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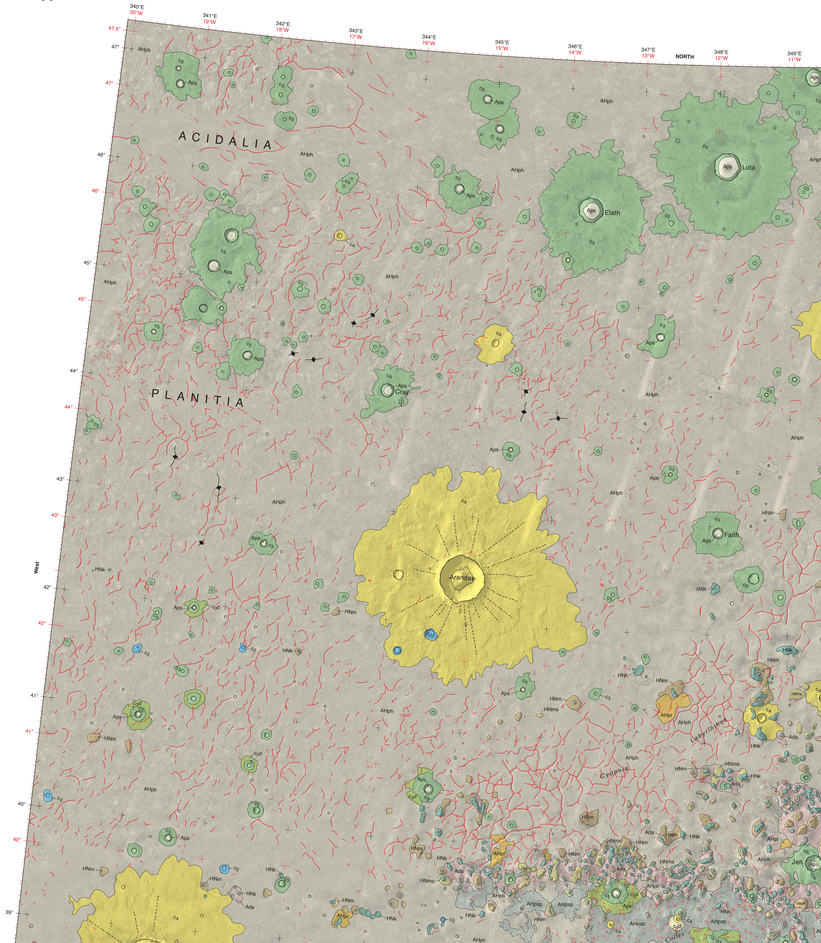
GEOLOGIC INVESTIGATIONS SERIES I–2811
ATLAS OF MARS: QUADRANGLES MTM 40007, 40012, 40017, 45007, 45012, AND 45017



Prepared on behalf of the Planetary Geology and Geophysics Program, Solar System Exploration Division, Office of Space Science, National Aeronautics and Space Administration.

Edited by Derrick D. Hirsch and Jan L. Zigler; cartography by Darlene A. Ryan and Bonnie C. Landgraebe.

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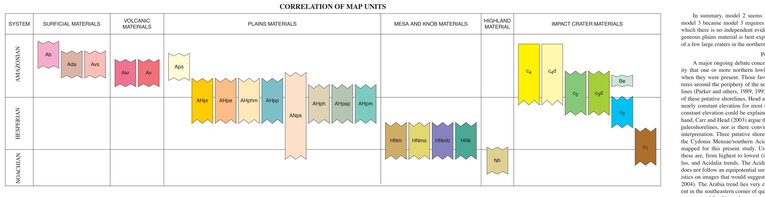
CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

SURFICIAL MATERIALS

Ab — **Bright material**—High albedo material in large irregular patches, commonly with wispy boundaries. *Interpretation*: Thin eolian veneer covering plains material.

Ada — **Debris apron material**—Very smooth to strongly lineated material surrounding knobs and mesas; albedo variable but generally similar to plains materials; commonly slightly elevated above adjacent plains materials. *Interpretation*: Shoes and lobes of material derived from knob and mesa slopes by mass-wasting processes

Avs — **Smooth material**—Smooth plains material; generally moderately elevated above surrounding plains materials. *Interpretation*: Erosional remnants of a once more widespread, thin deposit covering plains materials

VOLCANIC MATERIALS

Abr — **Ringed knob material**—Materials of ringed knobs in quadrangle MTM 40007 with contourlike, bright, concentric rings on their flanks; associated with plains material and small volcanic deposits. *Interpretation*: Volcanic constructs

Av — **Volcanic material**—Small patches of material characterized by a swirly pattern of variable albedo; slightly elevated above surrounding plains; closely associated with lava channels. *Interpretation*: Lava flows

PLAINS MATERIALS

Apk — **Smooth plains material**—Featureless and very smooth at scale of Viking images; albedo somewhat higher than plains materials; on floors of craters and in other topographically low areas

Aphp — **Rough plains material**—Same as homogeneous plains material but with a surface characterized by small hills, ridges, and hexagons from several hundred meter scale down to limit of resolution; albedo slightly higher than that of homogeneous plains material. *Interpretation*: Probably water-deposited sediment, but may be volcanic; surface crenulations caused by erosional processes

Aphe — **Etched plains material**—Similar to homogeneous plains material but characterized by small, irregular depressions. *Interpretation*: Eroded deposit

Aphmn — **Hummocky plains material**—Similar to homogeneous plains material but characterized by abundant, small, rounded hills. *Interpretation*: Probably water-deposited sediment with superposed small volcanic constructs

Aphpp — **Pitted plains material**—Material with a smooth to rough surface and abundant irregular pits. *Interpretation*: Probably volcanic or sedimentary or volcanic material with collapse pits

Aphpk — **Knobby plains material**—Hybrid unit consisting of very abundant small knobs, too small to map individually, that are separated by plains and debris apron materials; surface characteristics are a combination of other knob material of uncertain origin and younger plains materials and mass-wasting deposits

Aphpm — **Homogeneous plains material**—Generally smooth of Viking image resolution; albedo moderate; mostly uniform gray, but locally with very faint bright streaks; albedo and (or) topography numerous defining a roughly polygonal pattern at kilometer to tens of kilometers scale; albedo pattern may be subtle or nonexistent; albedo may be volcanic

Aphsp — **Spotted plains material**—Same as homogeneous plains material except covered with abundant bright spots that range in diameter from several hundred meters down to the limit of resolution; on MOC images the spots are resolved as irregular domes, pitted domes, and pitted cones; albedo higher than underlying plains. *Interpretation*: Plains material probably water-deposited sediment, but may be volcanic; bright centers are hydrothermal vents

Aphpn — **Mottled plains material**—Same as homogeneous plains material but with abundant irregular patches of hilly material that is much brighter than underlying plains material; patches range in diameter from ~100 m to several kilometers. *Interpretation*: Plains material probably water-deposited sediment, but may be volcanic; bright patches wind blown

MESA AND KNOB MATERIALS

HNm — **Mesa material**—Generally smooth, featureless material with albedo similar to homogeneous plains but forming mesas and butte landforms; *Interpretation*: Origin enigmatic, but probably residual inliers of a once more widespread deposit

HNms — **Subdued mesa material**—Similar to mesa material but scarps rounded and subdued rather than sharply defined. *Interpretation*: Origin enigmatic, but probably mesa material modified by mass-wasting processes

HNmb — **Banded mesa material**—Smooth, featureless material forming a single large mesa near the center of quadrangle MTM 45007; characterized by bands of differing albedo outlining the plan-view shape of the mesa. *Interpretation*: Origin enigmatic, but probably a large inlier of a once more widespread deposit

HNk — **Knob material**—Makes up numerous knobbike landforms that are rounded to irregular in plan form and that generally occur in clusters that may be roughly circular in overall shape. *Interpretation*: Origin enigmatic, but probably inliers of older materials

HIGHLAND MATERIAL

Nh — **Highland terrain**—Generally rough, with standing terrain in southeast corner of quadrangle MTM 40007; characterized by abundant small ridges not well resolved on the best available Viking images (~150 m/pixel); clearly embayed by surrounding plains materials. *Interpretation*: Inlier of old highland terrain; ridges probably eolian

IMPACT CRATER MATERIALS

Ae — **Fresh crater material**—Rim, floor, and ejecta materials of craters with complete and little modified rims and ejecta blankets and no younger superposed impact craters. *Interpretation*: Impact craters

Ec — **Fresh distal ejecta**—Relatively bright crater ejecta material too thin to obscure underlying landforms and materials; distal to ejecta blanket. *Interpretation*: Material due to hypervelocity impact

Ed — **Relatively degraded crater material**—Rim, floor, and ejecta materials of craters with complete but somewhat modified rims and ejecta blankets and no younger superposed impact craters. *Interpretation*: Hypervelocity impact materials

Ef — **Modified crater material**—Bright crater ejecta material too thin to obscure underlying landforms and materials; distal to main ejecta blanket. *Interpretation*: Material due to hypervelocity impact

Es — **Material of crater floors**—Smooth material in floors 55-km-diameter crater Barnard, which lies east of quadrangle MTM 40007. *Interpretation*: Hypervelocity impact material

Eg — **Degraded crater material**—Rim, floor, and ejecta materials of craters with many complete rims and with incomplete and highly modified ejecta blankets. *Interpretation*: Hypervelocity impact materials

Ef — **Rimless craters**—Craters that are filled, and, locally, floor and ejecta materials of craters with only fragments of a rim and generally with no surviving ejecta or floor materials. *Interpretation*: Hypervelocity impact craters

Contact—Dashed where approximately located. Internal contact separates different impacts

Fault—Bill and hat on downthrown block

Wrinkle ridge crest—Size of symbol may vary

Dome ridge crest

Scarp crest—Barb points downslope

Polygonal trough

Lava channel

Pitted cone

Edge of irregular depression

Crater rim—Showing crest; diameter between 1 and 3 km

Crater rim—Showing crest; diameter greater than 3 km

Radially grooved ejecta (schematic)

Secondary craters

Central peak

Rimless crater

INTRODUCTION

Cydonia Mensae lie adjacent to the boundary separating the highland terrain of western Arabia Terra from the northern lowlands (the dichotomy boundary), where this boundary is gradational rather than abrupt, as is generally the case. Cydonia Mensae are characterized by abundant knobs and mesas, most of which occur in well defined clusters that commonly are long and narrow. The adjacent lowland of Acidalia Planitia contains abundant knobs that define a crude, very large scale polygonal pattern. This pattern, and the troughs, are similar in size and spacing to those in Utopia Planitia (for example, McGill and Hills, 1992; Hiesinger and Head, 2000). The six 1:500,000-scale quadrangles mapped are MTM 40007, 40012, 40017, 45007, 45012, and 45017, which include northern Cydonia Mensae, part of southern Acidalia Planitia, and a small piece of Arabia Terra highlands. These six quadrangles are combined into a single map at 1:1,000,000 scale for this publication. Issues of interest addressed by this mapping include the crustal history implied by the knobs and mesas of Cydonia Mensae, the implications of the gradational dichotomy boundary, the age of the Acidalia plains materials, the origin and age of the giant polygons, the validity of putative shorelines inferred to be present in this area, and the origin of the very abundant small cones and domes, specifically if these imply the past presence of water or ice within the plains materials. Earlier maps (Wilhelms and Underwood, 1984; Scott and Tanaka, 1986; Tanaka and others, 2003) that included the area mapped for this study addressed some or all of these issues, but these maps were more regional in coverage and were at smaller scales. In addition, new orbital data from Mars Global Surveyor and Mars Odyssey missions were available only to Tanaka and others (2003). The intent of this present study is to address the issues listed by mapping at a scale large enough to permit greater map detail and to better understand the areal distribution of the materials and features of interest.

During the Viking mission Cydonia Mensae and adjacent southern Acidalia Planitia were subjected to several studies, in part prompted by the possibility of a Viking landing site in the area (Masursky and Crabill, 1976). These studies addressed the overall stratigraphy of the area, and most focused on the relative age and possible origin of the abundant small cones and domes (Chapman and others, 1979; Plescia, 1980), the abundant small domes and cones of Cydonia Mensae and southern Acidalia Planitia, and the origin of the giant polygons, the validity of putative shorelines inferred to be present in this area, and the origin of the very abundant small cones and domes, specifically if these imply the past presence of water or ice within the plains materials. Earlier maps (Wilhelms and Underwood, 1984; Scott and Tanaka, 1986; Tanaka and others, 2003) that included the area mapped for this study addressed some or all of these issues, but these maps were more regional in coverage and were at smaller scales. In addition, new orbital data from Mars Global Surveyor and Mars Odyssey missions were available only to Tanaka and others (2003). The intent of this present study is to address the issues listed by mapping at a scale large enough to permit greater map detail and to better understand the areal distribution of the materials and features of interest.

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STRATIGRAPHY

The stratigraphic units mapped fall into six categories based on inferred origin or on association with specific landforms: surficial materials, plains materials, volcanic materials, mesa and knob materials, highland material, and impact crater materials. There are 26 units: 3 surficial units, 9 plains units, 2 volcanic units, 4 mesa and knob units, 1 highland unit, and 7 crater units. Most of these units occur over areas too small to yield statistically significant samples of superposed impact craters. Most of the area mapped is underlain by homogeneous plains material, and this its age serves as a reference for the entire area. Moreover, the relative ages of the other mapped differences among plains materials indicates that this is a valid crater age for all of them except smooth plains material. Much of the plains material within the Cydonia Mensae/southern Acidalia Planitia region was mapped as part of the Vastitas Borealis Formation in the hemispheric-scale map of Tanaka and Scott (1987, 1986). Because this unit is essentially a conglomeration of various materials (Tanaka and others, 2003), it would be counterproductive to use it in mapping small areas to provide more detailed spatial information.

The crater age of the plains is based on combined counts from quadrangles MTM 40017, 45007, 45012, and 45017, which are almost entirely underlain by homogeneous plains material. The crater plot (fig. 1) has a break in slope at diameters between 6 and 12 km. This slope break suggests a dual age; the larger craters define a Hesperian age, but the small ones are Amazonian in age. However, a single straight line lying entirely between the 1 σ error limits fits the entire plot; this line indicates a Late Hesperian age for all of the homogeneous plains material. There is a marked clustering of the craters larger than about 10 km in diameter in the northern half of the area mapped, suggesting that the northern plains are slightly younger than the southern plains. If so, this apparent dual age raises a significant stratigraphic issue. Another important stratigraphic issue involves the age of the mesa and knob materials relative to the older plains units, as discussed in the section "Introduction."

HIGHLAND MATERIAL

Two exposures of highland terrain (Nh) occur at the southeast corner of quadrangle MTM 40007. This terrain is continuous with Arabia Terra highland terrain present in the adjacent quadrangle to the east (MTM 40007, 30007). Unfortunately, the zone in which this highland terrain grades into lowland terrain occurs where the best Viking coverage is at resolutions of 157–166 m/pixel. The highland terrain has a large albedo and is topographically higher than adjacent plains materials. Adjacent plains materials display highland terrain. This unit is based on the known age of the contiguous highland terrain of Arabia Terra (Wilhelms and Underwood, 1984).

MESA AND KNOB MATERIALS

Mesa and knob materials (unit **HNk**) are very abundant in quadrangles MTM 40007 and 40012, but they also occur in the eastern part of quadrangle MTM 40017, as sparsely scattered individuals in the southeastmost parts of quadrangle MTM 45007 and 45012, and in the northern part of quadrangle MTM 40017. Most of these occurs as east-west-trending groups that are commonly 100 km long. The largest such group (quadr. MTM 40012 to the eastern part of quadrangle MTM 40007) this is the area named Cydonia Mensae. The knobs and mesas are most low (1 km in diameter to a very large mesa or small plateau in quadrangle MTM 40007 that is about 25 x 37 km across. All mesas are elevated above the surrounding plains, but the relief varies from about 800 m to less than 200 m. Most mesas are mapped as mesa material (unit **HNm**), but those that appear to be degraded are mapped as subdued mesa material (unit **HNms**). Based on very limited crater data, at least some of the mesas are most consistent of Noachian material. Knob material (unit **HNk**) is characterized by small, round to oveoid pits. The pitted plains material appears to be a thin layer superposed on plains similar to homogeneous plains (unit **Aphpm**). Knobs range in size from about 1 km to as much as 100 km in diameter. Within Cydonia Mensae, all three of these mesa and knob material units are assumed to be the same age and they are assumed to be the same material. The assumption is reasonable for the mesas and knobs are erosional remnants of a once more widespread unit. Because it is difficult to envision processes that would form features indistinguishably different from each other, the erosional remnant model is strongly favored. This model also is favored by relations present east of the mapped area in Deuteronilus Mensae where erosional remnants of the mesas and knobs are spread Noachian plateau unit to form isolated plateaus and mesa remnants is especially clear (Sharp, 1973; McGill, 2000). A single, large mesa landform in quadrangle MTM 45007 is mapped as a separate unit, banded mesa material (unit **HNmb**), that may have a different origin than the other mesa and knob materials. The age and origin of the scattered knobs and mesas occurring throughout much of southernmost Acidalia Planitia may be the same as for the knobs and mesas within Cydonia Mensae itself, an issue that will be addressed in the discussion below.

Where exposed on the flat top of mesas, mesa material (unit **HNm**) is generally smooth and featureless at Viking resolutions with an albedo that is similar to that of the surrounding plains materials. At MOC resolutions, the surface of mesa material appears to be dominated by a network of fractures, although smaller lineations are present. Some of these issues stem from contradictory interpretations of relative ages by past workers. Several key observations are relevant.

1. The crater population present on Acidalia Planitia suggests two ages of materials, one Hesperian, the other Amazonian (fig. 1), as noted by Borello (1991; fig. 4 and table 2). A simple visual inspection of the geologic map indicates that the largest, fluidized ejecta craters responsible for the Hesperian age are generally absent in the southern part of the plains within the area mapped, suggesting the presence of two areally distinct plains units. However, no contact is evident in the imagery. A poorly constrained zone may be defined approximately coinciding with the boundary between quadrangles MTM 45007 and 45012 to the south and quadrangles MTM 40007 and 40012 to the south and then angling northwestward across quadrangle MTM 45017 to about the north-south center of that quadrangle's west boundary. North of this zone the craters appear to indicate a Late Hesperian age, south of it an Early Amazonian age.
2. Mesas and knobs similar to those occurring within Cydonia Mensae are present as scattered individuals within the plains of southern Acidalia Planitia. However, they are very rare north of the poorly constrained zone defined in observation 1 above. All impact craters in contact with the large troughs of the dichotomy boundary are complete rims of craters with only fragments of a rim and generally with no surviving ejecta or floor materials. *Interpretation*: Hypervelocity impact craters
3. Knobs with superposed fluidized ejecta craters are common in the southernmost part of the area mapped. The knobs are gutted by brighter, lower, and smoother floors than are the knobs not gutted by brighter floors, and, locally, floor and ejecta materials of craters with only fragments of a rim and generally with no surviving ejecta or floor materials. *Interpretation*: Hypervelocity impact craters

Observations 1 and 2 imply that the plains materials are compound. Homogeneous plains material (unit **Aphpm**) is by far the most widespread unit in the six quadrangles. Within most of quadrangle MTM 40007 and 40012, it is underlain by a thin layer of smooth plains material (unit **Apk**). Some of the larger craters in quadrangle MTM 40007 and adjacent quadrangles in MTM 40012 have rougher surfaces than the cause of this roughness is unclear but may be related to ejecta craters superposed on the mesas, an inference supported by one MOC image. Subdued mesa material (unit **HNms**) is similar to the mesas of Cydonia Mensae except the mesas are rounded and softened rather than being sharply defined. Banded mesa material (unit **HNmb**) also is similar to the mesas of Cydonia Mensae except it is distinguished by bands of differing albedo outline the plan-view shape of the mesa. *Interpretation*: Origin enigmatic, but probably a large inlier of a once more widespread deposit

Knob material—Makes up numerous knobbike landforms that are rounded to irregular in plan form and that generally occur in clusters that may be roughly circular in overall shape. *Interpretation*: Origin enigmatic, but probably inliers of older materials

HIGHLAND MATERIAL

Highland terrain—Generally rough, with standing terrain in southeast corner of quadrangle MTM 40007; characterized by abundant small ridges not well resolved on the best available Viking images (~150 m/pixel); clearly embayed by surrounding plains materials. *Interpretation*: Inlier of old highland terrain; ridges probably eolian

IMPACT CRATER MATERIALS

Fresh crater material—Rim, floor, and ejecta materials of craters with complete and little modified rims and ejecta blankets and no younger superposed impact craters. *Interpretation*: Impact craters

Fresh distal ejecta—Relatively bright crater ejecta material too thin to obscure underlying landforms and materials; distal to ejecta blanket. *Interpretation*: Material due to hypervelocity impact

Relatively degraded crater material—Rim, floor, and ejecta materials of craters with complete but somewhat modified rims and ejecta blankets and no younger superposed impact craters. *Interpretation*: Hypervelocity impact materials

Modified crater material—Bright crater ejecta material too thin to obscure underlying landforms and materials; distal to main ejecta blanket. *Interpretation*: Material due to hypervelocity impact

Material of crater floors—Smooth material in floors 55-km-diameter crater Barnard, which lies east of quadrangle MTM 40007. *Interpretation*: Hypervelocity impact material

Degraded crater material—Rim, floor, and ejecta materials of craters with many complete rims and with incomplete and highly modified ejecta blankets. *Interpretation*: Hypervelocity impact materials

Rimless craters—Craters that are filled, and, locally, floor and ejecta materials of craters with only fragments of a rim and generally with no surviving ejecta or floor materials. *Interpretation*: Hypervelocity impact craters

Contact—Dashed where approximately located. Internal contact separates different impacts

Fault—Bill and hat on downthrown block

Wrinkle ridge crest—Size of symbol may vary

Dome ridge crest

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Lava channel

Pitted cone

Edge of irregular depression

Crater rim—Showing crest; diameter between 1 and 3 km

Crater rim—Showing crest; diameter greater than 3 km

Radially grooved ejecta (schematic)

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Rimless crater

INTRODUCTION

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Figure 1. Crater diameter versus cumulative frequency plot for all craters 1 km in diameter or greater on plains materials of quadrangles MTM 40017, 45007, 45012, and 45017 (n=341). Note kink in plot for crater diameters between 6 and 12 km. Craters larger than 10 km project to Late Hesperian age; craters smaller than 10 km defined Early Amazonian age. However, a single straight line that remains between 1 σ error limits can be fit to entire plot. This line defines a Late Hesperian age for all craters. Red dots are calculated values; green triangles are 1 σ error limits.

Figure 2. Typical surface texture of homogeneous plains material (unit **Aphpm**). Part of MOC image M1003053, 3.65 m/pixel. North approximately toward top, illumination from left.

Figure 3. Surface texture of homogeneous plains material (unit **Aphpm**) where streaked with higher albedo material that is either eolian or very thin fan of dust material derived from adjacent large impact craters. Part of MOC image M0300375, 5.99 m/pixel. North approximately toward top, illumination from left.

Figure 4. Albedo boundary (arrows) within homogeneous plains material (unit **Aphpm**). This boundary may relate in part to ejecta from cluster of large craters within and northwest of image area. It also approximately coincides with north limit of ~100-m-deep depression in plains. More subdued character of large troughs north of boundary may be due to deposition of very thin layer of dust crater ejecta from these large craters or, alternatively, to thin layer of eolian sediment. Figures 2 and 3 indicate that plains surface is streaked north of albedo boundary but not south of it. Viking Orbiter image 673B54, 213 m/pixel. North approximately toward top, illumination from left.

Figure 5. Volcanic features superposed on plains in quadrangle MTM 40007. A *ridge* (*r*) extends from northeast to center, with two apparent lava fields (*lav*) associated with it. A third lava field occurs in southwest corner of figure area. At bottom center is a ringed knob (*kn*). Part of MOC image M0300393, 4.99 m/pixel; centered at lat 39.7° N., long 352.1° E. North toward top, illumination from left.

Figure 6. Examples of typical speckled plains material (**Aphpp**) and mottled plains material (**Aphpn**). Former is characterized by abundant, individual pitted cones (see fig. 7) with albedos higher than underlying plains. Latter is characterized by much larger patches of material mostly without resolvable individual cones but with same albedo as cones. Part of MOC image M0300393, 4.99 m/pixel; centered at lat 39.7° N., long 347.3° E. North approximately toward top, illumination from left.

Figure 7. Typical pitted cone (*c*) of type found in abundance within speckled plains material. Part of MOC image M0304566, 3.33 m/pixel; centered at lat 40.4° N., long 350.3° E. North approximately toward top, illumination from left.

Figure 8. Hverfjall, a tuff ring near Mývatn, north-central Iceland, that is morphologically similar to the speckled plains cones shown in figures 6 and 7. Tuff rings result from magma and water interacting and thus imply presence of shallow water at time of formation. U.S. Air Force aerial photograph, 3 m/pixel. North toward top, illumination from left.

Figure 9. Example of dome with spokes from plains part of MOC image M0301636, 3.60 m/pixel; centered at lat 40.0° N., long 348.0° E. North approximately toward top, illumination from left.

Figure 10. High-resolution image of bright patches characterizing mottled plains material (see fig. 6). Patches are resolved as clusters of closely spaced knobs that are much brighter than surrounding plains. Thickness of individual features and with low-relief rims. Many of these features are interpreted by some as the remains of a once more widespread, thin deposit covering plains materials. Part of MOC image M0300393, 4.99 m/pixel; centered at lat 39.7° N., long 347.3° E. North approximately toward top, illumination from left.

Figure 11. Typical pseudocraters on shoes of Mývatn, north-central Iceland. Pseudocraters imply presence of surface water at time of formation. U.S. Air Force aerial photograph, 3 m/pixel. North toward top, illumination from left.

Figure 12. Typical pseudocraters on shoes of Mývatn, north-central Iceland. Pseudocraters imply presence of surface water at time of formation. U.S. Air Force aerial photograph, 3 m/pixel. North toward top, illumination from left.

Geologic Map of Cydonia Mensae-Southern Acidalia Planitia, Mars: Quadrangles MTM 40007, 40012, 40017, 45007, 45012, and 45017

By
George E. McGill
2005

GEOLOGIC HISTORY

The oldest events recorded within the six mapped quadrangles are the emplacement of the highland material and 6.4 crater material in the southeast corner of quadrangle MTM 40007. The c_4 crater is not in contact with the highland material and thus their relative ages are not known. These materials are inferred to be of Noachian age because they are age of contiguous highland materials to the south.

Highland terrain was then resurfaced, most likely by erosion followed by emplacement of a cap of volcanic materials, forming a plateau. Large areas of this plateau still exist immediately south of the area mapped, where it has been dated as Middle Noachian (Wilhcek and Underwood, 1984). This highland plateau originally extended north of its present north limit at least as far as lat 40° N., which is the north limit of abundant mesas and knobs. The plateau was extensively eroded during the Hesperian. Erosional remnants of this plateau are present throughout much of the area mapped, but they are particularly abundant within the Cydonia Mensae area as densely crowded assemblages of mesas and knobs. The oldest plains materials surrounding the mesas and knobs are Late Hesperian; either the erosion of the plateau occurred in Late Hesperian or older plains surrounding the mesas and knobs are now completely buried by the Late Hesperian plains materials.

After erosion of the plateau the plains materials of Acidalia Planitia were emplaced and in most of the region immediately cut by the large troughs that define the giant polygonal terrain. Most likely all of these plains materials were emplaced in the Late Hesperian, but the crater frequency plot for the plains permits two ages: Late Hesperian and Early Amazonian, with the younger age characterizing plains materials immediately north of Cydonia Mensae. There is no obvious difference between the northern and southern portions of the plains, so contact is discernible, and giant polygon troughs do not show evidence for two episodes of formation, as would be expected if both ages are formation ages. Either the plains to the south were somehow protected from impact for a period of time or the difference in age is simply an artifact of low probability clustering of large craters to the north. The latter is considered the most likely explanation. Most of the Acidalia plains units mapped consist of the same underlying material, but surfaces vary because of local younger crenes. These superficial differences imply that processes of emplacement and erosion were still active, but at a more local scale than earlier.

Almost all of the impact craters used to date the Acidalia plains are in classes c_3 and c_4. Many of the larger c_3 craters are filled with up to a few hundred meters of smooth plains material, but c_3 craters are not, indicating a depositional event in the area after c_3 craters formed but before c_4 craters formed. It is not clear why smooth plains deposits appear to be confined to the northernmost part of the area mapped, but impact craters to serve as sediment traps if the smooth plains material is eolian. This deposition probably occurred in the Amazonian based on the near absence of craters superposed on smooth plains material.

Surficial materials are generally the youngest in the area, based on superposition and paucity of superposed craters. Debris apron material is very widespread, occurring adjacent to almost every mesa and knob in the area mapped. These aprons most likely by gravity-driven creep of water- or ice-rich debris derived from the scarps bounding mesas and knobs. Very smooth material is probably a small local remnant of a once more widespread, thin blanket of material of unknown genesis. Bright material appears to be fields of small dunes or sand sheets, and this is interpreted to be a thin eolian cover over older materials. The sparse population of craters superposed on these surficial materials indicates an Amazonian age.

The small pitted cones, pits, and domes that occur throughout the area, but which are particularly abundant within Cydonia Mensae, formed after the Acidalia plains materials were emplaced and after formation of the large troughs. Pitted cones have been mapped on top of all plains materials except etched plains material and smooth plains material. Pits are observed on debris apron material, but none have been found on the other surficial materials. All of them could be younger than debris apron material, in which case they all would be Amazonian. However, they may have formed over a significant time interval from Late Hesperian into Amazonian.

GEOMORPHOLOGY

SMALL CONES AND DOMES

Within the area covered by the six quadrangles mapped are large numbers of small cones, many with summit pits (fig. 6). Most of these features are less than 1 km in diameter. Where they are extremely abundant a separate plains unit, speckled plains material, has been mapped, as described in the stratigraphy section. Small cones are especially abundant in the Cydonia Mensae region in quadrangles MTM 40007 and 40012, but local clusters and isolated individuals occur throughout the mapped region. All individual cones with resolvable summit pits at Viking resolution have been outlined on the map with red circles. This provides a useful visual impression of the areas distribution of pitted cones within the area mapped. However, the apparent distribution is significantly biased by image resolution and clarity and thus is reliable primarily within quadrangles MTM 40007 and 40012 where the best images occur. Even along the southern borders of these quadrangles, there is a strip of poor resolution images that results in a sharp decrease in the number of mapped pitted cones that almost certainly is not real. Almost all of these pitted cones occur on plains materials (units **Aphpk**, **Aphpp**, **Aphpn**). Not a very few appear to be superposed on debris apron material (unit **Ada**).

Several papers address the origin of the small pitted cones of Cydonia Mensae and elsewhere on Mars. Most of these papers conclude that the best Earth analogs are lava tubes/pseudocraters (Frey and others, 1979; Frey and Jarosewich, 1982; Greeley and Fagents, 2001; Lanagan and others, 2001). Icelandic pseudocraters formed where this basaltic flows were extruded over water or marshy ground, as best exemplified along the shores of Mývatn, a lake in north-central Iceland. The lava flushed the surface water into steam which then created explosion pits that are referred to as pseudocraters, because there is no igneous plumbing beneath them (Thorarinsson, 1953). The pseudocraters near Mývatn are characterized by very low relief and by pits that are about as wide as the total constructs. Pitted cones in Cydonia Mensae have rather different morphologies, as shown in MOC images (fig. 7). Furthermore, the requisite conditions for forming pseudocraters essentially restrict their occurrence to small areas, as is the case in Iceland. In contrast, pitted cones are present over a very large area in Cydonia Mensae and Acidalia Planitia, and it is unlikely that the special conditions found in Iceland could be so widespread on Mars. Alternative analogs for Martian pitted cones are tuff rings (McGill, 2002b) such as Hverfjall (fig. 8), which also occurs near Mývatn. The implications of a tuff ring analog are significant because it implies volcanism that is, both require the presence of water at or near the surface at the time of formation.

Other models for Martian pitted cones include cinder cones (Wood, 1979), degraded impact craters (Carr and Schaber, 1977), pingos (Rossbacher and Judson, 1981), and mud volcanoes (Tanaka, 1997). Where resolution or image quality is poor, it is difficult or even impossible to distinguish pitted cones from small, degraded impact craters at left. On Earth, mud volcanoes are commonly associated with nonmetamorphosed or natural gas fields and thus are probably unlikely analogs for Martian pitted cones. The Martian pitted cones could be cinder cones, although they seem to have pitcone diameter ratios that are rather high for cinder cones. Unlike pseudocraters and tuff rings, cinder cones do not imply the presence of water.

Many features associated with pitted cones do not have summit pits resolvable in Viking images. These are not confined with end circles. Many of these probably are pitted cones, but with pits too small to be resolved. However, MOC images (fig. 9) show that some of these are low domes, commonly with several small, discontinuous summit pits. These domes may be analogous to pingos, but this is rather speculative at this time.

MOC images (fig. 10) indicate that the large patches of high albedo material used to separate mottled plains material from homogeneous plains material consist of abundant small pits with narrow, low rims, very similar to the morphology of the pseudocraters near Mývatn (fig. 11). These pits are too small to be resolved by even the best Viking images of this area and thus have not been included in any pore studies. Because these pits are more local in occurrence in the Cydonia Mensae area than the more common pitted cones and because of the morphology of the pits, it is likely that at least some of them are analogous to Icelandic pseudocraters.

At this time, one must conclude that the small cones and domes in this region were formed by more than one process. The distin