NASA MARS DATA ANALYSIS PROGRAM
NASA GRANT #NAG58265
INVESTIGATIONS OF MARTIAN IMPACT CRATER MORPHOLOGIES AND MORPHOMETRIES
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FINAL REPORT

Abstract:
Funding for a project entitled "Investigations of Martian Impact Crater Morphologies and Morphometries" (NASA Grant #NAG58265) was provided between May 1, 1999 and April 30, 2002. We have made substantial progress towards completion of the original objectives and are continuing to include new data from the Mars Global Surveyor MOC and TES instruments as they becomes available (the MOLA instrument has ceased operation as of 2002). The project funding has been used to provide salary support to the PI and several undergraduate students, cover publication charges for two papers, reimburse travel expenses to conferences and workshops incurred by the PI and students, and cover a number of other expenses such as software upgrades and production costs of slides and color prints. This study is revising the PI's *Catalog of Large Martian Impact Craters* with information obtained from MGS and is utilizing the data in the revised *Catalog* to investigate which planetary factors (such as location, elevation, terrain type, etc.) primarily affect the formation of specific ejecta morphologies and morphometries.

Original Goals and Work Plan

The proposal's objectives were to (1) utilize Mars Global Surveyor (MGS) data, specifically Mars Orbiter Camera (MOC), Mars Orbiter Laser Altimeter (MOLA), and Thermal Emission Spectrometer (TES) data, to update the PI's *Catalog of Large Martian Impact Craters* (originally produced from Viking data) and (2) utilize this updated *Catalog* to investigate the roles of crater diameter, latitude, longitude, elevation, terrain, and surface properties on the formation of specific crater morphologies and morphometries. We proposed to accomplish this through the following steps:

1) utilize MOC imagery to revise the preservational classifications (now using a 0 through 7 scale, with 0 being a very eroded "ghost" crater and 7 representing a pristine morphology).
2) utilize MOC imagery to review the ejecta and interior morphology classifications and update as necessary.
3) add new columns to incorporate TES information about terrain mineralogy and thermal inertia.
4) add new columns to incorporate MOLA elevation and crater morphometric data.
5) utilize MOC, MOLA, and Viking data to update information about ejecta blanket morphometries (i.e., ejecta extent, sinuosity, etc.).

We proposed to utilize these data to study the influence of planetary factors on the formation of specific crater morphologies and morphometries. The technique would involve researching the possible correlations of different ejecta morphologies, ejecta blanket measurements (area, perimeter, sinuosity, greatest ejecta extent, and average

ejecta extent), crater depth-diameter ratios, central peak characteristics, and central pit characteristics with various combinations of regional elevation, location, terrain type, and surface properties.

The goal of this project was to produce an improved database of martian impact craters characteristics and provide constraints on the planetary factors influencing the formation of crater morphologic and morphometric features.

The original Work Plan is as follows:

Year 1: May 1, 1999 to April 30, 2000

Task 1 (Incorporation of MGS Data into *Catalog*): The PI will hire an undergraduate student to help with inputting the currently available morphologic and morphometric information into the *Catalog*. The information incorporated during this time will come from the SPO1 and SPO2 data releases and will primarily consist of data from the MOC and MOLA investigations. The PI will be responsible for upgrading the preservational classes and reviewing the ejecta and interior classification, while the student will measure the ejecta maximum extents and incorporate the MOLA data as it becomes available.

Task 2 (Planetary Influences on the Formation of Crater Morphologies and Morphometries): Once the ejecta maximum extents have been incorporated into the *Catalog*, the PI and student will run the analysis to determine how ejecta maximum extent is related to crater diameter, latitude, longitude, and general terrain. Preliminary results of this analysis will be presented by the student at the March 2000 Lunar and Planetary Science Conference.

Year 2: May 1, 2000 to April 30, 2001

Task 1: The PI and student will continue to input MOC and MOLA data into the *Catalog* as the data become available. TES data will begin to become available in sufficient amounts to be incorporated into the *Catalog*. Ejecta areas and perimeters will be measured from MOC and Viking data and the average extent of ejecta blankets will be calculated.

Task 2: Regional elevation is expected to be constrained sufficiently at this point to allow the elevation comparisons to be conducted. The initial analysis of crater morphometric properties, particularly for the northern hemisphere, will be conducted. The analysis of how the extent of ejecta blankets correlates with the various parameters will be conducted. The PI will present results at the October 2000 Division for Planetary Sciences meeting in Pasadena, CA, and the student will present results at the March 2001 Lunar and Planetary Science Conference in Houston, TX. A paper detailing initial results from the analyses will be submitted to *Journal of Geophysical Research—Planets*.

Year 3: May 1, 2001 to April 30, 2002

Task 1: The remaining MOC, MOLA, and TES information will be incorporated into the *Catalog* by the PI and student.

Task 2: The effect of surface properties (obtained from TES) on the formation of the different morphologies and morphometries will be conducted. Crater depth-diameter ratios will be calculated for the craters which MOLA has provided depths for. Fresh crater depth-diameter ratios will be compared across the planet to determine if terrain, elevation, surface properties, and/or location have an effect on the values. Central peak heights, central peak basal diameters, and central pit diameters (from MOLA data) will be studied to determine if regional variations exist which may be related to terrain properties (including the presence of subsurface ice). The PI will present results of this research at the October 2001 Division for Planetary Sciences meeting and the student will present final results at the March 2002 Lunar and Planetary Science Conference in Houston. A paper detailing the final results will be submitted to *Journal of Geophysical Research--Planets.*

Status of Project—April 2002

We have made substantial progress in revising the *Catalog of Large Martian Impact Craters* due to this support. We have transferred the *Catalog* from its original R-Base Data Management system format to the ArcView/ArcInfo Geographic Information System (GIS) format. The original *Catalog* continues to be in high demand, with copies being distributed to an average of 8 to 10 researchers from around the world each year. There is substantial interest in the revised version of the Catalog being produced through this support.

The continued operation of the Mars Global Surveyor (MSG) mission and the ongoing stream of data products being received means that our job of updating the *Catalog* is far from over. We submitted a proposal in 2001 to the Mars Data Analysis Program for a continuation of this project to take advantage of the additional information being provided by MGS and we were granted a two-year additional funding cycle. We feel this will be sufficient to finish the revisions to the *Catalog* at the level originally proposed in this project.

An undergraduate student in the Department of Physics at the University of Central Florida has been employed half-time each year of this three-year funding period to assist with the data collection and analysis. In addition, other students (undergraduates and even some advanced high school students) have volunteered their time to help with the project. This was a great help since PI Barlow's other assignments (specifically teaching and program administration) have increased dramatically over the past 3 years with the continued growth of the astronomy program at the University of Central Florida. As such, she has been unable to devote as much time as originally planned to this project. The PI's administrative duties are expected to drop beginning in Fall 2002 when she leaves UCF and joins the Department of Physics and Astronomy at Northern Arizona University.

At the end of the 3-year initial period for the project, we have achieved the following:

1) Students have been involved in revising the preservational category of each crater using the 0 to 7 scale described in the original proposal (item 1 above).

MC Quadrangles 8 through 19 have been completed, corresponding to 14,141craters (~33% of the total number of craters in the *Catalog*). A report on this portion of the work was presented by student Frank Mackey at the 32nd Lunar and Planetary Science Conference in 2001 (*Mackey and Barlow, 2001*).

2) The PI and students have been involved in measuring the maximum extent of layered (previously called "fluidized" or "lobate") ejecta deposits, calculating the corresponding ejecta mobility ratios (ejecta extent/crater radius), and determining how ejecta mobility varies with latitude, terrain, and ejecta type (part of item 5 above). Ejecta mobility ratios have been computed for 4389 craters in MC Quadrangles 8 through 24. Results have been reported at the 31st Lunar and Planetary Science Conference (*Perez and Barlow, 2000*), 32nd Division for Planetary Sciences Conference (*Barlow, 2000c*), the 32nd Lunar and Planetary Science Conference (*Barlow, 2001a*), and the 33rd Lunar and Planetary Science Conference (*Barlow and Pollak, 2002*). A paper detailing the results of this study is in preparation for submission to *Journal of Geophysical Research—Planets* during summer 2002.
3) The PI has been an active participant in the Mars Crater Morphology Consortium, a group of researchers interested in the characteristics of martian impact craters and what they can tell us about near-surface properties, the geologic and degradational histories of Mars, and the process of crater formation. Other members of this group include Joe Boyce (NASA), Jim Garvin (NASA), Susan Sakimoto (NASA GSFC), Bob Craddock (NASM), Ruslan Kuzmin (Vernadsky Institute), Francois Costard (CNRS), David Roddy (USGS), Larry Soderblom (USGS), Olivier Barnouin-Jha (APL), Horton Newsom (UNM), and Sarah Stewart-Mukhopadhyay (Carnegie Institution of Washington). In 1999-2000, the PI led the group's effort to develop a standardized nomenclature for martian crater ejecta morphologies and served as the lead author of the resulting publication (*Barlow et al., 2000*). This standardized nomenclature is being incorporated into the revised *Catalog* (addresses item 2 above). Most of the craters in the northern hemisphere have been updated at this time.
4) New data (provided from other sources) which have been incorporated into the revised *Catalog* include the stratigraphic designations from the US Geological Survey maps and the elevation information from MOLA (part of item 4 above).

The planetary community has been kept updated on the status of the *Catalog* revision through presentations by the PI at the Lunar and Planetary Science Conference *(Barlow, 2000a)* and Division for Planetary Sciences Meeting *(Barlow, 2001c).*

Objectives from the original proposal which have not yet been achieved are as follows:

1) Item 3 in the objective list is to incorporate TES information about mineralogy and thermal inertia for the areas surrounding each crater. TES information was released in a usable format more slowly than originally anticipated and we are only now beginning to incorporate the mineralogy and thermal inertia data. PI Barlow attended the TES Data User's Workshop at Arizona State

University in November 2001 to become more familiar with the reduction technqiues.

2) Items 4 and 5 in the objective list discuss incorporating the morphometric information about each crater as derived from MOLA. The MOLA team, specifically Jim Garvin and his colleagues at Goddard Space Flight Center, have been developing a catalog of this morphometric information which they have offered to provide us for inclusion in this *Catalog*. As such, we elected to focus our efforts on other portions of this project. The morphometry catalog is just now being released and we will devote time over the next year to incorporating those data.

One issue which has arisen during the time that we have been revising the *Catalog* is the issue of coordinates of each crater. The Viking system, which was used in the original *Catalog*, has been supplanted by an aerocentric coordinate system derived from MOLA data. As such, all of the craters in the *Catalog* have had their latitude/longitude coordinates shifted, but unfortunately the amount of shift is not equal at all locations. The PI has been in close consultation with the US Geological Survey in Flagstaff (specifically Trent Hare and Randy Kirk) regarding the easiest way to translate the coordinates of the 42,283 craters in the *Catalog* and it appears we will be able to make this coordinate shift by later this year.

Task 2 in the original proposal was to utilize the data in the revised *Catalog* to investigate planetary influences on the formation of specific crater morphologies and morphometries. Abstracts related to such influences on crater preservation and ejecta extent include *Barlow (2000c)*, *Perez and Barlow (2000)*, *Barlow (2001a)*, *Mackey and Barlow (2001)*, and *Barlow and Pollak (2002)*. An investigation into the onset diameters for fluidized ejecta morphologies within the martian equatorial region was published in 2001 *(Barlow et al., 2001)* and another paper on regional variations in the distribution of specific ejecta morphologies has been submitted for publication consideration *(Barlow and Forman, 2002)*. We anticipate submitting a manuscript about the ejecta extent study and a comparison of preservational class with ejecta extent during summer 2002 to the *Journal of Geophysical Research*. Investigations of other correlations are currently underway and we expect to be presenting results of those investigations at upcoming conferences (specifically Division for Planetary Sciences meetings and the Lunar and Planetary Science Conference) and publishing the results in the peer-reviewed literature over the next 2 years.

Financial Aspects

The NASA funding for this project has supported the PI during summers and occasionally during the academic year as well as a number of undergraduate students throughout the 3 year funding cycle. The funding has also supported publication charges for the *Barlow et al. (2000, 2001)* papers, travel to major meetings and workshops for both the PI and the undergraduate students (Division for Planetary Sciences meetings, Lunar and Planetary Science Conferences, Mars Crater Morphology Consortium workshops, and a variety of focused Mars workshops), and production costs for slides and color prints (for publications). We anticipate that there will be some money

(~$30,000) left over as of the end of the funding period, mainly from unused salary support for the PI due to the unexpected increase in her administrative and teaching duties over the past 3 years.

Publications Resulting from this Work:

Abstracts:

Barlow, N. G., Updates to the *Catalog of Large Martian Impact Craters*, *Lunar Planet. Sci. XXXI*, Abstract #1475 (CD-ROM), 2000a.

Barlow, N. G., "Following the Water" on Mars: Where is it, how much is there, and how can we access it?, In *Concepts and Approaches for Mars Exploration Part I*, **LPI Contribution No. 1062**, 12a-12b, 2000b.

Barlow, N. G., Ejecta mobility studies of fresh Martian impact craters, *Bull. Amer. Astron. Soc.*, **32**, 1112, 2000c.

Barlow, N. G., Ejecta mobility results for impact craters in the northern hemisphere of Mars, *Lunar Planet. Sci. XXXII*, Abstract #1606 (CD-ROM), 2001a.

Barlow, N. G., Impact craters as indicators of subsurface volatile reservoirs, In *Abstracts for the Conference on the Geophysical Detection of Subsurface Water on Mars*, **LPI Contribution No. 1095**, 5-6, 2001b.

Barlow, N. G., Status of the *Catalog of Large Martian Impact Craters* revision, *Bull. Amer. Astron. Soc.*, **33**, 1105, 2001c.

Barlow, N. G. and A. Pollak, Comparisons of ejecta mobility ratios in the northern and southern hemispheres of Mars, *Lunar Planet. Sci. XXXIII*, Abstract #1322 (CD-ROM), 2002.

Barlow, N. G., C. B. Perez, and J. Koroshetz, A volatile-rich reservoir south of Valles Marineris, Mars, *Bull. Amer. Astron. Soc.*, **31**, 1134, 1999.

Mackey, F. and N. G. Barlow, Redefining the preservational categories of Martian impact craters, *Lunar Planet. Sci. XXXII*, Abstract #1599 (CD-ROM), 2001.

Perez, C. B. and N. G. Barlow, Martian layered ejecta morphologies: Ejecta mobility studies, *Lunar Planet. Sci. XXXI*, Abstract #1682 (CD-ROM), 2000.

Papers--Published:

Barlow, N. G., J. Koroshetz, and J. M. Dohm, Variations in the onset diameter for Martian layered ejecta morphologies and their implications for subsurface volatile reservoirs, *Geophys. Res. Lett.*, **28**, 3095-3098, 2001.

Barlow, N. G., J. M. Boyce, F. M. Costard, R. A. Craddock, J. B. Garvin, S. E. H. Sakimoto, R. O. Kuzmin, D. J. Roddy, and L. A. Soderblom, Standardizing the nomenclature of Martian impact crater ejecta morphologies, *J. Geophys. Res.*, **105**, 26733-26738, 2000.

Papers—Submitted or In Preparation:

Barlow, N. G. and C. B. Forman, Martian impact crater ejecta morphologies as indicators of the distribution of subsurface volatiles, submitted to *J. Geophys. Res.*, February 2002.

Barlow, N. G., Ejecta extent studies of Martian impact craters, in preparation for submission to *J. Geophys. Res.*, summer 2002.