MARS GEOLOGIC MAPPING: THE NEXT GENERATION. K. L. Tanaka¹*, James M. Dohm², Trent M. Hare¹, R. P. Irwin³, E. J. Kolb⁴, and J. A. Skinner, Jr.¹, ¹U.S. Geological Survey, Flagstaff, AZ (ktanaka@usgs.gov), ²U. Arizona, Tucson, AZ, ³Smithsonian Inst., Washington, DC, ⁴Arizona State U., Tempe, AZ

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TALK OUTLINE: FOCUS ON THE MAP

- WHAT ARE THE MAJOR ELEMENTS OF THE PRINTED MAP?
- HOW WERE MAP UNIT AGES DETERMINED?
- HOW DOES THIS NEW MAP COMPARE WITH PREVIOUS GLOBAL GEOLOGIC MAPS?
- WHAT ARE SOME OF THE NEW RESULTS?
- HOW CAN THE MAP BE UTILIZED?

For more information, see:

- conference abstract
- map sheet and pamphlet
- downloadable files at http://pubs.usgs.gov/sim/3292
MAP SYMBOLOGY

- 30 degree lat/long grid
- Landed spacecraft site
- IAU-approved geographic names
- Crater rims
- Internal contact
- Approximate contacts
- Certain contacts
- Linear features >100 km long
- Unit polygons >40 x 100 km
- Yardangs
- Unit label
- MOLA shaded relief base

Tanaka, 8th Mars Conference
**Unit groups defined by terrain type or origin**

**Color scheme similar to that used in Viking-based geologic map**

**Unit colors reflect group, origin, or extent**

**New unit group category:** Transition units

**Epoch crater-density boundaries according to Werner and Tanaka (2011)**

**Unit ages constrained to epoch boundaries**

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**CORRELATION OF MAP UNITS**

Cumulative crater-densities for epoch boundaries at 1, 5, or 16 km diameters are from Werner and Tanaka (2011), see table 1 for model absolute ages for the epoch boundaries. Map unit ages are resolved to nearest epoch. Included box edges indicate possible extended durations. The determinations rely on both stratigraphic relations as documented in the Description of Map Units and crater-size frequency distributions provided in tables 2, 3, and D1 and by other workers as referenced in the Geologic History section. See Age Determinations section of text for methodology discussion. Determination of ages from crater densities is complicated by the geologic history of the unit of interest, including size-dependent degradation and resurfacing, such that different crater diameter sizes (and the associated N(1), N(3), and N(16) values) may provide different age estimates for a given geologic unit. See tables 2 and D1 for examples of formation and resurfacing ages for some localities.

**PERIOD**

- **Lowland Units**
  - Impact Unit
  - Polar Units
  - Basin Units
  - Volcanic Units
  - Apron Units
  - Transition Units
  - Highland Units

**Epochs**

- **Noachian**
- **Hesperian**
- **Amazonian**

**Number of craters larger than 1, 3, and 16 km diameter per 1,000,000 km²**

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EXPLANATION OF MAP SYMBOLS

[For each feature type, typical morphologies and process origins are indicated. See the "Global Structure Digital Attribute Table" in the GIS database for additional information on preservation state (fresh, subdued, partially buried, and buried) and width (broad, >10 km; narrow, <10 km)]

Contact—Solid where certain, dashed where approximate, concealed, or gradational; internal contacts mark where superposition relations identify "y" (younger) and "o" (older) divisions

Wrinkle ridge—Ridge, sinuous, crenulated, tectonic contraction

Graben—Trough, linear or sinuous, en echelon; tectonic extension

Channel—Trough, sinuous, floor sloping downhill, dendritic branching or anastomosing; fluvial erosion

Scarp—Sinuous, crenulated or scalloped; erosional, also tectonic or volcanic

Lobate flow—Lobate flow axis and trend; volcanic flow

Crater rim—Circular ridge and (or) scarp; associated inner depression and outer apron; impact

Ridge—Simple form; erosional or volcanic

Spiral trough—Arcuate, deeper at lower elevations, asymmetrical in cross section, equator-facing steeper slope; ablation due to wind and insolation

Outflow channel—Long, wide, sinuous channel floors, often braided with bars and islands along the reach; catastrophic flooding, local collapse, and mass wasting

Yardangs—Parallel, narrow, linear to curvilinear ridges, some areas showing multiple orientations; eolian erosion

Pit-crater chain—Linear series of circular to semicircular, isolated to overlapping pits, typically associated with a trough, collapse associated with tectonic activity

Rille—Sinuous, steep-sided trough, narrows in down-slope direction, volcanic erosion and possible collapse

Caldera rim—Ovoid scarp, outlines single or multiple coalesced partial to fully enclosed depression(s); volcanic collapse, related to effusive and possibly explosive eruptions

Landing sites—Locations of landed spacecraft. Labels include Viking 1 (Viking 1 Lander), Viking 2 (Viking 2 Lander), Pathfinder (Mars Pathfinder-Sojourner), MER A (Mars Exploration Rover A—Spirit), MER B (Mars Exploration Rover B—Opportunity), PHX (Phoenix Lander), MSL (Mars Science Laboratory—Curiosity)
## DESCRIPTION OF MAP UNITS

[Note: Unit groups and labels are discussed in pamphlet. Unit definitions include morphologic character, infrared brightness or albedo (where diagnostic), nature of stratification (if observed), and typical unit thickness (where top and bottom of unit identified and assuming flat-lying materials; measured or estimated using MOLA elevation data). Additional characteristics include location, complete record of observed superposition relations with other map units (except with unit AHi, which displays complex age relations with other units), and other secondary and (or) local characteristics and associations including morphologies, spectrally based compositional information, and radar-sounding properties. See Geologic Summary in pamphlet for further discussion of map units, including references; tables 2 (locality numbers) and 3 and fig. 1 for crater-density data; and tables 6 and 7 for comparison with Viking-based, global mapping units.]

<table>
<thead>
<tr>
<th>UNIT LABEL</th>
<th>UNIT NAME AND DESCRIPTION (coordinates of center(s) of type area(s) and, where available, counting localities (fig. 1 and table 2))</th>
<th>ADDITIONAL CHARACTERISTICS</th>
<th>INTERPRETATION</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>LOWLAND UNITS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mAl</td>
<td><strong>Middle Amazonian lowland unit</strong>—Hummocky to undulating; grades into fields of knobs. Internally stratified. Tens of meters thick. (lat 51.43° N., long 118.45° E.)</td>
<td>Distributed within Vastitas Borealis and other northern plains; makes up the platforms of nearby pedestal-crater forms and perhaps whorled, low-relief ridge systems (thumbprint terrain, unmapped). Superposes units Av, AHv, eAb, lHl, lHt, Hpe, Hve, Hnt, eHt, INh, and mNh; underlies unit IApdr; relation with unit Apu unclear</td>
<td>Ice-rich loess. Periglacial modification formed thumbprint terrain</td>
</tr>
<tr>
<td>lHl</td>
<td><strong>Late Hesperian lowland unit</strong>—Planar to undulating; lobate and troughed marginal areas in places. Hundreds of meters to kilometers thick. (lat 21.40° N., long 118.20° E.; localities 1, 6, 10, 11)</td>
<td>Continuous across most of the northern plains. Embays units Iht, Hko, eHt, eHv, Hnt, INh, mNh, and mNh; superposed by units AHv, Av, eAb, Apu, mAl, lAv, and lApdr; temporal relation to units Hpe and Hpu unclear. Contains hundreds of superposed pedestal-crater forms, thumbprint terrain, topographically subdued wrinkle ridges, and narrow grabens northeast of Alba Mons</td>
<td>Fluvial/lacustrine/marine and colluvial sediments sourced from circum-lowland outflow channels and bounding highland terrains; likely intercalated with and underlain by lava and volcaniclastic rocks. Pervasively modified and obscured by periglacial, sedimentary diapirism, and particulate mantling</td>
</tr>
<tr>
<td>AHi</td>
<td><strong>Amazonian and Hesperian impact unit</strong>—Craters with rims and surrounding blankets; some include single to multi-lobed blanket forms, dense secondary crater chains, and (or) central peak or pit. Blanket thicknesses of meters to a few hundred meters. (lat 23.17° N., long 207.77° E.)</td>
<td>Global occurrence. Superposes Noachian units; other unit superposition relations diverse. High kilometer-scale surface roughness; crater floors may be smooth to rough</td>
<td>Upturned, ejected, and brecciated target rocks and sediments, with local areas of impact melt. Post-impact mass-wasting and fluvial-lacustrine and eolian infill of craters common</td>
</tr>
</tbody>
</table>
1. Type areas, image strips, and count areas selected

2. Crater database produced

3. Crater size-frequency distributions fitted to production function isochrones

4. Crater ages converted to Martian epochs (Table 1 in map pamphlet)

5. See also Platz et al. (2013)
GLOBAL CRATER DENSITIES

- Counts use global GIS crater database of Robbins and Hynek (2012)
- Automatic generation of \( N(1, 2, 5, 16) \) crater densities for Martian epoch fits (Tanaka, 1986; Werner and Tanaka, 2011)
- For outcrops with partly buried crater rims, superposed craters counted
MAP UNIT TIME-STRATIGRAPHIC ASSIGNMENTS

- Key map unit relationships
- Crater-count type localities
- N(1), N(5), N(16) data
- Published crater ages

Table 5. Basis for time-stratigraphic assignments for each map unit as shown in the Correlation of Map Units. —Continued

<table>
<thead>
<tr>
<th>Unit label</th>
<th>Key stratigraphic relations</th>
<th>Crater size-frequency data</th>
</tr>
</thead>
<tbody>
<tr>
<td>AHtu</td>
<td>&lt; Aa, Ave, IHv, eHv; ~ AHv; &gt; I Av</td>
<td>Localities 25, 27, and 30; N(5); Tanaka and others (2005); Kerber and Head (2010); Zimbelman and Scheidt (2012)</td>
</tr>
<tr>
<td>Htu</td>
<td>&lt; Nhu, Nve; ~ eHt, Hve; &gt; I Ht, Ht, Hto, AHtu</td>
<td>Localities 26 and 28; N(5); Kerber and Head (2010); Zimbelman and Scheidt (2012)</td>
</tr>
<tr>
<td>I Ht</td>
<td>&lt; e Ht, eHv, eHh; ~ AHv; &gt; Hto, IHl, AHtu</td>
<td>Localities 8 and 15; Tanaka and others (2005)</td>
</tr>
<tr>
<td>e Ht</td>
<td>&lt; l Nh; ~ eHv, Htu, Hnt; &gt; Ht, Hto, IHl, IHt, AHtu</td>
<td>Localities 2 and 16; Tanaka and others (2005)</td>
</tr>
<tr>
<td>Ht</td>
<td>&lt; eHt, eHh, eHv; ~ Hto; &gt; Htu, IHt</td>
<td>N(5)</td>
</tr>
<tr>
<td>Hto</td>
<td>&lt; AHv, IHt, eHh; ~ Ht; &gt; IHl</td>
<td>Locality 12; N(5); Rotto and Tanaka (1995); Tanaka (1997); Tanaka and others (2005); Chapman and others (2010)</td>
</tr>
<tr>
<td>Hnt</td>
<td>Noachian part: ~ eNh, mNh, l Nh. Hesperian part: &lt; l Nv; ~ eHt, eHh, Htu, Hve; &gt; eHv, IHt, IHl, AHtu</td>
<td>Locality 18; N(1), N(5), and N(16); Tanaka and others (2005)</td>
</tr>
</tbody>
</table>
## MARS GLOBAL MAPS: COMPARISONS

<table>
<thead>
<tr>
<th>Scott and Carr (1978)</th>
<th>Scott et al. (1986-87)</th>
<th>Tanaka et al. (2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mariner 9 images (1-2 km/pixel)</td>
<td>Viking Orbiter images (mostly 100-300 m/pixel)</td>
<td>MOLA DEM (460 m/pixel) THEMIS IR (100 m/pixel) CTX (5-6 m/pixel; limited use) MGS, ODY, MEX, MRO datasets consulted</td>
</tr>
<tr>
<td>Assembled from 30 1:5M geologic quadrangles</td>
<td>No larger-scale Viking-based mapping available</td>
<td>Consulted 22 local to regional Viking and post-Viking maps</td>
</tr>
<tr>
<td>24 units, 9 line features</td>
<td>90 units, 16 line and area symbols</td>
<td>44 units, 14 line features, landed spacecraft sites</td>
</tr>
<tr>
<td>Manual drafting</td>
<td>Manual drafting, GIS update</td>
<td>GIS drafting, attributing, editing, and data environment</td>
</tr>
<tr>
<td>- 3 chronostratigraphic periods</td>
<td>- 8 epochs with crater-density boundaries</td>
<td>- Each map unit name includes age</td>
</tr>
<tr>
<td>- No crater dating</td>
<td>- Limited crater dating of outcrops</td>
<td>- 48 type crater-count areas (D&gt;~100 m; Platz et al., 2013)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- All outcrops crater counted (D&gt;1 km; Robbins and Hynek (2012) database)</td>
</tr>
</tbody>
</table>

**Core mapping principles:** Consistency, simplicity, clarity, utility, communicability

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<table>
<thead>
<tr>
<th>Global map unit name, this map</th>
<th>Unit label</th>
<th>Area (10^6 km²)</th>
<th>Previously mapped Viking-based units (%) intersect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Hesperian transition unit</td>
<td>eHt</td>
<td>3.72</td>
<td>Hr (40), AHpe (11), Apk (10), Aa₁ (8), Aps (7), HNu (7), Npld (5)</td>
</tr>
<tr>
<td>Hesperian transition unit</td>
<td>Ht</td>
<td>0.91</td>
<td>Hcht (58), Hch (14), Npl₂ (7)</td>
</tr>
<tr>
<td>Hesperian transition outflow unit</td>
<td>Hto</td>
<td>1.28</td>
<td>Hch (33), Hchp (33), Aa₁ (19), Hr (12)</td>
</tr>
<tr>
<td>Hesperian and Noachian transition unit</td>
<td>HNt</td>
<td>2.81</td>
<td>HNu (48), Apk (13), Aa₁ (8), Npl₂ (5)</td>
</tr>
<tr>
<td>Hesperian and Noachian highland undivided unit</td>
<td>HNh</td>
<td>0.36</td>
<td>Npl₂ (47), Ah₅ (21), Nple (6), Hpl₃ (5)</td>
</tr>
<tr>
<td>Noachian highland undivided unit</td>
<td>Nhu</td>
<td>2.54</td>
<td>Hch (24), HNu (20), Hchp (14), Npl₁ (8), Npl₂ (5), Hr (5), Nf (5)</td>
</tr>
<tr>
<td>Early Hesperian highland unit</td>
<td>eHh</td>
<td>1.84</td>
<td>Hr (70), Hf (7), Npl₂ (6)</td>
</tr>
<tr>
<td>Late Noachian highland unit</td>
<td>LHh</td>
<td>8.78</td>
<td>Hr (29), Hpl₃ (16), Npl₂ (12), Npl₁ (10), Nplr (7), Npld (6)</td>
</tr>
<tr>
<td>Middle Noachian highland unit</td>
<td>mNh</td>
<td>30.41</td>
<td>Npl₁ (32), Npld (22), Npl₂ (14), Hr (8), Nplr (7)</td>
</tr>
<tr>
<td>Early Noachian highland unit</td>
<td>eNh</td>
<td>16.05</td>
<td>Npl₁ (36), Npld (30), Nplr (8), Npl₂ (5)</td>
</tr>
<tr>
<td>Noachian highland edifice unit</td>
<td>Nhe</td>
<td>0.21</td>
<td>Npl₁ (22), v (19), Nf (16), Nb (10), Nplh (7), Npl₂ (6), Hr (5)</td>
</tr>
<tr>
<td>Middle Noachian highland massif unit</td>
<td>mNhnm</td>
<td>1.86</td>
<td>Nplh (57), Hpl₉ (15), Npld (11), Npl₂ (6)</td>
</tr>
<tr>
<td>Early Noachian highland massif unit</td>
<td>eNhnm</td>
<td>1.95</td>
<td>Nh₁ (67), Nm (11), Npl₂ (11)</td>
</tr>
</tbody>
</table>

Differentiated by age and mix of primary and secondary geomorphic features

Early Noachian material not mapped

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TOP TEN NEW RESULTS: 1 & 5

① Mars is older! Early Noachian covers 12% (vs. 4%) and Early Hesperian 10% (vs. 16%) (Tanaka et al., 2014, PSS)

⑤ Well-preserved impact basins >150 km in diameter show a dramatically reduced rate of formation over time: >65 for Early Noachian, >15 for Middle Noachian, ~3 for Late Noachian, ~4 for Hesperian, and 2 for Early Amazonian.
MAP UTILITY

✧ AVAILABILITY

➢ Print (limited supply of flat copies for special requests; order from USGS Flagstaff RPIF)
➢ Digital files: http://pubs.usgs.gov/sim/3292/
➢ Google: https://maps.google.com/gallery (more to come)

✧ EDUCATION AND OUTREACH

➢ Overview of Mars geology
➢ Introduction to planetary mapping

✧ RESEARCH

➢ Geological and chronological context for local to regional studies
➢ Digital spatial format for spatial analyses using GIS tools

✧ MISSION SUPPORT

➢ Landing-site selection
➢ Targeting for orbital data collection
ENJOY THE NEW MAP!

QUESTIONS?

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