GEOLOGY OF THE TERRA CIMMERIA-UTOPIA PLANITIA HIGHLAND LOWLAND TRANSITIONAL ZONE: FINAL TECHNICAL APPROACH AND SCIENTIFIC RESULTS. J. A. Skinner, Jr. and K. L. Tanaka, Astrogeology Science Center, U. S. Geological Survey, 2255 N. Gemini Drive, Flagstaff, AZ 86001 (jskinner@usgs.gov).

Introduction: The southern Utopia highland-lowland transitional zone extends from northern Terra Cimmeria to southern Utopia Planitia and contains broad, bench-like platforms with depressions, pitted cones, tholi, and lobate flows [1-2]. The locally-occurring geologic units and landforms contrast other transitional regions and record a spatially partitioned geologic history [2-5]. We systematically delineated and described the geologic units and landforms of the southern Utopia-Cimmeria highland-lowland transitional zone for the production of a 1:1,000,000-scale geologic map (MTMs 10237, 15237, 20237, 10242, 15242, 20242, 10247, 15247, and 20247). Herein, we present technical and scientific results of this mapping project.

Technical Approach: Below are the tactics and strategies that we employed during construction and presentation of this geologic map.

Mapping Methods. Unit delineation and description was based primarily on a USGS-produced THEMIS daytime IR mosaic (100 m/px). Versions of the map base-derived contacts and units were refined through comparison with MOLA-derived products as well as the full range of THEMIS VIS, CTX, MOC, and HiRISE images via web-linked image footprints. This iterative approach provided an important step in refining the location and description of geologic units as well as their lateral spatial and temporal relationships. Despite the use of supplemental data sets, the overall fidelity of the linework was held to those required by map scale (vertex spacing of 250 meters).

Unit Names and Symbols. We generally adhere to the recommendations outlined in the 2009 Geologic Mapping Handbook [6]. We developed unit names that reflect spatial occurrence within three physiographic provinces (Utopia, Nepenthes, and Cimmeria) as a means to avoid the stratigraphic inspecificity of using morphology as primary unit descriptors [7]. Unit symbols identify (1) the chronologic period (**AH**=Amazonian/Hesperian period), (2) the physiographic province (**N**=Nepenthes province), (3) the geographic region (**np**=Nepenthes Planum region), and (4) the interpreted stratigraphic order ($_1$=the first of two or more related geologic units). Therein, the geologic symbol "**AHNnp$_1$**" refers to the Amazonian/Hesperian-age, stratigraphically lowest unit that occurs within and (or) adjacent to Nepenthes Planum, which is located within the Nepenthes province of the highland-lowland transitional zone. Deviations from the scheme presented herein are likely to be incorporated during final editorial stages and (or) based on map reviews.

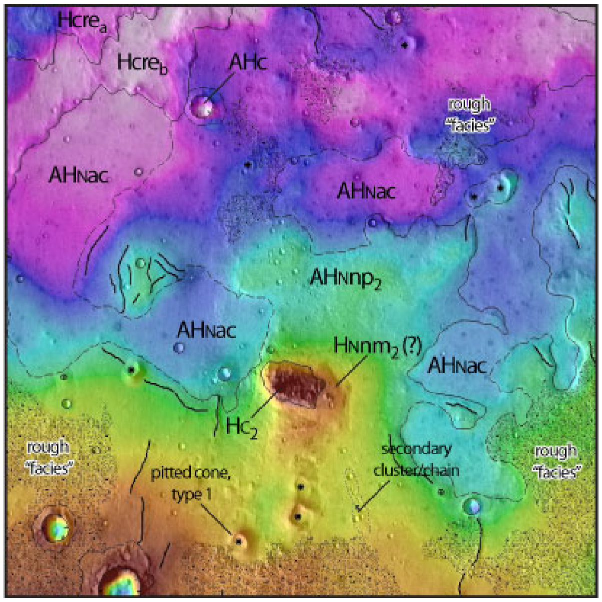

Figure 1. Excerpt of geologic map showing key units and geomorphic features. A "rough facies" surface of the Nepenthes Planum 2 unit (**AHNnp$_2$**) is shown by stipple pattern. Frame is approximately 100 km on each side and centered at 16.52°N, 111.87°E. MOLA DEM overlain on THEMIS base.

Geomorphic Features. We mapped a variety of geomorphic features, including two types of pitted cones, very small tholi, ridges (with terminal truncations), narrow ridges, flow fronts, radially grooved ejecta, shallow linear depressions, fractures, exposed crater rims, buried/degraded crater rims, scarps, raised rims of impact craters ($1 \leq D < 5$ km), secondary crater clusters, and rugged surfaces (applied only to a single geologic unit) (**Fig. 1**). Inclusion of these features provided an opportunity to give local geologic information without adding additional units. Symbols adhere to the Federal Geographic Data Committee recommendations for planetary features [*e.g.*, 6].

Stratigraphic relationships. Similar to past geologic maps, regional cross-cutting relationships show that geologic units become progressively younger at lower elevations [1,8]. Map-based temporal relationships were iteratively merged and refined with crater counts using all craters ≥1 km diameter. Crater statistics are ongoing and will be reported as cumulative size-frequency values for diameters of 1, 2, 5, and 16 kilometers.

Figures and Tables. In order to streamline the compilation, review, and production of planetary maps, recent guidelines emphasize the need for reducing (where possible) text and figures [6]. For critical geologic context, we included three figures that we recommend for inclusion on the map sheet (MOLA topography with nomenclature, annotated lowland boundary margin, and annotated pitted cones and mounds). Map area and surrounding regional context will be provided in the pamphlet figure. We are also in the process of compiling supplemental figures that we recommend be included in the digital product only (type locality panels for geologic units and landform features). Tables include a description of map units, stratigraphic relationships, and cumulative crater counts.

Science Results: The goal of this project was to clarify the geologic evolution of the Terra Cimmeria-Utopia Planitia highland-lowland transitional zone by identifying the geologic, structural, and stratigraphic relationships of surface materials. Below are key topical results regarding this evolution.

Lowland margin. The northern part of the map area is defined by the Utopia Planitia marginal unit (**AHUm**), which forms a planar to slightly undulating surface. The unit's margin consists of overlapping, south-facing lobes that commonly ramp onto (or terminate against) small knobs and plateaus that are tens of meters high [1-3]. Arcuate ridges and pitted cones dominate the surface of the unit within 50 km north of its margin. Ridges are nested and roughly parallel the marginal lobes. The lobe-forming margin is consistently traceable for >2800 kilometers [1-2]. We interpret the Utopia Planitia marginal unit as a Late Hesperian/Early Amazonian sedimentary sequence perhaps formed as mass flows or quiescent subaqueous (submarine?) deposition [3]. We interpret the characteristic "ridge and cone" morphology of the unit as landforms formed by the shoaling of a mass flow unit during emplacement or as secondary landforms related to seismically-induced liquefaction [3]. Alternatively, the features may represent moraine-like landforms related to de-volatilization and marginal retreat of the unit [9].

Lobate materials. We mapped three types of lobate materials within the central part of the map area [4]. The Nepenthes Mensae 3 unit (**AHNnp$_3$**) contains south-facing bright lobes that occur between knobs and plateaus of Nepenthes Mensae. Shadows and onlap relationships suggest these are <10 meters thick. The Nepenthes Planum 2 unit (**AHNnp$_2$**) contains rugged and smooth lobes that complexly overlap one another. Locally, these are >100 meters thick and emanate from pitted cones and tholi. The Amenthes Cavi unit (**AHNac**) consists of smooth materials that form within cavi floors and are sourced from narrow (<500-meter-wide) fractures that ring individual cavi. We interpret these units as Hesperian to Amazonian-age materials that were emplaced through various flow-related processes, likely associated with the mobilization and release of subsurface volatiles [3].

Crater facies. 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., 10]. 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 [11]. 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.

Summary: Geologic mapping has largely been completed and map components are currently undergoing technical and scientific edits. These efforts have resulted in advances that we hope will further the consistent production and use of geologic maps not only as tools for future research but also as high quality stand-alone scientific products. In an effort to streamline the geologic map text and minimize the more interpretive preferences of the map-based scientific study, we are scheduled to submit two peer reviewed articles in tandem with the geologic map. These will focus on the geologic and stratigraphic characteristics of (1) the Utopia Planitia marginal unit [3] and (2) the Nepenthes Planum Formation [2,4]. These articles will provide a formal mechanism for referencing key topical components of the geologic evolution without burdening the geologic map text [6]. We expect the map edits and supportive products to be completed by August 2010 and the map package to be submitted for formal review by October 2010.

References. [1] Tanaka et al. (2005), *USGS SIM 2888*, 1:15M scale. [2] Skinner et al. (2007), *Icarus*, 186, 41-59. [3] Skinner et al. (2008), *39th LPSC*, abstract #2418. [4] Skinner et al. (2009), *40th LPSC*, abstract #2459. [5] Skinner and Mazzini (2009), *Marine Pet. Geo.*, 26, 1866-1878. [6] Tanaka et al. (2009), Plan. Geo. Map. Handbook, *PGM 2009 abstract volume*. [7] Tanaka et al. (2010), *this volume*. [8] Scott et al. (1986-87), *USGS I-1802A-C*, 1:15M scale. [9] Grizzaffi and Schultz (1989), *Icarus*, 77, 358-381. [10] Schmidt et al. (1967), USGS I-515, 1:1M scale. [11] Melosh (1989), *Impact Cratering: A Geologic Process*, Oxford University Press.