THE GEOLOGY OF MARS: WHAT THE NEW GLOBAL MAP SHOWS. K.L. Tanaka[1], J.M. Dohm[2], C.M. Fortezzo[1], R.P. Irwin, III[3], E.J. Kolb[4], J.A. Skinner, Jr.[1], T.M. Hare[1], T. Platz[5], G. Michael[5], and S. Robbins[6], [1]U.S. Geological Survey, Flagstaff, AZ, ktanaka@usgs.gov, [2]U. Arizona, Tucson, AZ.

Introduction: We are nearing the completion of a global geologic map of Mars at 1:20M scale that will represent the most thorough characterization of global stratigraphic units since the Viking-based 1:15M-scale maps. Here, we describe how post-Viking data sets and our comprehensive, digital, team-based mapping approach have resulted in more robust unit identification, stratigraphic analysis, and understanding of geologic materials and features planet-wide.

Data: The new mapping is primarily based on post-Viking topographic (the Mars Orbiter Laser Altimeter (MOLA) digital elevation model at 460 m/pixel spatial and ~1 m vertical resolution) and image (Thermal Emission Imaging System (THEMIS) infrared images at 100 m/pixel) data. The MOLA topographic data are critical for determining pathways of lavas, fluvial runoff, ice, and mass-wasting debris; for detecting tectonic deformation and exposed and buried impact structures; and for measuring thicknesses and volumes. Because Viking-based topography was largely inadequate for meaningful global assessments of this kind, this data set alone yields substantial refinements for geologic mapping. Although Viking visible range images were generally of similar to somewhat lower (100 to 300 m) resolution than that of THEMIS images, greater detail could be mapped using THEMIS. Additional image data sets (e.g., THEMIS visual range, Viking, High Resolution Stereo Camera, and Context Camera) as well as transparent overlay of image data onto MOLA topography were also employed for enhanced geologic perspectives, based largely on factors such as landform orientations, camera pointing, sun angle, atmospheric conditions, etc. [1].

Approach: Material units are discriminated mainly by relative age, as supported by stratigraphic relations and crater densities. Additional distinguishing criteria include geographic setting and primary geomorphic characteristics indicative of process origins. In addition, feature mapping assists with documenting geological and hydrological processes, geometries of tectonic deformation, and transport pathways.

The use of GIS software enables and facilitates scale-based methodologies of drafting, editing, and embedding ancillary information into the map, providing enhanced capabilities to the mappers.

Crater Counting: The effort put forth in dating units in this global map is unprecedented. First, more so than in the Viking geologic map [2], we focus on discriminating units based on their ages according to the Martian epoch system [3]. This results in more definitive and precise characterization of the surface chronology. Second, type areas are selected and crater counted down to ~100 m and fitted to the Neukum-Ivanov crater production function [4]. These data validate the stratigraphic ages tentatively assigned according to their geomorphic appearance, define the crater size ranges accumulated and preserved from each unit's formation, and characterize timing and amount of resurfacing produced by the unit and post-unit resurfacing. Third, a recent global crater database enables determination of crater densities ≥1 km for every outcrop [5]. The database is used to determine cumulative densities for crater diameters of 1, 2, 5, and 16 km as a simple way to assign stratigraphic epochs. The size-frequency distributions generally fit well with derived formulations (in some cases after removing buried craters and merging crater material to improve accuracy) [3, 6].

Age Assignments: The combined mapping and crater dating approach results in different kinds of age assignments. Some assignments correspond to single epochs (where the Noachian (N), Hesperian (H), and Amazonian (A) are divided into Early (e), Middle (m), and Late (l) episodes). Although these units have the best constrained ages, the crater counts are capable of providing only mean ages. As such, our epoch assignments apply to the majority of the exposed unit outcrops, though in many cases minor amounts of the units likely range in age beyond the assigned epoch and/or may include some amount of other units of similar or differing age. Other units have broader age constraints spanning two or more epochs. This results from units that developed discontinuously in time and space such that averaging is unavoidable at map scale. In addition, broader ages are applied to units that are comprised of co-mingled materials of disparate ages (e.g., knobs of N material surrounded by H or A plains).

Geologic Interpretation: Here, we summarize the major types of geologic terrains and processes as they affected the planet's surface in space and time.

Impact basins: Large impact basins formed in the eN, of which Hellas, Argyre, and Isidis preserve rugged massifs that form their rims and perhaps high-standing ejecta deposits. N basins and craters are degraded and variously infilled with slope debris, fluvial/lacustrine and eolian sediments, and volcanic flows throughout Martian history

Highland strata: Layering is evident in N materials virtually wherever they are eroded, including steep scarps of Valles Marineris and in fluvial and outflow terrains. The layers likely include mixtures of volcanic flows, fluvial/lacustrine and other types of sediments, and impact ejecta blankets. The eN outcrops generally have high local relief and are more extensive than previously recognized, particularly in higher-elevation regions--especially surrounding the Hellas, Argyre, and Isidis basins but are less common in lower-standing Arabia Terra. The eN highland materials include large scarps that represent structures formed by impact basins and early tectonics. Embaying much of the eN outcrops are mN and to a lesser extent lN and eH outcrops of progressively lower relief and crater density indicative of highland regolith development. Fluvial valleys are common in eN and mN outcrops, but lN and eH outcrops form planar, undissected deposits likely comprised of fluvial and aeolian sediments.

Volcanic edifices. Recognizable volcanic edifices date back to the N, perhaps as early as the eN, and their activity extends to the lA. The majority of N edifices occur peripheral to the southern part of Tharsis. Some 20 denuded N mountains south of 30° S. may be volcanic, but lava flows or caldera structures are not recognized on them--possibly due to water/ice denudation. All N edifices except Ceraunius Tholus, which is marginally Noachian, occur in the southern hemisphere. Circum-Hellas volcanic edifices appear to be lN in age, whereas more central shields and domes of Tharsis and Elysium are H to A, with Olympus Mons being the youngest (lA). Edifice ages largely indicate when the volcanoes went extinct and generally do not reflect when the volcanoes originated.

Volcanic flows. Volcanic flow morphologies are susceptible to obliteration by processes such as impact gardening, and the earliest recognizable flows on Mars are lN. Earlier flows likely exist but are difficult to identify. We mapped prominent flow directions based on the trends of lobate margins.

We differentiate where possible discrete outcrops of flow materials according to their mean crater densities, where stratigraphic relations and/or crater distributions indicate that most exposed and near-surface flows are of similar age. However, we felt compelled to map the majority of the Tharsis and Elysium rises as a broad mix of ages (AH) because of their high spatial variability in crater density but lack of mappable boundaries within the outcrops. This result is in contrast to previous global mapping that distinguished such boundaries [2]. Outside of these rises, extensive flows formed Malea (lN), Hesperia (eH), and Syrtis Major Plana (eH) on the margins of Hellas and Isidis basins.

We also mapped volcanic fields consisting of groups of low, relatively small vent features and their flows in Tharsis and Elysium of lH and lA ages. The lA fields are among the youngest recognized eruption sites on Mars.

Transition zone. We define the transition zone to include temporally and spatially intermediate areas between highlands and lowlands. This zone is typified by slopes that were modified by mass wasting, outflow and fluvial activity, and subsidence and collapse, mostly between the lN and lH but locally into the A. The transition zone includes the highland/lowland boundary, chaotic terrains north and east of Valles Marineris (including Margaritifer Terra) and higher-standing N materials between Elysium rise and Amazonis Planitia. In these areas, N material was eroded during the H to A, resulting in channels, debris aprons, landslides, and plains deposits. Between Gale crater and Olympus Mons, we remap the Medusae Fossae Formation [2] and delineate a younger (lH to A) unit from an older unit (eH), which are separated by a hiatus indicated by exhumed craters, wrinkle ridges, and inverted channels. In Valles Marineris, light-toned layered deposits infilled canyon floors during the lH, then landslides occurred along canyon walls in the A.

Lowland materials. The majority of the northern lowlands are covered mainly with sediments derived from outflow channels, mud volcanism, and degradation of the north polar plateau. While the lowlands were likely infilled throughout the N and H by volcanic rocks and sediment, the majority of the lowlands have a lH crater retention age. Pedestal-type craters and thumbprint terrains attest to continued regional to local plains activity during the A.

Polar regions. Resurfacing by icy materials as indicated by their albedo, volatility, and radar transparency has occurred in the polar regions since the H. Both regions have a field of vent-like features that may be volcanic or cryovolcanic eruptive centers. The youngest, lA polar deposits are finely layered and include local and perhaps regional truncation surfaces.

Tectonic features. Wrinkle ridges are the most common structure mappable at global scale. However, they appear more prominent in lN to eH materials, especially in volcanic flows and surrounding the Tharsis rise. Wrinkle ridge development was minor during the A. Grabens are common in N and H parts of the Tharsis rise, especially surrounding the Thaumasia plateau and Alba Mons and on Tempe Terra, as well as extending SW from the Tharsis rise.

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