Abstracts of the Annual Meeting of Planetary Geologic Mappers, San Antonio, TX, 2009

Edited by:

Leslie F. Bleamaster III
Planetary Science Institute, Tucson, AZ

Kenneth L. Tanaka
U.S. Geological Survey, Flagstaff, AZ

Michael S. Kelley
NASA Headquarters, Washington, DC

June 2009

NASA STI Program ... in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA scientific and technical information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Report Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA Programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or co-sponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, and organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question via the Internet to help@sti.nasa.gov

- Fax your question to the NASA STI Help Desk at (301) 621-0134

- Phone the NASA STI Help Desk at (301) 621-0390

- Write to:
  NASA STI Help Desk
  NASA Center for AeroSpace Information
  7115 Standard Drive
  Hanover, MD 21076-1320

NASA/CP—2010–216680
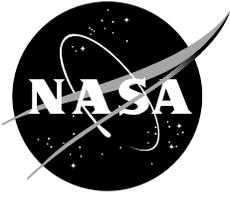
Abstracts of the Annual Meeting of Planetary Geologic Mappers, San Antonio, TX, 2009

Edited by:

Leslie F. Bleamaster III
Planetary Science Institute, Tucson, AZ

Kenneth L. Tanaka
U.S. Geological Survey, Flagstaff, AZ

Michael S. Kelley
NASA Headquarters, Washington, DC

June 2009

Acknowledgments

Available from:

NASA Center for AeroSpace Information
7115 Standard Drive
Hanover, MD 21076-1320
(301) 621-0390

This report is also available in electronic form at

http://astrogeology.usgs.gov/Projects/PlanetaryMapping/

Report of the Annual Mappers' Meeting
Trinity University
San Antonio, Texas
June 24-26, 2009

   The Annual Meeting of Planetary Geologic Mappers provides a unique opportunity for researchers and students to exchanges ideas, share experiences, and discuss methodologies and technological advances directly related to the endeavor that is geologic map making. The meeting also serves as the primary venue for Planetary Geology and Geophysics (PGG) funded Principal Investigators, and associated teams, to present the progress of their mapping projects. The 2009 meeting was convened by Les Bleamaster (Planetary Science Institute (PSI) and Trinity University), Ken Tanaka (US Geological Survey (USGS)), and Michael Kelley (NASA Headquarters) and was hosted by the Geosciences Department at Trinity University in San Antonio, Texas. Approximately 30 people attended this year's mappers' meeting and associated geographic information system (GIS) workshop. This volume is the compilation of abstracts submitted by meeting attendees, abstracts submitted in absentia, and additional materials appropriate for distribution to the planetary mapping community and other interested parties.
   This year's meeting kicked off on Wednesday, June 24th in Trinity University's Integrated Learning Center, home to twenty-eight individual workstations running ArcGIS 9.3, which allowed each GIS workshop participant a unique hands-on experience. The workshop, organized and run by Trent Hare, Jim Skinner, and Corey Fortezzo (all of the USGS, Flagstaff, Arizona), provided review and instruction on 1) geodatabase design, organization, and management, 2) vector shape creation, annotation, and editing, and 3) querying and spatial analysis. GIS workshops should continue to accompany the mappers' meeting (certainly when the meeting in convened in Flagstaff) as PGG-supported planetary mapping transitions to a 100% GIS publication format.
   Oral presentations and poster discussions took place on Thursday, June 25th and Friday, June 26th. Geologic Mapping Subcommittee (GEMS) chairperson, Les Bleamaster, welcomed everyone to Trinity and commenced the meeting. Ken Tanaka followed with a brief summary of the Planetary Geologic Mapping Program announcing the generation of a new planetary geologic mapping handbook (see appendix) and the restructuring of the USGS mapping website (anticipated update in 2010). Michael Kelley (PGG Discipline Scientist) provided a PGG program update highlighting several recently implemented changes and emphasizing his aim for balance within the program. Jim Skinner followed with a recap of the GIS workshop and a further introduction of USGS efforts to streamline the GIS base map generation and GIS products for use by new mappers. The first of several breakout sessions followed, allowing attendees to share printed map materials and solicit assistance from USGS personnel regarding the implementation of GIS technologies in their map preparation (a major theme of the meeting this year).
   Science presentations were arranged with respect to increasing planetary radius, and thus began with two lunar presentations. Tracy Gregg (University of Buffalo) reported on preliminary work in LQ-10 and opened a two-day discussion on the benefits and pitfalls of informal place names for lunar features (e.g., the informally named, yet very well known, Marius hills). Tracy, with assistance from Jen Blue and GEMS, will continue to

investigate lunar nomenclature issues. Scott Mest (PSI) discussed his efforts on Schrödinger basin near the lunar south pole. Jumping moons, David Williams (Arizona State University) provided an update on his recently submitted global Io map.

After lunch, the meeting proceeded with a Martian focus; Sharon Wilson and Jim Zimbelman (both of the Smithsonian Institution) presented new findings from the Uzboi-Ladon-Morava outflow system and the Medusae Fossae Formation, respectively. David Crown (PSI) discussed preliminary results of mapping and mineralogic investigations on the northwest side of Hellas Planitia, Mars. Corey Fortezzo (USGS) discussed the geologic evolution of highlands near Margaritifer, Arabia, and Noachis Terrae and Scott Mest returned to discuss Reull Vallis. David Williams wrapped up day one with an introduction to his new Olympus Mons mapping project.

Friday continued where we left off - with Mars. Tracy Gregg reported on her continued mapping of Tyrrhena Patera and Hesperia Planum, and Jim Skinner (USGS) discussed year two results from his mapping in the southern Utopia Planitia region and introduced a new project of Libya Montes. Ken Tanaka rounded out the Mars presentations discussing midway results of the five-year project to produce a new 1:20M-scale global map of Mars and introduced a slightly unconventional approach to mapping the Scandia region in the northern hemisphere.

Mapping presentations finished up with Venus. Les Bleamaster (PSI) presented progress on efforts in the Beta-Atla-Themis region. Jim Head (Brown University) summarized several efforts of his and co-authors in the Fortuna Tessera (V-2), Lada Terra (V-56), and Fredegonde (V-57) quadrangles. Debra Hurwitz (also of Brown University) wrapped up with her mapping of the Snegurochka Planitia (V-1) quadrangle. Kim Seelos (JHU/APL) ended the series of talks with a presentation of the Compact Reconnaissance Imaging Spectrometer for Mars (CRISM) website and offered guidance on how CRISM data could be integrated into the production of geologic maps.

The next mappers' meeting likely will be held between June 20-26, 2010 at the US Geological Survey in Flagstaff, Arizona.

CONTENTS (in alphabetical order by author)

Io

Appendix

Planetary Geologic Mapping Handbook - 2009

GEOLOGIC MAPPING OF THE BETA-ATLA-THEMIS (BAT) REGION OF VENUS; A PROGRESS REPORT.

Leslie F. Bleamaster III, Planetary Science Institute, corporate address - 1700 E. Ft. Lowell Rd., Suite 106, Tucson, AZ 85719; mailing – Trinity University, Geosciences Department, One Trinity Place #45, San Antonio, TX 78212; lbleamas@psi.edu

Introduction. The BAT province is of particular interest with respect to evaluating Venus' geologic, tectonic, and volcanic history and provides tests of global paradigms regarding her thermal evolution. The BAT is "ringed" by volcano-tectonic troughs (Parga, Hecate, and Devana Chasmata), has an anomalously high-density of volcanic features with concentrations 2-4 times the global average [1], and is spatially coincident with "young terrain" as illustrated by Average Surface Model Ages [2, 3]. The BAT province is key to understanding Venus' current volcanic and tectonic modes, which may provide insight for evaluating Venus' historical record.

Several quadrangles, two 1:5,000,000 scale – Isabella (V-50) Quadrangle and Devana Chasma (V-29) Quadrangle and two 1:10,000,000 scale – Helen Planitia (I-2477) and Guinevere Planitia (I-2457), are in various stages of production (Figure 1). This abstract will report on their levels of completion as well as highlight some current results and outstanding issues.

Isabella Quadrangle (V-50; 25-50°S, 180-210°E) is nearing completion; all units are mapped and the DOMU, SOMU, and text are being finalized. It is anticipated that V-50 will be ready for submission in fall '09. The primary unit within Isabella Quadrangle is a regional expanse of plains material (located in Nsomeka and Wawalag Planitiae), consisting of both high- and low-radar backscatter sub-members [4]. This unit is the northern extension of plains from the Barrymore Quadrangle (V-59) [5], located to the south. Within V-50, the plains are warped by broad north-trending topographic ridges and penetratively deformed by fine-scale north-trending lineaments (mostly wrinkle ridges). The plains also host numerous coronae and small volcanic centers (paterae and shield fields), which contribute local materials. With minimal tessera or highland material within the quadrangle, the majority of the oldest materials are the plains forming units; shield fields with relatively small flows embay the plains. In the northwest, several flows emerge and flow to the southeast from
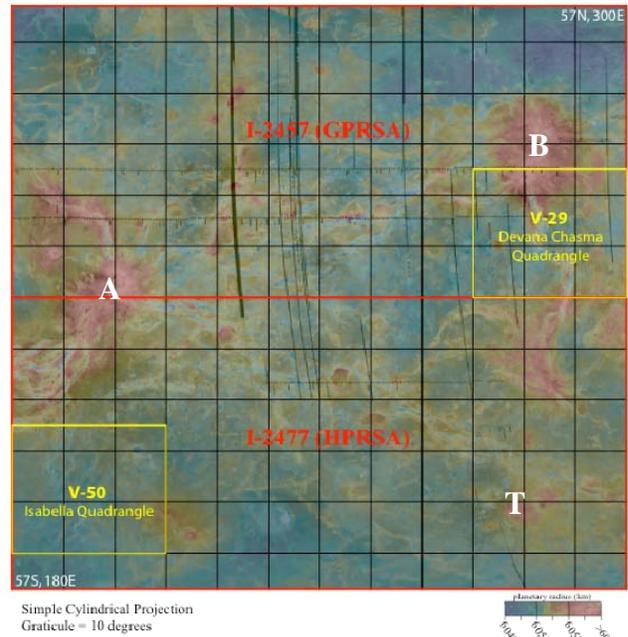
Figure 1. The BAT province is a region of anomalously high volcanic, tectonic, and relatively youthful activity. USGS cartographic boundaries of map regions (red – 1:10M: Guinevere Planitia in north, Helen Planitia in south; yellow – 1:5M: Devana Chasma in north, Isabella in south).

Diana-Dali Chasmata. In general, map relations are consistent with interfingered deformation (both extension and contraction) and volcanism; however, volcanic units in the northwest, near Diana-Dali Chasmata, preferentially embay contemporary topography and are less deformed by plains structures, suggesting that this area is a locus of more youthful activity.

Devana Chasma Quadrangle (V-29; 0-25°N, 270-300°E), on the other hand, is just beginning. Base materials have just arrived and initial evaluation has begun. The most prominent feature, and hence namesake of the V-29 quadrangle, is Devana Chasma - a narrow (~150 km) 1000 km long, segmented topographic trough (1-2 km deep with respect to the surrounding terrain). Devana Chasma is one of three radiating arms of tectonic

lineaments that trend south from Beta Regio; Beta Regio defines the northeastern apex of the BAT province (Figure 1, B). Approximately midway down the map from Beta Regio, Devana Chasma's lineament density decreases and changes trend to the southeast. Near the center of the map, the northern portion of Devana Chasma meets the southern section, which trends south and then veers to the west. Preliminary mapping has delineated major structural trends (mostly large normal faults), but has not revealed significant temporal relations between the north and south segments. Detailed evaluation of these troughs, stratigraphic, embayment, and crosscutting relations of their volcanic contributions, and structural analyses (estimating magnitudes of strain, evaluating orientations and spacing of structures) of the myriad of smaller structural elements will be conducted to constrain local timing and address the nature of the offset observed between these segments.

Helen Planitia (I-2477; 0-57°S/180-300°E) In conjunction with V-50, mapping of Helen Planitia, which covers over 70 million square kilometers (approximately $1/8^{th}$) of the surface of Venus, has been ongoing. This summer's efforts will focus on converting existing mapping into GIS compatible formats. This includes several hundred radial and circular structures and their associated digitate and lobate flows.

The majority of these radial/circular features lie within a few hundred kilometers of the Parga Chasmata rift system marking a southeast trending line of relatively young volcano-tectonic activity. Although some very localized embayment and crosscutting relationships display clear relative age relations between centers of activity, the majority of Parga Chasmata volcanism and tectonism overlaps in time from Atla Regio in the west to Themis Regio in the east, extending ~10,000 linear kilometers [6].

Dombard et al., [7] have used geophysical analyses to postulate seven sites within the BAT region that may represent contemporary activity. Four of these sites fall within the Helen Planitia region: Maram (600 km), Atete (600 km), Kulimina (170 km), and Shiwanokia (500 km). Mapping relations show that each of the four coronae represents some of the youngest local activity [8]. All four coronae also share similar

characteristics in plan form displaying radiating flows in excess of several hundred kilometers, fractures and faults that trend parallel to Parga Chasmata, and moderately steep concentric bounding scarps. They also fall directly along the main trend of Parga Chasmata rifting and may be indicative of active rifting and volcanism on the Venusian surface.

Guinevere Planitia (I-2457; 0-57°N/180-300°E) The Guinevere Planitia quadrangle covers the northern portion of the BAT and will allow an additional opportunity to study local relationships of a series of large and small volcano-tectonic features that transect several physiographic provinces (volcanic rises, to crustal plateaus, and through a region of lowland plains) and will include detailed mapping of the other potentially active centers identified by Dombard et al., [7]. Combining this mapping with prior work from the Helen Planitia area [8] will allow direct comparison (spatial, temporal, structural differences) between Parga and Hecate Chasmata, two bounding rifts of the BAT province. These two 1:10M maps will be the focus of the next funding cycle and will be submitted in GIS format within the next two years.

The degree which coronae and chasmata are related remains elusive given the inability to determine, at least with any certainty, Venus' surface age(s). This requires a more detailed determination of relative age than the static pre-, syn-, or post-tectonic classification. Evaluating spatial-temporal relations within the entire BAT province at a variety of scales and developing a detailed stratigraphic sequence (if one exists) coupled with ongoing geophysical examinations may provide the means to understand contemporary processes on Venus, which may then be cautiously extrapolated over the historical record – the present is the key to the past.

References: [1] Head et al., (1992) J. Geophys. Res., 97(E8), 13, 153-13,197. [2] Phillips, R.J. and Izenberg, N.R. (1995) Geophys. Res. Lett., 22, 1517-1520. [3] Hansen, V.L. and Young, D.A. (2007) GSA Special Paper. [4] Bleamaster III, L.F., (2007) Ann. Meet. Planet. Geo. Maps., Open-File Report 2007-1233. [5] Johnson, J.R. et al., (1999) USGS Geo. Inv. Sers. I-2610. [6] Bleamaster III, L.F. (2008), Ann. Meet. Planet. Geo. Maps. NASA/CP-2008-215469 [7] Dombard et al., (2007) J. Geophys. Res., 112, E04006, doi:10.1029/2006JE002731. [8] Bleamaster III, L.F. (2007) LPSC XXXVIII, abstract 2434.

GEOLOGIC MAP OF THE SNEGUROCHKA PLANITIA QUADRANGLE (V-1): IMPLICATIONS FOR TECTONIC AND VOLCANIC HISTORY OF THE NORTH POLAR REGION OF VENUS. D. M. Hurwitz and J. W. Head,

Department of Geological Sciences, Brown University, Providence RI 02912, debra_hurwitz@brown.edu

Introduction: Geologic mapping of Snegurochka Planitia (V-1) reveals a complex stratigraphy of tectonic and volcanic features that can provide insight into the geologic history of Venus and Archean Earth [1,2], including 1) episodes of both localized crustal uplift and mantle downwelling, 2) shifts from local to regional volcanic activity, and 3) a shift back to local volcanic activity. We present our progress in mapping the spatial and stratigraphic relationships of material units and our initial interpretations of the tectonic and volcanic history of the region surrounding the north pole of Venus.

Mapping Methods: We have used full-resolution (75 m/pixel) images where available to produce a detailed map in ArcGIS and a correlation chart of mapped units (Figures 1-3) in conjunction with the USGS planetary mapping effort [3]. On the basis of initial regional reconnaissance geological mapping, twelve material units and two structural units have been identified and mapped in detail and are found to be similar to those identified in previous studies [e.g., 4,5]. The material units include (from older to younger) tessera material (*t*), densely lineated plains material (*pld*), belts of ridged material (*rb*), deformed and ridged plains material, both radar dark and radar bright (*pdd*, *pbd*), shield plains material (*psh*), smooth radar dark plains material (*pds*), smooth radar bright plains material (*pbs*), belts of fractured material (*fb*), lobate plains material surrounding large edifices >100 km in diameter (*lp*), small edifice features (*ed*, ~20-100 km in diameter), and crater materials (*c*). Structural units identified are wrinkle ridges (*wr*) and lineaments (*lin*) that deform the material units.

Material and Structural Units: The tessera terrain is consistently the oldest material in the region and is characterized by high elevation, extensively deformed radar bright material that is embayed by younger plains units. The fractures that define this unit are generally characterized by at least two intersecting orientations of deformation (subunit *t1*), though localized exceptions to this trend have the radar bright, deformed morphology but lack the clear intersecting deformation patterns (subunit *t2*). In contrast, *pld* material, while also generally characterized by a rough surface texture, has a single primary orientation of fractures. Similarly, *rb* material has parallel lineations that have been confined to unique belts of material that often have distinctive topographic profiles with both positive and negative elevations observed. These three types of deformed plains are all typically embayed by surrounding plains units.

The next suite of material units identified includes the regional plains material units. The oldest plains units include *pdd* and *pbd*, material that is characterized by dense, small scale fractures and ridges. These units are commonly embayed by *ps*, material with a high concentration of small volcanic shields that range in size from 1-20 km in diameter. In turn, *psh* plains are embayed by the *pbs* and *pds* units, deposits that have generally not been heavily deformed by tectonic processes. Smooth *pbs* plains are commonly spatially related to small shield clusters, though there are examples of *pbs* that lack evidence of nearby shield volcanism.

The youngest material units in Snegurochka Planitia are *fb*, *lp*, and *ed*. Units of *fb* are characterized by local belts of fractured material and in some cases volcanism (e.g., 80°N, 260°E, 84°N, 95°E), indicating episodes of localized uplift possibly related to initial stages of volcanism. Deposits of *lp* material, mostly surrounding Renpet Mons (76°N, 235°E) and near the Itzpapalotl Tessera-Snegurochka Planitia boundary (76°N, 10°E), are characterized by lobate-tipped flows surrounding smaller edifice structures. Gash-like fractures (*lin*) and jagged wrinkle ridges (*wr*) are mapped as separate lines and are superposed on material units.

Geologic History: The most tectonically deformed material (*t*, *pld*, and *rb*) formed earliest in the observed history of Venus, suggesting that Venus was more tectonically active in the earlier phases of its recorded geologic history. This early period of deformation was followed by an initial phase of regional plains emplacement (*pbd*, *pdd*) that was subjected to subsequent tectonic deformation, though this deformation was less intense. This period of regional volcanism was followed by a period of more localized volcanism with overlapping flows that originated from clusters of small shield volcanoes (*psh*). This clustered distribution implies the presence of multiple conduits connecting a widespread shallow subsurface magma source to the surface.

After these smaller clusters of volcanoes formed, a massive resurfacing of Venus is thought to have occurred between 500 Ma and 1 Ga [2, 6] due to the widespread distribution of smooth plains material (*pds*, *pbs*). As the interior of Venus continued to cool over time, melting transitioned from facilitating distributed flood-basalt style volcanism to more localized magma upwellings that led to the formation of large shield volcanoes (*lp*, *ed*). These eruptions fed surface flows that in most cases cover the plains units described above, suggesting that this volcanism occurred more recently in Venus's geologic history. Also during this time, fracture belts (*fb*) developed as magma rose from the subsurface and caused localized extension. This is evident in the vicinity of Laka Mons (80°N, 260°E) and Szél-anya Dorsa (84°N, 95°E), where lava flows over belts of fractured material.

Key Results: The mapping presented here has led to key observations that provide insight into the tectonic and volcanic history of this region of Venus. Ridge belt material (*rb*) formed relatively early in the region's history, indicating that compression resulting from possible mantle downwelling pre-dated the vast regional volcanism that characterizes a period of extension within Snegurochka Planitia (V-1). In contrast, fracture belt material (*fb*) has been interpreted to be young and related to mantle upwelling and young edifice-forming volcanism. These observations suggest that localized regions of extensional deformation of the surface may be induced by mantle upwelling and may indicate the locations of stalled or actively ascending volcanic plumes. This evolution has implications for our understanding of both the formation of the neighboring Ishtar Terra highlands [7] as well as the emplacement of the identified volcanic features.
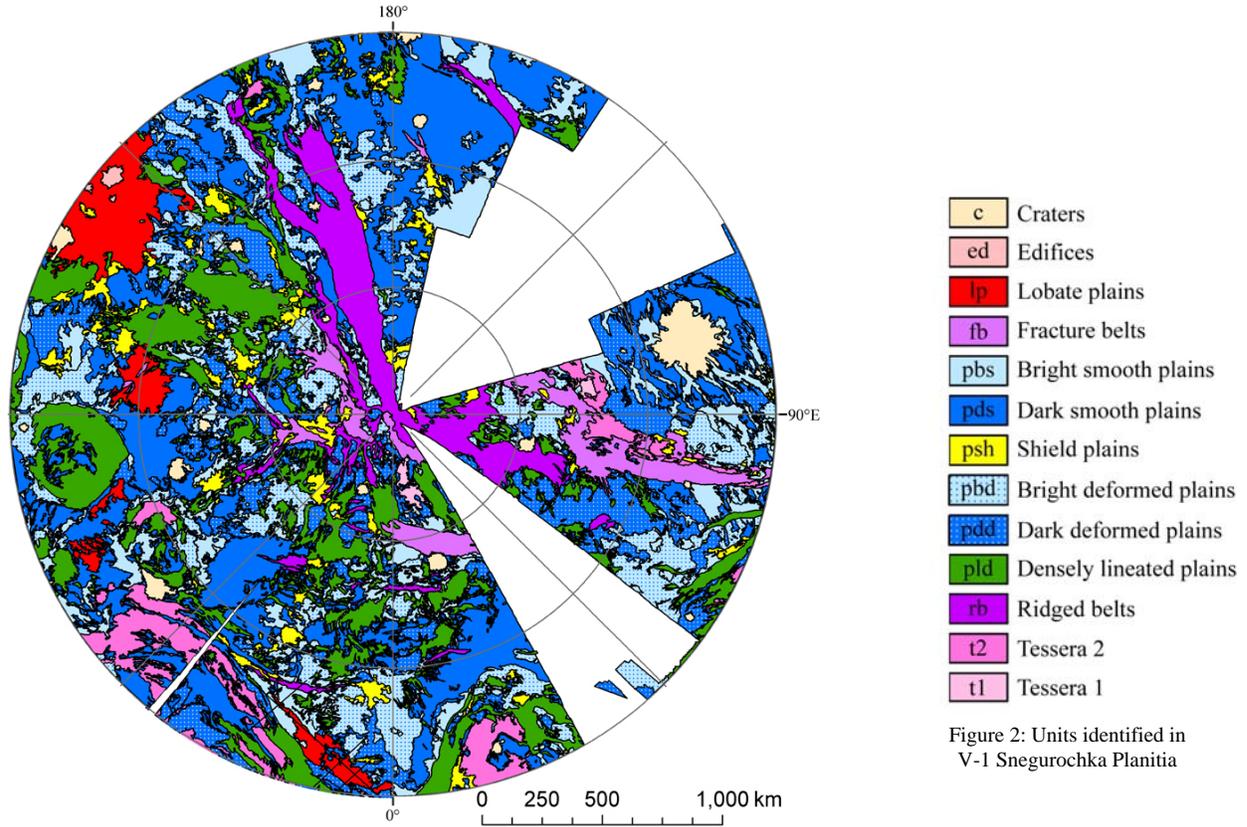
Figure 1: Geologic map of the V-1 Snegurochka Planitia quadrangle.

c	Craters
ed	Edifices
lp	Lobate plains
fb	Fracture belts
pbs	Bright smooth plains
pds	Dark smooth plains
psh	Shield plains
pbd	Bright deformed plains
pdd	Dark deformed plains
pld	Densely lineated plains
rb	Ridged belts
t2	Tessera 2
t1	Tessera 1

Figure 2: Units identified in V-1 Snegurochka Planitia
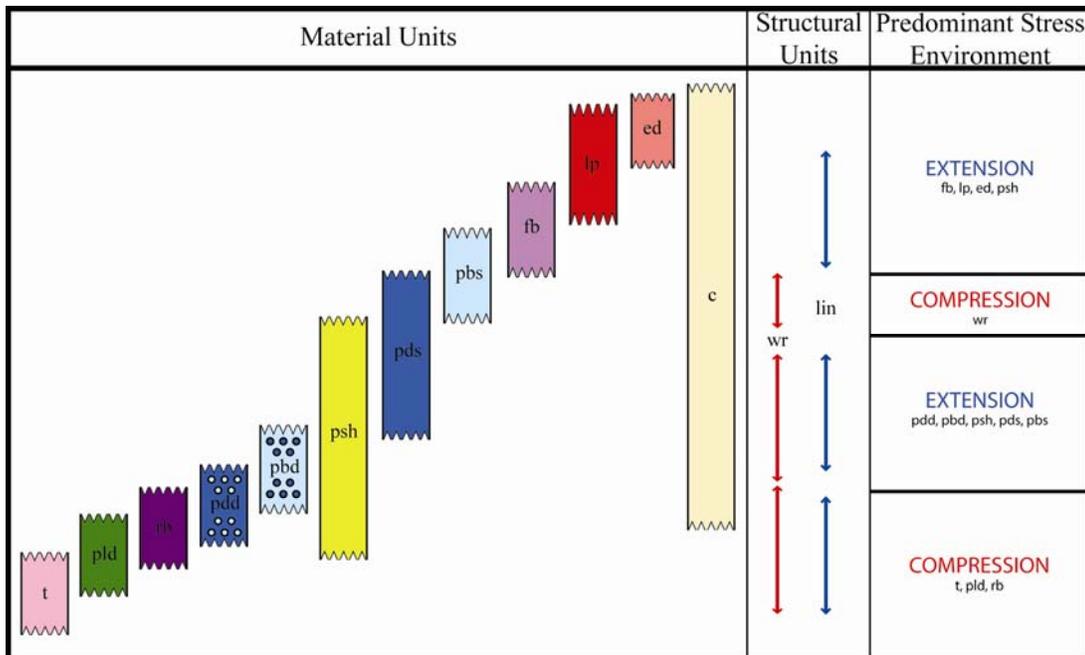
Figure 3: Correlation of mapped units for V-1 Snegurochka Planitia.

References: [1] J. Head et al., *EPSC* (abs.) 2008 [2] M. Ivanov et al., *LPSC* abs. #1391, 2008 [3] K. Tanaka, *USGS Open File Report 94-438*, 1994 [4] A. Basilevsky & J. Head *Plan. Space Sci.*, *48*, 75, 2000 [5] M. Ivanov & Head J. W. *JGR*, 106, 17,515, 2001 [6] A. Basilevsky and J. Head *Plan. Space Sci.*, 43(12), 1523-1553, 1995 [7] M. Ivanov and J. Head, *Plan. Space Sci., 56*, 1949-1966, *200*8.

PRELIMINARY GEOLOGICAL MAP OF THE FORTUNA TESSERA (V-2) QUADRANGLE, VENUS.

M. A. Ivanov[1,2] and J. W. Head[2], [1]Vernadsky Institute, RAS, Moscow, Russia, mikhail_ivanov@brown.edu, [2]Brown University, Providence, RI, USA, james_head@brown.edu.

Introduction: The Fortuna Tessera quadrangle (50-75°N, 0-60°E) is a large region of tessera [1] that includes the major portion of Fortuna and Laima Tesserae [2]. Near the western edge of the map area, Fortuna Tessera is in contact with the highest mountain belt on Venus, Maxwell Montes. Deformational belts of Sigrun-Manto Fossae (extensional structures) and Aušrā Dorsa (contractional structures) separate the tessera regions. Highly deformed terrains correspond to elevated regions and mildly deformed units are with low-lying areas. The sets of features within the V-2 quadrangle permit us to address the following important questions: (1) the timing and processes of crustal thickening/thinning, (2) the nature and origin of tesserae and deformation belts and their relation to crustal thickening processes, (3) the existence or absence of major evolutionary trends of volcanism and tectonics. The key feature in all of these problems is the regional sequence of events. Here we present description of units that occur in the V-2 quadrangle, their regional correlation chart (Fig. 1), and preliminary geological map of the region (Fig. 2).
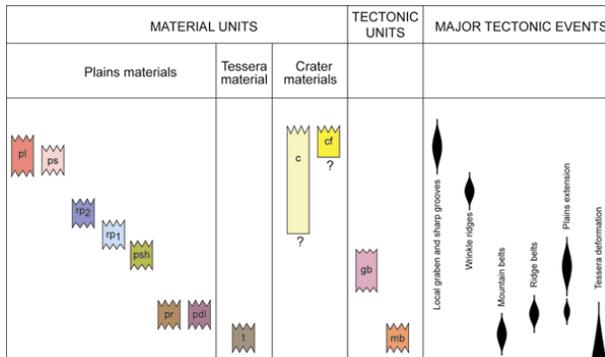
Fig. 1. Correlation chart of units mapped within the Fortuna quadrangle.

Topographic characteristics: The topographic variations within the quadrangle appear to reflect changes in crustal thickness [3]. The highest regions in the quadrangle are the tesserae and the mountain belt of Maxwell Montes. These topographic features represent large domains of thickened crust [4-7]. The western part of Fortuna Tessera is ~2 km higher than its eastern part and a broad depression separates western and eastern Fortuna. This may suggest that the eastern domain is more related to the lower Laima and Meskhent Tesserae than to the Maxwell-dominated western domain. Belts of contractional structures (dorsa) are preferentially associated with elevated flanks of the

tesserae, and belts of extensional structures (fossae) occur between major tessera regions within low-lying areas where they form local highs. Moderately deformed plains are in topographic lows between heavily deformed terrains. Tectonically undeformed plains occur on the slopes of large volcanoes.

Units and structures: During preliminary mapping of the V-2 quadrangle we have defined ten material units (including two units related to impact craters) and two structural units (Figs. 1,2) and placed them in stratigraphic sequence using embayment and cross-cutting relationships. From older to younger, these units are as follows. Tessera material (t): represents one of the most tectonically deformed types of terrain on Venus [8,9,1]. Both the material and tectonic structures play a key role in the definition of the unit. Tessera occupies the majority of the quadrangle (~50%, Fig. 2) and occurs in two major regions: Fortuna and Laima Tesserae. Type locality: 63.4°N, 19.5°E. Densely lineated plains material (pdl): heavily dissected by numerous densely packed narrow (<100s m), short (10s km), parallel and subparallel lineaments (fractures). Type locality: 52.4°N, 9.7°E. Mountain belts (mb): represent a structural unit that surrounds Lakshmi Planum and forms the highest mountain ranges on Venus [10,11,8,4,12,13]. Densely packed ridges that are 5-15 km wide and tens to a few hundreds of kilometers long characterize all mountain belts. Within the quadrangle, only the eastern portion of Maxwell Montes is represented. Type locality: 65.5°N, 0.9°E. Ridged plains material (pr): characterized by the morphology of lava plains and are deformed by broad (5-10 km) and long (10s km) linear and curvilinear ridges. In places, the ridges are concentrated into prominent belts (Aušrā Dorsa). Type locality: 53.2°N, 27.8°E. Groove belts (gb): represent a structural unit, which consists of dense swarms of linear and curvilinear subparallel lineaments (fractures or graben). Occurrences of the unit have a distinct belt-like shape. Between the structures within the belts, small fragments of preexisting units are seen in places. These fragments are usually too small to be mapped at the scale of the mapping (1:5M). Type locality: 56.4°N, 25.3°E.

Shield plains material (psh): characterized by abundant small (<10 km) shield- and cone-like features that are interpreted as volcanic edifices [14-17]. In places, the shields form clusters of structures. In contrast to the above units, the material of shield plains occurs at lower elevations and is mildly deformed by

tectonic structures (wrinkle ridges and sparse fractures/graben). Type locality: 61.4°N, 33.9°E. Material of the lower unit of regional plains (rp₁): is characterized by a morphologically smooth surface with a homogeneous and relatively low radar backscatter. The surface of the unit is mildly deformed by wrinkle ridges. The lower unit of regional plains occurs within low-lying areas and embays the heavily tectonized units and shield plains material. Type locality: 51.5°N, 25.6°E. Material of the upper unit of regional plains (rp₂): has a morphologically smooth surface that is moderately deformed by wrinkle ridges that belong to the same family of structures that deform the unit rp₁. The unit (in contrast to the unit rp₁) shows higher radar albedo and often forms flow-like occurrences that are superposed on the surface of the lower unit of regional plains. Type locality: 52.9°N, 7.2°E.

Smooth plains material (ps): has a morphologically smooth, usually dark and featureless surface, which is tectonically undisturbed. The unit makes small equidimensional and elongated patches a few tens of km across. Type locality: 54.8°N, 2.4°E. Lobate plains material (pl): is characterized by a morphologically smooth surface with an albedo pattern consisting of numerous bright and dark flow-like features. Material of lobate plains is tectonically undisturbed and fields of the unit are associated with several medium-sized (a few hundreds km across) volcanic centers near the northern and southern edges of the quadrangle. Type locality: 50.5°N, 22.0°E.

Impact crater materials, undivided (c): includes materials of the central peak, floor, walls, rim, and continuous ejecta. Type locality: 59.7°N, 26.8°E (crater Goeppert-Mayer). Impact crater outflow material (cf), type locality: 61.6°N, 36.2°E (outflow from crater Baker).

Evolutionary trends: Consistent relationships of cross-cutting and embayment among the mapped units/structures (Fig. 1) suggest progressive decline of the amount of tectonic deformation from heavily tectonized units such as tessera, densely lineated plains, ridged plains, and deformational belts through mildly deformed plains units (psh, rp₁, rp₂) to tectonically undeformed smooth and lobate plains. The elevated regions within the quadrangle correspond to the occurrences of the older and heavily tectonized units and mildly tectonized plains occur in topographic lows. This correlation suggests that the regional topographic patterns within the quadrangle were established during the earlier stages of the geologic history and that the processes of crustal thickening/thinning mostly operated at this time.

Clear morphological differences of the broad and mildly deformed plains units as well as their consistent age relationships (Fig. 1) suggest that there were significant changes in the volcanic style from shield plains (distributed small sources) through regional plains (volcanic flooding) to lobate plains (several major volcanic centers).

Fig. 2. Preliminary geological map of the Fortuna Tessera quadrangle.

References

1) Sukhanov, A.L., *In: Venus Geology, Geochemistry, and Geophysics*, V.L. Barsukov et al., eds. 82, 1992; 2) Sukhanov, A.L. et al., Geomorphic/geological map of part of the Northern hemisphere of Venus, scale 1:15M, USGS Map I-2059, Flagstaff, AZ, 1989; 3) Grimm, R.E., *Icarus*, 112, 89, 1994; 4) Head, J.W., *Geology*, 18, 99, 1990; 5) Keep, M. and V.L. Hansen, *JGR*, 99, 26015, 1994; 6) Hansen, V.L. and J.J. Willis, *Icarus*, 296, 1996; 7) Pritchard, M.E. et al., *GRL*, 24, 2339, 1997; 8) Barsukov, V.L. et al., *JGR*, 91, D399, 1986; 9) Bindschadler, D.L. and J.W. Head, *JGR*, 96, 5889, 1991; 10) Pettengill, G.H. et al., JGR, 85, 8261, 1980; 11) Masursky, H., et al., *JGR*, 85, 8232, 1980 12) Pronin, A.A., *In: Venus Geology, Geochemistry, and Geophysics*, V.L. Barsukov et al., eds. 68, 1992; 13) Ivanov, M.A. and J.W. Head, *PSS*, 56, 1949, 2008; 14) Aubele, J.C. and E.N. Slyuta, *EMP*, 50/51, 493, 1990; 15) Head, J.W. et al., *JGR*, 97, 13153, 1992; 16) Guest, J.E. et al., *JGR*, 97, 15949, 1992; 17) Ivanov, M. A. and J. W. Head, *JGR*, 109, doi:10.1029/2004JE002252, 2004.

GEOLOGICAL MAP OF THE FREDEGONDE (V-57) QUADRANGLE, VENUS, M. A. Ivanov[1,2] and J. W. Head[2], [1]Vernadsky Institute, RAS, Moscow, Russia, mikhail_ivanov@brown.edu, [2]Brown University, Providence, RI, USA, james_head@brown.edu.

Introduction: The area of V-57, the Fredegonde quadrangle (50-75°S, 60-120°E, Fig.1), is located within the eastern portion of Lada Terra within the topographic province of midlands (0-2 km above MPR [1,2]). Midlands form the most abundant portion of the surface of Venus and are characterized by diverse sets of units and structures [3-11]. The area of the Fredegonde quadrangle is in contact with the elevated portion of Lada Terra to the W and with the lowland of Aino Planitia to the NE. The transitions of the midlands to the lowlands and highlands are, thus, one of the main themes of the geology within the V-57 quadrangle. The character of the transitions and distribution and sequence of units/structures in the midlands are crucially important in understanding the time and modes of formation of this topographic province. The most prominent features in the map area are linear deformational zones consisting of swarms of grooves and graben and large coronae. The zones characterize the central and NW portions of the map area and represent regionally important, broad (up to 100s km wide) ridges that are 100s m high. Relatively small (100s km across, 100s m deep) equidimensional basins occur between the corona-groove-chains in the west and border the central chain from the east.

Here we describe units that make up the surface within the V-57 quadrangle and present a summary of our geological map that shows the areal distribution of the major groups of units.

Material and structural units and their relationships: During our mapping we have defined the following material units that can be divided into four groups on the basis of embayment and cross-cutting relationships. **I. The first, older, group** of heavily tectonized units includes two material units (pdl and pr) and one structural unit (gb). (1) Densely lineated plains material (pdl): The surface of this unit is heavily dissected by numerous densely packed lineaments (fractures), which are narrow (<100s m), short (10s km), and parallel or subparallel to each other. In the majority of occurrences of pdl the lineaments are packed so densely that they completely obscure the morphology of the precursor materials. In some fragments of the plains, however, remnants of the older lava plains are visible between the lineaments. These materials are interpreted to be volcanic plains, heavily deformed by extensional and/or shear structures. Type locality: 59.0^{o}S, 85.2^{o}E. (2) Ridged plains material (pr): characterized by morphology of lava plains that are deformed by broad (5-10 km) and long (10s km)

linear and curvilinear ridges. The ridges typically have a smooth surface and rounded and slightly undulating hinges, and appear to be symmetrical in cross section. In places, the ridges form prominent belts (Oshumare Dorsa). Type locality: 57.1^{o}S, 78.1^{o}E. (3) Groove belts (gb): represent a structural unit that is formed by swarms of numerous linear and curvilinear subparallel lineaments that are usually wide enough to be resolved as fractures or graben. The main morphologic differences between groove belts and densely lineated plains material are the shape and dimensions of occurrences (belts for gb and patch-like occurrences for pdl), as well as larger spacing, width, and length of structures in fracture belts. Type locality: 58.8^{o}S, 91.6^{o}E.

II. The second, middle, group consists of three material units. (1) Shield plains material (psh): is characterized by the presence of numerous small (<10 km) shield-like features that are interpreted as volcanic edifices [12-14]. The surface of both the shields and plains between them is morphologically smooth. Material of shield plains embays all units from the first group and represents the first unit in the stratigraphic scheme that displays no pervasive deformation and is mildly deformed by tectonic structures (wrinkle ridges). Type locality: 59.4^{o}S, 76.2^{o}E. (2) Material of lower unit of regional plains (rp$_1$): has a morphologically smooth surface with a homogeneous and relatively low radar backscatter but can be locally mottled. This unit is the most abundant within the quadrangle (~30% of the map area) and preferentially occurs on the floor of the low-lying basins. Type locality: 52.7^{o}S, 107.9^{o}E. (3) Material of upper unit of regional plains (rp$_2$): has a morphologically smooth surface that is moderately deformed by numerous low, narrow, and sinuous wrinkle ridges of the same family that deforms the unit rp$_1$. The key difference between the upper and lower units of regional plains is albedo variation. In contrast to the uniform and relatively low albedo of rp$_1$, the upper member of the plains has a noticeably higher albedo. The unit rp$_2$ covers ~20% of the map area and occurs usually as equidimensional or slightly elongated patches of flow-like shape from tens of kilometers to several hundred kilometers across. Type locality: 61.0^{o}S, 74.6^{o}E. Material of both units of regional plains embays shield plains and the older materials/structures.

III. The third, young, group includes three units. (1) Shield cluster material (sc): appears to be morphologically similar to shield plains (psh) [15] but, in contrast, is tectonically undeformed and displays small

lava flows superimposed on lava plains nearby. Small shields that form shield clusters and material that immediately surrounds them appear to be superposed on the adjacent regional plains (rp$_1$, rp$_2$). These relationships suggest that most of the clusters postdate the emplacement of regional plains. Type locality: 69.7^{o}S, 86.7^{o}E. (2) <u>Smooth plains material (ps):</u> has a morphologically smooth, tectonically undisturbed, and featureless surface. Areas of smooth plains are usually dark (smooth at the scale of the radar wavelength). The unit occurs as small equidimensional and elongated occurrences a few tens of kilometers across. Type locality: 71.6^{o}S, 92.5^{o}E. (3) <u>Lobate plains material (pl):</u> has a morphologically smooth surface that occasionally is disturbed by a few extensional features. The most characteristic feature of lobate plains is their non-uniform albedo pattern consisting of numerous bright and dark flow-like features. The flows can be several tens of kilometers long. Occurrences of the unit form equidimensional fields many tens up to a few hundreds of km across. In the V-57 quadrangle, lobate plains are associated with Dunne-Musun and Ambar-ona Coronae. Material of lobate plains embays wrinkle ridges. Type locality: 62.0^{o}S, 91.6^{o}E. The age relationships among the units sc, ps, and pl are sometimes not clear and they appear to form roughly simultaneously.

IV. The fourth group includes materials related to emplacement of impact craters and consists of two units. (1) <u>Impact crater materials, undivided (c):</u> this unit includes materials of the central peak, floor, walls, rim, and continuous ejecta. Type locality: 56.2^{o}S, 98.9^{o}E (crater Addams), and (2) Impact crater outflow material (cf), type locality: 57.0^{o}S, 101.7^{o}E (outflow from crater Addams).
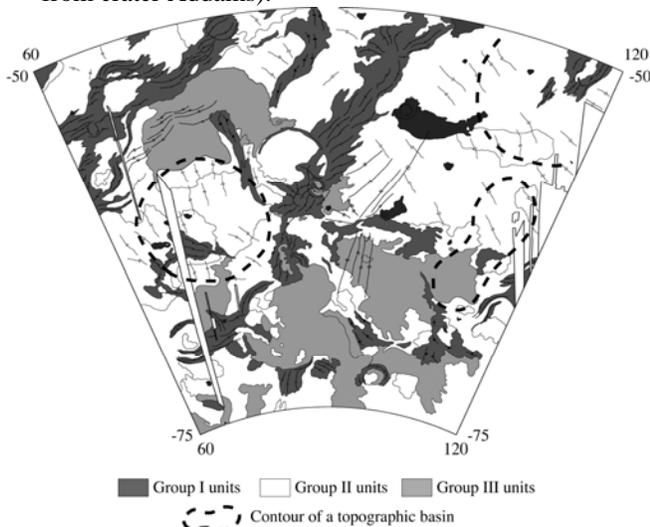
Fig. 1. Geological map of the V-57 quadrangle.

Summary: The results of the mapping in the V-57 quadrangle permit us to outline the major episodes of the geologic history of this region. Tectonic deformation played the most important role in the beginning of the history. The majority of deformation occurred early on and was related to the formation of the deformational belts, the most prominent of which are the corona-groove chains. During this period, the most important topographic features (broad linear ridges and equidimensional basins) of the midland portion of Lada Terra were established. During the middle and late periods, volcanism was more important and vast plains moderately deformed by tectonic structures were emplaced. There is a little evidence suggesting a continued development of the major topographic features during the middle stages of the geologic history of the region. The flow direction of lobate plains (from the broad ridges toward the floor of the basins) suggests that the overall topographic configuration of the midlands within the map area was established prior to emplacement of the youngest volcanic plains. The main topographic and structural elements of coronae appear to be older than both shield plains and regional plains. The youngest lobate plains, however, are typically associated with some coronae. This means that the corona structures were either reactivated late in the geologic history or volcanic activity at coronae continued until the late stages of history.

References: 1) Masursky, H., et al., *JGR*, 85, 8232, 1980; 2) Pettengill, G.H., et al., *JGR*, 85, 8261, 1980; 3) Barsukov, V.L. et al., *JGR*, 91, D399, 1986; 4) Solomon, S.C. et al., *JGR*, 97, 13199, 1992; 5) Head, J.W. et al., *JGR*, 97, 13153, 1992; 6) Guest, J.E. et al., *JGR*, 97, 15949, 1992; 7) Stofan, E.R. et al., *JGR*, 97, 13347, 1992; 8) Roberts, K.M. et al., *JGR*, 97, 15991, 1992; 9) Basilevsky, A.T. et al., in: *Venus II* S.W. Bougher et al. eds., UAP, 1047, 1997; 10) Hansen, V.L. et al., in: *Venus II* S.W. Bougher et al. eds., UAP, 797, 1997; 11) Smrekar, S.E. et al., in: *Venus II* S.W. Bougher et al. eds., UAP, 845, 1997; 12) Aubele, J.C. and E.N. Slyuta, *EMP*, 50/51, 493, 1990; 13) Addington, E.A., *Icarus*, 149, 16, 2001; 14) Ivanov, M.A. and J.W. Head, *JGR*, 109, doi:10.1029/2004JE002252, 2004; 15) Ivanov, M.A. and J.W. Head, Geologic map of the Mylitta Fluctus (V-61) quadrangle, *USGS Map 2920*, 2006.

GEOLOGICAL MAPPING OF THE LADA TERRA (V-56) QUADRANGLE, VENUS. P. Senthil Kumar[1,2] and James W. Head III[2], [1]National Geophysical Research Institute, Hyderabad 500007, India, senthilngri@yahoo.com; [2]Department of Geological Sciences, Brown University, Providence, RI 02912, USA, james_head@brown.edu.

Introduction: Geological mapping of the V-56 quadrangle (Fig. 1) reveals various tectonic and volcanic features and processes in Lada Terra that consist of tesserae, regional extensional belts, coronae, volcanic plains and impact craters. This study aims to map the spatial distribution of different material units, deformational features or lineament patterns and impact crater materials. In addition, we also establish the relative age relationships (e.g., overlapping or cross-cutting relationship) between them, in order to reconstruct the geologic history. Basically, this quadrangle addresses how coronae evolved in association with regional extensional belts, in addition to evolution of tesserae, regional plains and impact craters, which are also significant geological units of Lada Terra.

Geologic mapping: We used 250-m-per-pixel Magellan SAR images to prepare a geologic map at a scale of 1:5,000,000. Full-resolution (75-m-per-pixel) images were used for fine details of the mapped units and relationships. We used ArcGIS software for carrying out geological mapping. This quadrangle is bordered by Kaiwan Fluctus (V-44) [1] and Agnesi (V-45) [2] quadrangles in the north; Mylitta Fluctus (V-61) [3,4], Fredegonde (V-57) [5] and Hurston (V-62) [2] quadrangles in the west, east, and south, respectively. From the geologic mapping, we report on the distribution of the following material and structural units, and reconstruct the geologic history.

Material and structural units: Table 1 summarizes the material units and their relative age relationships. The oldest known material units are tesserae, radar bright areas characterized by multiple orientations of lineaments; two sets are dominant: NNW-SSE and ESE-WNW oriented lineaments. Tightly spaced ridges and troughs generally characterize tessera. The third dominant lineaments are NNE-SSW and NNW-SSE oriented along rift zones, namely, Chang Xi Chasmata and Seo-Ne Chasma; but these are apparently restricted to Cocomama Tessera. In the northeastern part of the quadrangle, terrains (tlt, Fig. 1) similar to tessera are found. They have NNE-SSW to NE-SW oriented ridges, which are cut by ESE-SNW to NW-SE oriented troughs. The spacing of these structures is greater than the structures of the tessera. The tessera units contain intra-tessera basins, which are filled by lava flows of different ages; most of them are derived from the units outside the tessera, and a few are from intra-tessera volcanism.

Regional plains units embay the tessera terrain; they have wrinkle ridges and a few young fracture systems. The oldest known plains (but younger than tessera) are densely lineated (pdl, Fig. 1), and are closely associated with shield plains and the tessera. The pdl is characterized by tightly spaced, NNW-SSE oriented fractures, which are also common in the tessera. Two types of shield plains are present: a few occur in the regional plains areas, while others occur in the core of coronae and adjoining areas. The youngest material units are lobate plains that are related to corona volcanism.

The older regional plains are cut by two regional extensional belts [6]: (1) NNW-SSE trending, 6000-km long and 50-200 km wide, Alpha-Lada (AL) belt, and (2) NNE-SSW trending, 2000 km long and 300 km wide, Derceto-Quetzalpetlatl (DQ) belt. These two belts are composed of fractures, rift basins and strike-slip zones. The DQ belt is punctured by Sarpanitum, Eithinoha and Quetzalpetlatl Coronae, while the Otygen, Demvamvit and Okhin-Tengri Coronae occur along the AL belt. A few coronae have a circular central dome and an outer concentric depression; they are defined by fractures, rift basins and ridge belts. Asymmetric and multiple coronae also occur in the southern part of the AL belt. Two other extensional belts branch from the AL belt. Coronae (Dyamenyuo and Toyo-uke Coronae and Loo-wit and Kshumay Montes) puncture these extensional belts. In many places, corona structures cut across the regional extensional belts, while in other places, the extensional belts cross the coronae structures. There is a clear overlapping time relationship, as one affects the formation of the other. Corona volcanism and tectonics are also closely related to one another. Lava flows erupt along the corona fractures, for example, in the Eithinoha Corona. Lava flows emanating from coronae travel several hundred kilometers across regional plains. Volcanism is also related to shield volcanoes in many places.

The DQ and AL belts separate the plains units of Lavinia Planitia, Aibarchin Planitia and Mugazo Planitia, where lava flows are abundant; principally there are four plain units, of which the oldest one appears to be common to all the planitia units. Most of the younger units are locally derived from the coronae. The regional plains occurring to the east of Otygen Corona have undergone intense fracturing and emplacement of graben (interpreted as dykes) after post corona-extensional belt deformation. These fractures occur in two directions: ENE-WSW and NW-SE. It appears that they represent the latest deformation, and could probably be related to terrain uplift, as is evident in many terrestrial examples.

Impact craters are the youngest geologic units, except for one that is affected by the extensional belt deformation and the other embayed by regional plains. Most impact craters show a complex geometry and a few are bowl-shaped. Many complex craters show

asymmetric run-out flows that are characteristic of oblique impacts.

Correlation of material units: Older tessera units are postdated by numerous plains units; areally, regional plains with wrinkle ridges are the most extensive, with shield plains generally predating these and some corona volcanism postdating them. Final detailed mapping is underway to document the spatial and temporal evolution of the material units and deformation events. We are also linking this geologic history to the geodyamic processes implied by this surface evolution.

References: [1] Bridges, N.T., and McGill, M.E., *USGS Scientific Investigations Map I-2747,* 2002. [2] http://astrogeology.usgs.gov/Projects/PlanetaryMapping/ MapStatus/VenusStatus/Venus_Status.html. [3] Ivanov, M.A., and Head, J.W., *USGS Scientific Investigations Map 2920,* 2006. [4] Ivanov, M.A., and Head, J.W., this volume. [5] Ivanov, M.A., et al., this volume. [6] Baer, G., et al., *J. Geophys. Res.*, 99, 8335-8369, 1994.
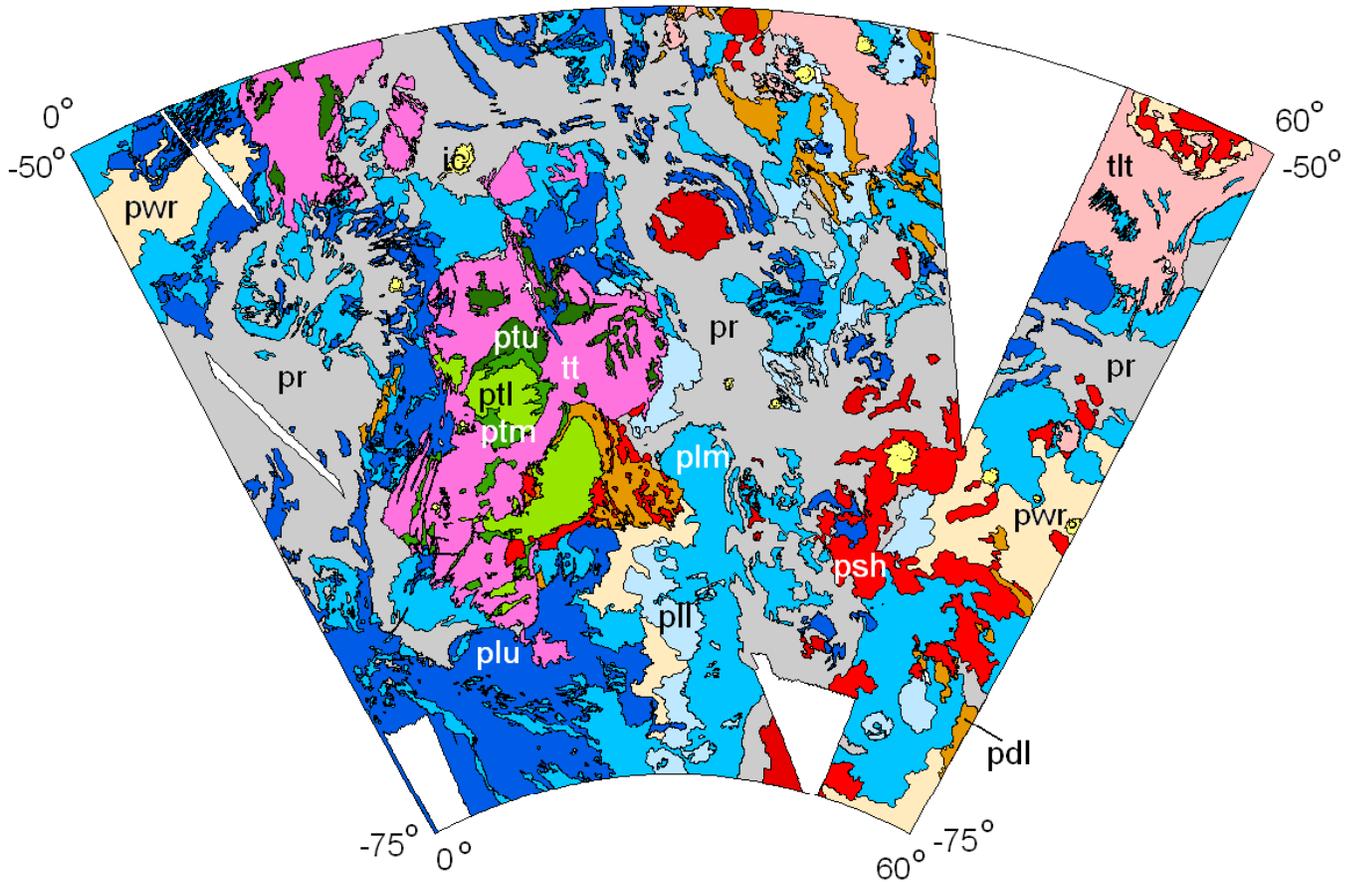
Fig. 1. Geological map of V-56 Lada Terra quadrangle. See table 1 for names of material units. Deformational structures are not shown here; these are currently being drawn on a separate map.

Table 1: Materials relative age relationships.

MATERIALS	RELATIVE AGES
Impact craters (ic)	--
Lobate plains upper (plu)	--------------
Lobate plains middle (plm)	-------------
Lobate plains lower (pll)	-----------
Wrinkle ridged plains (pwr)	---------------------------
Shield plains (psh)	-------------
Densely lineated plains	---------------
Tessera-like terrain (tlt)	------------------
Tessera (tt)	-----------------

GEOLOGIC MAPPING OF V-19. P. Martin[1], E.R. Stofan[2, 3] and J.E. Guest[3], [1]Durham University, Dept. of Earth Sciences, Science Laboratories, South Road, Durham, DH1 3LE, UK, (paula.martin@durham.ac.uk), [2]Proxemy Research, 20528 Farcroft Lane, Laytonsville, MD 20882 USA (ellen@proxemy.com), [3]Department of Earth Sciences, University College London, Gower Street, London, WC1E 6BT, UK.

Introduction:

A geologic map of the Sedna Planitia (V-19) quadrangle is being completed at the 1:5,000,000 scale as part of the NASA Planetary Geologic Mapping Program, and will be submitted for review by September 2009.

Overview:

The Sedna Planitia Quadrangle (V-19) extends from 25°N - 50°N latitude, 330° - 0° longitude. The quadrangle contains the northernmost portion of western Eistla Regio and the Sedna Planitia lowlands.

Seven plains materials units have been mapped in V-19: Sedna deformed plains material (unit pdS), Sedna patchy plains material (unit ppS), Sedna composite-flow plains material (unit pcS), Sedna homogeneous plains material (unit phS), Sedna uniform plains material (unit puS), Sedna mottled plains material (unit pmS) and Sedna lobate plains material (unit plS). These seven units range from relatively localized, limited extent units (e.g. unit pdS) to more regional plains units (e.g. unit phS). Similarly to other mapped quadrangles on Venus [1, 2], the quadrangle has a single regional-scale plains unit (unit phS), which dominates the northeastern half of the map; the southwestern half of the map is dominated by the composite plains material (unit pcS). Each of the plains units are composed of many smaller plains units of varying age, which we group together to form a mappable unit. These smaller plains units have been grouped owing to their similarity in appearance and stratigraphic position relative to other plains units. The remaining plains units, units pdS, ppS, puS, pmS and plS, tend to crop out as isolated patches of materials.

Within this quadrangle, sixteen units associated with volcanoes have been mapped, with multiple units mapped at Sif Mons, Sachs Patera and Neago Fluctūs. An oddly textured, radar-bright flow is also mapped in the Sedna plains, which appears to have originated from a several hundred kilometer long fissure. The six coronae within V-19 have a total of eighteen associated flow units. Several edifice fields are also mapped, in which the small volcanic edifices both predate and postdate the other units. In addition, impact crater materials and tessera materials are mapped.

Multiple episodes of plains formation and wrinkle ridge formation dominate the geologic history of the V-19 quadrangle, interspersed in time and space with edifice- and corona-related volcanism. The formation of Eistla Regio postdates most plains units, causing them to be deformed by wrinkle ridges and overlaid by corona and volcano flow units.

Conclusions:

V-19 is comparable with two of our previously mapped quadrangles, V-39 and V-46, in terms of the number of plains units [3, 4]. More plains materials units have been mapped in our other two previously mapped quadrangles, V-28 and V-53, than in V-19, V-39 and V-46 [5, 6]. However, V-19 is also comparable with V-28 and V-53, in that the formation of small volcanic edifices in these three quadrangles is not confined to any specific time period. In addition, all three quadrangles (V-19, V-28 and V-53) have very horizontal stratigraphic columns, as limited contact between units prevents clear age de-

terminations. While this results in the appearance that all units formed at the same time, the use of hachured columns for each unit illustrates the limited nature of our stratigraphic knowledge in these quadrangles, allowing for numerous possible geologic histories. The scale of resurfacing in these quadrangles is on the scale of 100s of kilometers, consistent with the fact that they lie in the most volcanic region of Venus.

References:
[1] Bender, K. C. et al., 2000, Geologic map of the Carson Quadrangle (V-43), Venus. [2] McGill, G. E., 2000, Geologic map of the Sappho Patera Quadrangle (V-20), Venus. [3] Brian, A. W. et al., 2005, Geologic Map of the Taussig Quadrangle (V–39), Venus. [4] Stofan, E. R. and Guest, J. E., 2003, Geologic Map of the Aino Planitia Quadrangle (V–46), Venus. [5] Stofan, E. R. et al., 2009, Geologic Map of the Hecate Chasma Quadrangle (V–28), Venus. [6] Stofan, E. R. and Brian, A. W., 2009, Geologic Map of the Themis Regio Quadrangle (V–53), Venus.

LUNAR GEOLOGIC MAPPING: A PRELIMINARY MAP OF A PORTION OF THE LQ-10 ("MARIUS") QUADRANGLE. T.K.P. Gregg[1] and R.A. Yingst[2]

[1]Department of Geology, 411 Cooke Hall, University at Buffalo, Buffalo, NY 14260; tgregg@buffalo.edu;[2] Planetary Science Institute, 1700 E. Ft. Lowell St., Suite 106, Tucson, AZ 85719; yingst@psi.edu.

Introduction: Since the first lunar mapping program ended in the 1970s, new topographical, multispectral, elemental and albedo imaging datasets have become available (e.g., Clementine, Lunar Prospector, Galileo). Lunar science has also advanced within the intervening time period. A new systematic lunar geologic mapping effort endeavors to build on the success of earlier mapping programs by fully integrating the many disparate datasets using GIS software and bringing to bear the most current understanding of lunar geologic history [1-3]. As part of this program, we report on a 1:2,500,000-scale preliminary map of a subset of Lunar Quadrangle 10 ("LQ-10" or the "Marius Quadrangle," see Figures 1 and 2), and discuss the first-order science results. By generating a geologic map of this region, we can constrain the stratigraphic and geologic relationships between features, revealing information about the Moon's chemical and thermal evolution [4].
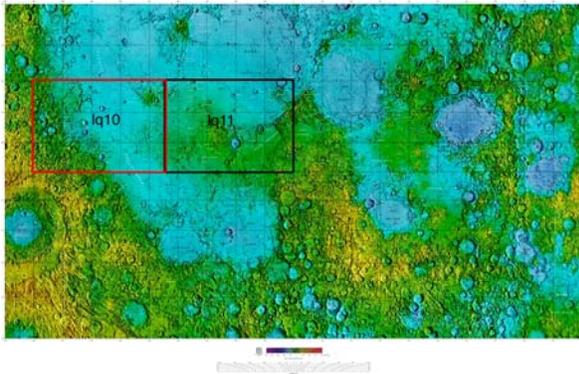
Figure 1. Location of LQ-10 (red box) on a topographic map of the lunar nearside [5]. LQ-11 (in black) is the "Copernicus Quadrangle," also being mapped [1, 2].

Science Rationale: In constructing a geologic map of LQ-10, we address the following science questions.

1) What are the origin, evolution, and distribution of mare volcanism? LQ-10 displays a wide variety of volcanic constructs, some of them unique to the Moon. LQ-10 contains the domes and cones of the Marius hills [6]; a high concentration of sinuous rilles within Aristarchus plateau [7-9]; young lava flows within Oceanus Procellarum [9-12]; and the approximate center of the Procellarum KREEP terrane [13-15]. LQ-10 is thus a prime testbed for hypotheses of lunar volcanic history, as any model must provide an explanation for each unique aspect of this region. Mapping reveals and characterizes relationships between disparate structures and units; these relationships contribute to understanding and constraining cause and effect of volcanic processes.
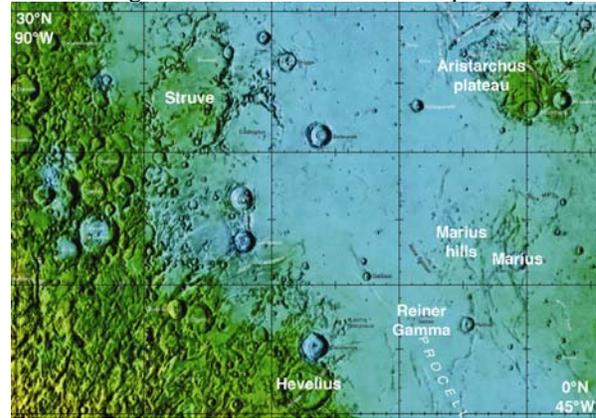
Figure 2. Topography and geography of LQ-10 [5].

2) What were the timing and effects of the major basin-forming impacts on lunar crustal stratigraphy? The western portion of LQ-10 is dominated by highlands modified by Orientale impact ejecta [7,16], whereas the boundary between the ejecta-covered highlands and the Procellarum maria intersects the quadrangle from northwest to southeast. The lavas appear to be thin where they embay the highlands, so that the underlying ejecta patterns locally control the lava emplacement [4]. Additionally, Mustard and Head [17] identified abundant cryptomaria in the region, affected by Orientale ejecta, indicative of volcanism within Oceanus Procellarum prior to the Orientale impact. LQ-10 thus contains connecting or intersecting examples of ancient highlands crust, mare material (surface and otherwise), basin material (including the proposed Oceanus Procellarum basin [7,18,19]) and impact ejecta. Identifying the spatial and stratigraphic relationships between these different units may reveal important information about the interplay between many crucial processes such as volcanic activity, ejecta emplacement, weathering and mixing. This is vital for our understanding of volcanic activity, as modeling volcanic processes requires a full inventory of volcanic material.

3) What are the Moon's important resources, where are they concentrated, and how can they be accessed? Ilmenite ($FeTiO_2$) is an excellent candidate source for lunar resources such as TiO_2 and FeO. Pyroclastics (iron-bearing volcanic glass) are likely to be important in this regard [20], and have been identified mantling the Aristarchus plateau [21]. Similar deposits are found on the Marius hills [6].

Because the surficial distribution of pyroclastics is related to their subsurface distribution, identifying and mapping pyroclastic deposits within LQ-10 will provide information about the distribution of these materials through space and time.

Mapping Procedure: We began by each individually mapping a subquadrangle of LQ-10, and comparing our preliminary results to identify differences in interpretation and mapping style; other teams of planetary mappers have successfully used this method when mapping large areas [5,22,23]. We each created a map of the region between 6.5° - 17.5°N and 281° - 291°E (Figure 3). This area was selected because it contains multiple, and representative, terrains and geologic contacts: maria, highlands, and fresh and degraded impact craters are observed. Clementine data (at all available wavelengths and band ratios) and Lunar Orbiter data were both used to interpret this sub-quad; however, both mappers used Lunar Orbiter images as the primary base map. Unit descriptions, boundaries and interpretations were compared, and differences noted. Special attention was paid to procedures in regions where craters have excavated material spectrally different from the surface material. We presented these results at the Lunar and Planetary Science Conference [23], and concluded that our mapping styles are similar and compatible.
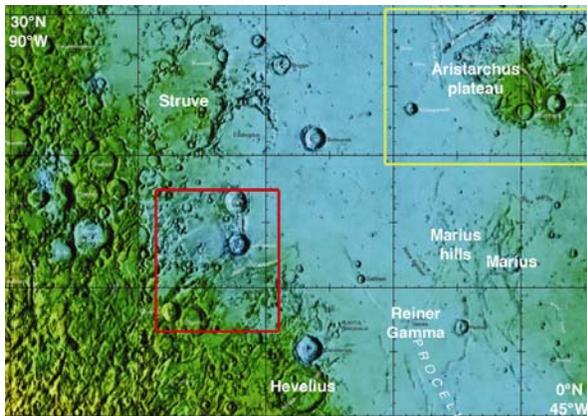
Figure 3. LQ-10, showing the area (red box) chosen for preliminary mapping and the region (yellow box) that is the subject of M.S. candidate Lough's research.

We subsequently divided LQ-10 into 4 equal quadrangles (NE, NW, SE and SW), with an additional map area around Aristarchus plateau that will receive special attention from Ms. Trevi Lough, an M.S. candidate under Gregg's advisement (Figure 3). Gregg will map the NE and SW quadrangles; Yingst will focus on the NW and SE quadrangles. We plan to meet at the upcoming Fall Geological Society of America Meeting to compare our units, and confirm areas for further scrutiny. Ms. Lough is unraveling the stratigraphy of the Aristarchus plateau as part of her M.S. thesis, and her goal is to finish this work by the Fall semester of 2010. Yingst and Gregg will incorporate Lough's results into the final map, which we plan to submit for review in approximately 12 – 18 months.

References: [1] Gaddis, L.R., et al. (2006) *LPSC XXXVII*, Abstract #2135. [2] Gaddis, L.R., et al. (2006) *USGS Open-File Report 2006-1263*. [3] Skinner, J.A., et al. (2006) *USGS Open-File Report 2006-1263*. [4] Gregg, T.K.P., and Yingst, R.A. (2008) *NASA/CP-2008-215469*. [5] Dohm, J.M. et al. (2007) *USGS Open-File Report 2007-1333*. [6] Weitz, C.M. and Head, J.W. (1999) *J. Geophys. Res. 104,* 18,933. [7] Wilhelms, D.E. (1987) *USGS Prof. Paper 1348*. [8] Guest, G.E. and Murray, J.B. (1976) *J. Geol. Soc. London 132,* 251. [9] Whitford-Stark, J.L. and Head, J.W. (1977), *Proc. Lun. Planet. Sci. VIII*, 2705. [10] Whitford- Stark, J.L. and Head, J.W. (1980) *Proc. Conf. Multi-ringed basins*, pp. 105. [11] Hiesinger, H., et al. (2003) *J. Geophys. Res. 108,* 5065. [12] Hiesinger, H. and Head, J.W. (2006) *Rev. Min. Geochem. 60*, 1. [13] Haskin, L.A., et al. (2000) *J. Geophys. Res. 105,* 20,403-20,415. [14] Jolliff, B.L., et al. (2000) *J. Geophys. Res. 105,* 4197. [15] Wieczorek, M.A. and Phillips, R.J. (2000) *J. Geophys. Res. 105,* 20,417. [16] Scott, D.H., et al. (1977) *USGS Misc. Invest. Ser. I-1034*. [17] Mustard, J.M. and Head, J.W. (1996) *J. Geophys. Res. 101,* 18,913. [18] Wilhelms, D.E. and McCauley, J.F. (1971) *USGS Misc. Invest. Series I-703*. [19] Feldman, W.C., et al. (2002) *J. Geophys. Res. 107(3)*, 1. [20] Hawke, B.R., et al. (1990) *PLPSC XX*, 249. [21] McEwen, A.S., et al. (1994) *Science, 266*, 1858. [22] Tanaka, K.L. et al. (2007) *USGS Open-File Report 2007-1333*. [23] Williams, D.A. et al. (2007) *USGS Open-File Report 2007-1333*. [23] Yingst, R.A. and T.K.P. Gregg (2009), *Lun. Planet. Sci. Conf. 40*, Abstract #1319.

GEOLOGIC MAPPING OF THE LUNAR SOUTH POLE, QUADRANGLE LQ-30: VOLCANIC HISTORY AND STRATIGRAPHY OF SCHRÖDINGER BASIN.

S.C. Mest[1,2], D.C. Berman[1], and N.E. Petro[2], [1]Planetary Science Institute, 1700 E. Ft. Lowell, Suite 106, Tucson, AZ 85719-2395 (mest@psi.edu); [2]Planetary Geodynamics Laboratory (Code 698), NASA GSFC, Greenbelt, MD 20771.

Introduction: In this study we use recent images and topographic data to map the geology and geomorphology of the lunar South Pole quadrangle (LQ-30) at 1:2.5M scale [1-4] in accordance with the Lunar Geologic Mapping Program. Mapping of LQ-30 began during Mest's postdoctoral appointment and has continued under the PG&G Program, from which funding became available in February 2009. Preliminary mapping and analyses have been done using base materials compiled by Mest, but properly mosaicked and spatially registered base materials are being compiled by the USGS and should be received by the end of June 2009.

The overall objective of this research is to constrain the geologic evolution of the lunar South Pole (LQ-30: 60°-90°S, 0°-±180°) with specific emphasis on evaluation of a) the regional effects of basin formation on the structure and composition of the crust and b) the spatial distribution of ejecta, in particular resulting from formation of the South Pole-Aitken (SPA) basin and other large basins. Key scientific objectives include: 1) Constraining the geologic history of the lunar South Pole and examining the spatial and temporal variability of geologic processes within the map area. 2) Constraining the vertical and lateral structure of the lunar regolith and crust, assessing the distribution of impact-generated materials, and determining the timing and effects of major basin-forming impacts on crustal structure and stratigraphy in the map area. And 3) assessing the distribution of resources (e.g., H, Fe, Th) and their relationships with surface materials.

Methodology: This project utilizes ArcGIS (v. 9.2) to prepare map layers (e.g., image mosaics, topography, spectral maps) and conduct the mapping, which follows the work of [5] in their mapping of the Copernicus Quadrangle (LQ-11). The Clementine UV-VIS 750-nm mosaic (100 m/pixel) is being used as the primary base to characterize geologic units from surface textures and albedos, identify unit contacts, and identify impact craters with diameters greater than 2 km; other mosaics and images (e.g., Lunar Orbiter, Clementine NIR) are being used as well.

Previous Work: Wilhelms et al. [6] provides the most detailed mapping effort of the lunar South Pole to date, which is Lunar Orbiter-based and mapped at 1:5M scale. Recent mapping of Shackleton crater [7] using Arecibo radar and SMART-1 AMIE images found that Shackleton formed ~3.6 bya, nearly 300 my older than previous estimates [6,8]. Our goal is to update the lunar map resource by incorporating the most recent and most complete datasets available.

Regional Geology: LQ-30 exhibits ~16 km of relief. The near side consists predominantly of cratered highlands, is more heavily cratered and displays higher elevations than the far side. This difference is due to the overwhelming presence of the South Pole-Aitken impact basin (discussed below), which encompasses nearly all of the far side map area.

Impact features in LQ-30 display morphologies ranging from simple to complex craters, to central peak-ring, peak-ring and multi-ring basins [6,8,9]. LQ-30 hosts all or part of 46 impact features greater than 100 km in diameter that would have significantly affected the structure of the crust and redistributed large amounts of material across the surface.

South Pole-Aitken Basin: SPA is the largest (D=2600 km) and oldest (pre-Nectarian) impact basin identified on the moon [6,8,10]. The basin's rim is defined by discontinuous mountain rings [6] and it exhibits nearly 18 km of relief. Models suggest that SPA formed by an oblique impact that excavated material from the upper crust [11,12] to the lower crust or upper mantle [13,14]. Galileo and Clementine multispectral data show enrichment in mafic materials within SPA [15-19], and LP-GRS data show enhancements in both Fe and Th within the basin relative to the surrounding highlands [20-23]. Although the exposed materials within SPA have likely been altered by billions of years of geologic processes (impacts, space weathering, etc.) or buried by local mare and pyroclastic deposits, the materials exposed within SPA could be used as a proxy for estimating the composition of the lower crust/upper mantle.

Other Impact Features: All or parts of 46 large (D>100 km) impacts occur within the map area. Most (30) were identified in previous studies [6,8] using Lunar Orbiter data. Preliminary mapping found four unnamed craters with diameters between 100 and 200 km [1], and recent work by Frey [24,25] identified 12 lunar basins with diameters ≥300 km. The presence of these basins not only affects the calculation of crater size-frequency distributions, which has implications for surface age, but the impact events would have significantly affected structural patterns within the upper crust and they would have distributed ejecta throughout the map area.

Results: Here we describe preliminary mapping results obtained for the Schrödinger basin. The Schrödinger basin (76 ºS, 134 ºE), located on the lunar far-side and just inside SPA, is a 2-3 km-deep multi-ring basin consisting of a 312-km-diameter outer ring and a ~160-km-diameter peak ring. Schrödinger is believed to be

Imbrian in age [6,26] and is likely one of the last major basin-forming impact events on the Moon, only slightly older than the Orientale impact, which emplaced secondary craters on Schrödinger's floor [26].

Structures: The predominant structures visible on the floor of Schrödinger basin are fractures that formed concentric and radial to the basin rim. The fractures dissect both peak ring and plains materials. They are only a few kilometers wide, and most fractures are tens of kilometers long.

Schrödinger Floor Materials: Nine primary units have been identified that compose the Schrodinger basin, and are organized into two groups: Plains Materials, and "Volcanic" Materials.

The Plains Materials cover most of Schrödinger's floor. These deposits show surfaces ranging from smooth to rugged, display lobate edges, and embay Schrödinger's peak ring and rim materials. *Schrödinger rugged plains material* (unit srp) appears to be stratigraphically the oldest plains material on the basin floor. Most exposures of the rugged plains are found outside of the peak ring and form heavily cratered knobby plateaus and massifs of moderately high albedo. Orientale secondaries are found within this unit in the eastern and southern parts of the basin [26]. *Schrödinger smooth plains material* (unit ssp) is found just inside the peak ring and embays the rugged plains where in contact. The smooth plains displays moderate to high albedo and contains fewer craters than the rugged plains. Antoniadi secondaries are found primarily within this unit in the eastern part of the basin, but a few have been identified in the rugged, mottled, and hummocky plains [26]. *Schrödinger mottled plains material* (unit smp) is found primarily in the center of the basin, but two small exposures are found among the massifs in the western and northeastern parts of the peak ring. The mottled plains display an overall smooth surface that is lower in albedo than the smooth plains, and slightly less cratered. *Schrödinger hummocky plains material* (unit shp) occupies much of the floor along the northern and western walls, and in the south where the peak ring is the most discontinuous. Hummocky plains displays moderately cratered, low albedo surfaces with gently rolling topography. These plains materials are interpreted to consist of impact melt from the time of basin formation and/or volcanic plains.

The *Schrödinger knobby plains material* (unit skp) forms two fairly high albedo deposits along the southern basin wall. These plains exhibit clusters of rounded and elongated knobs; elongation and some clusters appear to trend approximately north-south. Fissures within this unit appear subdued relative to those that bisect other plains units. This deposit is interpreted to be ejecta from Ganswindt crater, located on Schrödinger's rim, and/or the younger Amundsen crater ~150 km to the south.

"Volcanic" Materials are concentrated in the northern and eastern parts of the basin within the peak ring. Four patches of *Schrödinger dark plains material* (sdp) are found on the basin floor, three are located around the deposits of dark material and the fourth, and largest exposure, is located along the northern part of the peak ring. These deposits display smooth relatively featureless low albedo surfaces. In Clementine UVVIS color ratio maps, these units are distinct from the surrounding plains and appear mafic in composition. These deposits display no clear contact with adjacent materials, suggesting these materials get extremely thin toward their edges. Within the northern deposit, a long (a few 10s of kilometers) sinuous rille emerges from the mottled plains and terminates within the dark plains. The morphology of these plains, their spectral appearance, and the presence of this rille suggest these plains are composed of very fluid basaltic lavas [4].

The eastern part of Schrödinger contains a well-preserved ovoidal depression surrounded by dark materials. The depression has been interpreted as a "maar"-type crater [26], which is referred to here as a "pit crater." This pit crater has been identified as the source of pyroclastic eruptions [26,27]; this study has identified at least two distinct deposits surrounding the pit - *Schrödinger dark material 2* (sdm2) and *Schrödinger dark material 1* (sdm1) - suggesting at least two eruptive events [2-4]. The younger deposit (sdm2) shows a smooth surface and makes up the pit crater's flank; this deposit superposes the more heavily-cratered older deposit (sdm1).

References: [1] Mest, S.C. (2007) LPSC XXXVIII, **#1842**. [2] Van Arsdall, L.E. and S.C. Mest (2008) LPSC XXXIX, **#1706**. [3] Mest, S.C. and L.E. Van Arsdall (2008) NLSI LSC, NASA ARC, **#2089**. [4] Mest, S.C. (2008) GSA Joint Annual Mtg., **#324-3**. [5] Gaddis, L.R. et al. (2005) LPSC XXXVIII, **#2021**. [6] Wilhelms, D.E. et al. (1979) USGS MISM I-1162, 1:5M scale. [7] Spudis, P.D. et al. (2008) LPSC XXXIX, **#1626**. [8] Wilhems, D.E (1987) The Geologic History of the Moon, *USGS Prof. Pap.* **1348**. [9] Wood, C.A. and L. Andersson (1978) Proc. Lunar Planet. Sci. Conf., 9th, 3669-3689. [10] Spudis, P.D. et al. (1994) *Science*, **266**, 1848-1851. [11] Schultz, P.H. (1997) LPSC, XXVII, **#1259**. [12] Schultz, P.H. (2007) LPSC, XXXVIII, **#1839**. [13] Melosh, H.J. (1989) Impact Cratering - A Geologic Process, Oxford Univ. Press, 245 pp. [14] Cintala, M.J. and R.A.F. Grieve (1998) Met. and Planet. Sci., **33**, 889-912. [15] Belton, M.J.S. et al. (1992) Science, **255**, 570-576. [16] Head, J.W. et al. (1993) JGR, **98**, 17,149-17,182. [17] Lucey, P.G. et al. (1998) JGR, **103**, 3701-3708. [18] Pieters, C.M. et al. (1997) GRL, **24**, 1903-1906. [19] Pieters, C.M. et al. (2001) JGR, **106**, 28,001-28,022. [20] Lawrence, D.J. et al. (1998) Science, **281**, 1484-1489. [21] Lawrence, D.J. et al. (2002) New Views of the Moon, Europe, 12-14. [22] Lawrence, D.J. et al. (2002) JGR, **107**, doi:10.1029/200lJE001530. [23] Jolliff, B.L. et al. (2000) JGR, **105**, 4197-4216. [24] Frey, H.V. (2008) LPSC XXXIX, **#1344**. [25] Frey, H.V. (2009) LPSC, XL, **#1687**. [26] Shoemaker, E.M. et al. (1994) *Science*, **266**, 1851-1854.[27] Gaddis, L.R. et al. (2000) JGR, **105**, 4245-4262.

Geologic Mapping Along the Arabia Terra Dichotomy Boundary: Mawrth Vallis and Nili Fossae, Mars.

Leslie F. Bleamaster III[1,2], and David A. Crown[1], Planetary Science Institute, [1]corporate address - 1700 E. Ft. Lowell Rd., Suite 106, Tucson, AZ 85719; [2]mailing – Trinity University Geosciences, One Trinity Place #45, San Antonio, TX 78212, lbleamas@psi.edu.

Introduction. Geologic mapping studies at the 1:1M-scale are being used to assess geologic materials and processes that shape the highlands along the Arabia Terra dichotomy boundary. In particular, this mapping will evaluate the distribution, stratigraphic position, and lateral continuity of compositionally distinct outcrops in Mawrth Vallis and Nili Fossae as identified by spectral instruments currently in orbit. Placing these landscapes, their material units, structural features, and unique compositional outcrops into spatial and temporal context with the remainder of the Arabia Terra dichotomy boundary may provide constraints on: 1) origin of the dichotomy boundary, 2) paleo-environments and climate conditions, and 3) various fluvial-nival modification processes related to past and present volatile distribution and their putative reservoirs (aquifers, lakes and oceans, surface and ground ice) and the influences of nearby volcanic and tectonic features on hydrologic processes in these regions.

The results of this work will include two 1:1M scale geologic maps of twelve MTM quadrangles (Mawrth Vallis - 20022, 20017, 20012, 25022, 25017, and 25012; and Nili Fossae - 20287, 20282, 25287, 25282, 30287, 30282).

Mawrth Vallis, an extensive (500 km long) sinuous channel that dissects the heavily cratered surface of Arabia Terra, is located near the western extent of the Arabia Terra plateau. Considered one of the oldest of the outflow channels, along with Ares Vallis [1], this easternmost circum-Chryse Planitia channel may represent remnant scours of catastrophic outflow often attributed to failure of a subterranean aquifer and/or by persistent groundwater sapping. Mawrth Vallis, however, does not exhibit typical outflow channel source region characteristics [2] and may have resulted from a more protracted hydrologic history [3, 4]. Mawrth's source region is highly degraded and appears to head from a degraded crater (18°N, 13°W) but loses definition in both the up and down gradient directions and preserves few pristine bedforms. In addition, Mawrth Vallis channel deposits display inverted topography and several pedestal and buried craters are present indicating that significant modification and degradation has occurred in the region. In fact, much of the geology of the region has been degraded, modified, and reworked into what we observe today, a complex amalgam of geologic materials.

High-resolution image data, merged with spectral maps have revealed local relations between layered deposits and mineralogic assemblages suggestive of aqueous alteration (Figure 1). These local relations and the broader observation of significant burial and exhumation are suggestive of a highly active and protracted sedimentary history, which could potentially have involved several phases of deposition and erosion related to episodic transgressions and/or major climatic variations. The juxtaposition of considerable amounts of aqueous-altered rock (phyllosilicates) with what may have been an ancient Mars ocean is compelling (Mawrth Vallis' mouth is coincident with a portion of the putative Arabia shoreline [5, 6]).

Nili Fossae, located north of Syrtis Major volcano and west of Isidis basin, contains a series of curved depressions, which are oriented roughly concentric to the Isidis basin. The largest trough originates from Hesperian age volcanic flows, extends northward through Noachian etched and cratered units,
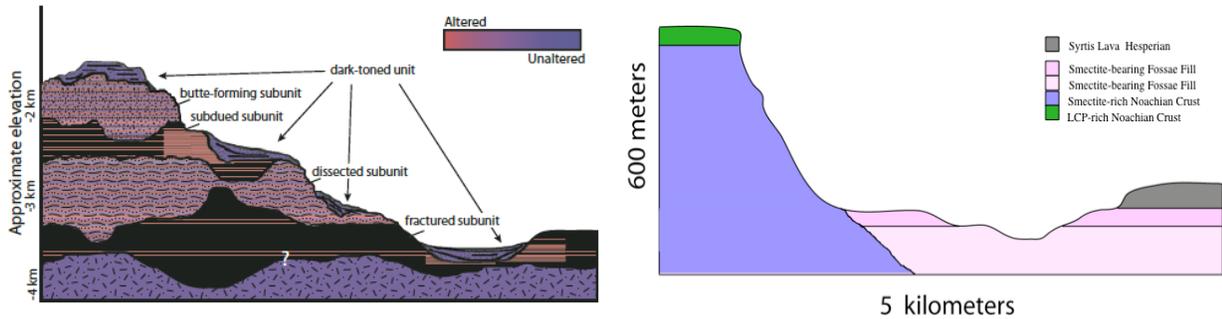
Figure 1. Relative "stratigraphic" positions or horizons of spectral units defined by Michalski and Noe Dobrea, 2007 in Mawrth Vallis (left) and J. Mustard in Nili Fossae (right); however 1:1M mapping has not identified a clear regional bedrock stratigraphy to match the mineralogic outcrops. Identification of geologic relations of these isolated studies and other high-resolution data with our mapping will help to integrate local observations into a regional geologic history and possibly improve constraints on the evolution of volatiles and geologic processes within these regions of Arabia Terra.

and ends near the dichotomy boundary [7, 8]. These structures most likely manifest as the surface expression of an outer ring fault related to the reasonably sized topographic and structural basin created by the Isidis impact into the underlying Noachian crust. Nili Fossae crosscuts materials that span the Noachian to late Hesperian and intersects with structural elements potentially related to original dichotomy formation, suggesting that Isidis has long been an influence on local geologic evolution.

Although masked in regions by volcanic flows from Syrtis Major, aeolian and fluvial deposition, and potential coastal deposits related to an ancient Martian ocean [5], subsequent stripping has revealed outcrops of significant geochemical importance. Like those observed in the Mawrth Vallis region, several outcrops of phyllosilicate-bearing Noachian materials have been revealed by the MEX OMEGA instrument [9, 10]. Phyllosilicates in this location point to the ancient history of Mars when the stability of ground and/or surface water was present for significant periods of time, facilitating the widespread aqueous alteration observed.

Figure 2. Screen shot of current Nili Fossae progress; colors indicate various designations of unit contacts and structural types; line work is ready for conversion to polygons.

References. [1] Nelson and Greeley, 1999: JGR, v. 104, no. E4, p. 8653-8669. [2] Parker, 2000: Mars Polar Science, abstract 4039. [3] Rodrogiuez et al., 2005: Icarus, v. 175, p. 36-57. [4] Michalski and Noe Dobrea, 2007, Geology, v 35., 951-954. [5] Parker, 1989: Icarus, v. 82, p. 111-145. [6] Webb, V.E., 2004: JGR doi:10.1029/2003JE002205. [7] Greeley and Guest, 1987: US Geol. Surv. Misc. Invest. Ser. Map I-1802B. [8] Craddock, 1994: LPSC XXV, pp. 291-292. [9] Poulet et al., 2005: Nature, v. 438, doi:10.1038/nature04274. [10] Mustard et al., 2005: Science, v. 307, p. 1594-1597.
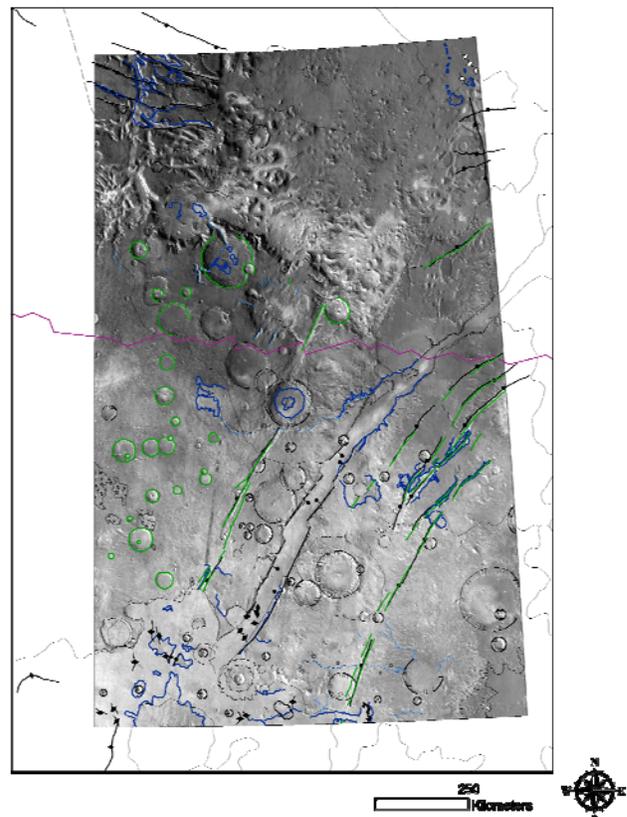
GEOLOGIC MAPPING INVESTIGATIONS OF THE NORTHWEST RIM OF HELLAS BASIN, MARS.

David A. Crown[1], Leslie F. Bleamaster III[1], Scott C. Mest[1], John F. Mustard[2], and Mathieu Vincendon[2], [1]Planetary Science Institute, 1700 E. Ft. Lowell Rd., Suite 106, Tucson, AZ 85719; crown@psi.edu, [2]Dept. of Geological Sciences, Brown University, Providence, RI 02912.

Introduction: The Hellas impact basin, spanning 2000+ km in the cratered highlands, is the largest well-preserved impact structure on Mars and its deepest depositional sink. The Hellas region is significant for evaluating Mars' hydrogeologic and climate histories, given the nature, diversity, and range in ages of potential water- and ice-related landforms [e.g., 1-2], including possible paleolakes on the basin floor [2-4]. The circum-Hellas highlands are of special interest given recent studies of potential localized fluvial/lacustrine systems [2, 5-17] and evidence for phyllosilicates around and within impact craters north of the basin [18-26].

Study Area and Mapping Objectives: Our current studies examine the evolution of Hellas' NW rim where basin floor deposits transition abruptly to the cratered highlands. We are producing a 1:1.5M-scale geologic map of eight MTM quadrangles (-25312, -25307, -25302, -25297, -30312, -30307, -30302, -30297) along Hellas' NW rim. The map region (22.5-32.5°S, 45-65°E) includes a transect across the cratered highlands of Terra Sabaea, the degraded NW rim of Hellas, and basin interior deposits of northwestern Hellas Planitia. No previous mapping studies have focused on this region, although it has been included in earlier global and regional maps [27-29]. Geologic mapping of the NW Hellas rim is providing new constraints on the magnitudes, extents, and history of volatile-driven processes as well as a geologic context for mineralogic identifications.

Geologic Mapping: Research to-date [30-32] has included general terrain characterization and comparison to other circum-Hellas regions, preliminary evaluation of geomorphology and stratigraphic relationships, preliminary exploration of compositional signatures using CRISM, and investigation of impact crater distribution, morphometry, and interior deposits, as well as production of a preliminary geologic map of part of the map area.

Hellas NW Rim Geology. The NW Hellas rim can be divided into four physiographic zones: 1) Terra Sabaea highlands (above 500m), 2) Terra Sabaea plains (-1800m - 500m), 3) Hellas rim (-5800m - -1800m), and 4) Hellas floor (below -5800m). All of these zones show significant numbers of moderate to large impact craters, suggesting that the basic geologic framework of the region was established early in Martian history with the formation of densely cratered terrains. The zones show clear differences in the types of landforms and materials exposed as well as differences in crater degradation states. A significant and complex sedimentary history can be inferred given that many large craters have been infilled and expose layered interior deposits, as well as by numerous scarps and valleys within intercrater plains.

The densely cratered highlands of Terra Sabaea contain impact craters of a wide range in size and that display a variety of degradation styles and states. Crater interiors and local, low-lying regions of the intercrater plains may be depositional sites for aeolian, fluvial, and/or lacustrine sediments.

The characteristics of the Terra Sabaea plains suggest lowering of the highland surface and creation of a younger shelf separating Terra Sabaea proper from the steeper basin rim zone. In THEMIS images, the plains in this zone show abundant scarps, a variety of subunits, and a multitude of surface variations. The zone, or shelf, appears to be part of a larger shelf along Hellas' northern rim and is located at elevations similar to those that exhibit smooth and channeled plains along Hellas' east rim [i.e., 2]. The east rim is interpreted to be a large depositional shelf potentially associated with flooding from Reull Vallis, large paleolakes within Hellas, and/or accumulation of atmospheric volatiles due to circulation patterns off of the south pole [e.g., 2, 4, 33-34].

The Hellas rim and floor zones exhibit buried and softened landforms as well as small valleys. In several locations, valley segments appear to form disconnected downslope patterns. Small lobate debris aprons are observed extending from local topographic highs. Layered surficial deposits are also evident.

Preliminary Mapping Results. Geologic mapping of a test region (22.5-29°S, 57.6-65°E) of NW Hellas indicates that surface materials can be divided into the following types: highlands, smooth plains, and crater floor deposits. Mapping shows an eroded and extensively buried ancient highland landscape, with partial exhumation indicated by etched surfaces and retreat of plains around eroded massifs and crater rims (Figs. 1, 2) [32]. Small valleys dissect the plains surface and are concentrated on sloping plains deposits at the margins of highland outcrops. Detailed mapping of this sub-region has resulted in the identification of a larger number of irregular depressions than was found in the initial survey of the entire study area [30]. In some cases the scarps defining these depressions

reveal finely layered outcrops. The occurrence of the irregular depressions and layered outcrops in both crater floor deposits and within the plains may indicate emplacement of sedimentary units on a regional scale.

Multispectral mapping with CRISM. Central to our investigation are compositional characterizations using MRO CRISM data. We have analyzed CRISM multispectral data for the NW Hellas map area for phyllosilicates and Fe-silicates (olivine-pyroxene). Fe/Mg phyllosilicate minerals (e.g., saponite, chlorite) are recognized on the basis of narrow absorption features between 1.8 and 2.4 µm. Phyllosilicates are typically observed in association with crater rims and massifs, but also are evident in some crater ejecta and floor deposits (Fig. 3), as for Tyrrhena Terra in general [26]. We are integrating these mineralogic results into our geologic mapping analyses.

Figure 1. CTX image (P12_005803_1532; centered at 61.76°E, 26.45°S; scene width = 17.5 km) showing irregular depression revealing layered deposits.

Figure 3. Phyllosilicate detections in CRISM data for NW Hellas shown in red. Background image: 200 m/pixel; R: 0.89, G: 0.71, and B: 0.60 µm.

Figure 2. THEMIS IR mosaic (centered at 60.15°E, 24.14°S) showing buried landscape, etched surfaces of plains, scarps, and valleys. Buried crater is 17 km across.

References: [1] Tanaka, K.L. and G.J. Leonard (1995), JGR, 100, 5407-5432. [2] Crown, D.A. et al. (2005), JGR, 110, E12S22, doi:10.1029/2005JE002496. [3] Moore, J.M. and D.E. Wilhelms (2001), Icarus, 154, 258-276. [4] Bleamaster, L.F. and D.A. Crown (2009), in USGS edit. [5] Lahtela, H. et al. (2003), Vernadsky Institute-Brown University Microsymposium 38, MS057. [6] Lahtela, H. et al. (2005), LPSC XXXVI, abstract 1683, LPI (CD-ROM). [7] Ansan, V. and N. Mangold (2004), 2nd Conf. on Early Mars, abstract 8006, LPI (CD-ROM). [8] Ivanov, M.A. et al. (2005), JGR, 110, E12S21, doi:10.1029/2005JE002420. [9] Korteniemi, J. et al. (2005), JGR, 110, E12S18, doi:10.1029/2005JE002427. [10] Kraal, E.R. et al. (2005), Role of Volatiles on Martian Impact Craters, abstract 3008, LPI (CD-ROM). [11] Mest, S.C. and D.A. Crown (2005), Icarus, 175(2), 335-359. [12] Mest, S.C. (2005), Role of Volatiles on Martian Impact Craters, abstract 3014, LPI (CD-ROM). [13] Mest, S.C. (2006), LPSC XXXVII, abstract 2236, LPI (CD-ROM). [14] Moore, J.M. and A.D. Howard (2005), JGR, 110, E04005, doi:10.1029/2004JE002352. [15] Moore, J.M. and A.D. Howard (2005), LPSC XXXVI, abstract 1512, LPI (CD-ROM). [16] Wilson, S.A. and A.D. Howard (2005), LPSC XXXVI, abstract 2060, LPI (CD-ROM). [17] Wilson, S.A. et al. (2007), JGR, 112, E08009, doi:10.1029/2006JE002830. [18] Poulet, F. et al. (2005), Nature, 438, 623-627. [19] Bibring, J.-P. et al. (2006), Science, 312, 400-404. [20] Costard, F. et al. (2006), LPSC XXXVII, abstract 1288, LPI (CD-ROM). [21] Murchie, S. et al. (2006), EOS Trans. AGU, abstract P33A-04. [22] Murchie, S. et al. (2007), JGR, 112, E05S03, doi:10.1029/2006JE002682. [23] Mustard, J.F. et al. (2007), LPSC XXXVIII, abstract 2071, LPI (CD-ROM). [24] Mustard, J.F. et al. (2007), 7th Inter. Conf. on Mars, LPI. [25] Pelkey, S.M. et al. (2007), LPSC XXXVIII, abstract 1994, LPI (CD-ROM). [26] Pelkey, S.M. et al. (2007), JGR, 112, E08S14, doi:10.1029/2006JE002831. [27] Scott, D.H. and M.H. Carr (1978), USGS Misc. Invest. Ser. Map, I-1083. [28] Greeley, R. and J.E. Guest (1987), USGS Misc. Invest. Ser. Map I-1802B. [29] Leonard, G.J. and K.L. Tanaka (2001), USGS Geol. Invest. Ser. Map I-2694. [30] Crown, D.A. et al. (2007), EOS Trans. AGU, abstract P41A-0189. [31] Mest, S.C. et al. (2008), LPSC XXXIX, abstract 1704, LPI (CD-ROM). [32] Crown, D.A. et al. (2009), LPSC XL, abstract 1705, LPI (CD-ROM). [33] Colaprete, A. et al. (2004), LPSC XXXV, abstract 2149, LPI (CD-ROM). [34] Colaprete, A. et al. (2005), Nature, 435, 184-188.

GEOLOGIC MAPPING OF THE MERIDIANI REGION OF MARS. G. Di Achille[1] and B. M. Hynek[1,2],
[1]Laboratory for Atmospheric and Space Physics, [2]Department of Geological Sciences (392 UCB, Univ. of Colorado, Boulder, CO 80309).

Introduction: The Mars Exploration Rover Opportunity observed an upper layer of a more than 600-m-thick sequence of light toned outcrops that characterize the Meridiani region of Mars. Results from the rover analyses have shown that the bedrock contains mineral and textural characteristics that require at least the interaction of, and possibly an overall formation by, water-related mechanisms in order to be explained [1]. Additionally, remote sensing studies of the region have suggested that the rocks sampled in places by the MER rover consist of many distinct layers extending over an area of more than 3×10^5 km^2 spanning 20º of longitude [2].

Geologic Mapping: To address the origin and history of these unique materials, we are completing a PG&G funded detailed geologic, stratigraphic, and thermophysical properties study of this widespread terrain. Specifically, we are drafting a 1:2M-scale geological map covering the full extent of these water-related deposits. In tandem with the mapping, Hynek and Phillips [1] have conducted an initial stratigraphic analysis of the stack of materials, whereas Hynek and Singer [3] focused on the coupled analysis of remote sensing and lander observations in order to improve the understanding of the physical composition of the region, providing also the requisite ground truth observations for the calibration of spacecraft data. The latter study is particularly helpful to enable the characterization of the surface composition after mapping based on the thermophysical datasets (TES and THEMIS) is complete. All of these tasks serve several purposes including gaining an understanding of the complex nature of these materials, their potential source region(s), and their timing of emplacement, as well as to place the observations by the Opportunity Rover in a broader context.

PI Hynek and Collaborators Gaetano Di Achille (CU/LASP), Roger Phillips (SwRI), Ken Tanaka (USGS) and Bruce Jakosky (CU/LASP) are currently funded to complete detailed geologic mapping at 1:2,000,000-scale in the Meridiani region. The study area is defined here as 5°S-15°N, 15°W eastward across the prime meridian to 15°E. This covers portions of the quadrangles MC-11 (Oxia Palus), MC-12 (Arabia), MC-19 (Margaritifer Sinus), and MC-20 (Sinus Sabaeus). In places of particular interest with sufficient data coverage, we are also mapping the terrain at a larger scale to truly detail the local geology. The numerous units in the study area will be refined from recent works [4-8]. Formal geological mapping has recently begun using a 100-m-resolution THEMIS base map produced by the USGS Flagstaff combined with MOLA gridded data. Additional data for mapping includes MOC WA images, THEMIS daytime and nighttime IR data, some THEMIS visible data, HRSC mosaics and stereo-derived high-resolution topography, MOLA topography, TES and THEMIS thermal inertia, some MOC NA images, CTX and HiRISE images, and mineral abundance maps from TES and OMEGA. We have completed mapping of regional valley networks to understand their potential link to the layers. Additionally, we have identified and characterized all craters in the region down to 1.5 km diameter. Our first thematic map was a thermophyiscal properties map to characterize the surficial units and assess their correlation (or lack thereof) with bedrock units. These results are discussed below. Formal mapping is now underway and we anticipate a near-final geologic/geomorphic map by fall 2009.

Stratigraphic and Thermophysical Analyses: We are currently focusing on the combined analysis of visible and thermophysical properties of the varied layers to derive possible compositional information of the materials in conjunction with their detailed stratigraphic analysis. Specifically, PI Hynek and Collaborator Roger Phillips recently mapped out the largest stratigraphic markers across the Meridiani region. Individual MOLA elevation data points along layer exposures show that most of these benchmark horizons: (1) are planar and coherent over at least a 100-km scale, and (2) have dip azimuth and magnitudes that are similar to the underlying regional slope, which was emplaced by 3.7 Ga. Mapping relations with nearby ancient river valleys suggest that these deposits also formed near this time and without significant contributions from precipitation-fed surface runoff.

We have also completed an analysis of the region based on the thermophysical properties from TES and THEMIS thermal inertia data (Fig. 1). The latter datasets were used to produce a thematic map of the entire region and to investigate the correlation between the thermophysical surface properties and the main geological units preliminarily outlined from textural, geomorphological, and mineralogical characteristics (Fig. 1a-b). The overall area is characterized by significant physical and compositional differences (Fig. 1b), possibly reflecting a changing paleodepositional environment and/or chemical alteration history. Several units could be mapped from the thermal inertia maps. However, we carefully evaluate each of the identified thermophysical regions in order to discriminate between

the bedrock/geological and/or secondary/physical significance of the thermophysical units. The latter, in fact, could not necessarily inform on the bedrock and geologic properties of the corresponding terrains but rather about their surface conditions (e.g. consolidated vs. unconsolidated; coarse- vs. fine-grained; dust-covered vs. deflated). Nonetheless, the main geological units identified based on textural, mineralogical, and morphological properties (e.g. etched terrains and hematite-rich deposits, Fig. 1a) show a strong correlation with the main provinces inferred from the thermal inertia maps. Particularly, units characterized by the exposures of etched terrains in the visible correlate well with high thermal inertia regions, whereas the hematite-rich terrains appear as low thermal inertia regions (Fig. 1a-b). Figure 1c shows a close-up from a contact region between the etched and hematite units. The geological contact is well evidenced by the sharp contrast in thermal inertia and can be mapped out for large portions of the studied region, though it tends to be less straightforward in places characterized by significant dust coverage and eolian features. On the other hand, a straightforward correlation between geological and thermophysical units does not exist elsewhere. Several units inferred from the analysis of textural and morphological characteristics are not differentiated by the thermal inertia maps (e.g. young volcanic materials in the NE corner of the map). In other cases, the thermal inertia maps show rather obvious anomalies possibly indicative of geological contacts, which are, in fact, not visible in the imagery and thus likely the result of secondary alterations (e.g. windblown craters and wind streaks clearly oriented in a NE-SW direction)

Summary: In our first 1.5 years of funding, significant progress has been made on stratigraphic and thermophysical analyses and initial delineation of major geologic units. A stratigraphic analysis of the region has been completed and we have found that most of the benchmark horizons are coherent over the 100-km-scale and are similar in dip azimuth and direction to the underlying long wavelength topography [1]. Mapping of the surficial units in THEMIS/TES data and comparison with MER Opportunity results show that some bedrock units have a strong correlation with thermal inertia while others do not. This work has helped identify the utility and pitfalls of using thermal data and provides input into our geologic mapping. Completion of the formal geologic/geomorphic mapping is slated for the upcoming year.

References: [1] Squyres, S. W., et al., *Science,* DOI: 10.1126/science.1170355. [2] B. M. Hynek and R. J. Phillips, *Earth and Plan. Sci. Lett.*, 274, 214-220. [3] B. M. Hynek and K. Singer, *Geophys. Res. Lett.*, doi:10.1029/2007GL029687, 2007. [4] B. M. Hynek et al., *J. Geophys. Res.*, doi:10.1029/2002JE 001891, 2002. [5] Edgett, K. S., and M. C. Malin, *Geophys. Res. Lett.*, doi:10.1029/2002GL016515, 2002. [6] Hynek, B. M., *Nature,* doi:10.1038/nature02902, 2004. [7] Edgett, K.S., *Mars,* doi:10.1555/ mars.2005.0002, 2005. [8] R. E. Arvidson et al., *Science*, doi:10.1126/science.1109509, 2005.
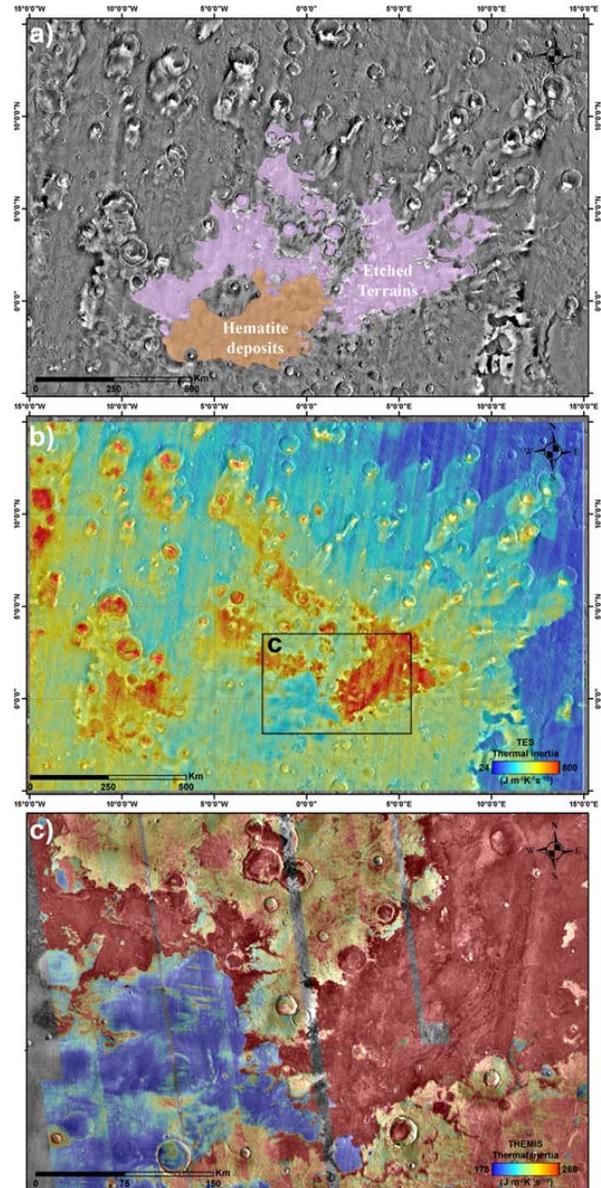
Figure 1. a) THEMIS mosaic showing the studied area and the extent of the *Etched terrains* and *Hematite-rich* units; b) TES thermal inertia shows the correlation between the above geological units and their corresponding physical properties; c) Close-up from the THEMIS thermal inertia showing the geological contacts between the *Etched* and the *Hematite-rich* units.

GEOLOGY OF A PORTION OF THE MARTIAN HIGHLANDS: MTMS -20002, -20007, -25002 AND -25007.

C. M. Fortezzo[1] and K. K. Williams[2], [1]United States Geological Survey, Astrogeology Science Center, Flagstaff, AZ, 86001, cfortezzo@usgs.gov; [2]Department of Earth Sciences, Buffalo State College, Buffalo, NY 14222.

Introduction. As part of a continuing study to understand the relationship between valleys and highland resurfacing through geologic mapping, we are continuing to map seven MTM quads in portions of the Margaritifer, Arabia, and Noachis Terrae. Results from this mapping will also help constrain the role and extent of past water in the region. The MTMs are grouped in two different areas: a 4-quadrangle area (-20002, -20007, -25002, -25007) and an L-shaped area (-15017, -20017, -20022) within the region [1-5]. This abstract focuses on the geologic units and history from mapping in the 4-quadrangle area, but includes a brief update on the L-shaped map area.

Geologic Units. The geologic/geomorphic units of the study area are divided into the megaregolith, basin, and crater-related units (not discussed here; see [6]).

Megaregolith unit 1 (Nm_1, N(16) = 86 ± 22): Forms broad plains that contain fluvial landforms. This unit is exposed in the scarp walls of the valleys and valley networks. Interpretation: megaregolith emplaced primarily through impact processes and intercalated to various degrees with volcanic rocks and sediments and possibly localized fluvial sediments or colluvium.

Megaregolith unit 2 (HNm_2, N(16): 81 ± 22): Forms relatively smooth and areally-expansive surfaces that contain north-south-trending narrow ridges or scarps, typically ~100 m in relief. Interpretation: megaregolith emplaced by similar processes as the Nm_1, though it is younger based on stratigraphic relationships and exposures in the walls of exposed valleys and craters. The ridges are crosscut by valleys in some locations and in other locations ridges crosscut the valleys, suggesting coeval and/or long-term contribution to unit development as a secondary characteristic. The ridges are likely tectonic (wrinkle) ridges formed by lateral shortening.

Basin unit 1 (Nb_1, N(16): 55 ± 32): This unit consists of angular plates typically <100 m^2 often separated by meter-scale fractures that are filled with low albedo material. Interpretation: brecciated basement rocks related to the formation of impact basins; may represent the original crater floor.

Basin unit 2 (Nb_2, N(2): 864 ± 611): This unit forms scarp-bounded blocks and islands of materials with hummocky surfaces. Within the islands, small linear to curvilinear ridges, similar to those that form the scarp margins of the islands, protrude out of the surrounding material. Interpretation: exhumed/preserved crater floor deposits possibly a mélange of breccia from the original impacts combined with ejecta materials from Newcomb crater. The boundary scarps and the internal ridges are volcanic or sedimentary dikes formed by materials filling fractures. An alternative hypothesis, which cannot be confirmed through current spectral mineralogy, is a hydrothermal origin.

Basin unit 3 (HNb_3, N(16): 87 ± 33): Forms large fans at the mouths of the valleys of the southeast, east, and northwest portions of Noachis basin. In addition, this material forms smooth surfaces in smaller basins located southwest, northeast and northwest of Noachis basin. Interpretation: sediment emplaced as valley networks debouched. In the eastern portion of Noachis basin, the unit likely includes some Newcomb crater ejecta material at its base.

Basin unit 4 (ANb_4, Present on the floors c_1, c_2, and c_3 craters): Forms the smooth floors of craters through non-fluvial processes. This unit has higher DN values (low thermal inertia) in THEMIS nighttime IR. In some locations, ridges are present at the margins of the floor, near the mass wasting deposits of the crater walls. Interpretation: volcanic or hydrothermal resurfacing material of the crater floors.

Geologic History. *Pre- Noachian and Noachian Period (>~3.7-3.5 Ga):* The ancient crust of Mars formed in the pre-Noachian. During the Early Noachian, late heavy bombardment continued to emplace large amounts of ejecta material, and volcanic processes, likely airfall deposition given the distance of the map area from volcanic constructs, forming the unit Nm_1.

During the Middle to early Late Noachian, Paraná basin formed, west of the map area. This was followed by the formation of Noachis basin as a multiple-ring impact basin and unit Nb_1 formed as the floor of the impact basin. Newcomb crater formed with a floor similar to that of Noachis basin (Nb_1). Newcomb ejecta deposits were emplaced on the floor of Noachis basin. The eastern flank of Noachis basin was overprinted by the rim of Newcomb crater, coinciding with the weakening or partial removal of the southeastern Noachis basin rim material. These three large impacts added to the thickness of the Nm_1 and the preserved HNm_2.

During the Late Noachian, contractional (wrinkle) ridges began forming in the HNm_2 and Nb_1 units, and impact rates began to decrease. Unit Nb_2 was likely emplaced as volcanic and impact airfall materials. Volcanic upwelling, sediment infilling, and/or hydrothermal mineralization in Noachis basin filled in fractures in unit Nb_1. The fractures served as conduits

for the material that formed the more resistant dikes in unit Nb_2.

Valleys began to form and to incise the loose megaregolith materials. The HNb_3 deposits began forming in Noachis basin as valleys transported material from the western flank of Newcomb crater and the plateau surface of Noachis Terra. The weakened or possible already breached southeastern rim of Noachis basin became the main conduit for water and sediment transported from the highlands into Noachis basin. The western and northern flanks of Newcomb crater were heavily dissected during this time which stripped the ejecta material from the area and formed a large scarp where the rims of Noachis basin and Newcomb crater would have overlapped. Paraná Valles formed during this time and began to erode headward toward the north-south-trending rise that was likely formed by a combination of the impacts that formed Noachis and Paraná basins. On the eastern flank of the rise, several small valleys began to incise the megaregolith and transport water and sediment through a series of small basins before finally debouching into Noachis basin.

Water began to pond in Noachis basin and likely in the smaller crater basins during this time. Because of the proximity of the remnant fans to the crater rims, the transported sediment settled out near the mouths of the valleys, beginning to form fan morphologies on the basin floor. It is likely that the U-shaped basin to the northwest of Noachis basin was beginning to undergo a degree of erosion due to groundwater. The groundwater was likely being transmitted from Noachis basin down the regional slope using the radial and circumferential fractures of the impact that formed Noachis basin. During the Late Noachian, at least the western portion of Noachis basin was filled with standing water, evidenced by the paucity of linking valleys between the eastern and southern portions of Noachis basin and its single outlet on the northwestern flank. A ~35 km diameter crater formed in northwest Noachis basin. This crater breached the rim of Noachis basin and filled with water and eventually spilled over into the U-shaped basin to the northwest of Noachis basin. This spillover likely triggered a flood event(s) that removed a large amount of the Nm_2 and HNm_2 units from the northwest portion of the map area. The smaller basins to the southwest, northwest, and northeast of Noachis basin also began amassing fluvially-transported sediment.

Hesperian Period (~3.7-3.5 Ga – ~3.3-2.9 Ga): The emplacement of the HNb_3 and ANb_4 units continued into the Early Hesperian. Fluvial dissection and headward erosion continued into the Hesperian as deposition into the basins peaked. Cratering during the Hesperian might have interrupted fluvial systems or buried those that were already extinct. In some areas, groundwater may have kept some systems active in the northern portions of the map area.

During the Late Hesperian, widespread fluvial activity ceased and Noachis basin emptied. The lack of water did not allow the valleys to react to the change in base level, leaving stranded valleys along the scarp to the west of Newcomb crater. Gullied interior walls of some of the c_2 unit craters indicate that surficial water activity may have continued into the Late Hesperian. Eolian and small impact processes began to overprint the surface geomorphology.

Amazonian Period (~3.3-2.9 Ga – Present): Eolian and impact processes became the dominant processes on the surface. Basin units began to erode with the material of the HNb_3 unit being differentially stripped from the interior of Noachis basin. The fan deposits of the HNb_3 unit were stripped of upper surface materials exposing the well-cemented and preserved negative relief portions of the valley floors. Eolian materials were organized into thin sheet-like mantles over most of the map area. Eolian ripples and small dune forms formed in some craters and transverse eolian ripples formed in some valley bottoms. Regionally, eolian materials, which typically have a very low thermal inertia, usually occur in the valleys that trend east-west. The valleys oriented more north-south are typically free of eolian ripples, although sediment does accumulate. The preferential orientation of valleys trending east-west may indicate the prevailing wind direction during, at least, the Late Amazonian.

Update of L-shaped map area. Mapping in three quads near Jones crater (MTMs -15017, -20017, and -20022) continues, and is addressing the timing of fluvial erosion and deposition in this area. Samara and Himera Valles meet southwest of Jones and continue to flow northward to the confluence with Loire Valles flowing from the southeast. These fluvial systems then emptied into Margaritifer basin. Mapping in MTM -20022 shows extensive fluvial erosion outside of Samara and Himera Valles that appears to predate the last fluvial activity in Himera Valles. In addition to erosion, at least three resurfacing deposits have been mapped in that quad. To the east and northeast, the relationship between Loire Valles and the surrounding units is being studied. At least one of the resurfacing units embays portions of Loire, helping to determine the relative timing of fluvial activity in the three main valles in this area.

References. [1] Grant, J.A. & D.A. Clark (2002) Planet. Map. Mtg. (abst.) [2] Williams, K.K. and J.A. Grant (2003) Planet. Map. Mtg. (abst.) [3] Fortezzo, C.M. and J.A. Grant (2004) Planet. Map. Mtg. (abst.) [4] Grant, J.A., et al., (2005) Planet. Map. Mtg. (abst.) [5] Grant, J.A. et al., (2009), USGS Map. [6] Fortezzo, C. M., (2009) Masters Thesis, Northern Arizona Univ.

GEOLOGIC MAPPING OF HOLDEN CRATER AND THE UZBOI-LADON-MORAVA OUTFLOW SYSTEM.

J. A. Grant, R. P. Irwin III, and S. A. Wilson, Center for Earth and Planetary Studies, National Air and Space Museum, Smithsonian Institution, 6th St. at Independence Ave. SW, Washington, DC 20560, grantj@si.edu.

Introduction: Geologic mapping in Margaritifer Terra (Fig. 1) yields important new information regarding the inventory, sources, and sinks of water during the Noachian and early Hesperian on Mars [1-7]. Drainage in southwest Margaritifer Terra is dominated by the segmented Uzboi-Ladon-Morava (ULM) meso-scale outflow system that traverses northward along the southwestern flank of the Chryse trough [4-9]. Mapping of lower Uzboi Vallis through Ladon basin highlights the extent and complexity of sedimentary deposits associated with the ULM system [5-13].
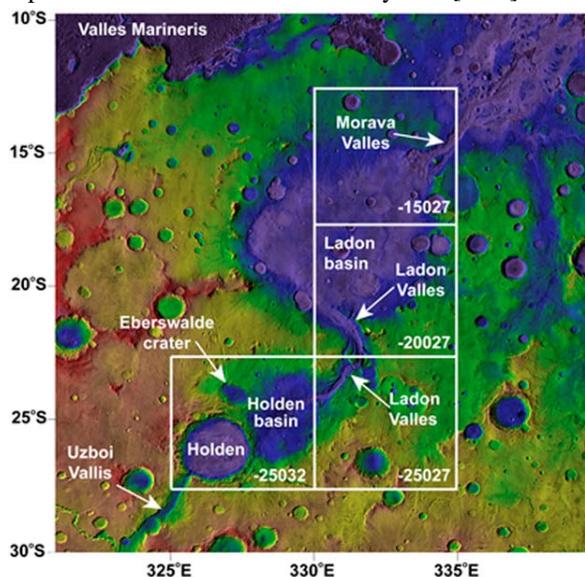
Figure 1. Topography in southwest Margaritifer Terra with major features labeled and showing outlines of maps discussed in text and shown in Fig. 2.

Overview of Geologic Setting: Ongoing mapping identifies a number of units associated with or near the ULM system (Fig. 2). The Early Noachian degraded Holden and Ladon multi-ringed impact basins [14] are the oldest features crossed by the ULM system. These basins imparted considerable structural and topographic influence on the course of the ULM drainage, with incised segments turning to become radial to basin centers. As a result, the ULM system is characterized by deeply incised trunk segments of 15–20 km width, separated by depositional plains partially filling the multi-ringed basins. Formation of these ancient impact basins was followed by prolonged evolution of the diverse cratered upland surface, which may correlate with resurfacing events that have been recognized farther to the east [4]. Crater statistics from the Ladon

basin floor and cross-cutting relationships between Holden crater and the ULM system indicate that activity along the system ended by the Early Hesperian [2,3,5,6].
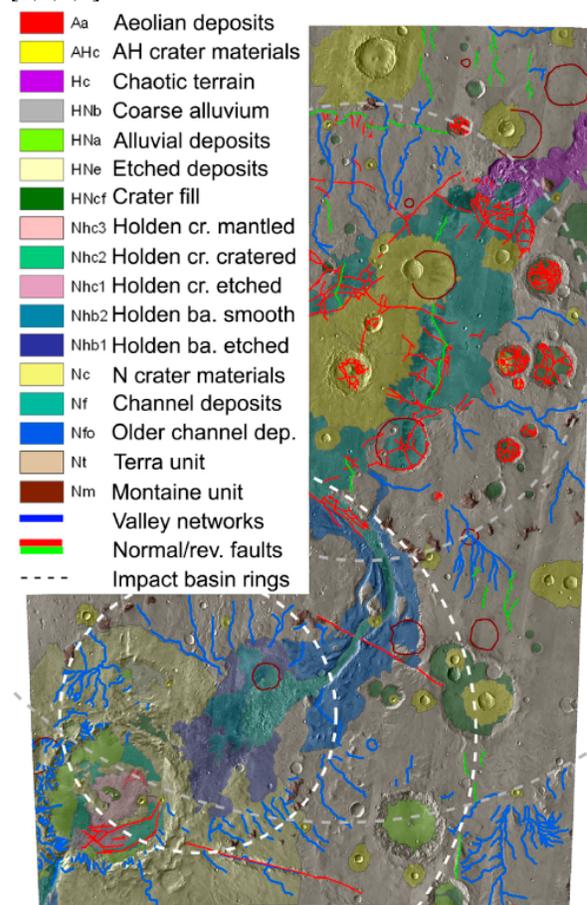
Figure 2. Preliminary draft map of MTM quadrangles -15027, -20027, -25027, and -25032 (see Fig. 1 for context). The Holden and Ladon multi-ringed impact basins, the ULM drainage, and associated tributaries dominate the landscape. Map base compiled using THEMIS daytime IR images.

Deposits in Uzboi Vallis and Holden Crater: The Holden crater rim blocked the previously through-flowing Uzboi Vallis segment of the ULM system. Back-flooding in Uzboi Vallis created an extensive and deep lake that rapidly drained into Holden crater after it overtopped and breached the rim at –350 m elevation. Longitudinal ridges on the floor of Uzboi may relate to scour associated with longitudinal vortices. Some deposits in Uzboi are relatively crudely bedded and are best preserved in embayments and al-

coves, where they were protected from high-magnitude drainage into Holden crater (Fig. 3). Other deposits are thin and occur near the basin margin at –350 m. The floor and walls of Uzboi reveal little incision, implying little activity following the breaching of Holden's rim.
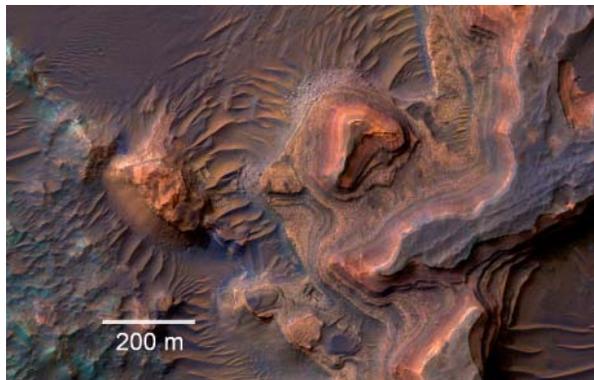
Figure 3. Subset of HiRISE PSP_010329_1525_RGB showing relatively coarsely bedded layers on the lower Uzboi Vallis floor. North is toward the top of image.

As water impounded in Uzboi drained into Holden crater, it eroded pre-existing, finely bedded deposits and emplaced a series of overlying, unconformable, coarsely bedded deposits on the crater floor. The older bedded deposits on the floor of Holden are more than 150 m thick, consist of three members, are phyllosilicate-bearing, and were likely emplaced as distal alluvial or lacustrine deposits fed by internal drainage from the crater walls [3]. High-magnitude discharge from Uzboi emplaced tens of meters of boulder-rich, alluvial deposits near the entrance breach and likely grade upwards and distally into lacustrine sediments deposited in a short lived, shallow lake [3].

Ladon Basin: The floor of Ladon basin is relatively flat (maximum relief 0.27 km over 350 km) and slightly higher in elevation than the floor of Holden crater. Discharge down Ladon Valles appears to have mantled much of the basin floor with sediments, and HiRISE images confirm the presence of extensive and finely layered deposits (Fig. 4). Occurrence of these layered deposits, which may be exposed in the walls of some craters excavating the basin floor, suggest that multiple depositional events contributed to infilling. CRISM data reveal phyllosilicates associated with at least some of these layered deposits [15], and THEMIS data hint at chloride deposits in one part of the basin [16]. The lateral extent of the beds and occurrence of phyllosilicates implies that they may have been deposited in a large, shallow lake controlled by the elevation of the outlet to Morava Valles to the northeast. If that is the case, then the occurrence of chlorides might be consistent with a terminal phase of the lake following late discharge from Ladon Valles.

Summary: The southwest Margaritifer Terra region is dominated by the ULM outflow system that created large channels and extensive layered deposits of mostly late Noachian to early Hesperian age. Deposits within Uzboi Vallis and Holden crater record lacustrine episodes of differing character and duration that may be contemporaneous with extensive alluvial or lacustrine deposits filling nearby Ladon basin and Eberswalde crater. These deposits likely require large inventories of surface water and active cycling of water between the surface and atmosphere as precipitation, implying that conditions were much more clement, and possibly habitable, during emplacement.

Figure 4. Subset of HiRISE PSP_006637_1590_RGB in Ladon basin near the mouth of Ladon Valles. Extensive, finely bedded deposits are widespread, and at least some incorporate phyllosilicates [15] and possibly chlorides [16]. North is toward the top of image.

References: [1] Grant J. A. (2000) *Geology, 28*, 223–226. [2] Grant J. A. and Parker T. J. (2002) *JGR, 107*, 10.1029/2001JE001678. [3] Grant J. A. et al. (2008) *Geology, 36*, 195–198. [4] Grant J. A. et al. (2009) USGS Sci. Inv. Map 3041, 1:500,000. [5] Irwin R. P. III and Grant J. A. (2009) in *Megafloods on Earth and Mars*, Burr D. M. et al. (eds.), Cambridge Univ.Press. [6] Grant J. A. et al. (2009) in *Lakes on Mars*, Cabrol N. A. and Grin E. A. (eds.), Elsevier (in press). [7] Saunders S. R. (1979) USGS Misc. Inv. Series I–1144, 1:5,000,000. [8] Parker T. J. (1985) M.S. thesis, Calif.State Univ. [9] Parker T. J. (1994) Ph.D. thesis, Univ. of Southern Calif. [10] Pondrelli M. A. et al. (2005) *JGR, 110*, E04016. [11] Moore J. M. et al. (2003) *GRL, 30* (24), 2292. [12] Malin M. C. and Edgett K. S. (2003), *Science, 302*, 1931. [13] Moore J. M. and Howard A. D. (2005) *JGR, 110*, E04005. [14] Schultz P. H. et al. (1982) *JGR, 87*, 9803–9820. [15] Milliken R. E. et al. (2008) *Geol. Soc. Am. Prog. With Abs*, Abstract 134-1. [16] Osterloo M. M. et al. (2008) *Science, 319*, 5870, 1651–1654.

MAPPING TYRRHENA PATERA AND HESPERIA PLANUM, MARS. Tracy K.P. Gregg[1] and David A. Crown[2], [1]Department of Geology, 876 Natural Sciences Complex, University at Buffalo, Buffalo, NY 14260, tgregg@geology.buffalo.edu; [2]Planetary Science Institute, 1700 E. Ft. Lowell Rd., Suite 106, Tucson, AZ 85719, crown@psi.edu.

Introduction: Hesperia Planum, characterized by a high concentration of mare-type wrinkle ridges and ridge rings [1-4], encompasses > 2 million km^2 in the southern highlands of Mars (Fig. 1). The most common interpretation is that the plains were emplaced as "flood" lavas with total thicknesses of <3 km [4-10]. The wrinkle ridges on its surface make Hesperia Planum the type locale for "Hesperian-aged ridged plains" on Mars [e.g., 9], and recent investigations reveal that wrinkle-ridge formation occurred in more than one episode [4]. Hesperia Planum's stratigraphic position and crater-retention age [e.g., 9, 11-12] define the base of the Hesperian System. However, results of geologic mapping reveal that the whole of Hesperia Planum is unlikely to be composed of the same materials, emplaced at the same geologic time. To unravel these complexities, we are generating a 1:1.5M-scale geologic map of Hesperia Planum and its surroundings (Fig. 1). We have identified 4 distinct plains units within Hesperia Planum and are attempting to determine the nature and relative ages of these materials (Fig. 2) [13, 14].

The volcano Tyrrhena Patera (22°S, 104°E) is located within Hesperia Planum. Its products are both embayed by, and superpose, Hesperia Planum materials [15, 16]. We were previously funded to generate a 1:1 million scale map of Mars Transverse Mercator (MTM) quadrangles -15257 and -20257, which include the Tyrrhena Patera materials north and west of the Tyrrhena Patera summit. The goal for these maps was to constrain the nature and extent of the Tyrrhena Patera deposits, and to determine the relationship between Tyrrhena Patera materials, Hesperia Planum, and the adjacent highlands [16].

Mappable Materials: Geologic units within Hesperia Planum can be broadly classified as those associated with Tyrrhena Patera, and those that are not (Fig. 2). Crown and others [14] discuss the characteristics and relative ages of the Tyrrhena Patera materials. The plains materials to the south and southeast of Tyrrhena Patera are heavily affected by fluvial, ice, and possibly lacustrine processes [17-19], making interpretations of the original nature of the materials difficult. Here, we discuss previously unidentified plains units within eastern Hesperia Planum and the adjacent highlands.

The region of Hesperia Planum located to the east of Tyrrhena Patera (Fig. 2) is the typical "Hesperian ridged plains" [7, 9]. Aside from Tyrrhena Patera, no obvious volcanic vents have been found within Hesperia Planum [cf. 4, 12, 16, 20, 21]. Lava flows can be seen at available image resolutions in the Tyrrhena Patera lava flow field [22] that post-dates the ridged plains, but lava flow lobes are not readily apparent within the ridged plains. Rare channels can be observed in THEMIS infrared and visible images: channels tend to be linear and generally trend north-south; in one case deposits can be observed at the channel margins.

In eastern Hesperia Planum, we have identified the following plains units: *highland knobby plains*, *smooth plains*, *highland smooth plains*, and *knobby plains*. MOLA data reveal that the east and west boundaries of the continuous topographic basin that defines Hesperia Planum closely follow the 2-km contour, and most of what has been geologically defined as Hesperia Planum [cf. 1, 7] is contained within that contour line. In contrast, highland plains occur in isolated outcrops surrounded by highlands material (Fig. 3). Units with the descriptor "highlands" are found at elevations above 2 km [23]. Jones-Krueger [23] discusses the potential for these basins to have been sites of temporary lakes, fed by highland valley networks.

The highlands materials surrounding Hesperia Planum show various abundances of gullies/channels and the sharpness (or roundness) of their summits [23]. It is unlikely, however, that these erosional variations reflect material properties, but rather differing degrees of erosion.

Mapping Progress: MTM quadrangles -15257 and -20257 have been mapped; crater size-frequency distributions have been calculated using Barlow's crater database for craters ≥5 km in diameter. However, we would like to complete a more detailed crater count, using craters >1 km in diameter. We plan to have the MTM map submitted for review by the end of this summer. Within the Hesperia Planum map area, the plains-forming materials are mapped; we are mapping the highlands materials and comparing our results with those found in published 1:500K-scale maps of the region. Crater statistics are being compiled. We hope to have this map submitted for review by the end of the calendar year.

References: [1] Scott, D.A. and M. Carr (1978) *USGS Misc. Series I-1083*. [2] Chicarro, A.F., P.H. Schultz and P. Masson (1985) *Icarus 63*:153. [3] Watters, T. and D.J. Chadwick (1989) *NASA Tech.*

Rpt. 89-06:68. [4] Goudy, C., R.A. Schultz and T.K.P. Gregg, *J. Geophys. Res. 110*: E10005 10.1029/2004JE002293. [5] Potter, D.B. (1976) *USGS Misc. Series I-941*. [6] King, E.A. (1978) *USGS Misc. Series I-910*. [7] Greeley, R. and P. Spudis (1981) *Rev. Geophys. 19*:13. [8] Scott, D.A. and K. Tanaka (1986) *USGS Misc. Series I-1802A*. [9] Greeley, R. and J. Guest (1987) *USGS Misc. Series I-1802B*. [10] Leonard, J.G. and K. Tanaka (2001) *USGS Misc. Map Series I-2694*. [11] Tanaka, K.L. (1986) Proc. LPSC 17th, JGR Suppl. 91, E139-E158. [12] Tanaka, K. (1992) in *Mars*, U. Arizona Press, p. 345. [13] Gregg, T.K.P. and D.A. Crown (2007) *Lun. Planet. Sci. Conf. 38th,* Abstract #1190. [14] Crown, D.A., D.C. Berman and T.K.P. Gregg (2007) *Lun. Planet. Sci. Conf. 38th*, Abstract #1169. [15] Gregg, T.K.P., D.A. Crown and R. Greeley (1998) *USGS Misc. Series I-2556*. [16] Farley, M.A., T.K.P. Gregg and D.A. Crown (2004) *USGS Open File Rpt. 2004-1100*. [17] Mest, S. and D.A. Crown (2001) *Icarus 153*:89. [18] Ivanov, MA et al. (2005) JGR 110, E12S21. [19] Crown, D.A., L.F. Bleamaster III and S.C. Mest (2005) *J. Geophys. Res. 110, E12S22*, doi:10.1029/2005JE002496. [20] Gregg, T.K.P. and M.A. Farley (2006) *J. Volcanol. Geophys. Res. 151*:81-91. [21] Ivanov, M. et al. (2005) JGR 110, E12S21. [22] Greeley, R. and D.A. Crown (1990) *J. Geophys. Res. 95*:7133. [23] Jones-Krueger, T. (2007) *M.S. Thesis*, University at Buffalo, Buffalo, NY, 94 pp.

topographic highs (Tyrrhena Patera summit is ~3 km above mean planetary radius) and blues are lows.
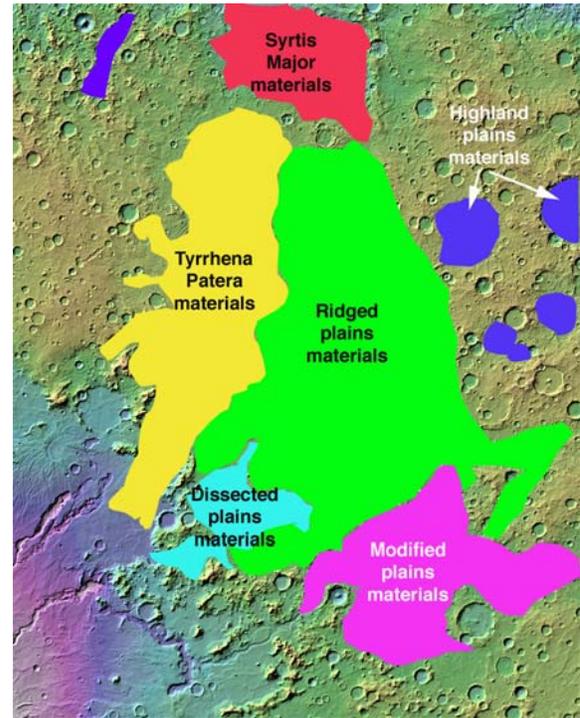
Figure 2. Rough boundaries of identified plains materials within Hesperia Planum. Portions of these materials were originally mapped as "Hesperian-aged ridged plains" at 1:15 million [9].
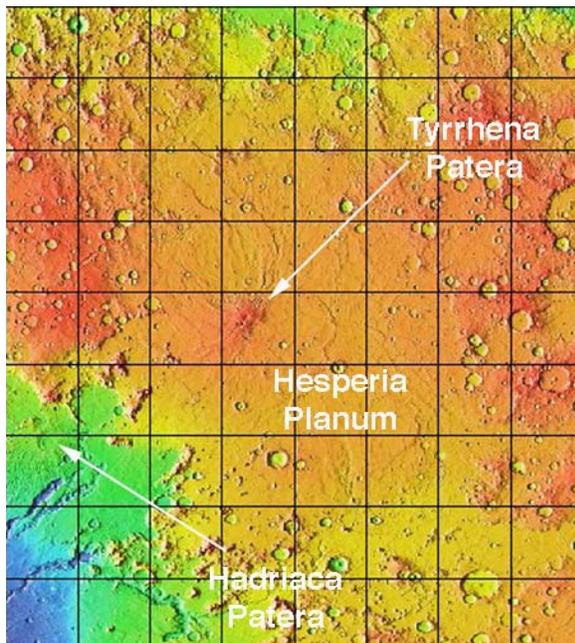
Figure 1. Gridded MOLA data (128 pixels/degree) of the area being mapped at 1:1.5 million. Reds are
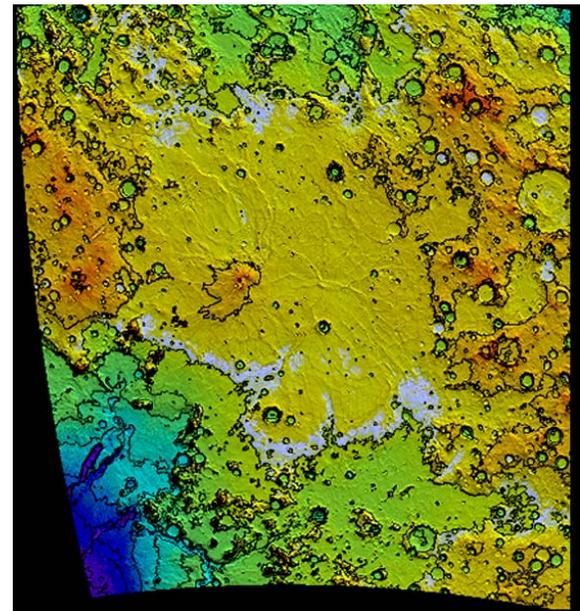
Figure 3. Hesperia Planum with 1-km-interval contour lines. The boundary of Hesperia Planum [9] roughly corresponds with the 2-km elevation line [21].

GEOLOGIC MAPPING OF ATHABASCA VALLES.

L. P. Keszthelyi[1], W. L. Jaeger[1], K. Tanaka[1], and T. Hare[1], [1]U.S. Geological Survey, Astrogeology Team, 2255 N. Gemini Dr., Flagstaff, AZ 86001.

Introduction: We are approaching the end of the third year of mapping the Athabasca Valles region of Mars. The linework has been adjusted in response to new CTX images and we are on schedule to submit the 4 MTM quads (05202, 05207, 10202, 10207) and accompanying paper by the end of this fiscal year.

Previous Work: The study area is of special interest for several reasons: (a) it is central to the controversial and now disproven "Elysium Sea" [1,2]; (b) it contains one of the best preserved outflow channels on Mars [2-4]; (c) the lavas that drape the entire channel system are the best example of a turbulent flood lava anywhere in the Solar System [2,5]; (d) the extremely young lavas have interesting stratigraphic relationships with the long-puzzling Medusae Fossae Formation (MFF). The map area also covers the confluence of lavas from the Elysium rise, multiple small vents, and vast flood lavas [6-9]. Moreover, the remnant knobs of ancient highlands in this region may help constrain the current nature of the Highlands-Lowlands Boundary (HLB).

Mapping Methodology: Two factors drive us to map the Athabasca Valles area in unusual detail: (1) the extremely well-preserved and exposed surface morphologies and (2) the extensive high resolution imaging. The mapping has been done exclusively in ArcGIS, using individual CTX, THEMIS VIS, and MOC frames overlying the controlled THEMIS IR daytime basemap. MOLA shot points and gridded DTMs are also included. It was found that CTX images processed through ISIS are almost always within 300 m of the MOLA derived locations, and usually within tens of meters, with control. The generally good SNR and minimal artifacts make the CTX images vastly more useful than the THEMIS VIS or MOC images. Furthermore, even without control, the location of the CTX images was better (compared to MOLA) than the controlled THEMIS IR mosaic.

The bulk of the mapping was done at 1:50,000. The location of certain contacts is generally accurate to a few pixels (tens of meters). Approximate contacts indicate that the actual contact (e.g., a flow margin) is not directly visible but the location can be inferred from a change in texture. Where CTX data were not available, mapping was often done at 1:100,000 and most contacts are mapped as inferred/queried. Some inferred contacts underneath thin lava and other mantling deposits are noted using the symbol for a buried contact. Contacts within a flow field are labeled as "other" and show as white lines in Fig. 1.

Athabasca Valles Flood Lava: The central goal of this mapping project is to study the flood lava that Jaeger et al. [2] showed coating Athabasca Valles. Jaeger et al. [5] show that the flow was a turbulent flood of lava with eruption rates peaking around 10^7 m^3/s. This flood lava is a proper lithochronologic unit that we have called the Athabasca Valles Lava (Aav).

The Aav exhibits a series of lava facies, from drained channels near-vent to platy-ridged surfaces in the medial portion to inflated pahoehoe at the distal margins. The most difficult contacts to identify are where the marginal inflated pahoehoe from different eruptions intermingle. The most surprising aspect of the Aav is that some parts of it appear to be being exhumed from underneath ~100 m of the Medusae Fossae Formation (MFF).

Other Geologic Features: Few events have taken place since the emplacement of the Aav. There are patches of recent aeolian dunes and, as noted earlier, some mantling by the MFF and dust. Some of the tectonic features in the study area record young deformation, probably via reactivation of older faults. For example, a wrinkle ridge near the western edge of the mapped extent of Aav is coated by lava but also appears to have deformed it.

We have also been able to decipher a large part of the sequence of lava flows erupted from small shields and fissures prior to the Aav. These are found predominantly in the southeastern section of the map area. The widely distributed vents are divides into tholi, fissures, and point vents labeled with letters in Fig. 1. Most appear to have fissure segments generally parallel to the Cerberus Fossae. We are starting to see hints that some of the vents may have fed multiple eruptions, or at least long-lived multi-phase eruptions. These details can only be observed because of the extremely pristine nature of the flow surfaces.

Remaining Work: The mapping is largely complete, though some more detail in the Elysium rise lavas is desired. The supporting text and figures are not yet ready for submission but we still expect to submit the map by the end of FY09.

References: [1] Murray J. B. et al. (2005) *Nature, 434*, 352-356. [2] Jaeger W. L. et al. (2007) *Science, 317*, 1709-1711. [3] Tanaka and Scott (1986) *LPS XVII*, 865. [4] Burr D. M. et al. (2002) *Icarus, 159*, 53-73. [5] Jaeger W. L. et al. (in revision) *Icarus*. [6] Plescia J. B. (1990) *Icarus, 88*, 465-490. [7] Lanagan P. D. (2004) *Ph.D Thesis*, Univ. Arizona. [8] Keszthelyi, L. et al. (2004) *G³*, 5, 2004GC000758.

Figure 1. Export of ArcGIS project with THEMIS IR basemap overlain with colorized MOLA elevations and geologic linework (contacts and vent structures). Vents for the smaller pre-Athabasca Valles Flood Lava flows are labeled. Tholi are labeled ta, tb, and tc. Fissures are marked with fa, fb, and fc while small vents are va, vb, and vc. Note that there are 4 separate locations that are all labeled va because they appear to have been simultaneously active (feeding flows on both sides of a wrinkle ridge). Fissure b is mapped having fed two separate flow fields, though it is possible that these are the products of different episodes of the same eruption.
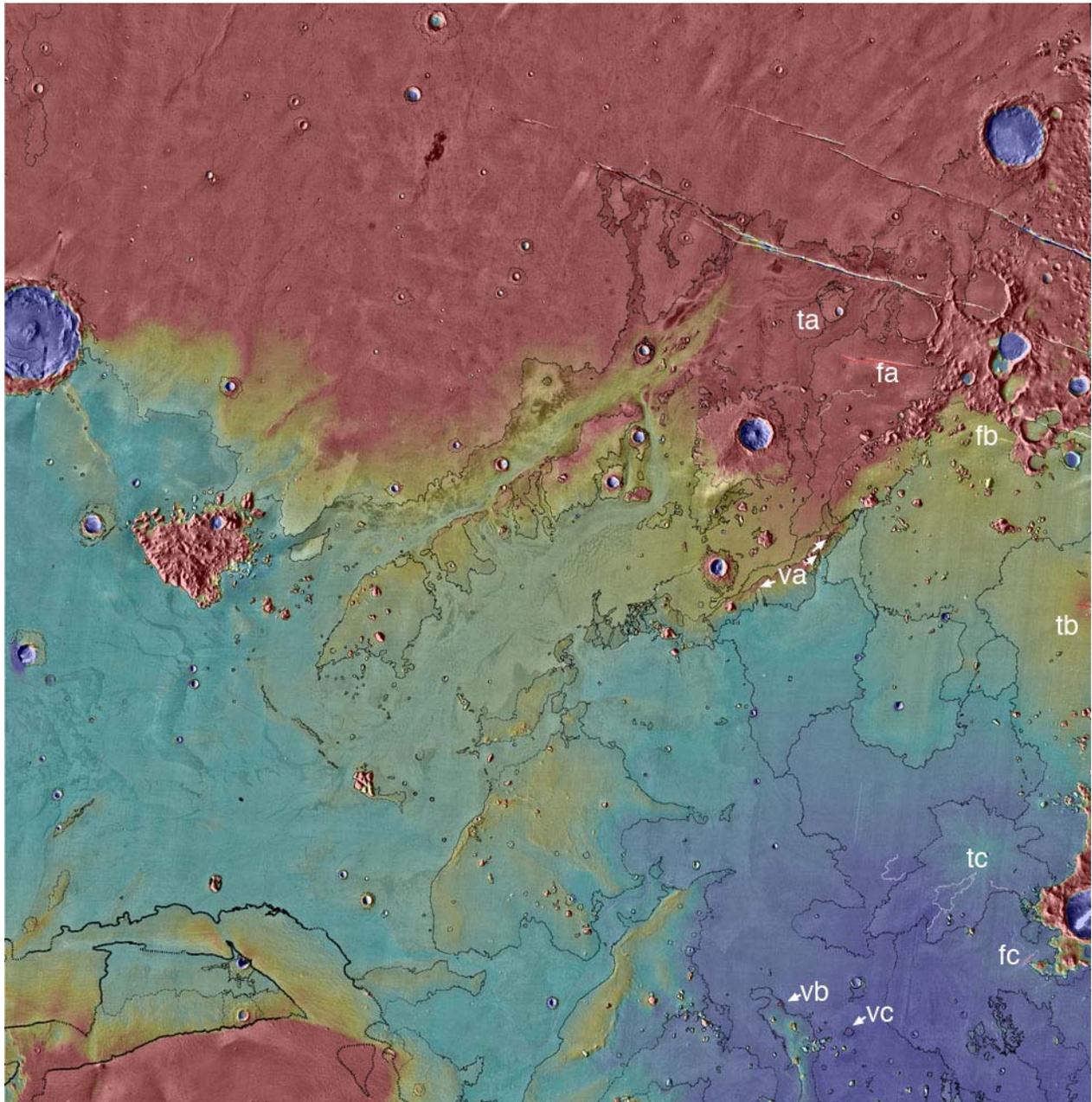
GEOLOGIC MAPPING OF MTM -30247, -35247 AND -40247 QUADRANGLES, REULL VALLIS REGION, MARS. S.C. Mest[1,2] and D.A. Crown[1], [1]Planetary Science Institute, 1700 E. Ft. Lowell Rd., Suite 106, Tucson, AZ 85719-2395, mest@psi.edu; [2]Planetary Geodynamics Lab, NASA GSFC, Greenbelt, MD 20771

Introduction: Geologic mapping of MTM -30247, -35247, and -40247 quadrangles is being used to characterize Reull Vallis (RV) and to determine the history of the eastern Hellas region of Mars. Studies of RV examine the roles and timing of volatile-driven erosional and depositional processes and provide constraints on potential associated climatic changes. This study complements earlier investigations of the eastern Hellas region, including regional analyses [1-6], mapping studies of circum-Hellas canyons [7-10], and volcanic studies of Hadriaca and Tyrrhena Paterae [11-13]. Key scientific objectives include 1) characterizing RV in its "fluvial zone," 2) analysis of channels in the surrounding plains and potential connections to and interactions with RV, 3) examining young, presumably sedimentary plains along RV, and 4) determining the nature of the connection between the segments of RV.

Project Status: This analysis includes preparation of a geologic map of MTMs -30247, -35247, and -40247 (compiled on a single 1:1M-scale base). The current map area is included in previous Viking-based mapping efforts at regional [5,6] and local (1:500K; MTM -30247) scales. Crater size-frequency distributions compiled for the regional analysis [5,6] will be used in conjunction with newly generated statistics for units mapped in the current study using new datasets (e.g., MOC, THEMIS, CTX and HiRISE). This mapping effort will combine past results and new analyses to complete MTM-scale mapping of the entire RV system.

Mapping Results: This section describes observations made during geologic mapping and integrates new results with previous mapping of this area [e.g., 5,6].

Tectonism: Wrinkle ridges and ridge rings are the most prominent tectonic features in the map area and occur predominantly within ridged plains. Two dominant trends are observed—NE–SW (Hellas radial) and NW–SE (Hellas concentric)—indicating either multiple stress regimes were active concurrently or the stress regime shifted over time [14-16]. Crosscutting relationships suggest that ridge formation occurred after plains emplacement (Early Hesperian) and prior to collapse events and fluvial dissection associated with the formation of upper RV (mid-Hesperian?) [5,6].

Fluvial Modification: Fluvial processes have modified most highland and plains terrains. Most highland channels are incised within a sedimentary unit that fills intermontane areas [5-8]. These networks consist of narrow (<1 km) valleys up to several tens of kilometers in length and exhibit rectilinear patterns. Several narrow, steep-walled, flat-floored channels are also found within the plains adjacent to RV and some intersect RV. These channels are only a few kilometers in length, but some extend for several tens to hundreds of kilometers. The morphology and connections of these channels to RV suggests their formation may be related.

Several large craters in the map area exhibit degraded rims, parallel interior gullies, and eroded ejecta blankets. Most craters are partially filled by smooth or hummocky deposits, and several craters contain debris aprons that extend from their interior walls onto their floors. The range of crater preservation and the presence of gullies and debris aprons suggest that a combination of fluvial and mass wasting processes are responsible for erosion and degradation of highland craters [2,5-8,17-21].

Reull Vallis System: Segment 1 (S1) and part of Segment 2 (S2) of RV are found within the map area. S1 (~240 km long, 8–47 km wide, 110–600 m deep) displays erosional scarps, scarp-bounded troughs, small theater-headed channels that converge at a large (~50 km across) depression, streamlined inliers of ridged plains material, and scour marks on the canyon floor. To the south, RV opens into a series of irregular scarp-bounded basins that contain blocks of ridged plains on their floors. Floor materials are generally smooth to rough (at MOC scale) and likely include fluvial deposits, as well as debris contributed by collapse of vallis walls. The morphology of S1 suggests formation by combined surface and subsurface flow and collapse of ridged plains. S1 is believed to be the source area for at least some of the fluids that carved RV [5,6,22].

An obvious connection between S1 and S2 is not apparent. Recent work using HRSC data suggests that the "Morpheos basin" marks the site of the intersection of S1 and S2 [23,24]. It is believed that during the early stages of RV's formation water flowing south from S1 accumulated in this basin and was released to carve S2.

Segment 2 consists of morphologically distinct upper (S2-U) and lower (S2-L) parts. S2-U (6 to 13 km wide, 110 to 650 m deep) displays sinuous morphology and extends for ~240 km through degraded highlands. This segment preserves evidence that at least this part of RV was formed by surface flow including layering or terracing along canyon walls, and braided channels incised in floor material [5,6].

A portion of S2-L occurs in the southwest part of the map area, and begins where a narrow (1–2 km wide), shallow (~100 m deep) canyon downcuts into the main canyon floor [5,6]. Here, S2-L displays steep walls and a relatively flat floor, and is narrower (6 km) and shallower (140–350 m) than S2-L to the west [7,8]. Unlike S2-U, S2-L does not display features on its floor indicative of fluvial erosion, though the main canyon walls contain small-scale layering/terracing (tens to hundreds of meters thick) near the U-L transition. Floor material consists of debris infilling the canyon from fluvial deposition and wall collapse, and exhibits pits and lineations that parallel the vallis walls.

The morphology of S2 suggests formation by fluvial processes and subsequent modification by collapse and mass wasting. Several narrow, steep walled and flat-floored canyons enter S2-U suggesting fluvial contributions to RV. These tributaries begin within and cut through various plains units adjacent to RV.

Regional Stratigraphy: Materials forming highland terrains - *highland material* and *highland plateau material* - are found in the southern part of the map area and previously mapped as the basin rim unit and mountainous material [5,6,29]. *Highland material* is the

most rugged, exhibits the most topographic relief, and tends to form isolated knobs and massifs. *Highland plateau material* is less rugged and forms more continuous expanses. Highland channels are generally found within highland plateau material. In THEMIS day IR and Viking Orbiter images, these highland units appear mountainous and very rugged. However, in high-res images, the highland surfaces are rounded and mantled by a fairly continuous deposit [25,26]. At the peaks of some of the steepest highland massifs, as well as along some crater rim crests, this mantling unit is being removed downslope via mass wasting

The northern part of the map area consists primarily of *ridged plains material*. This unit has been interpreted as flood lavas [27-29], although no obvious flow fronts are visible. In THEMIS day IR images, inter-ridge areas display relatively smooth and featureless surfaces except for the presence of low-relief scarps and small sinuous channels, interpreted to be fluvial in origin. However, high-res images show that inter-ridge areas contain dune features, accumulations of smooth materials in low areas, and small knobs adjacent to some ridges. Subsequent fluvial activity, including collapse and erosion to form S1 and smaller channels, and deposition of sediments has significantly modified portions of the ridged plains in this area; these deposits are identified as *modified ridged plains*. The ridged plains sequence is interpreted to be sedimentary and/or volcanic material that was modified by fluvial and eolian processes, including erosion, mobilization and deposition of surficial materials. *Dark plains material* is found along the western edge of S1, and one exposure occurs in the ridged plains east of S1. These plains display lower albedo relative to adjacent materials. The western exposure displays a distinct scarp edge and appears stratigraphically higher than the ridged plains, and is indistinct from adjacent exposures of the modified ridged plains. The eastern exposure occurs in an irregular depression; this exposure appears to embay the surrounding ridged plains.

Several plains units are found in the southern part of the map area; most plains occupy local low-lying regions and are observed to embay highland massifs. *Smooth plains material* displays smooth surfaces, but in high-res images smooth plains display low-relief scarps, small channels, pits and scattered knobs suggesting sublimation and collapse of volatile-rich material, as well as modification by fluvial and eolian processes. The largest exposure of these plains occurs adjacent to S2-U, but smaller exposures are found among the highlands. The *modified smooth plains material* is stratigraphically lower than the smooth plains material and forms the lower wall material along S2-U. These materials were likely exposed during the formation of RV. An additional smooth plains unit - *smooth plains material 1* - forms a few small exposures in the vicinity of S2-U, and in most places is adjacent to smooth plains material. Although these two units are currently mapped separately, they may be similar materials. The smooth plains sequence is interpreted to be a mixture of sediments deposited prior to and during the formation of RV by overflow of the canyon and from erosion via valley networks, and may also include materials deposited via mass wasting [5-8].

Three distinct plains units occupy the southeast portion of the map area. *Etched plains material* is found at the origin of S2-U in the location corresponding to the "Morpheos basin" [23,24]. In THEMIS day IR images, etched plains display a mottled appearance, which in high-res images is due to low albedo materials being eroded to form yardangs and exposure of underlying higher albedo plains. A small exposure of *knobby plains material* is found along the eastern edge of the map area. This unit consists of small (10s of meters in diameter) knobs surrounded by relatively smooth plains. Inspection of this unit in high-res images reveals that the knobs may be remnants of the mottled plains to the south and west. M*ottled plains material* occupies much of MTM -40247; these plains appear smooth at most scales and fill low-lying areas around highland massifs and degraded craters. The mottling and lack of detail expressed throughout much of these plains suggests these materials may be eolian in nature, similar to the mantled highlands unit mapped by [6], and may be related to a regional mantling unit [25,26].

Mass wasting formed some of the youngest deposits in the map area. Debris aprons [1,5-8,19-21] and viscous flow features [25,26] are found along massifs and crater walls. Massif-associated features typically have uniform or mottled albedo, lobate frontal morphologies, and appear to be composed of multiple coalescing flows. Crater-associated features are relatively small and display mottled albedo, relatively featureless surfaces, and arcuate to lobate fronts. Some crater floor deposits contain rings concentric to the crater walls, similar to concentric crater fill [30,31].

References: [1] Crown, D.A., et al. (1992) Icarus, **100**, 1-25. [2] Crown, D.A., et al. (2005) JGR, **110**, E12S22, doi:10.1029/2005JE002496. [3] Tanaka, K.L. and G.J. Leonard (1995) JGR, **100**, 5407-5432. [4] Leonard, G.J. and K.L. Tanaka (2001) USGS GISM I-2694. [5] Mest, S.C. (1998) M.S. Thesis, Univ. of Pittsburgh. [6] Mest, S.C., and D.A. Crown (2001) Icarus, **153**, 89-110. [7] Mest, S.C. and D.A. Crown (2002) USGS GISM I-2730. [8] Mest, S.C. and D.A. Crown (2003) USGS GISM I-2763. [9] Price, K.H. (1998) USGS MISM I-2557. [10] Bleamaster, III, L.F. and D.A. Crown (2008) USGS, in review. [11] Greeley, R. and D.A. Crown (1990) JGR, **95**, 7133-7149. [12] Crown, D.A. and R. Greeley (1993) JGR, **98**, 3431-3451. [13] Gregg, T.K.P., et al. (1998) USGS MISM I-2556. [14] King, E.A. (1978) USGS MISM I-1073. [15] Watters, T.R., and D.J. Chadwick (1989) Tech. Rpt. 89-06, LPI, Houston. [16] Porter, T.K., et al. (1991) LPSC XXII, 1085–1086. [17] Craddock, R.A., and T.A. Maxwell (1993) JGR, **98**, 3453–3468. [18] Grant, J.A., and P.H. Schultz (1993) JGR, **98**, 11,025–11,042. [19] Pierce, T.L., and D.A. Crown (2003) Icarus, **163**, 46-65, doi:10.1016/S0019-1035(03)00046-0. [20] Crown, D.A., et al. (2006) LPSC XXXVII, #**1861**. [21] Berman, D.C., et al. (2006) LPSC XXXVII, #**1781**. [22] Crown, D.A. and S.C. Mest (1997) LPSC XXVIII, 269-270. [23] Ivanov, M.A., et al. (2005) JGR, **110**, doi:10.1029/2005JE002420. [24] Kostama, V.-P., et al. (2007) JGR, **112**, doi:10.1029/2006JE002848. [25] Mustard, J.F., et al. (2001) Nature, **412**, 411-414. [26] Milliken, R.E., et al. (2003) JGR, **108**, E6, doi:10.1029/2002JE002005. [27] Potter, D.B. (1976) USGS MISM I-941. [28] Greeley, R. and P.D. Spudis (1981) Rev. Geophys., **19**, 13-41. [29] Greeley, R., and J.E. Guest (1987) USGS MISM I-1802B. [30] Squyres, S.W., and M.H. Carr (1986) Science, **231**, 249-252. [31] Carr, M.H. (1996) <u>Water on Mars</u>, Oxford Un. Press, NY.

Topography of the Martian Impact Crater Tooting.

P. J. Mouginis-Mark[1] H. Garbeil[1] and J. M. Boyce[1], [1]Hawaii Institute Geophysics and Planetology, Univ. Hawaii, Honolulu, HI 96822.

Introduction: Tooting crater is ~29 km in diameter, is located at 23.4°N, 207.5°E, and is classified as a multi-layered ejecta crater [1]. Our mapping last year identified several challenges that can now be addressed with HiRISE and CTX images, but specifically the third dimension of units. To address the distribution of ponded sediments, lobate flows, and volatile-bearing units within the crater cavity, we have focused this year on creating digital elevation models (DEMs) for the crater and ejecta blanket from stereo CTX and HiRISE images. These DEMs have a spatial resolution of ~50 m for CTX data, and 2 m for HiRISE data. Each DEM is referenced to all of the available individual MOLA data points within an image, which number ~5,000 and 800 respectively for the two data types.
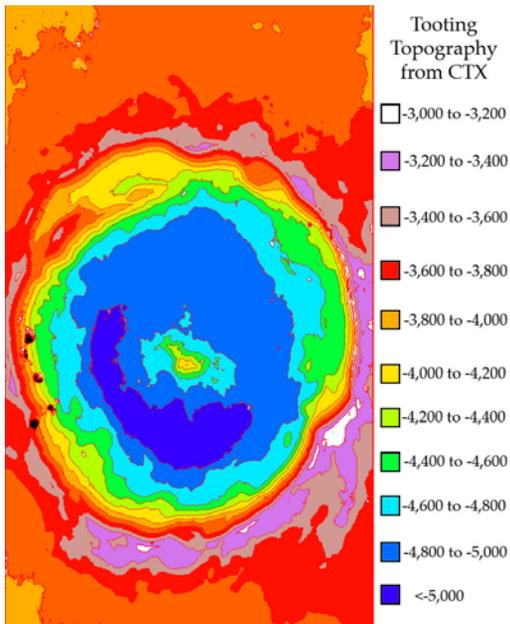
Fig. 1: DEM of Tooting crater (referenced to Mars datum) that we have produced from the stereo coverage provided by CTX images P01_001538_2035 and P03_002158_2034.

Mapping from DEMs: The young age of Tooting crater [2] permits the distribution and structure of the terraces to be investigated in detail. We illustrate the advantage of the digital topography to recognize the vertical extent of individual wall units (Fig. 2) and the surprisingly large amount of relief of the terrace blocks (Fig. 3).
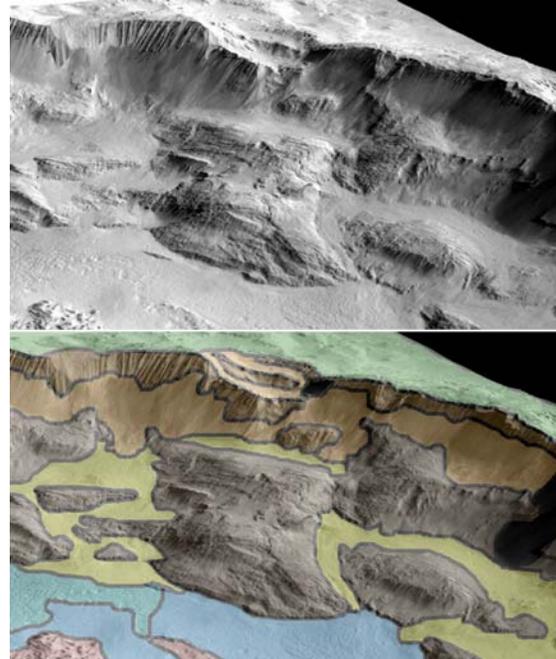
Fig. 2: Perspective view (looking south) of the southern wall of the cavity (top image). Remobilized sediments (in yellow, in bottom image) are found as high as 750 m above the crater floor. Rim is ~1,800 m high. CTX image P01_001538_2035.
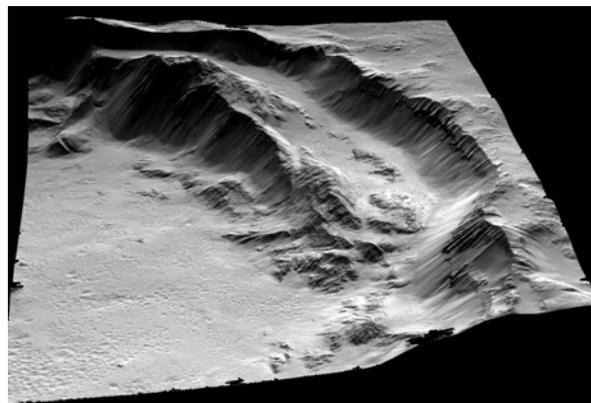
Fig. 3: Perspective view (looking west) of the terrace block on NW side of the cavity. Highest point on block is >560 m higher than ponded sediments on top of block. CTX image P01_001538_2035.

Topography of lobate flows. Although we are producing a 1:100K scale geologic map of Tooting crater, much of our attention this past year has focused on mapping at considerably higher resolution (>6 m/pixel) to better understand the origin of the different units. As an example, we show in Fig. 4 a series of lobate flows on the southern inner wall that superficially resemble pyroclastic flows but are here interpreted to be granular flows.

Several outcrops of gullied and fluted wall material (Fig. 4a) occur at elevations between -4,600 to -4,350 m (Fig. 4b). Water appears to have been released from these outcrops and subsequently fed the identified ridged and lobate flows, and indicates that several layers of the target were wet at the time of impact. We are currently studying the topography of the rest of Tooting crater to gain a better understanding of the target stratigraphy.

Fig. 4a: Geomorphic units on the SW inner wall of Tooting crater, mapped at a resolution of 3 m/pixel. See Fig. 4b for our derived topography of this area. Inset shows HiRISE subscene of flow, which has numerous channels and overlapping flow lobes.
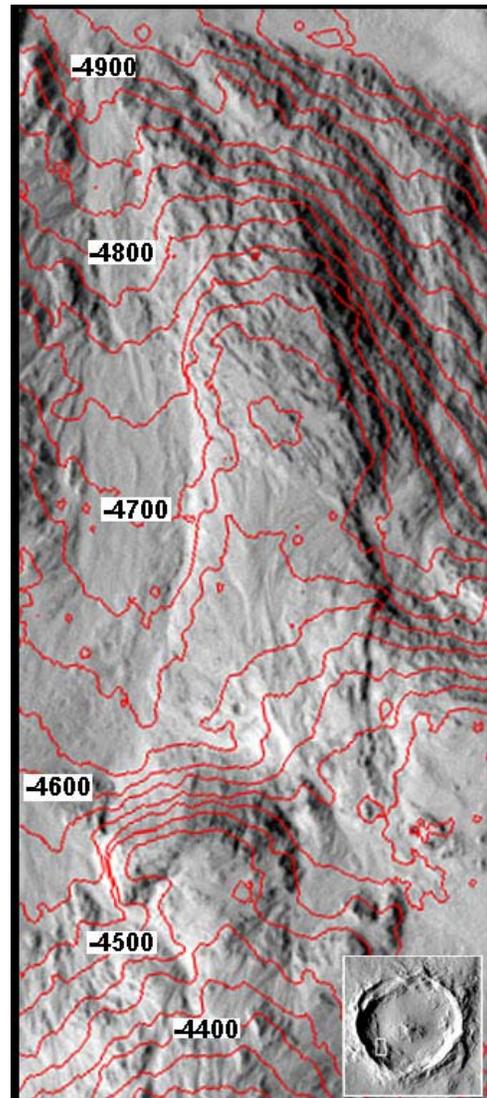
Fig. 4b: Inner wall topography of Tooting crater, derived from stereo CTX data. Contour interval is 25 m, referenced to Mars datum. Inset shows location.

References: [1] Barlow et al. (2000). *JGR* 105: 26,733 – 26,738. [2] Mouginis-Mark, P. and H. Garbeil (2007). *Meteoritics Planet. Sci.* 42: 1615 – 1626.

MARS STRUCTURAL AND STRATIGRAPHIC MAPPING ALONG THE COPRATES RISE.

R. Stephen Saunders, LPI, rssaunders@earthlink.net

Introduction: This geologic mapping project supports a topical study of structures in east Thaumasia associated with the Coprates rise. The study examines cuesta-like features on the east flank of the Coprates rise first identified by Saunders et al. [1]. Mapping combines detailed local stratigraphy, structural geology and topography. Hogbacks and cuestas indicate erosion of tilted rock units. The extent of the erosion will be determined in the course of the mapping. The region of interest lies along the eastern margin of Thaumasia bounded by latitudes -15 and -35 and longitudes 50 to 70 W (Figure 1).

Three MTM geologic quadrangles are being compiled for publication by the USGS (-20057, -25057, -30057). All existing data sources are used including THEMIS, MOC, CTX, HiRISE, MOLA and gravity, as well as higher level data available through the PDS data nodes at ASU, UA and Washington University. The extremely valuable ASU JMARS tools are used for analysis of many of the data sets. ArcGIS software has been obtained and is being learned for the map compilation.

Discussion: Erosional landforms that reveal stratigraphy and structure are common on Earth but less so on Mars. Cuesta landforms occur on the eastern flank of the Coprates rise, at about 60° west on the eastern edge of the Tharsis region [1]. The Coprates rise ridge had been identified previously using Goldstone radar to obtain topographic profiles. At that time this was the only reliable topographic data available. The erosional landforms were barely resolved in the Viking images.

Wise et al. [2] published a detailed outline of the Tharsis region that included the structural geology. Plescia and Saunders [3] produced a detailed multi-phase tectonic history of the Tharsis region and identified the faulting in eastern Thaumasia as the oldest tectonic activity. More recently, others have produced detailed studies of the regional structure, and noticed and commented on the cuesta and hogback features on the eastern edge. Schultz and Tanaka [4] addressed the structures associated with the Coprates rise. A detailed regional study is by Dohm and Tanaka [5]. Borracinni et al. [6] have studied the regional structure of eastern Thaumasia. The most comprehensive study of the entire western hemisphere is by Anderson et al. [7] There are many other regional studies that help to provide the context for a more detailed examination using recently obtained high resolution data.

The geologic mapping of the three MTMs will illustrate the topical study of the regional structure and stratigraphy from detailed cross sections through the eroded hogbacks and cuestas. Several archived data sets cover the region. MOLA topography is used to determine slopes and stratigraphic column thickness. THEMIS IR images are particularly useful and cover most of the region. Figure 2 shows part of a daytime IR image obtained by THEMIS. The basic resolution of the THEMIS IR images is 100m per pixel. Higher resolution images from HiRISE, THEMIS VIS, CTX, CRISM and MOC are also used, primarily to examine small

features of the erosion to understand the erosion mechanisms and the surface material properties.
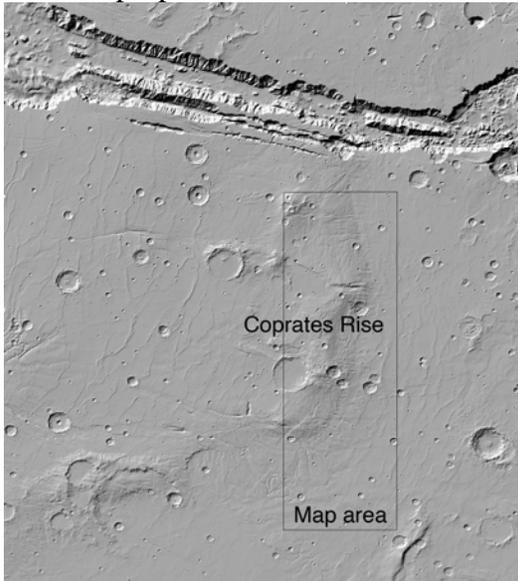
Figure 1 – Eastern Thaumasia and the Coprates rise map area.

The detailed mapping of this area is addressing questions in more detail than the previous regional studies. For example:

- ❖ What is the thickness of the stratigraphic column revealed in the upturned beds?
- ❖ How does this stratigraphic section relate to the material exposed in the wall of Coprates Chasma to the north?
- ❖ What is the nature and timing of the structural features of the area?
- ❖ How much material has been stripped off by erosion in the map area?
- ❖ What are likely processes that produced the erosion?
- ❖ What are the material properties of the eroded section?
- ❖ When did the erosion occur?
- ❖ What was the erosion rate?

Not all of these questions can be answered with available data but multiple hypotheses can be framed and tested to the extent the data allow.

References: [1] Saunders, R. S. (1980), LPSC XI, p. 977-978. [2] Wise, Donald U. et al. (1979) *Icarus*, 38, Issue 3, 456-47. [3] Plescia, J. B. and R. S. Saunders, (1982), *JGR* 87, 9775-9791. [4] Schultz, Richard A. and Kenneth L. Tanaka (1992), LPSC XXIII, 1245-1246. [5] Dohm, James M. and Kenneth L. Tanaka (1999), *Planetary and Space Science*, 47, Issues 3-4, 411-431. [6] Borraccini, F. et al. (2007), *JGR.*, 112, E05005. [7] Anderson, Robert C. (2001), *JGR,* 106, E9, 20563-20586.

Figure 2 – THEMIS daytime IR image of cuestas. Crop of I01975002BTR.

GEOLOGY OF LIBYA MONTES AND THE INTERBASIN PLAINS OF NORTHERN TYRRHENA TERRA, MARS: PROJECT INTRODUCTION AND FIRST YEAR WORK PLAN.

J.A. Skinner, Jr.[1], A.D. Rogers[2], and K.D. Seelos[3]; [1]Astrogeology Science Center, U.S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ 86001 (jskinner@usgs.gov); [2]Stony Brook University, 255 Earth and Space Science Building, Stony Brook, NY 11794; [3]Johns Hopkins Applied Physics Laboratory, MP3-E140, 11100 Johns Hopkins Road, Laurel, MD 20723.

Introduction: The highland-lowland boundary (HLB) of Mars is interpreted to be a complex tectonic and erosional transition that may hold evidence for past geologic processes and environments [1-3]. The HLB-abutting margin of the Libya Montes and the interbasin plains of northern Tyrrhena Terra display an exceptional view of the earliest to middle history of Mars that has yet to be fully characterized [4]. This region contains some of the oldest exposed materials on the Martian surface [4-5] as well as aqueous mineral signatures that may be potential chemical artifacts of early highland formational processes [6-7]. However, a full understanding of the region's geologic and stratigraphic evolution is remarkably lacking. Some outstanding questions regarding the geologic evolution of Libya Montes and northern Tyrrhena Terra include:

- Does combining geomorphology and composition advance our understanding of the region's evolution?
- Can highland materials be subdivided into stratigraphically discrete rock and sediment sequences?
- What do major physiographic transitions imply about the balanced tectonism, climate change, and erosion?
- Where is the erosional origin and what is the post-depositional history of channel and plains units?
- When and in what types of environments did aqueous mineral signatures arise?

This abstract introduces the geologic setting, science rationale, and first year work plan of a recently-funded 4-year geologic mapping proposal (project year = calendar year). The objective is to delineate the geologic evolution of Libya Montes and northern Tyrrhena Terra at 1:1M scale using both "classical" geomorphological and compositional mapping techniques. The funded quadrangles are MTMs 00282, -05282, -10282, 00277, -05277, and -10277 (**Fig. 1**).

Regional Setting. Physiographically, the map region extends from the Libya Montes southward into Tyrrhena Terra and to the northern rim of Hellas basin (**Fig.1**). The western Libya Montes are obscured by materials of southeastern Syrtis Major Planum, which locally forms a gentle (<1°), east-facing slope dominated by arcuate wrinkle ridges. The >1000-m-high Oenotria Scopulus extends >1500 km from Tyrrhena Terra to Syrtis Major Planum and may be an impact ring. A low-lying plain (*palus*) forms a topographic and drainage divide between Isidis and Hellas basins.
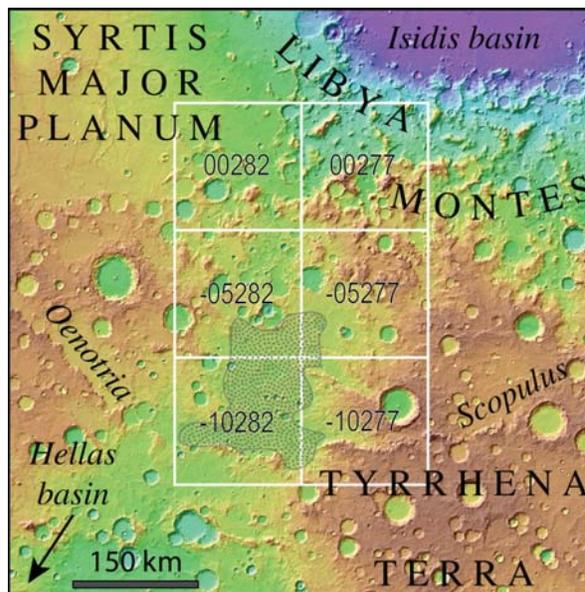
Figure 1. MOLA color shaded relief image showing the map region, which extends from 75 to 85ºE, -12.5 to 2.5ºN. Isidis is located to the NE and Hellas is located to the SW. Oenotria Scopulus bounds a topographic divide and unnamed *palus* (low-lying plain, delineated by stipple).

Geologically, the map region can be reduced into three geologically, stratigraphically, and topographically distinct surfaces, based on geologic contacts identified in *Viking Orbiter* images [4-5]. In stratigraphic order these are: (1) high-standing massifs (units Nm and Nplh), which constitute 28% of the proposed map area, (2) intermediate-elevation dissected plains (units Npld and Nple), which constitute 50% of the proposed map area, and (3) low-lying plains (units Hpl3, Hr, and Hs), which constitute 22% of the map area. These geologic terrains collectively represent very ancient, uplifted and eroded crustal blocks related to the Isidis and (perhaps) Hellas impacts, dissected intercrater plateaus likely composed of intercalated colluvium volcanic sequences, and depositional sedimentary plains [4-5].

Datasets and methods. The primary geomorphologic base map is a THEMIS daytime IR mosaic (100 m/px). Compositional base maps include regional THEMIS DCS images (100 m/px) and CRISM summary parameters (231 m/px), which will be supplemented by local TES and CRISM hyperspectral observations. Supportive datasets include hotlinked THEMIS VIS images, MOLA topography and derivatives layers, and CTX images. Higher-resolution images (including MOC NA and HiRISE) will

be used intermittently to provide localized views of unit surfaces, geologic contacts, and type localities.

Mapping layers are co-registered in GIS, which serves as the digital mapping environment. Past mapping experience indicates that 1:250,000 scale is optimal for digital mapping using the THEMIS daytime IR base map. Linework is streamed using a digital map tablet or mouse with an anticipated vertex spacing of 250 meters (1 vertex/mm at mapping scale). Line attributes are assigned on-the-fly and unit polygons will be constructed and attributed periodically to allow progressive revision.

Task Summary. Our approach to detailing and reconstructing the geologic evolution of Libya Montes and northern Tyrrhena Terra is divided into four overlapping tasks: (1) geologic mapping, (2) compositional assessments, (3) integration and analyses, and (4) deliverable production.

Task 1: This task consists of 1:1M scale geomorphologic, structural, and stratigraphic characterizations within the map region. These efforts include delineation of tectonic fabrics, erosional patterns, impact crater populations ($\geq$ 1 km), geomorphic type localities, and major cross-cutting relationships.

Task 2: Task 2 consists of 1:1M scale compositional characterizations using visible, near IR, and thermal IR spectral data. This task is two-fold in approach using first regional and then local observations. These efforts include delineation of compositionally-unique regional units using THEMIS multispectral and CRISM summary parameters and determining mineralogical type localities.

Task 3: The geologic character of the transitions between and within the Libya Montes and northern Tyrrhena Terra (including contrasts between type localities, relative ages, tectonic signatures, and compositional landforms) provide the basis for "reconstructing" the regional geologic evolution. Task 3 consists of integrating Task 1 and 2 results in order to describe type surfaces, analyze the geologic character of physiographic transitions, and place the results into a global context.

Task 4: The specific separation of deliverable products from other tasks helps clarify and benchmark the progress of mapping over the life of the project. Task 4, in chronological order, consists of conference presentations, a letter-size interim results publication, a paper-size type-locality and evolutionary scenario publication, a USGS Scientific Investigations Map, a paper-size HLB comparison publication, and a non-technical, popular interest USGS Circular.

Year 1 Work Plan. The project contains a detailed work plan that describes major milestones and personnel obligations. These plans provide a framework for benchmarking progress and will be adapted as necessary over the life of the project. Year 1 consists of managerial components, GIS and dataset construction, and preliminary mapping efforts.

Management: This project benefits from the inclusion of researchers from diverse backgrounds, including "classical" geomorphologic mapping (PI J. Skinner and Co-I K. Tanaka) as well as THEMIS- and CRISM-based compositional mapping (Co-I D. Rogers and Co-I K. Seelos, respectively). This project also benefits from the diverse skill sets of collaborators, including T. Hare, L. Crumpler, L. Bleamaster, and D. Crown. Year 1 management obligations have been dominated to date by project set-up responsibilities. For example, we recently secured the requisite agreements for conveyance of funds to cooperating institutions (Stony Brook and JHU-APL). Also, we held a "kick-off" meeting at the 40th LPSC as a means to introduce the region and Year 1 tasks, which was attended by all team members.

Dataset Collation: One of the first components of a geologic mapping project is the accumulation of datasets. As stipulated by PGG, the USGS Astrogeology cartography group produced a THEMIS daytime IR mosaic and MOLA DEM excerpts in the publication projection (Mars Transverse Mercator). These were included in a GIS mapping template and distributed to team members in March, 2009. In addition, CTX images, THEMIS DCS mosaics, and CRISM summary parameters are being processed and included in the GIS project. The GIS project will serve as the basis for all digitized linework and will be updated and re-distributed to the team, as necessary.

Preliminary Mapping: Geomorphologic and compositional mapping recently began, with initial focus on the center two quadrangles in order to identify unique surfaces. Mapping tactics, as proposed, will proceed separately as a means to maintain objectivity with approaches and datasets. Collation of results will occur at the end of Year 1 and vector information will be distributed to the team. In addition, we will digitally catalog all impact craters $\geq$1 km in diameter located within the quadrangle boundaries using tabulation software built by T. Hare. Finally, nomenclature updates and requests will be submitted at the end of Year 1 and each subsequent year, as necessary.

References. [1] Nimmo, F., and Tanaka, K.L. (2005), *Annu. Rev. Earth. Planet. Sci. 33*. [2] Tanaka et al., (2005) *USGS SIM 2888*, 1:15M scale. [3] Skinner, J.A. Jr. et al., (2007) *Icarus, 186*, 41-59. [4] Crumpler, L.S. and Tanaka, K.L. (2003), *JGR, 98*. [5] Greeley, R. and Guest, J.E., (1987) *USGS I-1802-B*, 1:15M scale. [6] Bibring et al. (2005), *Science, 307*. [7] Bishop et al. (2007), *7th Int. Conf. Mars.*, abs. #3294.

GEOLOGY OF THE SOUTHERN UTOPIA PLANITIA HIGHLAND-LOWLAND BOUNDARY PLAIN: SECOND YEAR RESULTS AND THIRD YEAR PLAN. J. A. Skinner, Jr., K. L. Tanaka, and T. M. Hare. Astrogeology Team, U. S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ 86001 (jskinner@usgs.gov).

Introduction: The southern Utopia highland-lowland boundary (HLB) extends >1500 km westward from Hyblaeus Dorsa to the topographic saddle that separates Isidis and Utopia Planitiae. It contains bench-like platforms that contain depressions, pitted cones (some organized into arcuate chains and thumb-print terrain), isolated domes, buried circular depressions, ring fractures, polygonal fractures, and other locally- to regionally-dispersed landforms [1-2]. The objective of this map project is to clarify the geologic evolution of the southern Utopia Planitia HLB by identifying the geologic, structural, and stratigraphic relationships of surface materials in MTMs 10237, 15237, 20237, 10242, 15242, 20242, 10247, 15247, and 20247.

The project was originally awarded in April, 2007 and is in its final year of support. Mapping is on-schedule and formal map submission will occur by December, 2009, with finalization anticipated by April, 2010. Herein, we (1) review specifics regarding mapping data and methods, (2) present nomenclature requests that we feel will assist with unit descriptions, (3) describe Year 2 mapping and science accomplishments, and (4) outline Year 3 technical and managerial approaches for finalizing the geologic map.

Datasets and methods. The base map is a THEMIS daytime IR mosaic (100 m/px). Though the temptation is to integrate all available data, we find that selected data sets provide the most critical information for production of a geologic map at 1:1M scale. In particular, THEMIS VIS images (viewed via internet hotlink), MOLA topography and derivatives (viewed as layers), and CTX images (viewed as layers), are the most helpful in describing geologic units and delineating their temporal relationships. We have used other datasets intermittently.

Mapping layers are co-registered with global datasets in a GIS, which also serves as the digital mapping environment. We find that map scales ranging from 1:200,000 to 1:300,000 are optimal for geologic mapping on the THEMIS daytime IR base map. We delineate surface features >500 meters in diameter (0.5 mm at map scale). We digitally stream vector linework using a digital map tablet with a vertex spacing of 250 meters. Line attributes are assigned on-the-fly. Unit polygons are built periodically from digitized contacts and iteratively attributed and revised. In order to preserve locational detail, vector layers will only be smoothed during final stages of map edit.

Nomenclature. Planetary names objectively (i.e., non-genetically) identify features of spatial and/or to-pographic uniqueness in order to provide context for consistent description. To assist in unit delineation and description for this map region, we recently submitted a nomenclature request to the IAU to uniquely identify the region located between Nepenthes Mensae and Amenthes Cavi (**Fig. 1**). We proposed a name for the 275-km-wide, gently-sloping plain in order to highlight its high-standing character, relative to the smooth plain located north of Amenthes Cavi. We also requested names for three impact craters in Nepenthes Mensae and Planum (**Fig. 1**), each of which have unique ejecta and rim morphologies.
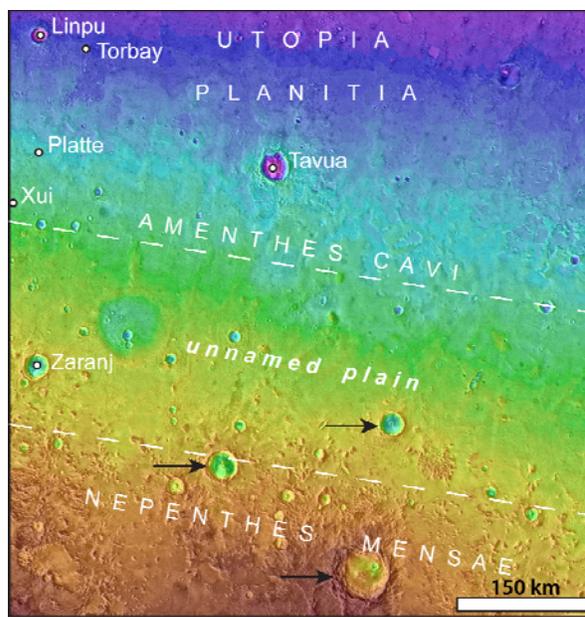
Figure 1. Subset of the map region showing existing and proposed physiographic features. The approximate boundary of the unnamed plain is defined by hachured lines. Black arrows identify unnamed craters for which we requested names. White dots show named craters.

Year 2 Accomplishments. During Year 2, we completed unit mapping, began stratigraphic analysis, and submitted deliverable components, as outlined in the original proposal. Below, we outline details regarding the current status of geologic mapping.

Mapping: Year 1 was devoted to identifying Amazonian and Hesperian geologic units that are located in the northern parts of the map region [1]. Year 2 was similarly devoted to identifying Hesperian and Noachian geologic units that are located in the central and southern parts of the map region. These units constitute the areal bulk of the map region and make up the knobby terrains of Nepenthes Mensae (3 units), the undulating plains of the proposed plain (3 units), and

the smooth plains that line Amenthes Cavi (2 units). With the Amazonian units, we currently identify 10 non-crater geologic units within the map region.

Impact craters show widespread and diverse morphologies within the map region, necessitating a more detailed mapping approach than employed in previous geologic maps. Morphologic complexity of crater materials can implicate strength and/or volatile content characteristics of target rocks and strata [3-4]. Because impact cratering appears to be a fundamental aspect of the regional geologic history, we subdivide crater units into facies, using the approaches employed in pre-Apollo lunar geologic maps [e.g., 5]. We use an undivided unit (AHc) for impact craters with rim diameters ≥3 and <15 km throughout the map region. Noachian craters in this diameter range are heavily-eroded and are identified by line symbol only. There are 21 impact craters with rims ≥15, which are generally considered "complex" impact craters [4]. Of these, 12 craters have mappable facies, including distal ejecta, proximal ejecta, rim, wall, floor, and peak materials. The remaining 9 complex craters are eroded and identified either as rim material or by symbol. Crater material for impacts with rim diameters <3 km are not mapped as separate geologic units.

Stratigraphy: We tabulated and quality-checked all primary impact craters that have rim diameters ≥1 km throughout the map region, for a total of 1987. Crater counts have not been completed to date due to the on-going iteration of geologic units, though past investigations provide context for regional stratigraphy [1-2, 6]. Original work plans included subdivision of tabulated craters into morphologic states (i.e., "preserved" versus "eroded"), an approach we now find subjective and ambiguous to the point of irrelevance. As a result, we intend to present crater counts based on total populations and use stratigraphic relationships and past studies to assist in assigning temporal relationships. This approach, though more straight-forward and repeatable, will require a more detailed discussion of age determinations in the map text.

Deliverable: A strong approach to a geologic mapping project is the presentation of map-based scientific analysis. The effect of deliverable preparation is threefold. First, it promotes review by the scientific community over the course of the project, allowing for refinement of approach, techniques, and hypotheses. Second, it provides a means to publish preferred hypotheses outside the more rigorous objectivism required in USGS geologic maps. Third, it allows for considerable slimming of the geologic map text so that hypotheses can be referenced rather than presented in full.

We prepared two science deliverables during Year 2. We presented an abstract for LPSC in March, 2009,

which outlines the characteristics and formational scenarios for the lobate materials of the circum-Amenthes Cavi materials [7]. In addition, we published an article in a terrestrial journal, which reviews the standing hypotheses for extraterrestrial mud volcanism [8]. The latter contains a detailed description of the map region and explores the possibility of both violent eruption and quiescent extrusion of fluidized sediment as a means to form the Amenthes Cavi and associated mounds, cones, and smooth and rugged lobate materials.

Year 3 Work Plan. In order to maintain the proposed schedule of map production, the Year 3 work plan will include completion of map components and preparation of final deliverable products. We note that some technical aspects of our finalized map will deviate from previously-published standards. For example, we envision revised approaches to presenting the correlation of map units (COMU) and description of map units (DOMU). We will use physiographic divisions in the COMU based on hemisphere-scale work by [1] and may include "un-mapped" units in the COMU for reference. In addition, we find that hierarchical unit groupings (i.e., the Amenthes Formation) are useful to provide strength to geologic interpretation, similar to the approach in *Viking*-based geologic maps [9].

Geologic maps fundamentally assist with interpretation and their utility can be tied to succinct and streamlined presentation of map information. As such, we will employ a minimalist approach so that we avoid the cluttering effect commonly associated with superfluous map text, figures, and tables. For example, our DOMU will describe geologic units only as they appear in the THEMIS daytime IR base map. Unit characteristics as observed in supplemental datasets will be tabulated and included in the map pamphlet. Moreover, the map sheet will include only a "Summary of Geologic History" along with appropriate references. Our goal is to have the map be a stand-alone product for easy use. An accompanying map pamphlet will contain map details, including rationale, datasets, methods, and tabulated unit characteristics. To supplement, we will submit a topical science letter and geologic summary paper for publication during map review.

References. [1] Tanaka *et al.*, (2005) *USGS SIM 2888*, 1:15M scale. [2] Skinner, J.A. Jr. *et al.*, (2007) *Icarus, 186*, 41-59. [3] Wilhelms, D.E., (1990) in *Planetary Mapping* (R. Greeley and R.M. Batson (eds.)), Cambridge U. Press. [4] Melosh, H.J. (1989), *Impact Cratering: A Geologic Process*, Oxford University Press. [5] Schmidt, H.H. *et al.,* (1967) *USGS I-515*, 1:1M scale. [6] Tanaka, K.L. *et al.*, (2003a) *JGR, 108*, (E4). [7] Skinner, J.A., Jr., *et al.* (2009), *LPSC XL*, abs. #2459. [8] Skinner and Mazzini, (2009), *JMPG*, in press. [9] Greeley, R. and Guest, J.E., (1987) *USGS I-1802-B*, 1:15M scale.

MARS GLOBAL GEOLOGIC MAPPING: ABOUT HALF WAY DONE. K.L. Tanaka[1], J.M. Dohm[2], R. Irwin[3], E.J. Kolb[4], J.A. Skinner, Jr.[1], and T.M. Hare[1]. [1]U.S. Geological Survey, Flagstaff, AZ, ktanaka@usgs.gov, [2]U. Arizona, Tucson, AZ, [3]Smithsonian Inst., Washington, DC, [4]Google, Inc., CA.

Introduction: We are in the third year of a five-year effort to map the geology of Mars using mainly Mars Global Surveyor, Mars Express, and Mars Odyssey imaging and altimetry datasets. Previously, we have reported on details of project management, mapping datasets (local and regional), initial and anticipated mapping approaches, and tactics of map unit delineation and description [1-2]. For example, we have seen how the multiple types and huge quantity of image data as well as more accurate and detailed altimetry data now available allow for broader and deeper geologic perspectives, based largely on improved landform perception, characterization, and analysis. Here, we describe mapping and unit delineation results thus far, a new unit identified in the northern plains, and remaining steps to complete the map.

Unit mapping progress: Each mapper is compiling information for each of their map units in a spreadsheet, which contains fields for: *unit name, symbol, unit group, region, type locality, primary* and *secondary characteristics, adjacent units* and their *contact and superposition relations, relative age, interpretation, other comments* (including how previously mapped), and *references*. Tanaka is compiling and organizing the map units. Thus far, we have collectively identified and mapped 29 units (5 highland units, 2 apron units, 1 crater unit, 2 channel floor units, 1 chaotic terrain unit, 3 boundary plains units, 3 northern plains units, 4 polar units, and 8 volcanic units). The number of units will increase, as some volcanic sequences, Noachian/Hesperian basin materials, and other units will be subdivided based on distinctive age and primary morphologic characteristics.

Our mapping progress is shown in Figure 1. To simplify the map, we grouped the units by age and do not show the various types of contacts and structures. It is evident that northern plains mapping, including Elysium, has largely been updated from [3]. New mapping is shown for younger materials in most parts of the highlands. Many of the flow units in Tharsis are only partly mapped, as more challenging sections need greater scrutiny.

New northern plains unit: A new unit we have discovered is a subtle, younger Vastitas Borealis unit that appears to superpose older, more typically-identified Vastitas Borealis units and covers a substantial area of 3.7 million km^2. This unit was identified by combining surface appearance and apparent burial of underlying materials in MOLA altimetry and THEMIS infrared and visible image data sets. It appears to be tens of meters thick, similar in thickness of the pedestals underlying pedestal craters in the same region [4-5]. Thus, the unit appears to have retreated from a former extent. Preliminary analysis of crater counts and stratigraphic relations suggests that the unit is long-lived, likely emplaced over multiple episodes. These and other observations and interpretations are the topic of a paper in preparation by Skinner and Tanaka, to be submitted in summer of 2009.

Remaining work: Mapping tasks that remain include: (1) delineating and describing Noachian and other unfinished younger units and structures and completing the unit description spreadsheet, (2) confirming the accuracy of all contact and structure linework using the most recent THEMIS IR and VIS images (and, to a lesser degree, HRSC and CTX images), (3) identifying and detailing descriptions of type locality unit surfaces (some units may have multiple type localities), (4) finalizing the merging of units as well as cleaning and smoothing linework, (5) determining the relative ages of map units based on superposition relations and interpretation of detailed crater counts of units, including their type localities, and summarizing results in tables and a correlation chart, (6) writing the map text, including notes on data and methodologies, unit descriptions, and summary geologic history of the map units and structures, and (7) preparing the map for review, responding to reviews, and formatting the GIS products for USGS editing and publication (including the organizing of mapping layers and creating metadata). Tanaka, Skinner, and Hare, under the guidance of the NASA PGG GEMS committee, are presently updating guidelines for planetary geologic map formatting in GIS. This map will serve as an example of a final product.

References: [1] Tanaka K.L. et al. (2007) *7th Intl. Conf. Mars* Abs. #3143. [2] Tanaka K.L. et al. (2008) *LPSC XXXIX,* Abs. #2130. [3] Tanaka K.L. et al. (2005) *USGS Map SIM-2888.* [4] Skinner J.A. et al. (2006), *LPSC XXXVII,* Abs. #1476. [5] Kadhish S.J. et al. (2009) *LPSC XV,* Abs. #1313.
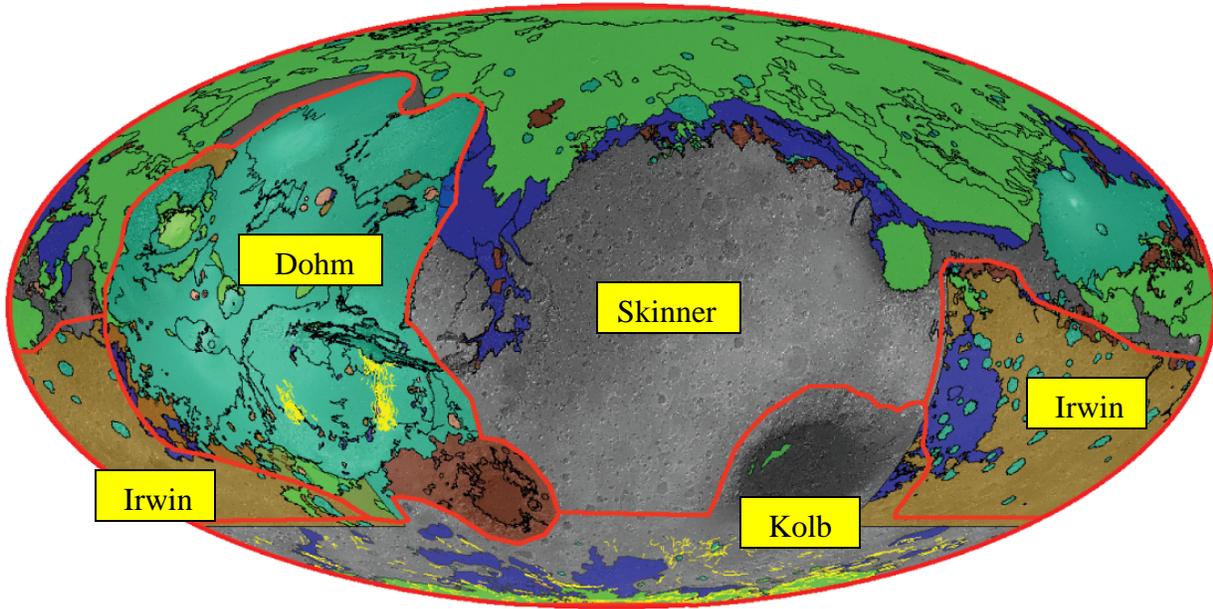
Figure 1. Progress in geologic mapping of Mars (generalized). Red outlines show regions assigned to mappers. Diverse units are grouped and colored by age. Yellow lines show structures. Note that many tentative contact lines in the Tharsis region remain unclosed, and colored highland areas require further subdivision. Unmapped areas are largely Noachian highlands. (Map compiled with assistance of C. Fortezzo, USGS.)

NEW GEOLOGIC MAP OF THE SCANDIA REGION OF MARS. K.L. Tanaka[1], J.A.P. Rodriguez[2], J.A. Skinner, Jr.[1], R.K. Hayward[1], C. Fortezzo[1], K. Edmundson[1], and M. Rosiek[1]. [1]U.S. Geological Survey, Flagstaff, AZ, ktanaka@usgs.gov, [2]Planetary Science Institute, Tucson, AZ

Introduction: We have begun work on a sophisticated digital geologic map of the Scandia region (Fig. 1) at 1:3,000,000 scale based on post-Viking image and topographic datasets. Through application of GIS tools, we will produce a map product that will consist of (1) a printed photogeologic map displaying geologic units and relevant modificational landforms produced by tectonism, erosion, and collapse/mass wasting; (2) a landform geodatabase including sublayers of key landform types, attributed with direct measurements of their planform and topography using Mars Orbiter Laser Altimeter (MOLA) altimetry data and High-Resolution Stereo Camera (HRSC) digital elevation models (DEMs) and various image datasets; and (3) a series of digital, reconstructed paleostratigraphic and paleotopographic maps showing the inferred distribution and topographic form of materials and features during past ages.
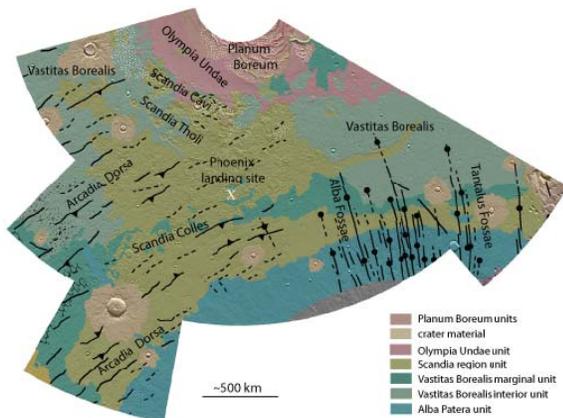
Figure 1. Geologic map of the Scandia region of Mars extracted from the northern plains regional map of [1]. Unit colors are draped over shaded-relief base derived from MOLA data; region ranges 45-85°N, 160-195°E; Polar Stereographic projection; north pole at top.

Background: The Scandia region unit consists of a zone of accentuated resurfacing within the northern plains of Mars [1, 2]. The broader region, which was apparently influenced by the Scandia region processes (herein referred to as the "Scandia region") covers ~5 million km^2 and seven regionally-identified geologic units that span the Late Hesperian to the Late Amazonian (Fig. 1). The Scandia region unit, as defined by [1], has an irregularly-shaped margin that encloses ~2 million km^2 of depositional and modificational lowland materials. The unit dominates a broader region of the northern plains that extends from the northern flanks of the Alba Patera volcanic shield northward to the sand seas and marginal scarps of Planum Boreum (Fig. 1). This geographic setting suggests that Alba Patera volcanism and tectonism

may be responsible for regional resurfacing events and the formation of the Scandia region unit [1, 2], possibly leading to deposition of basal materials of Planum Boreum [3].

The Scandia region unit was interpreted to have formed through a complex mix of surface degradation, deflation, deformation, and material emplacement related to magmatically-induced mud volcanism and/or sedimentary diapirism and the subsequent erosion and redistribution of these materials [1, 2]. Alternatively, Fishbaugh and Head [4] interpreted the Scandia Tholi and Cavi as lag deposits associated with glacial-like retreat of the polar layered deposits. More recently, Tanaka et al. [3] added to the story of how Scandia materials have been redeposited as the thickly- and evenly-layered basal materials of Planum Boreum, which form the distinctive Rupes Tenuis unit. This unit is distinguished from an irregularly, finely, and locally cross-bedded unit from which dark dunes and rippled sand sheets appear to originate [4, 5]. Based on detailed geologic mapping of the north polar region [3], these geologic relations can be summarized in a schematic geologic section that shows likely sources and sinks of Scandia and north polar materials (Fig. 2).

We thus see how geologic mapping of the north polar plateau has greatly elucidated those parts of the Scandia region unit, showing how they can be clearly distinguished as new map units and where they fit into the development of Planum Boreum. However, the remainder of this unit in the present state of mapping continues to be an unsorted mélange of terrains and materials. For example, the southern margins of the units are defined by the extents of knobs and not by embayment relations. This is strongly indicative that the unit is mainly deflational and degradational in character, similar to the knobby terrains along highland/lowland margins of Mars, which include isolated depressions (making up the Hesperian-Noachian Nepenthes unit of [1]; the Deuteronilus Mensae and Utopia Planitia units also share some of these characteristics). What are the ages of the knobs? Do they have multiple origins? Could many of them be pedestal craters? Do they define one or more broad surfaces that have since been eroded, such as those of the Vastitas Borealis units? Additional deflation is represented by depressions that appear to result from collapse and subsidence. When did these form, and by what processes and drivers? Does this overall history conform to the suggested history of progressively lower resurfacing of the northern plains, from the Late Noachian on into the Amazonian as proposed by [2]? What evidence is there for tectonic, vol-

canic, and hydrologic associations spatially and temporally between Alba Patera and Scandia?
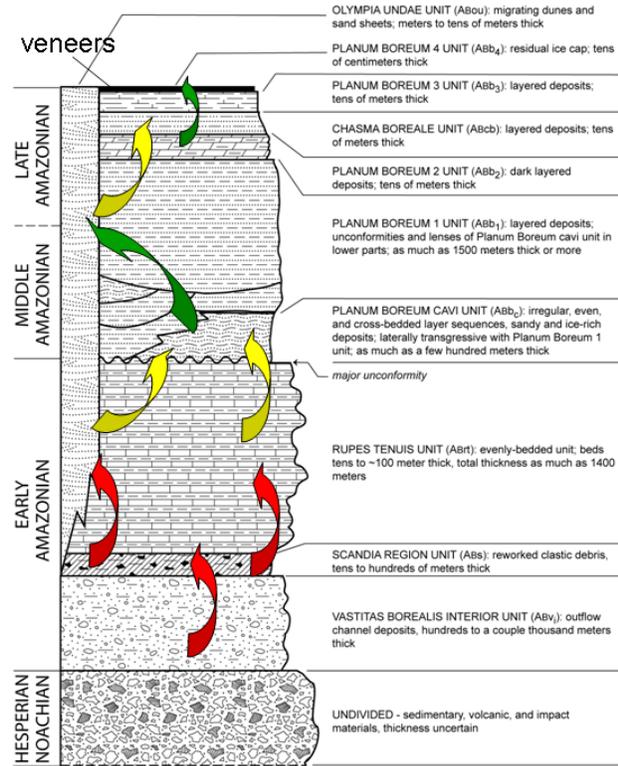
Figure 2. *Stratigraphic column of the north polar region showing paths of sedimentary recycling. Green arrows are demonstrated pathways ([6] for upper arrow and [3] for the lower one). Yellow and green arrows are pathways that are being addressed by an MDAP project (led by Tanaka). Paths shown by red arrows involving the Scandia region unit will be investigated in this proposal.*

Approach: We can begin to see how to address such questions by examining how the complexities within the Scandia region can be systematically unraveled. We can do this by dividing the Scandia region into zones of similar geomorphic characteristics and determining what sorts of features can be mapped and described within them. Our initial inspection reveals at least three such zones from south to north, as follows. (1) The knobby zone constitutes extensive fields of knobs, including Scandia Colles, along the lower northern flank of Alba Patera. Along sinuous, well-preserved wrinkle-like ridges, knobs commonly form denser clusters. A few rimmed, fractured mesas also occur along wrinkle ridges along the Alba Patera margin. In addition, there are numerous occurrences of discontinuous circular ridges composed of knobs; these landforms are likely erosional vestiges of impact crater rims indicative of pervasive degradation. (2) The subdued zone contains widespread "ghost" impact craters and topographically-subdued wrinkle ridges. Its gradation from the knobby zone closely follows the -4000 m elevation contour. Numerous craters with preserved ejecta blankets appear partly degraded. Knobs and mesas are generally less dense and more dispersed compared to the knobby zone. Irregular depressions with knobby floors, generally <100 km across and <200 m deep, are scattered throughout this zone. The Phoenix landing site occurs within the subdued zone. (3) The tholi zone is characterized by populations of irregularly-shaped raised-rim depressions 100s of km across and 100s of m in relief (including Scandia Cavi), nested depressions and pits 10s to >100s of km across and locally >300 m deep, and ovoid, knobby mounds with moats 10s to 1000s of km across in isolation and in clusters (Scandia Tholi). The tholi, deeper depressions, and cavi generally occur below -4700 m elevation. The Scandia zones also contain an array of tectonic structures (grabens, wrinkle-like ridges, fractures, and narrow linear ridges that may be dikes) and impact crater morphologies. Additional contextual information is provided by the topographic and geologic characteristics of Alba Patera lava flows that locally reach into Scandia, of subjacent and adjacent Vastitas Borealis units, and of north polar layered deposits and dunes of Planum Boreum and surroundings.

The Scandia region unit includes widespread remnants of Vastitas Borealis units and perhaps other deposits eroded and modified to form distinctive classes of features largely confined within topographic zones. These features can be mapped and measured, from which the volumes of eroded material can be calculated. When such mapping and measurements are put into their geologic and temporal contexts, a resurfacing history emerges that can constrain rates of geologic activity.

References: [1] Tanaka K.L. et al. (2005) *USGS Map SIM-2888.* [2] Tanaka K.L. et al. (2003) *JGR, 108,* 10.1029/2002JE001908. [3] Tanaka K.L. et al. (2008) *Icarus, 196,* 318-358. [4] Fishbaugh K. and Head J.W. (2005) *Icarus, 174,* 444-474. [5] Byrne S. and Murray B. (2002) *JGR, 107* (E6). [6] Rodriguez J.A.P. et al. (2007) *Mars, 3,* 29-41.

GEOLOGIC MAPPING OF THE MEDUSAE FOSSAE FORMATION ON MARS AND THE NORTHERN LOWLAND PLAINS OF VENUS. J. R. Zimbelman, CEPS/NASM MRC 315, Smithsonian Institution, Washington, D.C., 20013-7012; zimbelmanj@si.edu.

Introduction: This report summarizes the status of mapping projects supported by NASA grant NNX07AP42G, through the Planetary Geology and Geophysics (PGG) program. The PGG grant is focused on 1:2M-scale mapping of portions of the Medusae Fossae Formation (MFF) on Mars. Also described below is the current status of two Venus geologic maps, generated under an earlier PGG mapping grant.

Medusae Fossae Formation, Mars: Work on mapping of the heavily eroded western portions of MFF has progressed well, particularly with the assistance of Lora Griffin, a PGGURP-supported 2008 summer intern at NASM. Attributes of MFF as documented in Mars Orbiter Camera images were the basis for a reevaluation of the numerous hypotheses of the origin for MFF, with the conclusion that an ignimbrite origin is the hypothesis most consistent with the observations [1]. Interpretations of various aspects of yardangs that are abundant within the intensely eroded lower member of MFF were reported to the science community at two major conferences [2, 3] and at the 2008 Mappers meeting in Flagstaff, AZ [4]. The yardangs reveal that MFF materials have multiple series of internal layering [5], as revealed by differences in competency resulting from erosion and mass wasting, a result that appears to be most consistent with variable degrees of welding often present within volcanic (ignimbrite) deposits [1]. A preliminary geologic map of the **MC-23 NW** quadrangle (Fig. 1), which covers the southwestern edge of the MFF deposits, was presented
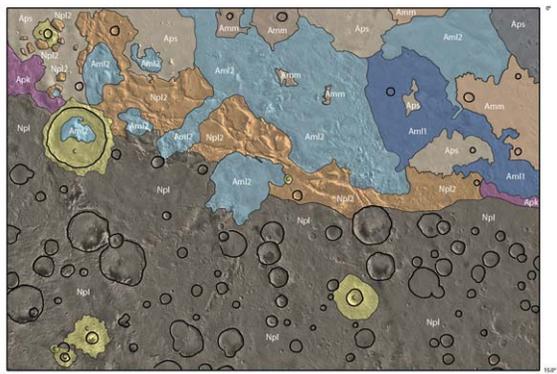
Figure 1. 2008 version of the MC-23 NW geologic map of southwestern MFF (blue and light tan units).

both at the 2008 Mappers meeting [4], and in a poster at the 40th Lunar and Planetary Science Conference

[3]. The mapping reveals numerous outliers that we interpret to be portions of the lower member of MFF, suggesting that the previous extent of MFF materials may have been considerably larger than what is expressed by the present MFF deposits on Mars [3, 4].

One distinctive feature to come out of the mapping in western MFF is the common occurrence of many sinuous positive-relief ridges [5], which are particularly well exposed in portions of the lower member of MFF [6]. These sinuous ridges are interpreted to be inverted paleochannels [5-7] (Fig. 2), representing prolonged flow of a liquid perhaps coincident with the emplacement of the lower member of MFF [5-9].
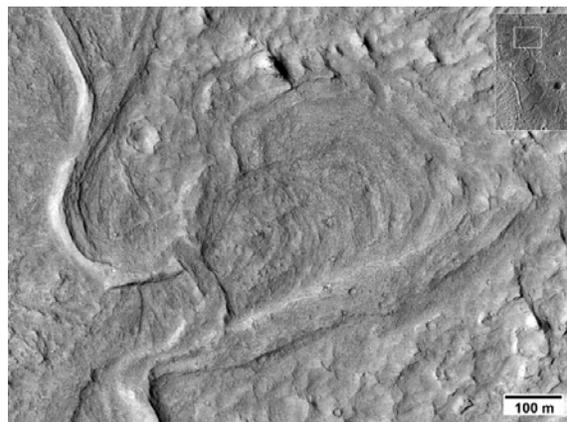
Figure 2. Sinuous ridge interpreted to be inverted topography of well-developed cut-off meander deposits [5]. Portion of HiRISE image PSP_006683_1740, 6.0S, 153.6E. Inset shows location within portion of the browse image.

In early 2009, some salary money in the current grant was reallocated (with the approval of the PGG discipline scientist) to purchase a Dell desktop computer, on which was loaded ArcGIS software through a licensing agreement with the Smithsonian Institution. The 2008 Mappers meeting made it very clear that this is the preferred software (by the USGS) for all future planetary maps, so the investment should pay dividends for mapping projects both now and in the future. The learning curve for ArcGIS is very steep, and the PI is still becoming familiar with the intricacies of the software, but already he can see the long-term advantages that it holds for geologic mapping projects. The geologic map of MC-23 NW [3, 4] will be the basis for the first geologic map produced by the PI using ArcGIS. Once the PI is familiar enough with the ArcGIS

software to generate an entire geologic map, the PI will then commence work on making an ArcGIS version of a revised geologic map for **MC-8 SE**, using the earlier (Illustrator 9) mapping product [10] as a guide to the newly mapped geology.

Northern Lowland Plains, Venus: The map and text for the Kawelu Planitia quadrangle (**V-16**) have been in review with the USGS for many years [11]. A revised version, addressing all reviewer comments, was submitted to the USGS in 2008, at which time it became apparent that the linework (which dated from mapping carried out on hardcopy base materials) was not uniformly registered to the digital photobase that is the current standard for production of published maps. Careful review of all of the linework revealed that no single shift or warp could correct the situation, due to map revisions that were made at different times to various sections of the map. Late last year, all of the V-16 linework was manually adjusted to register with the digital photobase, through the helpful assistance of a NASM volunteer. We have not yet had time to regenerate the unit polygons in Adobe Illustrator 9, the software used to make the present version of the map, but we intend to do so later this year. Once the adjusted linework is reconstituted into a map registered to the digital base, V-16 should be able to continue through the revision process. The Bellona Fossae quadrangle (**V-15**) was mapped preliminarily several years ago [12] under a previous PGG grant, also initiated on hardcopy base materials like V-16. When the V-16 map is finally back on track, we will redo the V-15 geology in ArcGIS, using the prior map as a guide while generating the new linework.

Future Plans: Plans for the third year of funding include submission of the MC-23 NW map to the USGS, completion of a revised version of the geologic map for MC-8 SE in ArcGIS, followed by completion of a revised version of the geologic map for V-15 in ArcGIS. Parallel to this effort will be any revisions needed for the ArcGIS version of the map for MC-23 NW and the Illustrator version of the V-16 map. After progress has been made on the above maps, preliminary mapping (in ArcGIS) will be started for **MC-16 NW**, the last of the MFF mapping areas identified in the original proposal.

References: [1] Mandt, K.E., et al. (2008) JGR-Planets, 113, E12011, doi: 10.1029/2008JE003076. [2] Zimbelman, J.R. (2008) Eos Trans. AGU, 89(24) Abs. P34A-05. [3] Griffin, L.J., and Zimbelman, J.R. (2009) LPS XXXX, Abs. 1196. [4] Zimbelman, J.R. (2008) NASA Mappers mtg, NASA/CP-2008-215469, 77-78. [5] Zimbelman, J.R., and Griffin, L.J. (in press) Icarus, doi: 10.1016/j.icarus.2009.04.003. [6] Burr, D.M., et al. (2009) Icarus 200, 52-76, doi: 10.1016/ j.icarus. 2008.10.014. [7] Williams, R.M.E., et al. (2009) Geomorphology, doi: 10.1016/j.geomorph.2008.12.015. [8] Burr, D.M., et al. (2008) Second Workshop Mars Valley Networks, Smithsonian Inst., 7-10. [9] Burr, D.M., et al. (2008) GSA Abs. Prog., 40(6), Abs. 195-12. [10] Zimbelman, J.R. (2007) NASA Mappers mtg, ZIMBELMANa2007PGM.PDF. [11] Zimbelman, J.R. (2007) NASA Mappers mtg, ZIMBELMANb2007 PGM.PDF. [12] Zimbelman, J.R. (2004) NASA Mappers mtg, ZIMBELMAN2004PGM.PDF.

VOLCANISM ON IO: INSIGHTS FROM GLOBAL GEOLOGIC MAPPING. D.A. Williams[1], L.P. Keszthelyi[2], D.A. Crown[3], P.E. Geissler[2], P.M. Schenk[4], Jessica Yff[2], W.L. Jaeger[2]. [1]School of Earth & Space Exploration, Arizona State University, Tempe, Arizona 85287 (David.Williams@asu.edu); [2]Astrogeology Team, U.S. Geological Survey, Flagstaff, Arizona; [3]Planetary Science Institute, Tucson, Arizona; [4]Lunar and Planetary Institute, Houston, Texas.

Introduction: We are preparing a new global geologic map of Jupiter's volcanic moon, Io. Here we report the type of data that are now available from our global mapping efforts, and how these data can be used to investigate questions regarding the volcano-tectonic evolution of Io.

Previous Work: During recent years we developed techniques for global mapping using a low-resolution *Galileo* regional mosaic [1], and began mapping on our base, a series of 1 km/pixel mosaics produced by the USGS from the combined *Galileo-Voyager* image data sets [2]. Global mapping was completed in 2008 using ArcGIS™ software. We have also begun production of an Io database [3] that will include most Io data sets to address the surface changes due to Io's active volcanism. Previously [4] we reported the percentage of Io covered by each of 14 geologic material units, such that the whole surface of Io has now been characterized into process-related material units and structures. These data, which include the areal extents and latitude-longitude locations of every resolvable lava flow field, patera floor, mountain, plains unit, and diffuse deposit, as well as the locations of hot spots detected from previous missions, can be used for statistical studies to investigate Io's geologic processes.

Results: We are using the new map to investigate several specific questions about the geologic evolution of Io that previously could not be well addressed, including (for example) a comparison of the areas vs. the heights of Ionian mountains to assess their stability and evolution (**Fig. 1**). The area-height relationships of Io's visible mountains show the low abundance and low relief of volcanic mountains (tholi) relative to tectonic mountains, consistent with formation from low-viscosity lavas less likely to build steep edifices. Mottled mountains are generally less high than lineated mountains, consistent with a degradational formation.

Correlation of Map Units: Fig. 2 shows the stratigraphic relationship of map units. The oldest materials exposed at the surface are crustal materials that have been uplifted to form the various mountain units. Our mapping and other studies support the hypothesis of [5] that the accumulation of volcanic materials on the surface causes compression of the upper crust, eventually leading to tectonic fracturing, faulting, and uplift of crustal blocks forming mountains (our Lineated Mountain material). Over time these materials

are mantled and undergo gravitational collapse, forming Mottled Mountain materials that grade into Layered Plains. Surrounding the mountains are the various Plains materials, whose upper surfaces must be very young, based on the lack of impact craters, but whose lower layers are likely the same crustal materials that make up the mountains.

We suggest that volcanism on Io has been happening for at least the last few Ma to create the stress conditions necessary to form the mountains. Volcanism has probably been going on for a much longer period of time, although the rapid reworking of the crust has obliterated any evidence of older activity. The currently visible paterae and lava flow fields (*fluctus*, pl. *fluctūs*) probably formed subsequently (in most cases) to the currently visible mountains. The oldest volcanic surfaces are related to centers that became inactive in the last decades to millennia and are mapped as Undivided Patera Floor materials and Undivided Flow materials. More distinct volcanic constructs, including the Bright Tholus material, probably formed more recently. The visible surfaces of the plains are formed from the coalescence and homogenization of older eruptive products (pyroclastics and lavas).

The time frame of decades to years marks the period of spacecraft observations, from *Voyager* (1979) to *Galileo* (1996-2001) to *New Horizons* (2007). While no new mountains or paterae have formed in this time interval, we have witnessed the formation of the Zamama flow field between *Voyager* and *Galileo*, and ongoing emplacement of new flow fields, patera floors, and diffuse deposits at many volcanoes. These are the source for the other geologic units, including Bright and Dark Patera Floor materials, Bright and Dark Flow materials, and all five types of Diffuse materials. The most recent spacecraft flyby (*New Horizons*, Feb. 28, 2007) recorded evidence of surface changes in both lava flow fields and diffuse deposits at several locations on Io [6].

References: [1] Williams, D.A. et al. (2007), *Icarus*, *186*, 204-217. [2] Becker, T. and P. Geissler (2005), *LPS XXXVI*, Abstract #1862. [3] Rathbun, J.A. and S.E. Barrett (2007), *LPS XXXVIII*, Abstract #2123. [4] Williams, D.A. et al. (2008), *LPS XXXIX*, Abstract #1003. [5] Schenk, P. and Bulmer, M. (1998), *Science, 279*, 1514-1517. [6] Spencer, J. et al. (2007), *Science, 318*, 240-243.
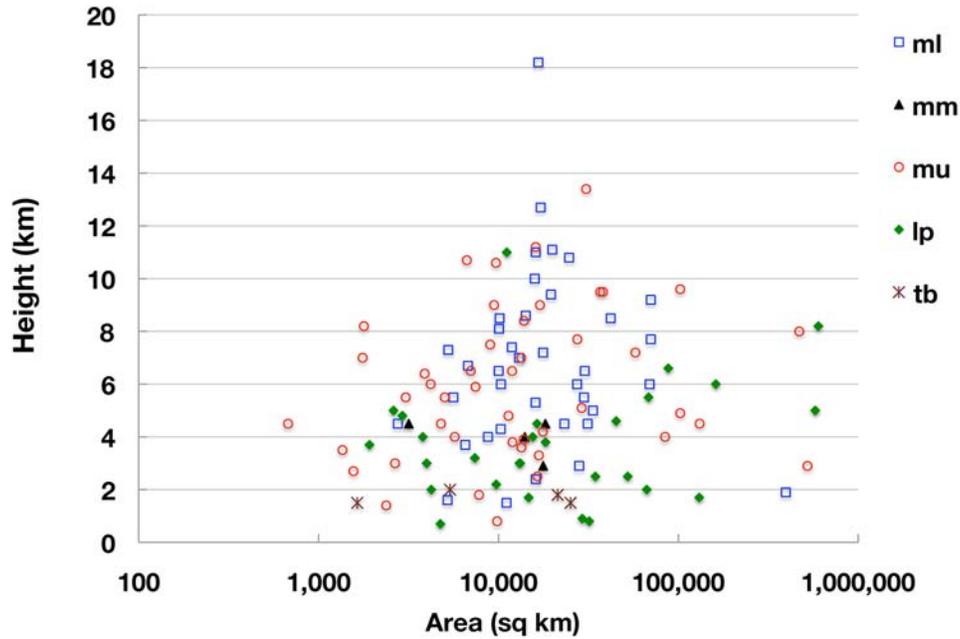
Figure 1. Plot of area-height relationships of Io's mountains. Mottled mountains (mm) are generally less high than lineated mountains (ml), consistent with their degradational formation. Undivided mountains (mu) are widely distributed, as lack of resolution inhibits better characterization. Tholi (volcanic mountains, tb) are of low relief, consistent with formation from low-viscosity lavas. Layered plains (lp) are mostly <6 km high, consistent with highly degraded mountains, grading into eroded plains (i.e., 'resurfacing' by mass wasting, a minor process on Io).
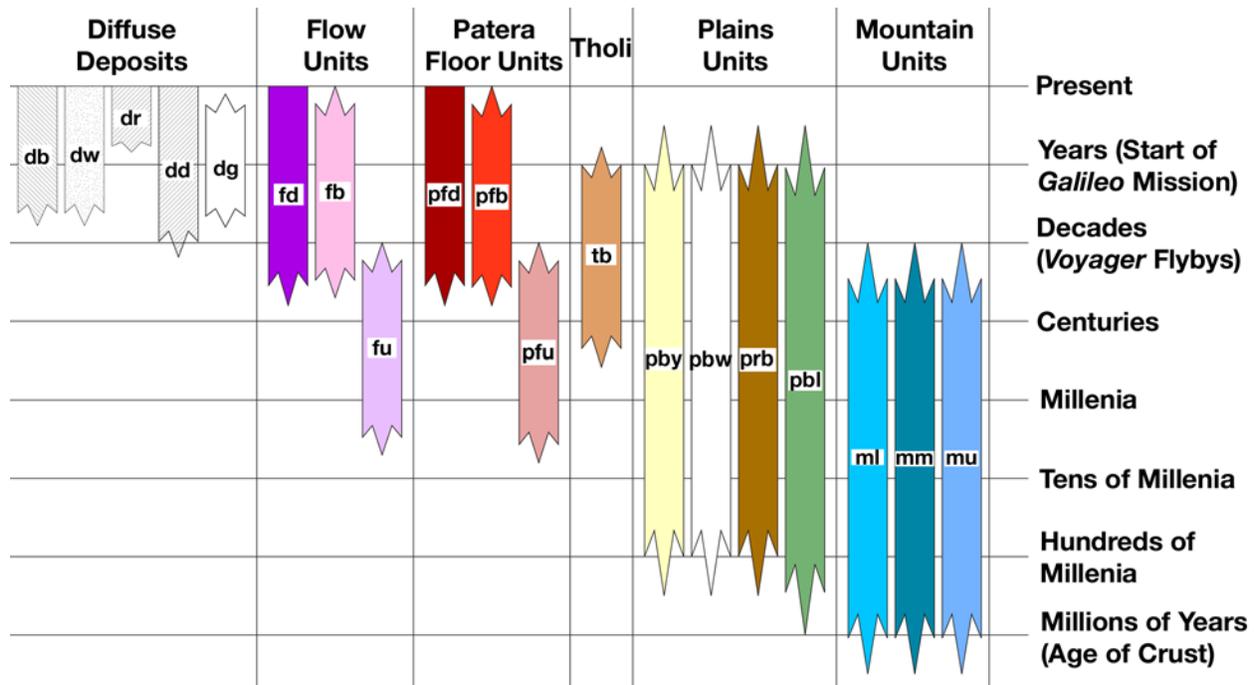
Figure 2. Correlation of exposed map units on Io. Symbols: ml, lineated mountains; mm, mottled mountains; mu, undivided mountains; pby, yellow bright plains; pbw, white bright plains; prb, red-brown plains; pbl, layered plains; tb, bright tholi; pfd, dark patera floors; pfb, bright patera floors; pfu, undivided patera floors; fd, dark flows; fb, bright flows; fu, undivided flows; db, bright diffuse deposits; dw, white diffuse deposits; dr, red diffuse deposits; dd, dark diffuse deposits; dg, green diffuse deposits.

Planetary Geologic Mapping Handbook – 2009

K.L. Tanaka, J.A. Skinner, Jr., and T.M. Hare
U.S. Geological Survey, Astrogeology Science Center
2255 N. Gemini Dr., Flagstaff, AZ 86001

Endorsed by:

The Geologic Mapping Subcommittee (GEMS) of the NASA Planetary
Cartography and Geologic Mapping Working Group (PCGMWG)
M.S. Kelley[1], L.F. Bleamaster III[2], D.A. Crown[2], L.R. Gaddis[3], T.K.P. Gregg[4],
J.R. Johnson[3], S.C. Mest[2], and K.K. Williams[5]

[1]NASA Headquarters, Washington, DC
[2]Planetary Science Institute, Tucson, AZ
[3]U.S. Geological Survey, Astrogeology Science Center, Flagstaff, AZ
[4]University at Buffalo, Buffalo, NY
[5]Buffalo State College, Buffalo, NY

TABLE OF CONTENTS

1. INTRODUCTION

Geologic maps present, in an historical context, fundamental syntheses of interpretations of the materials, landforms, structures, and processes that characterize planetary surfaces and shallow subsurfaces (e.g., Varnes, 1974). Such maps also provide a contextual framework for summarizing and evaluating thematic research for a given region or body. In planetary exploration, for example, geologic maps are used for specialized investigations such as targeting regions of interest for data collection and for characterizing sites for landed missions. Whereas most modern terrestrial geologic maps are constructed from regional views provided by remote sensing data and supplemented in detail by field-based observations and measurements, planetary maps have been largely based on analyses of orbital photography. For planetary bodies in particular, geologic maps commonly represent a snapshot of a surface, because they are based on available information at a time when new data are still being acquired. Thus the field of planetary geologic mapping has been evolving rapidly to embrace the use of new data and modern technology and to accommodate the growing needs of planetary exploration.

Planetary geologic maps have been published by the U.S. Geological Survey (USGS) since 1962 (Hackman, 1962). Over this time, numerous maps of several planetary bodies have been prepared at a variety of scales and projections using the best available image and topographic bases. Early geologic map bases commonly consisted of hand-mosaicked photographs or airbrushed shaded-relief views and geologic linework was manually drafted using mylar bases and ink drafting pens. Map publishing required a tedious process of scribing, color peel-coat preparation, typesetting, and photo-laboratory work. Beginning in the 1990s, inexpensive computing, display capability and user-friendly illustration software allowed maps to be drawn using digital tools rather than pen and ink, and mylar bases became obsolete.

Terrestrial geologic maps published by the USGS now are primarily digital products using geographic information system (GIS) software and file formats. GIS mapping tools permit easy spatial comparison, generation, importation, manipulation, and analysis of multiple raster image, gridded, and vector data sets. GIS software has also permitted the development of project-specific tools and the sharing of geospatial products among researchers. GIS approaches are now being used in planetary geologic mapping as well (e.g., Hare and others, 2009).

Guidelines or handbooks on techniques in planetary geologic mapping have been developed periodically (e.g., Wilhelms, 1972, 1990; Tanaka and others, 1994). As records of the heritage of mapping methods and data, these remain extremely useful guides. However, many of the fundamental aspects of earlier mapping handbooks have evolved significantly, and a comprehensive review of currently accepted mapping methodologies is now warranted. As documented in this handbook, such a review incorporates additional guidelines developed in recent years for planetary geologic mapping by the NASA Planetary Geology and Geophysics (PGG) Program's Planetary Cartography and Geologic Mapping Working Group's (PCGMWG) Geologic Mapping Subcommittee (GEMS) on the selection and use of map bases as well as map preparation, review, publication, and distribution. In light of the current boom in planetary exploration and the ongoing rapid evolution of available data for planetary mapping, this handbook is especially timely.

2. PURPOSE OF THIS HANDBOOK

The production of high-quality geologic maps is a complex process involving a wide range of data, software tools, technical procedures, mapping support specialists, review steps, and publication requirements. This handbook provides a comprehensive 'how to' mapping guide that covers each of these topics to clarify the process for map authors. This guide emphasizes the production of planetary geologic maps in a digital, GIS format, because this format is required by NASA PGG for maps beginning in (1) 2011 that are submitted for technical review and (2) 2013 that are finalized for publication. Because of continual changes in data availability and mapping techniques, it is understood that the geologic mapping process must remain flexible and adaptable within time and budgetary constraints. Users are advised to seek the latest edition of this handbook, which will be updated periodically as an appendix to the annual abstracts of the Planetary Geologic Mappers' (PGM) meeting (downloadable at the PGM web page; see below for a complete list of web links). Other updates, including recently published maps, will be posted on the USGS Astrogeology Science Center's (ASC) PGM web page.

First, we describe the steps and methods of map proposal, creation, review, and production as illustrated in a series of flow charts (Figs. 1-4). Second, we include basic formatting guidelines for each map component. Third, we provide a list of web sites for useful information and download.

3. MAP PROCESSING

Planetary geologic maps as supported by NASA and published by USGS are currently released under the 'USGS Scientific Investigations Maps' (SIM) series. In this section, we summarize the process of completing USGS SIM series planetary geologic maps from proposal submission to publication (Figs. 1-4; note that the SIM series was formerly named Geologic Investigations Series and Miscellaneous Investigations Series and both used "I" for the series abbreviation for published maps; all I and SIM series share a common, progressive numbering scheme). These processing steps are subject to change as they are dictated in many cases by higher-level organizational policies, budget constraints, and other circumstances. Planetary geologic mapping support personnel are listed in Section 7; these are subject to change on an annual basis.

a. Proposals*. Planetary geologic maps published by USGS have been sponsored largely by the NASA PGG program. Thus, maps submitted to USGS for publication must have been accepted under a NASA PGG grant (see the NASA research opportunities web page) and/or have the approval of the NASA PGG Discipline Scientist. Map publication and printing costs are covered by separate PGG funding and thus are not included in PGG research proposals. The proposal submission deadline is generally during the spring, and selections are usually announced by the following winter (depending on when funds can be released from NASA). Those considering proposing for a grant to perform planetary geologic mapping should visit the USGS Planetary Geologic Mapping web page, where information on current mapping programs and projects, map preparation guidelines, and links to published maps can be found. While a variety of map areas, scales, and projections are potentially feasible for publication, some issues may make a conceived map untenable for publication (e.g., NASA PGG has a limited budget and multiple and oversized map sheets may be prohibitive in cost). Mappers are highly encouraged to contact

the USGS Map Coordinator (MC) regarding the maps to be proposed for prior to proposal submission to ensure that preparation of the desire map base and publication of the final product are feasible. (See table in Section 7 listing PGM personnel names and email addresses). Generally, proposals should address:

1) Digital production: Will the map be generated in GIS software compatible with ESRI's ArcGIS® software (the USGS standard)?

2) Map base: The proposal should include a description and justification of the desired map base that addresses the following questions. What data set is desired for the map base (which forms the map background) and are all the needed data released? Does USGS have the capability to generate the map base with available capability and resources? (Consult with the USGS Map base Specialist to find out.) What other data sets are desired and can they also be imported into the GIS geodatabase? Does the work plan allow for adequate time for USGS to construct the base (usually within 6 months after the USGS is notified by the PGG Discipline Scientist of the proposal's award), depending on complexity?

3) Map printing: At the proposed scale and projection, will the map be oversized (i.e., >40x56 inches)? Will multiple sheets be required for a given map area? (Consult with the USGS Map Coordinator for estimates of potential extra costs.) Proposer should be aware that increased complexity adds considerable time for preparation, review, and publication.

4) Map reviews: Proposers should be prepared to review two other planetary geologic maps for each intended map publication. It is appropriate to budget your time to review maps in each new mapping proposal that you submit.

5) Supplemental digital products: Digital map supplements may be proposed. These can include helpful figures and ancillary GIS raster and vector layers that can greatly enhance the map product but may not fit on the printed map.

6) Additional analyses and products: Detailed and interpretative analyses outside of the scope of the map product may be desired (for example, to test existing and construct new hypotheses, model observations, etc.), but these should be expressed as tasks independent of map generation (best suited for publication in science journals). Maps will no longer contain such material.

7) Attendance at mappers meetings: Proposal budgets must include funding for attendance at the annual Planetary Geologic Mappers' meetings and possible GIS workshops.

b. *Map base package* *(Fig. 1).* The map base forms the background image (usually in reduced contrast form) upon which the drafted geologic map units, symbols, and nomenclature are superposed. It is a geometrically controlled product that is the fundamental data set upon which map drafting is performed. In some cases, there are adequate data available from a particular data set, but the map base itself does not yet exist when the mapping proposal is submitted. Thus USGS must generate the map base. (In special cases, the proposer may construct the base, with advance permission from the USGS Map Coordinator). Sometimes, data gores can be filled in with other lower-quality yet useful data. Even if a desirable data set is released, there may be as-yet unresolved issues in radiometric and geometric processing and/or in data volume that prevent USGS from producing a map base with that particular data set. For example, the number and volume of images may be too large to generate a map base with available resources. Alternatively, such data may be readily viewable as individual frames by using image-location

footprints as GIS shapefiles having web links to data repositories. Other ancillary data in various forms may be provided at the request of the author if there is a demonstrated need for the data and if they can be readily integrated into a GIS geodatabase. The USGS Map base Specialist is tasked by PGG to produce the digital map base and ancillary data products and to satisfy reasonable and tractable mapping requests by map authors.

Typically, the USGS must generate several map base packages in a given year; these are generally compiled in order of increasing complexity and/or areal extent. Map bases for Venus quadrangles are usually the simplest and are thus generated first during each funding cycle. Map bases for Mars quadrangles may require mosaicking of many individual image frames that must be compared visually and stacked in order of quality and then collectively processed for tone balance. More complex maps may require several months to complete after USGS is notified to produce them.

For GIS mapping projects, the USGS GIS Project Specialist generates a GIS map template after quality-checking and collating GIS data layers. The template includes map bases and a map-ready geodatabase with pre-populated symbols. These products are compiled and delivered using ESRI's ArcGIS® software. (USGS can import shapefiles produced from other software in some cases, but authors should consult with USGS GIS specialists *prior* to mapping to ensure that their map files will be usable.)   In addition, a variety of GIS thematic maps can be downloaded and imported into the project, as well as other GIS tools, as administered by the USGS GIS PIGWAD Specialist (see PIGWAD web site). For Mars, Moon, and Venus maps, the mapping projects will include a stand-alone DVD volume (or equivalent compressed, digital file) of global datasets that can be incorporated into the project-specific GIS template.

c. Digital mapping. Mappers presently are mapping mostly in Adobe Illustrator or ArcGIS. For proper building of polygons in Illustrator layers, see the help web site. For ArcGIS, contact and structure mapping is generally done first as polyline shapefiles.   Vertex snapping is important for later generation of polygons.   Point shapefiles can be used to indicate unit identification for each outcrop. At an advanced stage in mapping, the contacts can be cleaned, smoothed, and converted to polygons. We recommend that the final GIS linework have a vertex spacing of ~0.3 mm at map scale (equivalent to 300 m for a 1:1,000,000-scale map). We also recommend that a consistent scale is used to digitize linework, usually a factor of 2 to 5 larger than the published map to ensure adequate precision but not overkill (e.g., map at 1:200,000 to 1:500,000 for a 1: 1,000,000 map). GIS tools can be applied to generalize and smooth linework to achieve the desired result, such as rounded corners. Also, outcrops should generally be at least 2 mm wide at map scale. Reasonably sized cutoffs should also be defined for line feature lengths (for example, 1 or 2 cm long at map scale). Point features can be used to show the distribution of important features such as craters and shields that are too small to map (their size ranges should be indicated). For clarity and completeness, we encourage the compilation and summary of digital mapping approaches and settings for inclusion in the map text.

d. Mappers' meetings and GIS workshops. These meetings are announced by the GEMS Chair and are also posted on the NASA Mars Exploration Program Analysis Group (MEPAG) calendar web page and the Planetary Exploration Newsletter (PEN) calendar of events. While under active NASA mapping grants, mappers are expected to submit and present abstracts for the Annual Meeting of Planetary Geologic Mappers typically held in late June each year. Others are encouraged to attend as a means to benefit from various aspects of the program.   At these

meetings, mappers demonstrate their progress and discuss mapping issues and results. Preliminary map compilations are also displayed and informally reviewed by other attendees during poster sessions. In addition, programmatic issues, mapping standards and guidelines, and related scientific issues are presented and discussed. Expert-led GIS workshops and/or geologic field trips to nearby localities of interest are commonly attached to the mappers' meeting. When possible, associated GIS workshops are held prior to or immediately following mappers' or other appropriate workshops (and occasionally as stand-alone meetings) throughout the year. These GIS workshops are customized to assist planetary geologic mappers in developing proficiency in GIS software and tools as applied toward planetary geologic maps published in the USGS SIM series. Abstracts and related reports are published in an abstract volume in either a USGS or NASA publication series, and they can be downloaded from the USGS Planetary Geologic Mappers web page.

e. Submission and technical review (Fig. 2). Mappers are expected to prepare maps in accordance with guidelines herein (see Map Contents section below) as well as with those posted on the USGS Planetary Geologic Mappers web page. Once the map is produced according to required guidelines, it is submitted in digital form to the USGS Map Coordinator (MC). The MC reviews the map submission for completeness. If the map is incomplete, the MC returns the map to the corresponding author for revision. If the map is complete, the MC assigns two reviewers, with the approval of the GEMS Chair. The MC fills out an Information Product Review and Approval Sheet (IPRAS; Figure 5) in which all reviewers are listed. Both reviewers must approve (in rare cases, a third reviewer may be assigned to help resolve reviewer conflicts). Maps are returned to authors one or more times until review comments are adequately addressed as determined by the MC. The MC may adjudicate some issues that arise (for more challenging cases and in cases of potential conflict of interest, the MC consults with the GEMS Chair). Normally, initial map reviews are expected to be returned within 1 to 2 months and any additional reviews within 2 weeks.

f. Map Coordinator review (Fig. 3). Once the technical reviews are complete, the MC, with assistance from other USGS specialists as needed, performs a review that ensures that (1) the map conforms to the proper scale and projection, (2) final technical reviewer comments were adequately addressed, (3) map materials follow PSC author submission checklist guidelines, (4) map information conforms to established USGS and GEMS conventions, (5) nomenclature is sufficient, given what the map text discusses, and (6) stratigraphic inferences are properly conveyed and supported by observations. Map authors respond to the MC review comments and resubmit the map package. Name requests for mapped or referenced features are made by the author as needed using the online form; these can be made anytime during the mapping process. New name proposals may take 4 to 8 weeks or longer for approval. Proposed names *may not be used* in publications until they have been approved by the International Astronomical Union.

g. Nomenclature review (Fig. 3). The USGS Nomenclature Specialist then reviews the map to assess whether the use of nomenclature accurately reflects the current terminology in the IAU Gazetteer of Planetary Nomenclature. The map itself should have a nomenclature layer that presents all available formal names. Note that some exceptions to this naming requirement may apply in special situations; for example, overly small named features may exist only for a sub-

region of the map. (For a brief review of how IAU nomenclature is being managed and developed in the case of the Moon, see Shevchenko and others (2009)).

h. *USGS metadata preparation (GIS maps only; Fig. 3).* Metadata is the necessary ancillary documentation that describes each GIS layer in a geologic map, including rationale, authorship, attribute descriptions, spatial reference, and other pertinent information as required by the metadata standard. This information is archived with and becomes part of the map layer. The USGS GIS specialists will oversee metadata preparation and will tap authors for information when needed. Metadata for a map is comparable to the documentation required by NASA's Planetary Data System for digital planetary data, but it is created specifically for geospatial data sets. USGS GIS specialists will oversee incorporation of metadata for the mapped layers according to USGS publication standards and Federal Geographic Data Standards (FGDC). Metadata and readme files are required when the manuscript is submitted to PSC for publication. The PSC Digital Map Editor reviews general information (such as correct USGS contact information, information in appropriate fields, etc.).

i. *USGS Publications Services Center (PSC) editing and production (Fig. 3).* The PGM Administrative Specialist works with other USGS staff to ensure that the product is complete for PSC processing, and sends the product and review materials on CD or DVD and hardcopy form according to PSC guidelines (see PSC author submission and Astrogeology submission checklist web pages). PSC contacts the Map Coordinator and estimates costs for PSC editing and production and printing through a contractor selected by the Government Printing Office (GPO). Based on available funds for these costs, maps are put into the editing and production queue for the current or next fiscal year. A USGS PSC Map Editor then is assigned to the map and works with the author to produce the edited copy. Next, the map goes to the PSC Production Cartographer to produce a printable version in Adobe Illustrator®. The author has an opportunity to proof the map before it is finalized for publication; however, no significant content changes are allowed (authors will be responsible for proofing non-standard items such as special characters (small caps, diacriticals, etc.)). Also, if there is room on the map, the author may be notified by PSC that appropriately sized tables and/or figures can be shifted from the pamphlet and/or digital supplement to the map.

j. *Map printing and web posting (Fig. 3).* The PSC Production Cartographer submits the completed map to GPO for bid and printing. Generally, 100 copies of the map are sent to authors, and 300 copies are received by the USGS Regional Planetary Image Facility (RPIF) in Flagstaff, Arizona, for distribution to other RPIFs and PGG investigators on a mailing list provided by the PGG Discipline Scientist. Extra copies are kept by the USGS RPIF and can be requested by investigators through the Map Coordinator. Digital files of map materials are posted by the PSC Web Master on a USGS server for downloading, including: (a) PDFs of all printed materials produced by PSC, (b) author-provided Adobe Illustrator® files, and (c) GIS database, metadata, readme, and additional data files provided by PSC (a copy of these final files is provided to the author). Minor corrections and cosmetic improvements of the digital map product can be generated by authors as a new digital version of the map and submitted to the Map Coordinator for review, editing, and posting (however, consult first with the MC before initiating such a product, as authors have to pay for this service). Minor, non-science changes are shown by a decimal number, for example, correcting spelling of a name throughout the

publication or correcting a number in a table would generate a version upgrade from 1 to 1.1. Changing science on the map or adding data would generate a version upgrade from 1 to 2.

4. MAP CONTENTS

Planetary geologic maps in the past have varied widely in content and arrangement, largely at the preference of map authors. Though some flexibility is desirable to convey the geologic data and interpretation in ways that are suitable for each particular geologic map, unnecessary divergences and details come at a cost. Highly complex and uniquely assembled maps require more effort from mappers, reviewers, cartographers, and editors to prepare the map for publication. This handbook, under the direction of GEMS, defines a basic content template for planetary geologic maps, so that they become more uniform in format and thus simpler for users to assimilate and use as well as easier and cheaper to produce. In addition, following established USGS style guidelines in initial text preparation will result in less editing and revision. Mappers should refer to recently published geologic maps for examples of proper style in terms of spelling, word usage, grammar, and formatting, as well as the USGS Tips web page that addresses common formatting and editing issues. *Doing so will save time and effort!*

a. Map sheet components. To keep the printed map sheet as small as possible, authors are requested to keep map components to a minimum.

1) Map: Of course, the map itself is the fundamental product. It should be complete with map base at correct scale and projection, outcrops clearly colored and labeled, and structures consistently mapped. (The PSC Production Cartographer will cosmetically fine tune these elements, as well as add the map scale and grid and any notes on base, but cannot be expected to complete or decipher any aspects prepared incompletely or unclearly.) To avoid clutter, highly detailed information may be included in the digital product as a layer (see the digital data products section below). Printed maps normally must be contained within a single sheet having a maximum size of 40 x 56 inches (larger or additional sheets result in significant additional printing costs; authors desiring multiple or oversized sheets may choose to pay for the extra costs, with prior approval via the Map Coordinator).

2) CMU/SMU: Each map will include a Correlation or Sequence of Map Units (CMU/SMU) chart. The chart is organized horizontally left to right showing the following elements:

a) *Stratigraphic column*: Formal or informal stratigraphic divisions (where available).

b) *Map units*: Units can be arranged in groups according to location or unit type. Units that form groups closely related in provenance and/or definitive characteristics may have similar unit names and symbols (e.g., Utopia Planitia 1 unit, Utopia Planitia 2 unit) and should be juxtaposed horizontally and/or aligned vertically in the CMU/SMU. Also, younger units and unit groups divided by region or morphologic type generally are placed toward the left, and older and diverse (e.g., 'undivided highland materials') and widespread (e.g., 'crater material') units are placed to the right. If more complex relations are portrayed, such as unconformities, time transgressive contacts, and other juxtaposition relations, they may be explained using a key (e.g., Young and Hansen, 2003; see also GEMS guidelines for Venus SMUs and Appendix D in Tanaka and others, 1994).

c) *Major geologic events (optional)*: Juxtaposed chart to the right of the CMU/SMU showing inferred episodes of geologic activity (such as deposition, erosion, deformation, etc.; e.g., Tanaka and others, 2005).

d) *Crater density scale (where data are available)*: Cumulative density of craters larger than specified diameter(s) (e.g., Tanaka and others, 2005). Supporting text should be provided in the 'age determinations' text section (see below).

3) Nomenclature: Published USGS maps are expected to display nomenclature completely (with minor exceptions, such as features that are spatially insignificant at map scale) and accurately according to the International Astronomical Union (IAU) Gazetteer of Planetary Nomenclature. Whenever named features are mentioned anywhere in the map, including the text, they should be properly capitalized and spelled (including the Latin plural forms for descriptor terms). In this regard, the IAU recommends that the initial letters of the names of *individual* astronomical objects be capitalized (e.g., "Earth is a planet in the Solar System"). Also, 'crater' is not capitalized: "Mie crater occurs in northeastern Utopia Planitia, north of Elysium Mons and Albor and Hecates Tholi." Informal terrain terms (e.g., 'Utopia basin' and 'dark lava plains') should not be capitalized and non-IAU-approved proper names should not be introduced. If a feature needs a name or name redefinition, the USGS Nomenclature Specialist can assist with a name proposal. Nomenclature needs can be addressed at any time over the course of mapping, but keep in mind that it generally takes one to two months for a name to be approved. Informal names should be identified clearly as such (e.g., 'the feature dubbed Home Plate…'). Formal names proposed to the IAU should not be used in maps or publications until the approval process is complete. Name proposals should be based on the need to single out for identification as-yet unnamed features in the map area (a need for names for use in journal articles may also qualify). Consult with the USGS Map Coordinator and Nomenclature Specialist when nomenclature issues arise.

4) Geologic sections: A limited number of geologic sections can be shown on the map. These must be drafted in ArcGIS® or Illustrator®. Unit colors and symbols and other symbology and nomenclature should be identical to those on the map. The sections should be at the same horizontal scale as the map, and the amount of vertical exaggeration should be indicated and minimized.

5) Map symbol legend: The legend is a chart on the map sheet that includes all line, point, and stipple symbols, with a feature type name and brief explanation (see recently published maps for examples). Where possible, the features should follow official, published USGS cartographic symbols (see FGDC web page as well as examples recently published in planetary geologic maps). The Production Cartographer will assist with converting symbols into final forms when necessary (e.g., when converting from GIS format to Illustrator®). See Tanaka and others (in press) for a discussion of types of tectonic structures found on particular planetary bodies.

6) Unit legend: The unit legend is a list of map units organized by the unit groupings as illustrated graphically in the CMU/SMU. The units include a box showing the unit color (perhaps overlying the base) and are ordered from youngest to oldest exactly as in the Description of Map Units (DMU; see Tanaka and others, 2005). The only text shown is the unit name (this is a new policy); all unit information is included in the DMU table. However, if the DMU can be included on the map sheet, the unit legend will not be necessary, and colored unit boxes will be added to the DMU.

7) <u>Selected figures, tables, and text</u>: During the map sheet layout construction phase, the USGS Production Cartographer may determine that there is room for additional material on the map sheet, and he/she will notify the author. The author then selects appropriate figures and tables from already submitted material that will fit. For smaller maps with brief text, all the material may fit on the map sheet (e.g., Price, 1998).

8) <u>Map envelope</u>: The map sheet (sometimes accompanied by a pamphlet with descriptive text) is contained within an envelope. In addition to standard publication citation information, the envelope may include an index map showing the map region typically on a hemispherical view of the planet. Digital data generally will be provided on-line only, as inclusion of a DVD in the map envelope is cost prohibitive.

b. *Text components*. Text will appear in a pamphlet or, when room is available, on the map sheet. Note that unit and feature descriptions are to be put into tables (i.e., delimited text files or other GIS compatible formats), which will encourage concise presentation and easier conversion to metadata for GIS maps.

1) <u>Introduction and background</u>: This section of the map text introduces the map area, including its geography and general geologic setting. It also acknowledges previous work for the map area, particularly any published geologic maps. However, it should not expound on existing scientific controversies. The rationale and purpose of the map are also described here. If the description of geography is extensive, a separate section devoted to it may be provided.

2) <u>Data</u>: Data sets should be described that were used to construct the map base and that were needed to identify and discriminate elements of map units and features critical to the mapping. Additional data sets that were consulted should also be mentioned, along with how they benefitted the mapping (or not). Relevant parameters and descriptions that affect mapping-related understandings should be stated, including what particular subsets of data were particularly useful for mapping; examples of such include pixel or other spatial resolution, solar incidence angle, solar longitude, wavelength bands, night vs. day time acquisition of thermal data, look-direction for synthetic aperture radar data, etc. Many of the most useful data sets for planetary mapping are available from the USGS PIGWAD and Map-a-Planet web sites. Where appropriate, key data sets may be shown in supplemental figures or as GIS layers as digital products. Also, data measurements applicable to the mapping might be shown in tables (e.g., morphometric measurements of landforms, radar properties of map units, etc.).

3) <u>Mapping methods</u>: A variety of techniques can be employed in showing unit names, groupings, symbols, colors, and contact and feature types. The actual methods used should be clearly described and consistently applied.

   a) *Unit names:* Popular approaches to unit naming include morphologic type (e.g., 'corona material', 'crater material'), geographic names ('Utopia Planitia material'), relative age/stratigraphic position ('lower/older crater material') and combinations thereof. Closely-related units (e.g., units in a sequence or morphologic variations of otherwise similar units) may be mapped as members (e.g., 'lower member of the Utopia Planitia material') or units having names showing their close association with other units ('Utopia Planitia 1 unit, Utopia Planitia 2 unit…').

   b) *Unit groups*: Units commonly are grouped by their geographic occurrence (e.g., 'highland materials') or morphologic type (e.g., 'lobate materials'). Capitalize only

proper nouns in unit and group names (e.g., 'Alba Patera Formation', 'Utopia basin unit', 'western volcanic assemblage').

c) *Unit symbols:* These can indicate chronostratigraphic age (e.g., 'A' for 'Amazonian'), unit group (e.g., 'p' for 'plains materials'), specific unit designations (including morphology, albedo/reflectivity, and associated geographic feature name), and unit member (commonly as subscripts; may include numbered sequences, as in 'member 1', 'member 2'…). Small capital letters have been used for unit groupings (e.g., 'E' for 'Elysium province'). Also, capital letters have been used for geographic names on Venus (e.g., 'fG' for 'Gula flow material'). On the geologic map, some symbols may be queried to show that the unit assignment is highly uncertain.

d) *Unit colors:* Unit color hues may be applied according to suitable precedents, or they may reflect the group they are in (e.g., warm colors for volcanic materials, cool colors for sedimentary rocks, yellows for crater materials, browns for ancient highland materials), or their relative age using a color spectrum for scale (e.g., Tanaka and others, 2005). Also, color saturation can reflect general areal extent of unit outcrops (low saturation for extensive units and high saturation for small units), which assists in finding smaller units. Colors must follow USGS publication guidelines, which ensure that they will print well. Generally, colors should not be changed after submission to PSC.

e) *Contact types:* The quality of contacts varies considerably on most maps. Definitions for contact types are not precisely expressed in most geologic maps, including terrestrial ones. Thus, contact types should be used as consistently as possible for a given map and they should also be defined (e.g., Tanaka and others, 2005). For example, (1) a 'certain' contact may indicate that the contact is confidently located; (2) an 'approximate' contact indicates that the confidence is not well defined (perhaps due to data quality or the surface expression of the juxtaposed units being unclear); (3) a 'buried' contact indicates that surficial material buries the contact but morphologically the contact is still traceable, although subdued; (4) a 'gradational' contact means that the contact is broadly transitional at map scale (which may reflect a gradually thinning, overlapping unit or a unit margin expressed by gradually thinning out of numerous outcrops too small to map, as in the margin of a dune field or of a field of relict knobs); and (5) an in 'inferred' contact, which may be used to delineate map units where the validity of the map unit or distinction between the units is hypothetical (e.g., the contact between the Vastitas Borealis interior and marginal units in Tanaka and others (2005) was drawn as inferred, because the marginal unit may be or may not be the same material as the interior unit).

f) *Feature types:* Mapped geologic features involving line and point symbols and stipple patterns are listed in the map symbol legend. Also, the feature table (see below) provides a format to systematically describe the features and their geologic relationships and interpretations.

g) *Drafting parameters:* Note minimum sizes of outcrops and linear features mapped, as well as the size range of features mapped with point symbols. For GIS maps, note the vertex spacing, digitizing scale, line smoothing methods, and any other important digital controls and processing applied.

4) <u>Age determinations</u>: Techniques and reliability of relative and absolute-age determinations for map units should be discussed, as they vary widely according to data quality and preservation and exposure state of key features. These include superposition and cross-cutting relations and crater densities. For quantitative approaches, error analysis should be included. As absolute-age models are based both on cratering theory, lunar sample dating, and empirical data on bolide populations, they are subject to high uncertainty. Appropriate references should be used throughout. Where possible, crater statistics can be summarized in the unit stratigraphic relations table described below.

5) <u>Geologic history</u>: A summary of the geologic history of a map region serves to provide a context for the entire geologic map and is encouraged. The synthesis is intended to be a brief yet informative review of unit development, tectonic deformation, and erosional and other modifications of the surface and shallow subsurface, with first-order interpretations on geologic and climate process histories as appropriate. However, lengthy considerations of previous and new hypotheses and other interpretive discussions that go beyond immediate mapping results and implications are to be left out.

6) <u>References</u>: The list of references and reference citations in the text follows USGS style guidelines; see published maps and this handbook for examples. Note that for more than 5 authors in a reference, only the first 3 are listed and "and x others" substitutes the number of unlisted authors for their names (see reference for Tanaka and others, 1994). Also, note formats for commonly used conference publications in the reference list below, as follows: *American Geophysical Union meeting abstract*: Banerdt, 2000; *Lunar and Planetary Science Conference abstract*: Skinner and Tanaka, 2003; *NASA Technical Memorandum abstract*: Grant, 1987; *edited NASA Special Publication*: Howard and others, 1988; *book chapter*: Wilhelms, 1990; *web-posted geologic map*: Young and Hansen, 2003.

7) <u>DMU table</u>: To simplify map texts, the Description of Map Units (DMU) table now forms a concise description of the map units, their stratigraphic relations, interpretation, and other pertinent information (previously, most planetary geologic maps provided a separate, stratigraphic narrative resulting in redundant information in the two sections). The DMU table will consist of four columns of information for each unit:

   a) *Unit symbol and name*

   b) *Definition:* Defining, primary characteristics essential to identifying and delineating each map unit from all others. In most cases, 2 to 5 characteristics define a unit, including aspects such as morphology/texture, albedo/reflectivity/spectral character, stratigraphic position or relative age, relative elevation, regional occurrence, and source feature. Where not obvious, mention the critical data sets. Type localities are optional and should be placed at the end of the definition.

   c) *Additional characteristics:* Brief discussion of additional aspects such as relation to units in previous and adjacent maps, local anomalies in unit character, and prominent secondary features (that may obscure or be partly controlled by primary features).

   d) *Interpretation:* Interpreted unit origin focusing mainly on origin of primary features and stratigraphic relationships; secondary features may also be discussed as they relate to the unit (i.e., fracture systems related to contraction, compositional information relating to surface alteration, etc.); and model crater absolute age (optional). As maps are meant to be enduring products, the interpretations should be inclusive of all reasonably possible alternatives, and wording should reflect the

8) <u>Unit stratigraphic relations table</u>: For each unit, show total areal extent in map area and relative-age relations (younger, older, similar in age, or younger and older) for every adjacent unit. Where crater density data are available, show helpful crater density values, including standard deviations. Additional columns can be used for assigned chronologic units and model crater absolute ages. Use footnotes to explain abbreviations used and other important details.

9) <u>Feature table(s)</u>: Additional tables(s) can be added as needed to describe the characteristics, relationships, and interpretation of other mapped features, such as tectonic structures, volcanic features, erosional and modificational features, surficial materials, and impact craters.

10) <u>Additional tables</u>: Other useful map information can often be summarized in a table for easier reference and comparisons, such as quantitative aspects of map units, their appearance in specific image data sets, etc.

11) <u>Figures</u>: Figures typically will not be included in the pamphlet. See digital data and map sheet components sections for formatting and possible placement.

12) <u>Digital supplement table</u>: All materials appearing in a digital supplement should be listed in a summarized fashion, such as data and mapping layers, measurements and statistics, and figures.

c. *Digital data products*. Authors are encouraged to make use of digital repositories for useful ancillary data products and figures. When in GIS form, the products are more accessible to researchers via digital tools and methods. Map authors should follow all guidelines, so that modifications using the original digital files by the USGS Production Cartographer and perhaps other specialists will be minimal in order to meet publication standards.

1) <u>Supplemental figures</u>: These may include, for example, a few reduced-scale images of the map region showing key data sets, distributions of key features, contact relationships, and geologic cross sections. However, additional, digital-only figures can be used generously to show unit characteristics, superposition relations, crater size-frequency distributions, and secondary features as desired. Images, image mosaics, and thematic maps should include in the caption or on the figure as appropriate the data source, type, and resolution (e.g., 'THEMIS daytime infrared mosaic at 100 m/pixel'), solar/incoming energy incidence angle and azimuth, north direction, scale bar (or image width), and latitude/longitude grid. Figures should be prepared at intended publication size with consistent label font types and sizes.

2) <u>GIS layers</u>: For GIS maps, authors can construct raster and vector data layers that are georegistered to map bases as digital-only supplements. These can be used to effectively show ancillary data sets and detailed feature mapping.

3) <u>GIS maps</u>: USGS GIS specialists will convert map files and supplemental figures and GIS layers as needed to conform to USGS geodatabase and FGDC metadata standards. GIS data supplements will be served via the web.

4) <u>On-line map</u>: The map, text, and supplemental figures will be converted to pdf format and made available for download via a USGS server and web page by the USGS PSC. GIS products, if available, will also be included for download.

5. REFERENCES

Banerdt, W.B., 2000, Surface drainage patterns on Mars from MOLA topography: Eos, Transactions of the American Geophysical Union, fall meeting supplement, v. 81, no. 48, Abstract #P52C–04.

Grant, J.A., 1987, The geomorphic evolution of eastern Margaritifer Sinus, Mars, *in* Advances in planetary geology: Washington, D.C., National Aeronautics and Space Administration Technical Memorandum 89871, p. 1–268.

Hackman, R.J., 1962, Geologic map and sections of the Kepler region of the Moon: U.S. Geological Survey Miscellaneous Geologic Investigations I-355 (LAC-57), scale 1:1,000,000.

Hansen, V.L., 2000, Geologic mapping of tectonic planets: Earth and Planetary Science Letters, v. 176, p. 527-542.

Hare, T.M., Kirk, R.L., Skinner, J.A., Jr., and Tanaka, K.L., 2009, Chapter 60: Extraterrestrial GIS, *in* Madden, Marguerite, ed., Manual of Geographic Information Systems: Bethesda, The American Society for Photogrammetry and Remote Sensing, p. 1199-1219.

Howard, A.D., Kochel, R.C., and Holt, H.E., eds., 1988, Sapping features of the Colorado Plateau—A comparative planetary geology field guide: Washington, D.C., National Aeronautics and Space Administration Special Publication, NASA SP-491, 108 p.

Price, K.H., 1998, Geologic map of the Dao, Harmakhis, and Reull Valles region of Mars: U.S. Geological Survey Geologic Investigations Map I-2557, scale 1:1,000,000.

Shevchenko, V., El-Baz, F., Gaddis, L., and 5 others, 2009, The IAU/WGSPN Lunar Task Group and the status of lunar nomenclature [abs.], *in* Lunar and Planetary Science Conference XV: Houston, Tex., Lunar and Planetary Science Institute, Abstract #2016, [CD-ROM].

Skinner, J.A., Jr., and Tanaka, K.L., 2003, How should planetary map units be defined? [abs.], *in* Lunar and Planetary Science Conference XXXIV: Houston, Tex., Lunar and Planetary Science Institute, Abstract #2100, [CD-ROM].

Tanaka, K.L., Moore, H.J., Schaber, G.G., and 9 others, 1994, The Venus geologic mappers' handbook: U.S. Geological Survey Open-File Report 94-438, 66 pp.

Tanaka, K.L., Skinner, J.A., Jr., and Hare, T.M., 2005, Geologic map of the northern plains of Mars: U.S. Geological Survey Science Investigations Map 2888, scale 1:15,000,000.

Tanaka, K.L., Anderson, R., Dohm, J.M., and 5 others, in press, Planetary structural mapping, *in* Watters, T., and Schultz, R., eds., Planetary Tectonics: New York, Cambridge University Press.

Varnes, D.J., 1974, The logic of geological maps, with reference to their interpretation and use for engineering purposes: U.S. Geological Survey Professional Paper 837, 48 pp.

Young, D.A., and Hansen, V.L., 2003, Geologic map of the Rusalka Planitia quadrangle (V–25), Venus: U.S. Geological Survey Geologic Investigations Series, I–2783, scale 1:5,000,000 [http://pubs.usgs.gov/imap/i2783/].

Wilhelms, D.E., 1972, Geologic mapping of the second planet: U.S. Geological Survey Interagency Report, Astrogeology, v. 55, 36 pp.

Wilhelms, D.E., 1990, Geologic mapping, *in* Greeley, R, and Batson, R.M., eds., Planetary Mapping: New York, Cambridge University Press, p. 208-260.

6. USEFUL WEB PAGES

FGDC (Federal Geographic Data Committee) Digital Cartographic Standard for Geologic Map Symbolization: http://ngmdb.usgs.gov/fgdc_gds/geolsymstd.php
IAU Gazetteer of Planetary Nomenclature home page: http://planetarynames.wr.usgs.gov/
IAU Gazetteer of Planetary Nomenclature descriptor terms: http://planetarynames.wr.usgs.gov/jsp/append5.jsp
IAU Gazetteer of Planetary Nomenclature feature name request form: http://planetarynames.wr.usgs.gov/jsp/request.jsp
NASA MEPAG calendar: http://mepag.jpl.nasa.gov/calendar/index.html
NASA research opportunities: http://nspires.nasaprs.com
USGS Planetary Geologic Mapping: http://astrogeology.usgs.gov/Projects/PlanetaryMapping/
USGS Planetary Interactive GIS on-the-Web Analyzable Database (PIGWAD): http://webgis.wr.usgs.gov/
USGS Map-a-Planet: http://www.mapaplanet.org/
USGS PSC author submission checklist for planetary maps: http://astrogeology.usgs.gov/Projects/PlanetaryMapping/guidelines/PSC_author_checklist_7-20-09.pdf
USGS Astrogeology manuscripts to PSC submission process: http://astrogeology.usgs.gov/Projects/PlanetaryMapping/guidelines/AstroSubmitProcess_june2009.pdf
USGS tips and information for preparation of astrogeology maps: http://astrogeology.usgs.gov/Projects/PlanetaryMapping/guidelines/preparationTips.pdf
USGS instructions on building polygons in Illustrator: http://astrogeology.usgs.gov/Projects/PlanetaryMapping/guidelines/layersexample_small.pdf

7. PLANETARY GEOLOGIC MAPPING SUPPORT PERSONNEL

Position/Function	Name	Email	Institution
Map Coordinator	Ken Tanaka	ktanaka@usgs.gov	USGS ASC
GIS Data Specialist	Trent Hare	thare@usgs.gov	USGS ASC
GIS Project Specialist	Jim Skinner	jskinner@usgs.gov	USGS ASC
Map base Specialist	Bob Sucharski	bsucharski@usgs.gov	USGS ASC
Nomenclature Specialist	Jen Blue	jblue@usgs.gov	USGS ASC
PGM Administrative Specialist	Jen Blue	jblue@usgs.gov	USGS ASC
Regional Planetary Image Facility Director	Justin Hagerty	jhagerty@usgs.gov	USGS ASC
Regional Planetary Image Facility Manager	David Portree	dportree@usgs.gov	USGS ASC
Digital Map Editor	Jan Zigler	jzigler@usgs.gov	USGS PSC
Production Cartographer	Darlene Ryan	dryan@usgs.gov	USGS PSC
Map Submission Editor	Carolyn Donlin	cdonlin@usgs.gov	USGS PSC
GEMS Chair	Leslie Bleamaster	lbleamas@psi.edu	NASA PGG
Discipline Scientist	Michael Kelley	Michael.S.Kelley@nasa.gov	NASA PGG

8. ABBREVIATIONS

ASC	Astrogeology Science Center (part of USGS)
CMU	Correlation of Map Units
DMU	Description of Map Units
FGDC	Federal Geographic Data Committee
GEMS	Geologic Mapping Subcommittee (of PCGMWG)
GIS	geographic information system
GPO	Government Printing Office
IAU	International Astronomical Union
MC	Map Coordinator
NASA	National Aeronautics and Space Administration
PCGMWG	Planetary Cartography and Geologic Mapping Working Group (part of PGG)
PEN	Planetary Exploration Newsletter
PGG	Planetary Geology and Geophysics Program
PGM	planetary geologic mapping
PIGWAD	Planetary Interactive GIS on-the-Web Analytical Database
PSC	Publications Services Center
SMU	Sequence of Map Units
USGS	U.S. Geological Survey

Figure 1 – GIS MAPPING TEMPLATE PREPARATION

Map Funded → USGS notified → Special need map?
- YES → Needs Coordinated → Map Control Document
- NO → Map Control Document

Map Control Document → GIS Production ↔ Basemap Production → Build GIS project → Internal Quality Check → Quality OK?
- NO → GIS Production
- YES → Compile Project Components → Backup Project / Burn project to deliverable media → Mail project media to author → Author receives

Legend:
- NASA Discipline Scientist
- USGS ASC Map Coordinator
- USGS ASC GIS Specialists
- USGS ASC Map Base Specialist
- USGS ASC Nomenclature Specialist
- USGS PSC Map Editor
- USGS PSC Production Cartographer
- Technical Map Reviewers
- Government Printing Office
- Map Author

17

Figure 2 – SUBMISSION AND TECHNICAL REVIEW
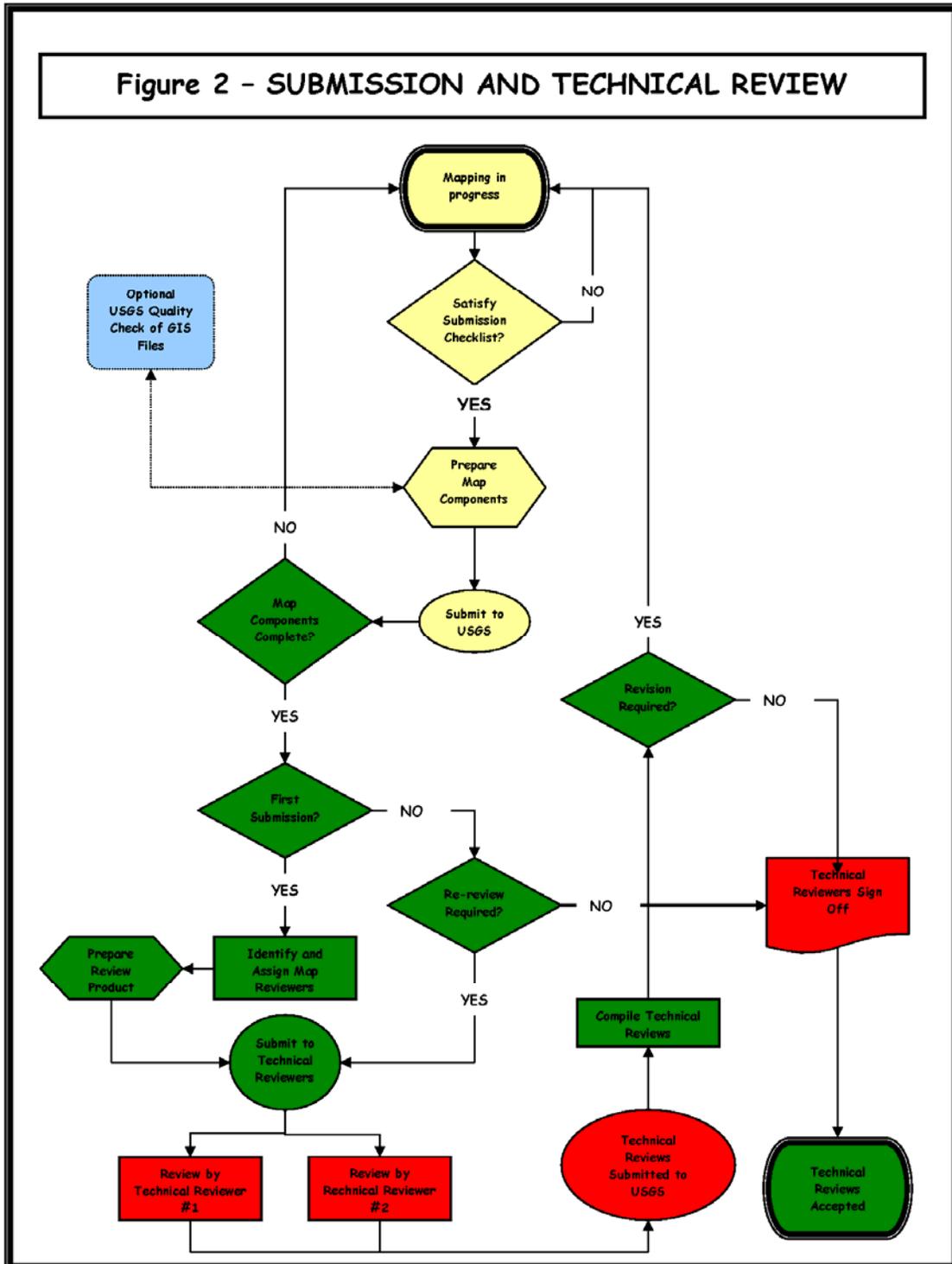
Figure 3 – USGS REVIEW AND PRODUCTION
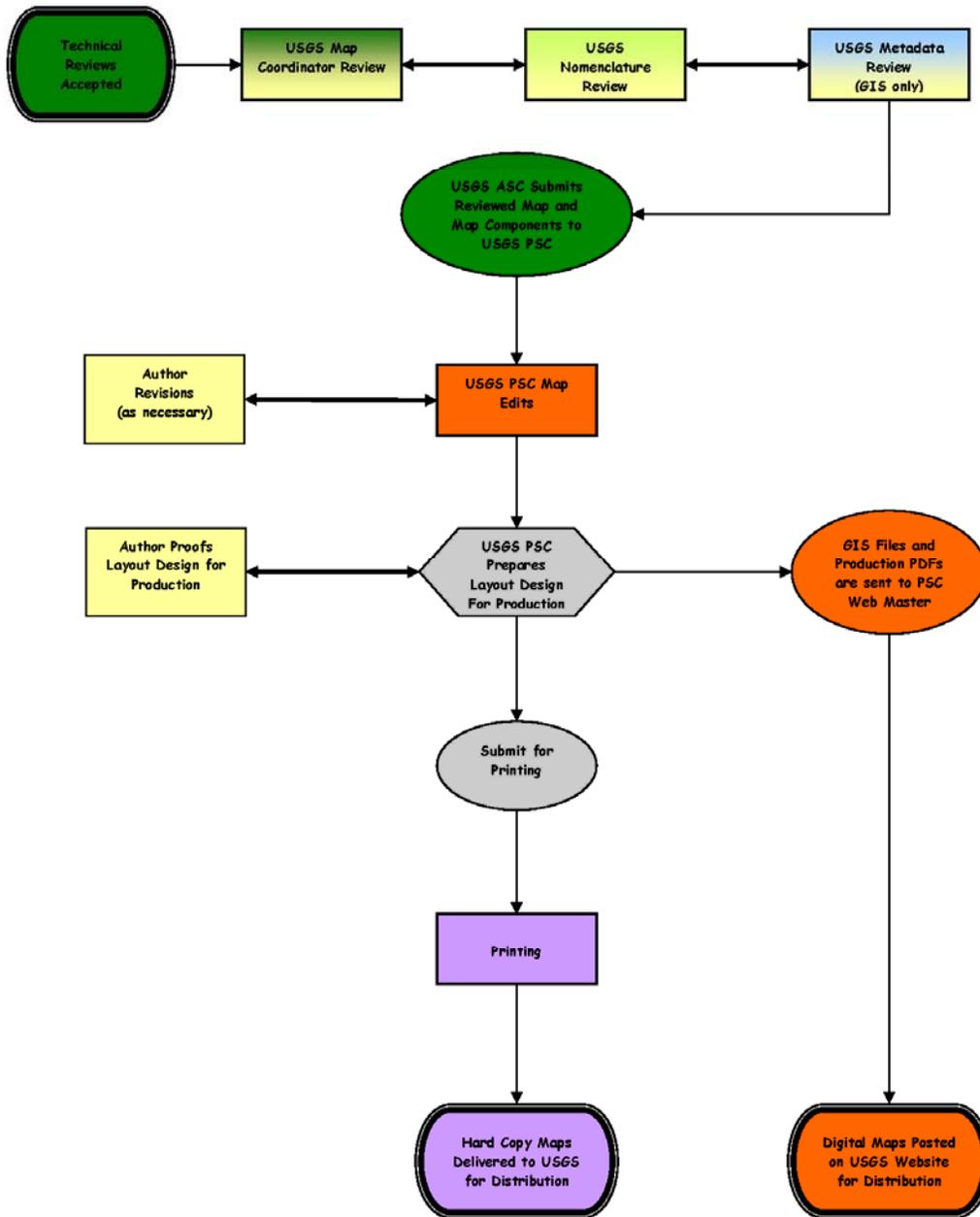
Figure 4 - FLOWCHART SYMBOL DEFINITIONS

Symbol	Symbol Name	Symbol Description and Example Activity
	Terminator	Terminators show the start and stop points in a process flow. *A proposed map is accepted for funding.*
	Process	A process or action step, perhaps comprised of multiple segmented actions. *Layout and proofing of final map.*
	Alternate Process	A process or action step that is an alternate (or option) to normal process flow. *Preparation of non-standard map base.*
	Decision	Indicates a critical question or branch in the process flow. *Does the submitted map adhere to submission requirements?*
	Preparation	Any step that is substantially comprised of preparation and/or collation of digital and/or hard copy product. *Creation of map base.*
	Manual Operation	Any step that is substantially comprised of manual (non-automated) input. *Map reviews.*
	Document	Any process flow step that results in the creation of a critical document. *Map Control Document.*
	Multi-document	Any process flow step that results in the creation of a critical package of documents. *Prepare Review Package.*
	Copy to digital media	Any process flow step that results in the creation of (transitory) digital copy. *Copy to DVD for review.*
	Back-up	Any process flow step that results in the creation of permanent digital copy. *Copy to map base to USGS hard-drive.*
	Shipping/Delivery	Denotes process step comprised of packaging, shipping, or delivery. *Submit map project to USGS.*

Form 9-1325 (revised, August 2006) USGS	**INFORMATION PRODUCT REVIEW AND APPROVAL SHEET**	**SCIENCE CENTER** Yucca Mountain Project Branch	**INFORMATION PRODUCT TRACKING NO.** IP-

AUTHOR(S): (last name first; show first name and(or) initials as shown in manuscript)

TEMPLATE! SAVE AS: your document filename_RAS
in X: Publications/From Authors folder (write access granted)

TITLE:

SCIENCE CENTER CONTACT:
(name, address, telephone, fax, email)
Pamela B. Daddow
U.S. Geological Survey
Box 25046 MS 421 DFC Building 53
Denver, Colorado 80225
303-236-5050, ext. 249 Fax 303-236-5047
pbdaddow@usgs.gov

FORM OF PUBLICATION

USGS series
- [ ] Administrative Report
- [ ] Circular
- [ ] Data Series
- [ ] Fact Sheet
- [ ] General Information Product
- [ ] Open-File Report
- [ ] Professional Paper
- [ ] Scientific Investigations Map
- [ ] Scientific Investigations Report
- [ ] Techniques and Methods

- [ ] Outside information product
- [ ] Edit requested
- [ ] No edit requested
- [ ] Abstract

PUBLISHER, JOURNAL, OR MEETING:

Format
- [ ] Print
- [ ] CD-ROM
- [ ] WWW
- [ ] Video
- [ ] Print on Demand
- [ ] Other

Check all of above that apply

TOTAL PAGES (including title page and all page-size figures and tables)
_____

_____ **TABLES COVERING** _____ **PAGES**

NUMBER OF ILLUSTRATIONS:

Color	B&W	
_____	_____	Line drawings
_____	_____	Photographs
_____	_____	Plates

IF PART OF A MULTICHAPTER USGS PUBLICATION:

Total number of chapters [ ] To be published [ ] Together [ ] Separately

DEADLINE:

ARE GEOLOGIC NAMES USED? IF YES, REVIEW REQUIRED. Yes [ ] No [ ]

SUPERSEDES OPEN-FILE REPORT? No [ ]
Yes, number: _____

REMARKS: (with initials, add additional pages if needed)

PUBLICATION CONTENTS
- [ ] New interpretive
- [ ] Previously approved interpretive
- [ ] Noninterpretive

NAME, TITLE, AFFILIATION	DATE IN	DATE OUT (indicate hours spent)	Author Submission	Supervisor Approval	Peer Review	Technical Specialist Review	Office of Communications Review	Science Center Approval	Editorial Review	PSC Approval	Bureau Approval	SIGNATURE (or attach e-mail)

CHECK PROCESSING STEP WITH "X"

CONTINUE ON ADDITIONAL FORMS IF NECESSARY

Figure 5: USGS Information Product Review and Approval Sheet.