta with main crater but no ejecta with the smaller ricochet part.

HRSC will be very important to provide topography over entire crater, unlike the profiles from MOLA.

Doublet craters: Due to breakup of single impacting object or satellite-primary impact? Unclear, but wouldn't expect much breakup under current climatic conditions based on work by Hartmann and Popova. But definitely expect to see the small crater uprange from larger crater when due to atmospheric breakup, which is what we tend to see. Due to thicker climate in past?

Could ricochet and double craters result from decapitation of the impacting object? Ability to undergo decapitation depends largely on the strength of the projectile material. Schultz's experiments showing decapitation use projectiles which are probably not really analogous to planetary materials.

Lunar and experimental impacts do not show any rim on uprange and downrange directions. But martian craters always have an uprange rim and most of the time you have a downrange rim. Perhaps this is due to Mars not having volatile-rich target material.

Uprange forbidden V-zone produced due to tilting of excavation flow. Downrange forbidden zone not present in low-speed experiments.

Ricochets do not exhibit a rampart.

Joe Boyce: Impact Related Features Outside the Second Layer of Martian Double-Layer ejecta craters: What they tell us about the Parent Crater

Double-layer ejecta (DLE) craters have 2 layers: an ~circular inner layer and a sinuous outer layer, neither with obvious ramparts. Usually see striations across the inner layer as well as pressure ridges around pre-existing terrain which are probably indicative of flow velocities. Secondary craters are rare around DLE—this lack of secondaries requires ejecta blocks to be weak or not produced at all. DLE craters are found in close proximity with other types of craters (such as single layer ejecta (SLE) of same the size and freshness. Continuous ejecta deposits outward from outer ejecta layer of DLE may form, but are thin and easily eroded.

THEMIS Crater Campaign: Several fresh craters have been extensively, but incompletely, imaged. The plan is for complete coverage out to 100 km radius to trace secondaries and any other related features.

DLE characteristics, especially the striations, are similar to base surge deposits for volcanic and nuclear explosions. In a supersonic blast surge, the flow lines are straight and will cross over pre-existing obstacles until the velocity drops below supersonic. Once the velocity is subsonic, the flow lines curve around obstacles. Based on morphology, DLE craters have the inner layer emplaced first, then the outer layer is emplaced as a base surge deposit.

The few DLE craters displaying secondaries are found only in smooth Vastitas Borealis Formation materials.

Conclusions:

- Typically see DLE morphology craters in close proximity with craters of different ejecta morphologies of similar apparent age.
- Morphology of DLE is consistent with supersonic surge deposits seen around volcanoes
- Lack of secondaries likely due to water or ice in target materials.

- Development of radial striations = a relatively thick atmosphere and/or water or ice in target materials.
- DLE craters form close to SLE and MLE craters at nearly the same time suggesting significant fluctuations in near-surface volatiles (in both space and time) on Mars.

Note: Phil Christensen is very interested in getting target proposals for the THEMIS crater campaign (VIS).

Audrey Rager—Pyroclastic flows as analogs for layered ejecta morphology

Pyroclastic flows can override bottom layers to give superposed layers. Perhaps a similar mechanism operates to give rise to layered ejecta morphology (especially multiple layer ejecta) on Mars.

Model is based on Schultz's atmospheric model. Larger blocks create a curtain near the base of the ejecta flow. Larger blocks move ballistically, but smaller stuff gets entrained by the atmosphere behind ejecta curtain.

Volatiles in the target material would enhance this process. From pyroclastic flow studies, the flow moves faster and the column goes higher when more volatiles are present.

Tuesday, Oct. 17: AM Session:

Barlow: Comparison of Central Pit Craters on Mars and Ganymede

Central pits are small depressions at the centers of craters on Mars and icy moons. They are distinct from peak rings. Two models have been proposed for their formation: (1) vaporization of subsurface target volatiles during crater formation, and (2) impact of volatile-rich projectiles.

Martian central pits are categorized as floor pits (which occur directly on the crater floor) and summit pits (which occur on central rise or peak). Distributions of each type are similar to each other. Floor pits are more common in craters up to 20-km-diameter while summit pits more commonly seen in larger craters. However, both floor pits and summit pits are seen in craters up to 50-km-diameter. Floor pits are generally larger relative to their parent crater than summit pits. Pit craters are found in craters displaying a wide range of preservational states, indicating that the conditions producing central pits have been present over most if not all of the planet's history. For craters still retaining an ejecta blanket, pit craters are most commonly associated with a multiple layer ejecta structure.

Ganymede central pits are categorized as floor pits or dome pits. Our current analysis indicates that central pit craters are found on both dark and bright terrain, although there is some preference for dark regions. The parent craters have diameters ranging up to 100 km. Most central pit craters on Ganymede are between 25 and 60 km in diameter.

Comparisons between central pit craters on Mars and Ganymede:

- Martian central pit craters are evenly distributed across the planet. There appears to be a slight preference for Ganymede central pit craters to form on low albedo units, although some are also found on the bright units.
- Martian central pit craters tend to be smaller (<25 km diameter) than Ganymede central pit craters (<60 km).
- Central pits on Ganymede tend to be larger relative to their parent crater than martian central pits.
- The higher concentration of ice and/or greater thickness of the ice on Ganymede may be responsible for these observations.

Trent Hare: Software tools for crater research

Barlow and USGS have a Mars Fundamental Research award to develop tools to use with the Mars crater data on PIGWAD. The latest addition is a tool to obtain crater statistics. In addition, geologic units are correctly registered and can be overlain onto the crater maps.

Everything is geodesically correct to give correct distances, etc.

Elevation profile tool—grabs 200 points along length of line, so as line gets longer the points are spread out.

Also developing a crater density tool.

Suggestions from participants:

- Provide way to get total list of craters with diameter and locations
- Change selection so person can type in values (like specific crater diameters)
- Include incremental plot and Hartmann's isochron plots.

Latest ArcMap data is provided on the DVD which all MCC participants receive. The new data includes Jim Skinner's updated geologic map and the THEMIS IR Mosaic.

Google Mars was launched earlier this year. Two other similar programs:

- NASA World Wind (worldwind.arc.nasa.gov). This program is able to pull in data from multiple sites. It can be used for science or just visualization.
- Onmars.jpl.nasa.gov

Ken Herkenhoff—HiRISE Overview

The Mars Reconnaissance Orbiter (MRO) was launched in August of 2005 and arrived at Mars in March 2006. Aerobraking was completed in September and the mission is now in the Primary Science/Relay stage. The Primary Stage begins in earnest on November 8.

Periapsis occurs 255 km over south pole.

MRO is expected to return more data than all previous Mars missions combined.

HiRISE: 0.5-m primary mirror. 14 CCDs (2048 x 128 pixels). 10 CCDs form the red channel (20,000 px). 2 CCDs form blue-green channel (4000 px). 2 CCDs form Near IR (NIR) channel (4000 px)

Time delay and integration increases signal.

HiRISE can acquire stereo data by rolling off nadir.

Resolution: 30 cm/pixel at 300 km altitude

6 km swath width (red band) at 300 km altitude. 3-color swath width of 1.2 km (at 300 km). Maximum image size: 20,000 x 65,000 pixels. Signal-to-noise: >100:1.

Stereo topographic precision: ~20 cm vertical precision over ~15 m^2 areas.

Color Bandpasses:

Red: 550-850 nm
Blue-Green: 400-600 nm
NIR: 800-1000 nm

Initial observations will be concentrated in the northern hemisphere, particularly targeting the Phoenix landing site.

Alfred McEwen is now the lead for cratering. Some of the issues to be addressed:

- Are most small craters primary or secondary? What is the relative role of primaries versus distant secondaries? Shoemaker thought the crossover diameter was ~300 m. What are the implications for dating young surfaces and is there evidence of recent climate change?

- Meteorites from Mars: Probability of finding a rock ejected from Mars on Earth is 10^{-6} to 10^{-7}. Many fragments must fall back onto Mars, forming secondary craters. No impact craters on Zunil—pits are interpreted as melt sheet pits, not impacts. ~10^{7}-10^{8} secondaries > 10-m-diameter are estimated from Zunil.
- When does secondary crater SFDs roll over? All crater counts appear to roll over as crater diameters approach image resolution. Is there a well-documented observation of real secondary rollover? Tycho: rollover occurs at about 100 m over the highlands. Zunil rollover is due to resolution. HiRISE will measure features down to ~1.5 m, but SFD may roll over due to atmospheric screening.
- Ages of fine layered deposits: Ages are controversial but some must be old because there are large embedded craters in them. But small craters must erode away. Estimated ages from Neukum production function requires erosion rate that would eliminate a 10 km thick section in <200 Ma. But if secondaries are highly clustered in space and time an erosion rate of ~1 m/Ma can lead to a mostly crater-free surfaces. This allows the layers to be billions of years old. Hartmann: there is some confusion between crater retention ages versus the actual ages of the underlying rocks. Big question about Mars: We get these recent processes which create specific erosion rates, but then why do we still have really old features?
- 4 large craters seem extremely young based on number of superposed small craters: Zunil (10 km), Pangboche (10.4 km), McMurdo (23 km), and Tooting (29 km). Ages: <10^{4} yrs for Zunil; ~10^{5} yr for other 3. 10^{2}-10^{3} discrepancy between age estimates from large and small craters. Neukum production function predicts far too many small primary craters. Pangboche just south of Olympus Mons caldera—source of secondaries across caldera?
- Craters on Gusev floor have low d/D suggestive of being secondaries.

Future Measurements, Research, Questions:

- Lunar Reconnaissance Orbiter (LRO) cameras will re-image Apollo metric camera coverage at 0.5 m/px. Expect ~50 new craters 10-100 m in diameter in 37 years over 5% of Moon.
- LRO Camera and HiRISE will image young surfaces far from suspected concentrations of secondaries. This will allow better determination of the upper limits to the primary production functions for small craters.
- Can high resolution morphometry distinguish recent primaries from recent secondaries?
- Why are secondaries shallow? Over which terrains are primaries also shallow?

HiRISE Targets for Chronology

- Large recent craters—count superposed craters
- Small craters—at what diameters does the distribution roll over due to atmospheric breakup or degradation?
- Any pristine craters, to give info on primary processes
- Rays
- Degraded craters go to other science themes
- Layers exposed in crater walls goes to stratigraphy science teams

HiRISE color images show ejecta of small fresh craters. The camera is resolving craters down to a few meters in diameter.

HiRISE images will be released soon after image acquisition: everyone shares in scientific discovery process.

Goal is to provide everyone opportunities to submit image observation suggestions and to access HiRISE data products using similar services available to HiRISE team and MRO Project.

To achieve this goal, a user-freindly interface is being developed: http://marsoweb.nas.nasa.gov (HiWeb). This interface will be opened up to the public in November (~Nov. 8). All HiRISE image suggestions should be submitted via HiWeb. Suggestions will be prioritized by HiRISE team through invited science community workshops sponsored by MRO project, EPO Partner, and automated filtering scheme. Collaboration between science community and HiRISE team is strongly desired—we value your inputs!

Data will be released in JPEG 2000 format.

CTX and Descent Camera are run by MSSS so keep in mind that they use the west longitude system. Everything else uses east longitude. MSSS uses aerographic coordinates; everyone else uses aerocentric.

ISIS3 is being used to process HiRISE data.

Issues:

- Is it time for an update to the Barlow et al. (JGR, 2000) nomenclature paper in light of the new insights obtained from high-resolution imaging?
- How do we categorize craters <5 km?
  - Morphology, morphometry, rays, ramparts
  - Primaries vs secondaries (how to discriminate?)
- If crater catalogs are generated through automated computer techniques, are they useful when they lack the morphological information?
- The current MCC crater catalogs (Barlow, Boyce, Costard, Kuzmin, etc.) are generally global catalogs. Many other researchers have developed or are developing crater databases which are more localized. Do we accept these local catalogs into the general database we are producing? If so, how?

Possible topics for future workshops organized by MCC:

- Determining the crater production function (identification of local candidate surfaces, such as the eastern Amazonis region discussed by Hartmann)
- Resurfacing histories of various surfaces
- Target vs atmospheric volatile effects
- Ongoing rampart characterization
- Other?