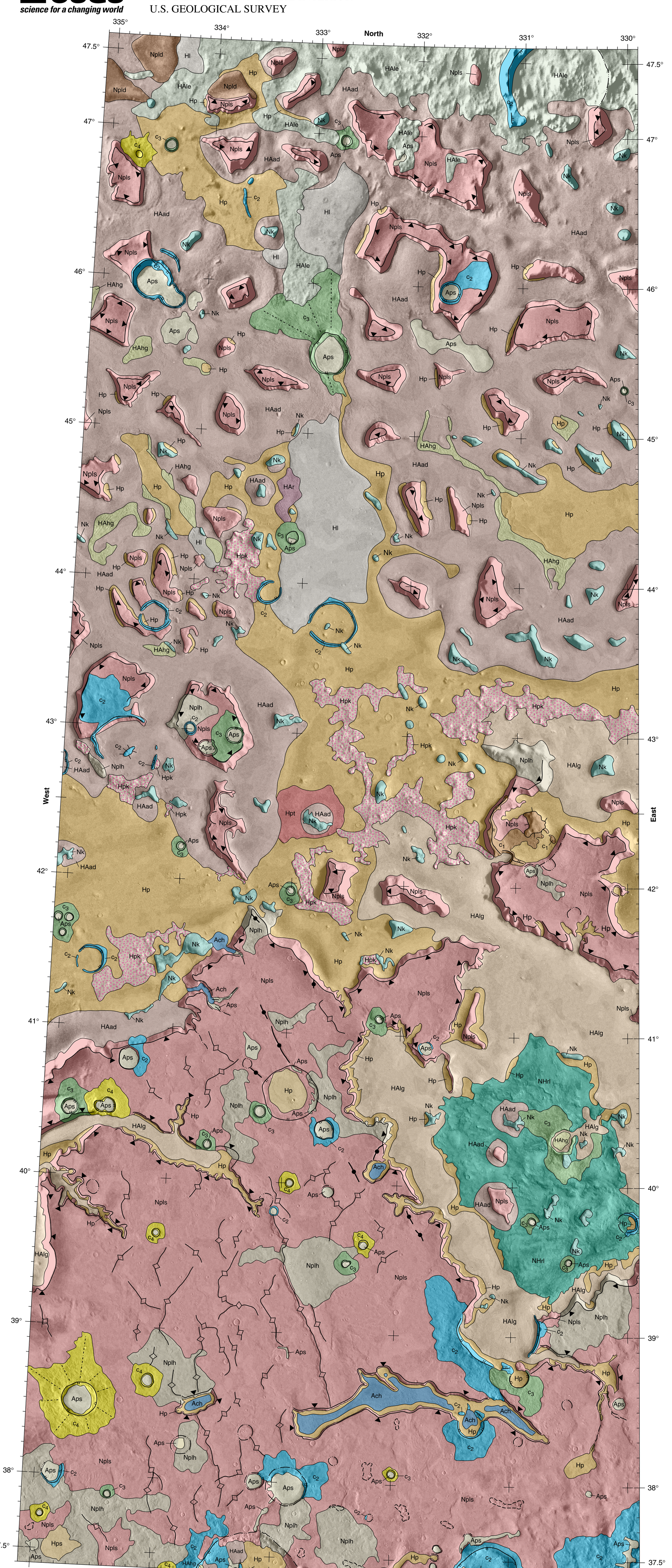

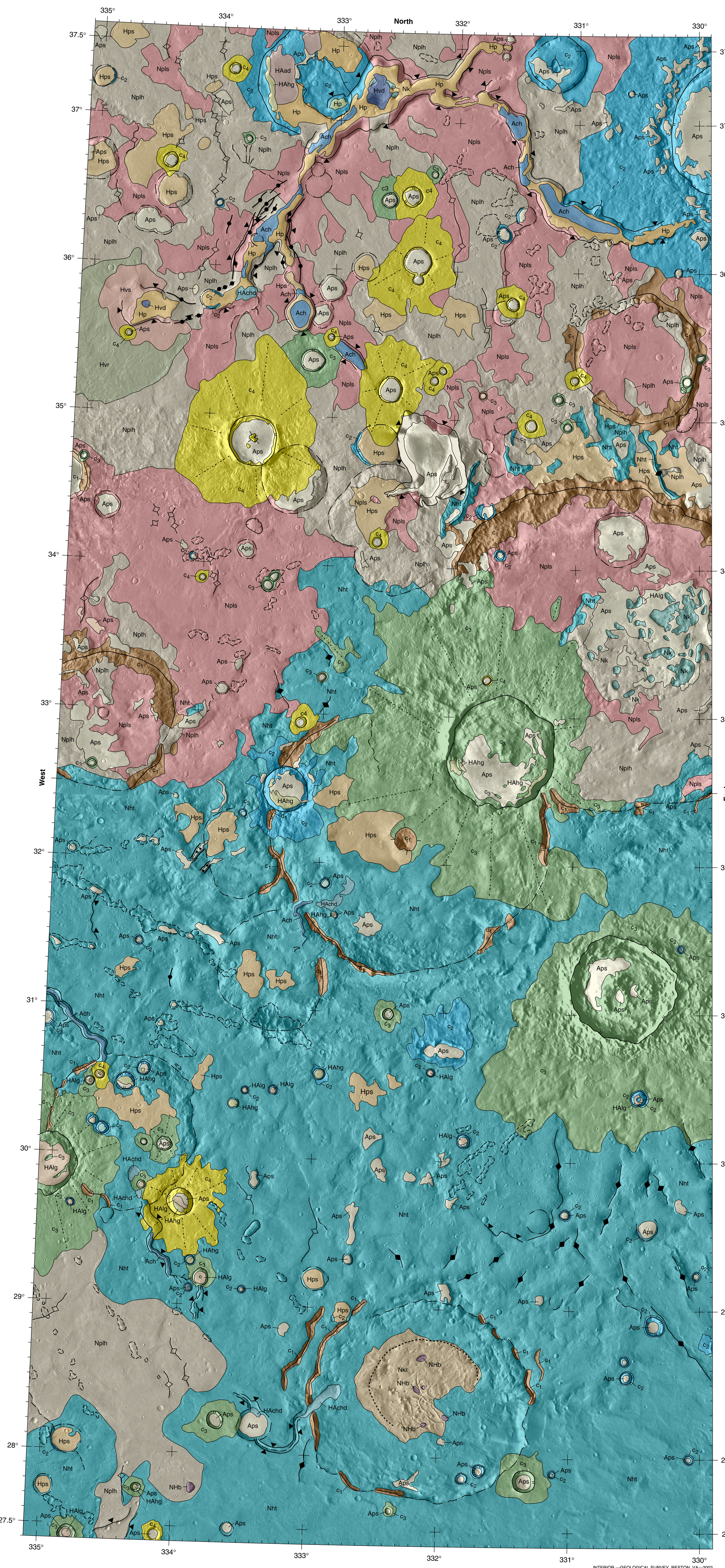

SCALE 1:1 004 000 (1 mm = 1.004 km) AT 50° LONGITUDE
TRANSVERSE MERCATOR PROJECTION
20 0 20 40 60 80 100
KILOMETERS

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—2002

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; cartography by Darlene A. Ryan and Hugh F. Thomas

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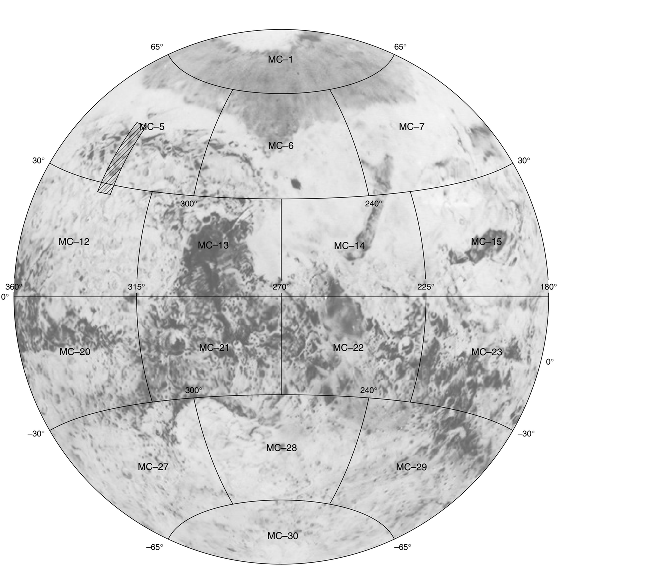


QUADRANGLE LOCATION
Photomosaic showing location of map area. An outline of 1:5,000,000-scale quadrangles is provided for reference.

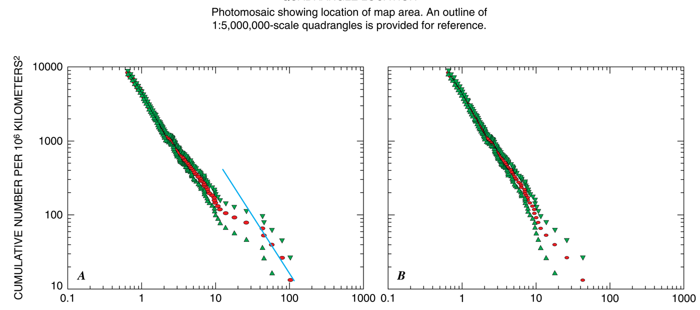


Figure 1. Cumulative diameter versus frequency plots of all craters having diameters greater than 650 m in quadrangle 30332. ***A***, Four largest craters, all mapped as c_1 craters, project to an N16 age of 300 (blue line; Early Noachian). n=634. ***B***, Same plot but with the four large c_1 craters omitted. N5 age is 330±65 (Late Noachian), implying a major resurfacing of an Early Noachian terrane in the Late Noachian. Red ovals are calculated cumulative frequencies and green triangles are one-sigma error limits.

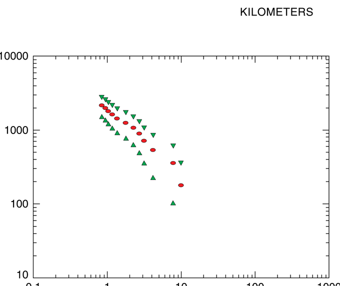


Figure 2. Cumulative diameter versus frequency plot of 12 craters having diameters greater than 800 m on rough lowland material (unit NHrl) in quadrangle 40332. N5 age is 420±250 (uppermost Middle Noachian), whereas N2 age is 1100±550 (Early Hesperian). Symbols same as figure 1.

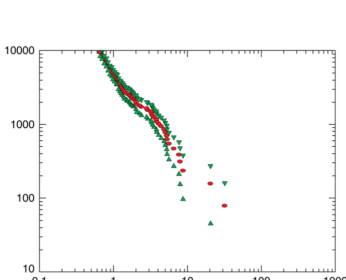


Figure 3. Cumulative diameter versus frequency plot of 120 craters on plateau materials (units Npls and Nplh, undifferentiated) in center of quadrangle 40332. N5 age is 785±250 (Middle Noachian). Symbols same as figure 1.

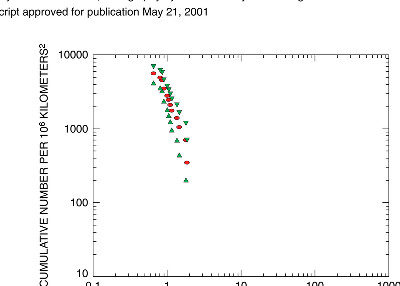


Figure 6. Cumulative diameter versus frequency plot of 16 craters having diameters greater than 650 m on lobate lowland material (unit Hl). N1 age is 2850±1000 (Late Hesperian). Symbols same as figure 1.

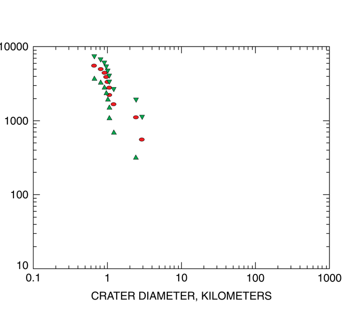


Figure 4. Cumulative diameter versus frequency plot of 10 craters having diameters greater than 650 m on smooth and rilled volcanic materials (units Hvs and Hvr, undifferentiated) in quadrangle 35332. N1 age is about 3400±1400 (Early Hesperian). Symbols same as figure 1.

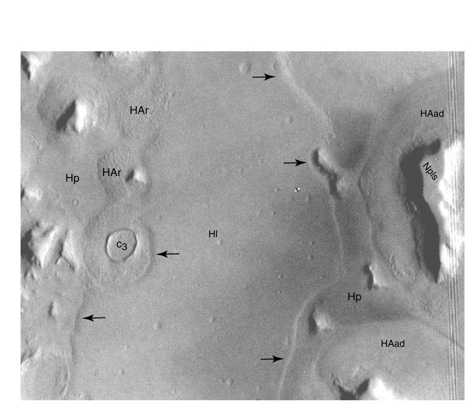


Figure 5. Lobate lowland material (unit Hl) in quadrangle 45332. Contacts (arrows) are rounded, convex-upward, and indicate material stands higher than underlying materials. Note moderately abundant but degraded small craters. Hp, smooth lowland plains material; HAr, ribbed material; HAad, debris apron material; Npls, smooth plateau material. Part of Viking Orbiter image 267S44, 95 m/pixel (centered near 44.5° N., 332.8° W.).

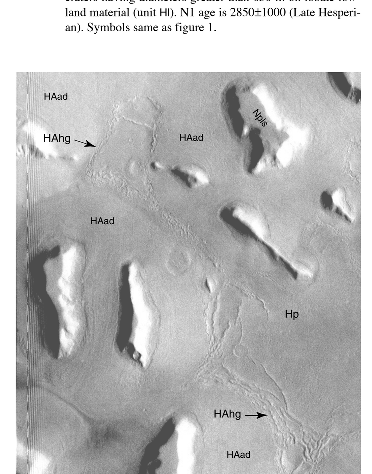
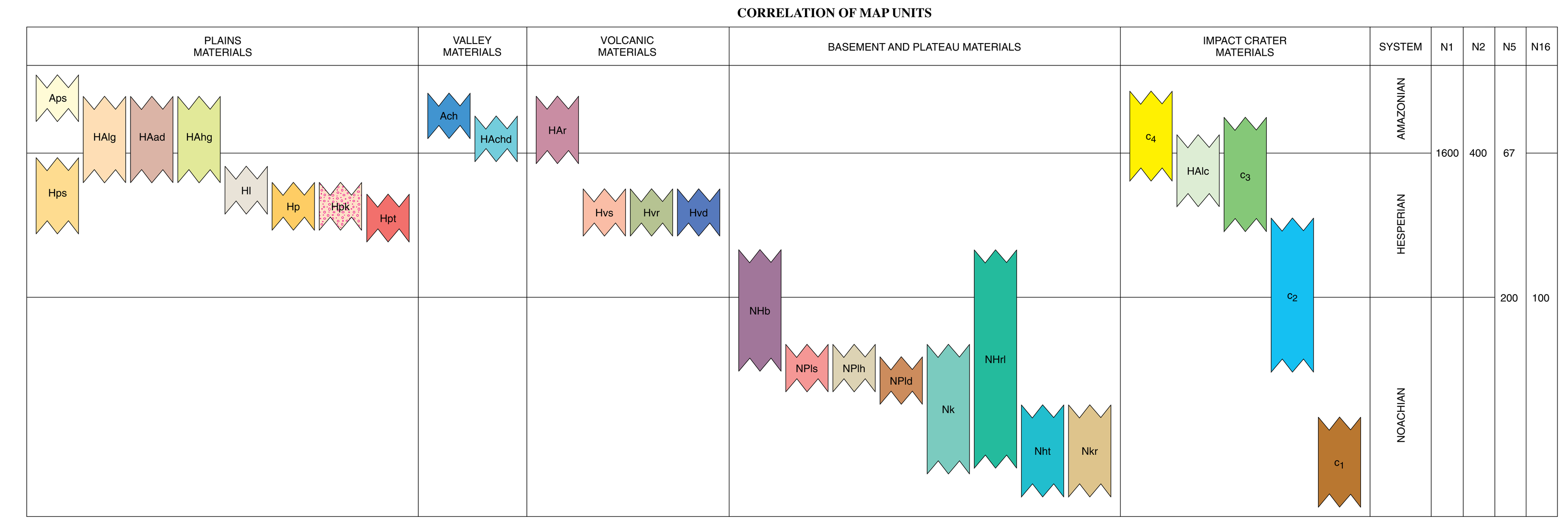


Figure 7. Typical appearance of debris apron material (unit HAad) and heavily grooved lowland material (unit HAhg). Note tendency for pronounced grooves at edges of debris aprons, especially where two aprons abut. Hp, smooth lowland plains material; Npls, smooth plateau material. Part of Viking Orbiter image 267S46, 94 m/pixel (centered at 44.6° N., 331.3° W.).

GEOLOGIC MAP TRANSECTING THE HIGHLAND/LOWLAND BOUNDARY ZONE, ARABIA TERRA, MARS: QUADRANGLES 30332, 35332, 40332, AND 45332

By
George E. McGill
2002

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

Nht **Highland terrane material**—Irregular surface locally characterized by large ridges, large formless depressions, hilly and hummocky topography, or flat to gently rolling terrane; probably about coeval with the largest and oldest craters; gradational from south to north into plateau materials. *Interpretation*: Mostly ancient crater and basin ejecta, but some intermixed volcanic materials may also be present

Figure 8. Large zones of faulting or fracturing (bound by dashed lines) in quadrangle 45332. Such zones may have controlled erosion responsible for creating fretted terrane.

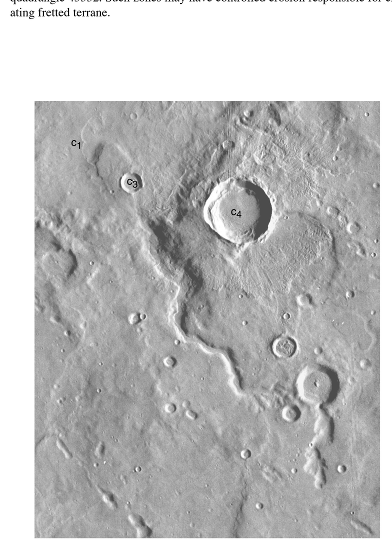


Figure 9. Example of small channel in quadrangle 30332, showing delta where channel debouches into large crater (c_1). Parts of Viking Orbiter images 231S06, 07, and 08, 60 m/pixel (centered at 29.3° N., 334.1° W.).

STRATIGRAPHY

… Twenty-eight units have been defined: eight basement and plateau units, nine plains units, two valley-floor units, four volcanic units, and five impact crater units. Unit symbols are based on feature association or textural characteristics (lower-case letters) preceded by an upper-case modifier (N, H, or A) indicating the time-stratigraphic assignment (Noachian, Hesperian, and Amazonian, respectively) for the unit.

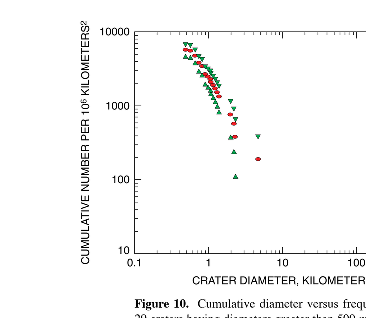


Figure 10. Cumulative diameter versus frequency plot of 29 craters having diameters greater than 500 m on ejecta of a c_2 crater that is superposed on Ismeniae Fossae channel. N2 age is 750±300 (middle Hesperian), which thus is upper limit on age of channel cutting. Symbols same as figure 1.

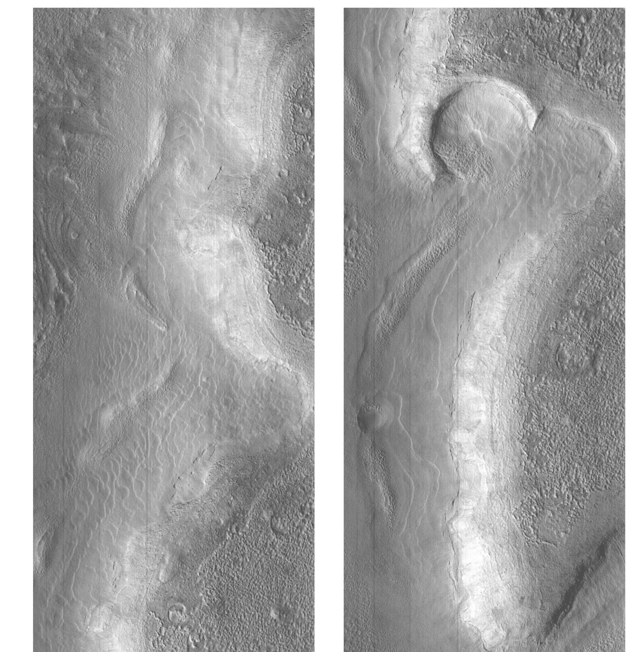


Figure 11. Parallel "bands" along west flank of mesa centered at 46.65° N., 334.85° W. in quadrangle 45332. Sun is to left, and north is approximately up. Bands appear to be ridges, because they are brighter toward sun than away from sun. Mars Orbiter Camera (MOC) image M01-000232 is divided into north (left) and south (right) halves. Width of image strip is 3 km. Resolution of original MOC image is 6 m/pixel.

… been suggested, including erosional modification of craters by fluvial processes (Craddock and Maxwell, 1993; Grant and Schultz, 1990, 1993), infilling of craters by airfall deposits or lava flows (Moore, 1990; Wilhelms and Baldwin, 1989; Tanaka, 2000), and mantling by deposits from an ocean (Edgett and Parker, 1997). The absence of any evidence for concentrated runoff on the rims of ancient craters argues against running water from rainfall or sapping as the cause of resurfacing, and the rather rough topography of the highland terrane material argues against burial by lava or sediment thick enough to mask this rough topography. A sedimentary mantle is consistent with the total loss of small craters but does not fit the nature of the degradation of the surviving large craters. These large craters appear partially filled in, and their ejecta blankets can no longer be discerned, characteristics that could be due to mantling. However, a sedimentary mantle could not obliterate part or most of the rims while leaving remnants with significant relief. A combination of running water partially destroying the rims of large craters followed by an airfall blanket, a sequence proposed by Grant and Schultz (1990), could explain the crater population, as could a combination of running water and ocean deposition. No unequivocal evidence is present in this area to support either of these hypotheses.

Small craters, with diameters less than the mapping cutoff diameter of 3 km, are very abundant on most of the area underlain by highland terrane and plateau materials. However, from the northernmost part of quadrangle 40332 northward into quadrangle 45332 these small craters are rare and are essentially absent over most of quadrangle 45332. Either an erosional or a depositional event (or both) must have taken place after emplacement of the plateau materials, and this event must have increased in intensity northward. The apparent local erosional loss of the uppermost plateau materials to expose the underlying layer of dark plateau material in the northwestern corner of quadrangle 45332 and the northward decline in relief between plateau and mesa surfaces and adjacent lowland surfaces support erosion rather than deposition as the process modifying the surface of the plateaus. Although speculative, a possible explanation for this event is deposition from an ocean or coastal erosion during recession of the inferred ocean (Edgett and Parker, 1997).

Small craters are very rare on most lowland materials. In part this must be due to the very young ages of these materials, but that explanation probably does not entirely account for the paucity of craters. As shown in figure 5, the craters superposed on lobate lowland material (unit Hl), and used to determine its crater age, are all degraded in appearance. Craters of the same size on highland materials are mostly fresh and crisp. Because many of the lowland plains materials exhibit characteristics suggestive of flow, it is possible that small craters were rapidly degraded if flow continued after crater formation.

VALLEYS

Small, somewhat sinuous valleys are present but not abundant in areas underlain by highland terrane and plateau materials. This paucity of small valleys and valley networks is a regional characteristic of the entire Arabia Terra area (Carr, 1996). Most of the small valleys present in the area mapped are on highland terrane (unit Nht) in quadrangle 30332, and the remainder are on plateau materials in quadrangle 35332 and the southernmost part of quadrangle 40332. Typically, the valleys range in width from about 3 kilometers down to the limit of resolution and in length from a few tens of kilometers to about 100 kilometers. At their sources, most of the valleys consist of one or more narrow, roundheaded troughs, but some appear to begin in craters. Most valleys widen downstream, and all have few or no tributaries. Valleys eroded into highland terrane material generally drain into impact craters, whereas all valleys eroded into plateau materials drain into large fretted valleys. Locally, small deltas (fig. 9) are present at the mouths of these valleys, strongly implying the presence of lakes within some of the old craters. The time of formation of these small valleys is difficult to estimate. Valleys cut into highland terrane must be Late Noachian or younger, otherwise they would have been obliterated by the process that destroyed most of the c_1 craters. Those valleys that cut into plateau materials and that drain into fretted valleys must be the same age or younger than the fretted valleys, placing an old age limit on those valleys of Early to early Late Hesperian (see below). Estimating young limits is generally not possible, but one of the valleys (fig. 9) is clearly older than a 3.5-km-diameter c_3 crater and a 10-km-diameter c_4 crater, and thus is most likely of Hesperian age.

Fretted valleys have been explained as due to running water (Lucchitta, 1978), sapping (Sharp, 1973; Sharp and Malin, 1975), or one or more mass wasting processes (Lucchitta, 1984; Carr, 1995, 1996). The morphology of the Ismeniae Fossae valley segment present in quadrangle 35332 has been described in detail by Carruthers (1996) and Carruthers and McGill (1998). Both sources of this fretted valley coincide with deep, irregular depressions, the floors of which are significantly lower than the floors of the valley branches flowing out of them. Regardless of the origin of these deep depressions, this topographic evidence points to the presence of lakes in the depressions, and that in turn indicates an important role for running water in cutting the fretted valley. As discussed elsewhere (Carruthers, 1996; Carruthers and McGill, 1998), evidence exists for a hydrovolcanic origin for at least one of these deep depressions, which also supports the presence of liquid water.

The depth of the Ismeniae Fossae fretted valley within quadrangle 35332 indicates a complex formation and modification history. From the western source to the irregular, possibly volcanic, depression at 37.2° N., 332.7° W. the valley is 600 to 1000 m deep. Within the putative volcanic depression the depth is 1800 to 2000 m. Downstream from this depression the valley shallows to a depth of 450 m and then deepens again to 1000 m before leaving the area of the quadrangle. Within this area, the elevation of the bounding plateau surface varies by only about 300 m, and thus the valley depths represent real differences in floor elevation.

The age of the Ismeniae Fossae fretted valley can be constrained rather well. It must be younger than the plateau materials it cuts, which places a Middle Noachian old age limit on formation. In the northeast corner of quadrangle 35332 and in the adjacent quadrangle to the east, a large c_2 crater is superposed on this valley, completely burying a short section of it (McGill, 2000). The crater population (fig. 10) superposed on the ejecta blanket of this crater yields an N2 age of 750±300 (middle of the Hesperian). Thus the valley must be older than middle Hesperian. The putative volcanic deposits around the deep depression at the western source of the fretted valley yield an Early Hesperian age (fig. 4), and thus if one accepts a genetic association between the formation of the depression and the cutting of the valley, the most likely time of fretted valley cutting is Early Hesperian.

The floor of the fretted valley is characterized by grooved and lineated material (unit Ach) that has been interpreted as due to mass wasting, most likely some form of debris flow (Squyres, 1978, 1979; Lucchitta, 1984; Carr, 1995, 1996). This material is essentially devoid of superposed impact craters. Furthermore, even though the large Hesperian c_2 crater in the northeastern part of quadrangle 35332 is clearly superposed on the valley, the valley floor materials are equally clearly superposed on crater ejecta. These observations lead to the conclusion that valley floor material is young, most likely Amazonian in age, and thus very much younger than the age of formation of the valley itself. Mass wasting processes almost certainly have modified the fretted valley, but no evidence exists to suggest that they actually formed the valley.

FLOW DEPOSITS

The materials inferred to have formed by some process of viscous flow have been thoroughly studied (Squyres, 1978, 1979; Lucchitta, 1984; Kochel and Peake, 1984; Carr, 1995, 1996; Colaprete and Jakosky, 1998). These authors envisage unconsolidated materials flowing under the influence of gravity because of interstitial water or ice, analogous to slow debris flows and rock glaciers on Earth. The use of the term "debris flow" here to encompass all of these mapped materials is a matter of convenience and does not imply any preference for ice versus water as the interstitial material. Generally, past studies have concentrated on the lineated valley floor and debris apron materials. The debris aprons surround most knobs and mesas in the lowland and are present adjacent to the scarps that rise to the highland plateau surface. In the northwest corner of quadrangle 40332, MOLA track ap00023k crosses a debris apron and the plateau scarp. The apron exhibits the anticipated gentle, convex-upward slope, which averages about 1.9° (McGill, 2000). The slope of the plateau scarp is about 15°, and other scarps in this area have slopes of 15° to 25°, similar to values determined by Parker and others (1989).

The grooves and ridges that characterize most of these materials can form either parallel to the flow direction or normal to it (Squyres, 1978). Squyres (1978) favored formation normal to flow in most instances because the most pronounced grooves and ridges are found at the convergence of debris aprons or where flow is confined by scarps, an observation verified by detailed mapping here. He argues that the lineated valley floor material is due to converging flow from opposite walls of the valley and that the major flow direction is transverse to the valley itself. However, Lucchitta (1984) notes examples of grooves and ridges that enter a valley normal to its length and then curve into parallelism, suggesting dominant flow parallel to the valley. Detailed mapping indicates that the lineated valley floor material is generally separated from the valley walls by an older surface that slopes gently toward the valley center (Parker and others, 1989) and that the contact of the lineated material is rounded, convex upward. This relation also argues for dominant flow parallel to the valley. However, the presence of heavily grooved lowland material (unit HAhg) at the edges of debris aprons and where aprons are in contact with each other is consistent with formation of the grooves and ridges normal to the flow direction. Furthermore, the formation of valley-parallel grooves and ridges by valley-parallel flow in completely enclosed valleys is difficult to understand.

In addition to the valley and apron deposits, areally extensive deposits of ungrooved and lightly grooved lowland materials (units Hl and HAlg) are neither confined to valleys nor found as convex-upward aprons surrounding knobs and mesas. The sources of the materials making up these deposits are not apparent.

All of the debris flow deposits are younger than the smooth lowland plains material (unit Hp) and its local variants textured and knobby lowland plains materials (units Hpt and Hpk). Whatever its genesis, the apparent presence of smooth lowland plains material along the edges of valleys and erosional re-entrants into the highlands provides further evidence for the completion of the erosion that formed fretted terrane and fretted valleys before the onset of demonstrable mass wasting on a large scale.

KNOBS AND MESAS

Abundant knobs and mesas that range in size from features near the resolution limit of the images to large mesas many tens of kilometers across characterize the lowland portions of the area mapped. The large mesas are almost certainly erosional remnants of highland plateaus. Smaller features also have been mapped as plateau remnants if they are mesas; that is, if they preserve a remnant of a flat top. The implication is that these mesas are capped by materials younger than the Early Noachian basement that most likely underlies the northern plains materials. Knobs do not have flat tops, so their origin is less certain. Some of the largest knobs are probably plateau remnants that have eroded enough to be all in slope; that is, no flat top is preserved. Other knobs, especially the abundant small ones, are probably inliers of pre-plateau materials, as seen at other lowland localities on Mars (Maxwell and McGill, 1987; McGill, 1989; McGill and Dimitriou, 1990). Because separating knobs according to origin is not possible, their age range overlaps most other Noachian materials on the correlation chart.

Between the plateau edge in the northwest corner of quadrangle 40332 and the north border of quadrangle 45332 the elevations of the mesa tops decline very gently. As measured on two MOLA tracks (ap00023k and ap00372k) this elevation change of the plateau surface is about 500 m over a horizontal distance of about 375 km, for an average slope of about 0.08°.

Bands on Mesa Flank

MOC image M01-000232 provides a detailed view of the west flank of a small mesa centered at 46.65° N., 334.85° W. Narrow bands characterize this flank along most of its length (fig. 11). These bands are especially clear near the north end of the mesa, where two bands maintain uniform spacing …

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