RESURFACING OF THE NORTHERN PLAINS OF MARS BY SHALLOW SUBSURFACE, VOLATILE-DRIVEN ACTIVITY. K. L. Tanaka, J. A. Skinner, T. M. Hare, T. Joyal, and A. Wenker. U.S. Geological Survey, 2255 N. Gemini Dr., Flagstaff, AZ 86001, USA; ktanaka@usgs.gov.

Introduction: Geologic mapping of the northern plains of Mars, based on Mars Orbiter Laser Altimeter (MOLA) topography and Viking and Mars Orbiter Camera (MOC) images, reveals new insights into geologic and climatic events in this region during the Hesperian and Amazonian Periods. The region includes two major basins, Utopia and north polar, and is surrounded by highland cratered terrains and volcanic complexes (Tharsis and Elysium). Major erosional features indicate degradation of highland material and transport of clastic debris into the northern plains; in turn, the plains are marked by a variety of landforms indicating complex modification of the plains. Here, we focus on a revised stratigraphy for the older lowland units and new interpretations for structural and resurfacing histories that highlight the role of subsurface volatile activity, in contrast to scenarios dominated by surface water and ice.

Stratigraphy: We mapped the geology of the northern plains largely with the use of MOLA-based maps of elevation, slope, slope direction (aspect), and shaded relief. We also consulted Viking and MOC-context image mosaics and MOC narrow-angle images. The following stratigraphy (from oldest to youngest units) includes significant modifications to previous mapping [1-2].

The *knobby plateau unit* consists of knobs and mesas of highland rocks and intervening slope and plains materials. The unit forms much of the highland margin and underwent degradation starting at the end of the Noachian and extended into the Early Hesperian [1-3]. Along southern Utopia Planitia, the basal unit elevations are remarkably uniform (mostly within ~200 m). Along Arabia Terra and Utopia Planitia, the unit includes broad, confined depressions and low terraces. Interpretation: Highland rocks fractured and collapsed due to basal sapping of volatiles and mass-wasted debris.

The oldest northern plains unit, *boundary plains material*, occurs adjacent to older highland and plateau materials including the knobby plateau unit along the highland margin in Utopia, Chryse, Amazonis, and Arcadia Planitiae. The unit slopes gently away from the highland margin and appears relatively smooth at subkilometer scale but rougher at longer length scales. Locally, and particularly near its contact with highland material, irregular depressions and scarps many 10's of km across mark the unit, giving it a broadly hummocky appearance. The unit also includes local circular depressions kilometers to tens of kilometers across and mostly <200 m deep, having rims a few tens of meters high. Interpretation: Where the unit occurs adjacent to the knobby plateau unit, it likely results from erosion, transport, and deposition of highland clastic material, perhaps by volatile-assisted slope processes. Elsewhere, the unit also may include or be dominated by fluid lava flows or fluvial sediments.

Channeled plains material covers the floors of outflow channels in Chryse Planitia and formed near the end of the Hesperian [2]. Interpretation: Sediments, including debris flows [e.g., 4], generated by outflow channels.

The *Vastitas Borealis Formation (VBF)* covers the majority of the map region. This unit is marked by numerous low hillocks and arcuate ridges (in places organized into thumbprint terrain); by local systems of wrinkle-ridge-like, mostly asymmetric, low ridges; by dozens of circular depressions (ghost craters) up to tens of kilometers in diameter; and by many superposed, relatively high-albedo, mostly rampart and locally some pedestal craters. Previously, the VBF was divided into grooved, ridged, mottled, and knobby members [2]. These members may largely reflect differences in style and degree of modification rather than in lithology or age. Also, Parker et al. [5] mapped a plains unit (bordered by their contact 2) that in places coincides with the VBF contact. Because the more widespread, subtler morphologic features characterizing the VBF commonly are more detectable with high-resolution (~500 m) MOLA gridded topography than Viking images, we have been able to map the VBF contact more accurately than previously possible. However, we do not detect any major subunits of a stratigraphic kind within the VBF; the VBF contact itself may be structural rather than stratigraphic. Interpretation: We propose that the VBF is a mixture of predominantly Noachian to Hesperian material [6-7] and local outflow-channel sediments (probably debris flows) that have been highly and pervasively altered by periglacial processes involving the operation of mainly subsurface volatiles [e.g., 8]. The Chryse outflow-channel sediments likely were restricted to the north polar basin, given (1) the paucity of ghost craters (which would have been buried by the younger sediments) in the channel-ward part of the basin, and (2) the lack of an obvious outflow-channel connection in the saddle between the north polar basin and Utopia basin. The unit has an overall Late Hesperian crater density [1] but pervasive modification of the VBF probably continued into the Early Amazonian in some parts of the north polar basin.

Overlying the VBF along the northwest periphery of the Alba Patera shield, the Early Amazonian (?) *Scandia unit* (unit As) forms the discontinuous mesas and knobs of Scandia Colles that range from 20 to 200 m high. Interpretation: Previously, the unit was inter-

preted to be remnants of ancient material because of degraded crater forms within the unit [2]. However, now it appears that the same degradation that modified the unit also eroded its superposed craters. Thus the unit instead may be a relatively young, largely eroded, friable, planar deposit. The origin of the unit is uncertain and may include polar dust deposits and/or eolian deposits of fines produced by Alba Patera volcanism or by disruption and erosion of the VBF.

Chaos material forms depressions within Chryse outflow channels as well as in the Cydonia and Acidalia Mensae regions, postdating the channeled plains material and the VBF. Interpretation: Zones of late-stage volatile discharge and subsequent collapse.

The *tholi unit* forms circular to irregular domical hills and rugged complexes tens to a few hundred kilometers across and tens to hundreds of meters high. The larger complexes have interior depressions tens to hundreds of meters deep and a few narrow sinuous ridges a couple kilometers wide and tens of kilometers long. Many of the hills are bounded by shallow moats. Interpretation: Lava, mud, or ice extrusions formed the domes and perhaps phreatic or cryoclastic eruptions and discharge-related collapse produced the depressions and moats. The depressions and associated features do not appear to us as having a glacial origin, as suggested by [9].

The *lower polar layered deposits (LPLD)* form the base of Planum Boreum and possibly high-standing knobs and mesas south of Chasma Boreale and underlie the evenly bedded polar layered deposits. The unit's texture resembles that marking the adjacent VBF and may be indicative of similar modification as that of the VBF. The unit may be up to a kilometer thick along the margins of Chasma Boreale and thins out away from there; it presumably underlies much of Planum Boreum. MOC images and MOLA data reveal that this unit has irregular bedding, locally steep scarps, and a dark color. Interpretation: Possibly an eroded sand sea [10] or modified polar layered deposits. Potentially, the Scandia unit and LPLD could be remnants of a single, very broad deposit. Formerly, LPLD likely were more extensive in places, perhaps accounting for some of the material underlying pedestal craters in the plains surrounding Planum Boreum.

Other younger, Middle to Late Amazonian units in the northern plains include lavas and possible volcanic flow deposits in Amazonis, Elysium, and Utopia Planitiae; the upper polar layered deposits; and polar dunes. These units apparently postdate the widespread modification of plains materials as documented in older units.

Tectonism: Most of the extensive systems of subtle, linear ridges throughout the northern lowlands [11] have asymmetric topographic profiles. Within VBF, any pre-VBF ridges may have been largely destroyed by outflow channel sedimentation and formation of the tholi and chaotic units. Compressional stresses were probably the result of planetary contraction and Tharsis loading [e.g., 12], with structural orientations locally controlled by Utopia basin. We therefore see the ridge systems as displaying only the waning strain history, rather than as partly buried features as suggested by [13].

A few narrow grabens of Tantalus Fossae cut NE Alba. Many are buried by the VBF but a few cut this unit, indicating that Tantalus Fossae development likely extends from Early to Late Hesperian into the Amazonian.

Resurfacing: We suggest that the latest resurfacing of the northern plains did not occur by sedimentation within an ocean or by widespread volcanism, but rather by the latest stages of long-term periglacial and thermokarst modification, with progressively reduced intensity occurring during the Hesperian through Early Amazonian. This activity obliterated or heavily modified earlier landforms, resulting in huge collapse structures, ghost craters, valley networks, highland/lowland fretted and knobby terrains, polar cavi terrains, and lowland thumbprint terrains. Such resurfacing likely involves erosion, ductile deformation, collapse, and effusive and violent eruptions of volatile-charged material. The elevation dependence of the reworking may be related to gradual lowering of the threshold for near-surface volatile activity, as governed by the composition and distribution of subsurface volatiles and by the geothermal gradient. The difficulties to making Mars warm in the past and the lack of significant chemical weathering on Mars [14] seem to preclude substantial liquid water at the surface in the form of long-lived fluvial, lacustrine, and wet-based glacial activity. Instead, northern plains resurfacing may result mainly from the *subsurface* activities of *both* H_2O and CO_2 (CO_2 being more volatile), as well as from local discharges of sediment enriched with these volatiles.

References: [1] Tanaka K.L. (1986) *JGR, 91,* E139-E158. [2] Scott D.H. et al. (1986-87) *USGS Map I-1802-A, B, C*. [3] Maxwell, T.A. and McGill G.E. (1987) *PLPS, 18,* 701–711. [4] Tanaka, K.L. (1997) *JGR, 102,* 4131-4149. [5] Parker, T.J. et al. (1989) *Icarus, 82,* 111-145. [6] Kreslvasky M.A. and Head J.W. III (2001) *LPSC Abs. #1001*. [7] Frey H. et al. (2001) *GRL*, in press. [8] Carr, M.H. and Schaber G.G. (1977) *JGR, 82,* 4039-4053. [9] Fishbaugh K.E. and Head J.W. III (2000) *JGR, 105,* 22455-22486. [10] Murray B.C. et al. (2001) *Eos Trans. AGU, 82,* F694. [11] Smith D.E. et al. (2001) *Science, 284,* 1495-1503. [12] Tanaka K.L. et al. (1991) *JGR, 95,* 15617-15633. [13] Thomson B.J. and Head J.W. III (2001) *JGR, 106,* 23209-23230. [14] Christensen P.R. et al. (2001) *JGR, 106,* 23823-23871.