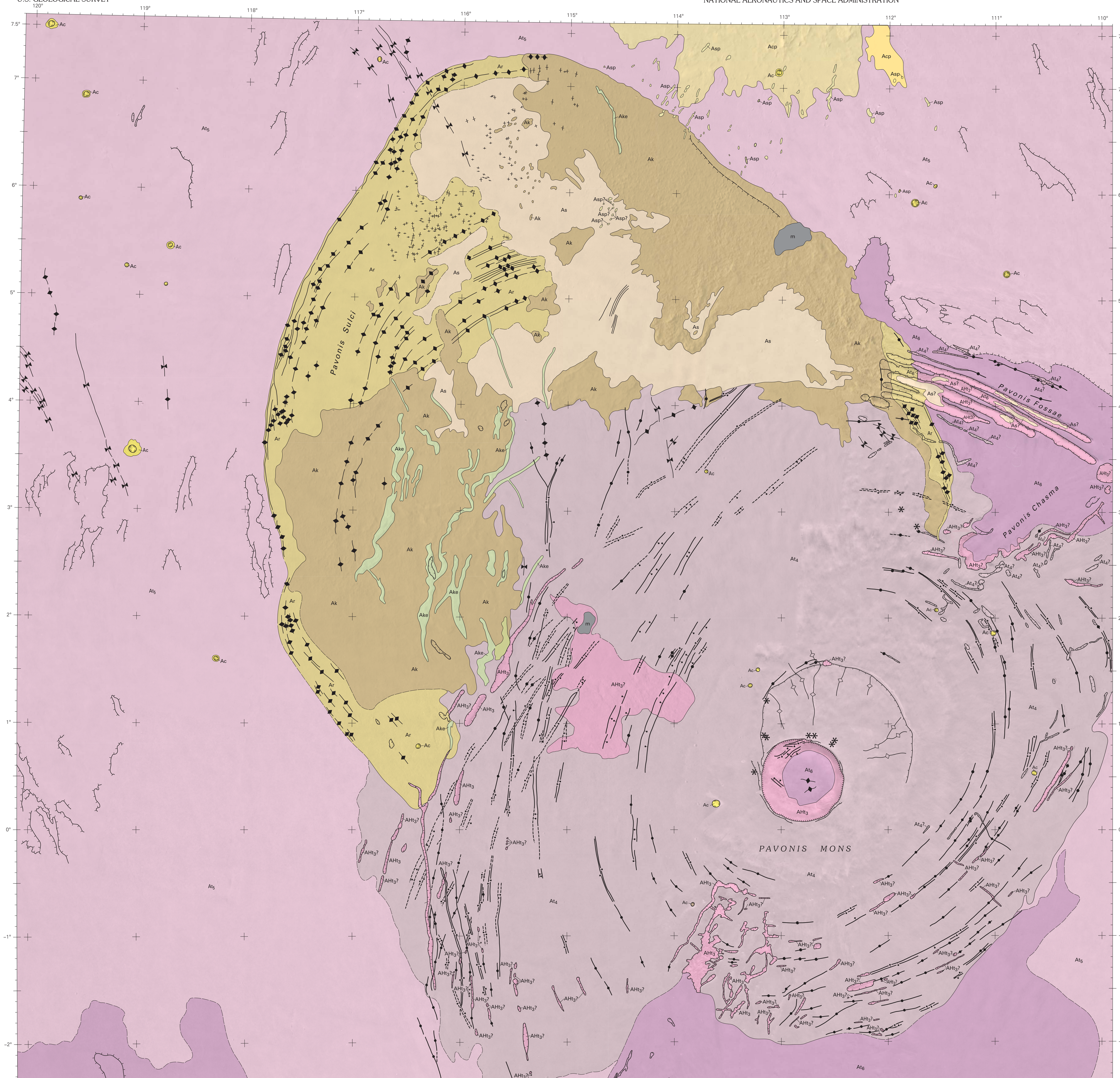

Base from U.S. Geological Survey, 1992 a, b, c, d

SCALE 1:1 004 000 (1 mm = 1.004 km) AT 115° LONGITUDE
TRANSVERSE MERCATOR PROJECTION

INTERIOR—GEOLOGICAL SURVEY, RESTON, VA—1998

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

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Manuscript approved for publication August 8, 1995

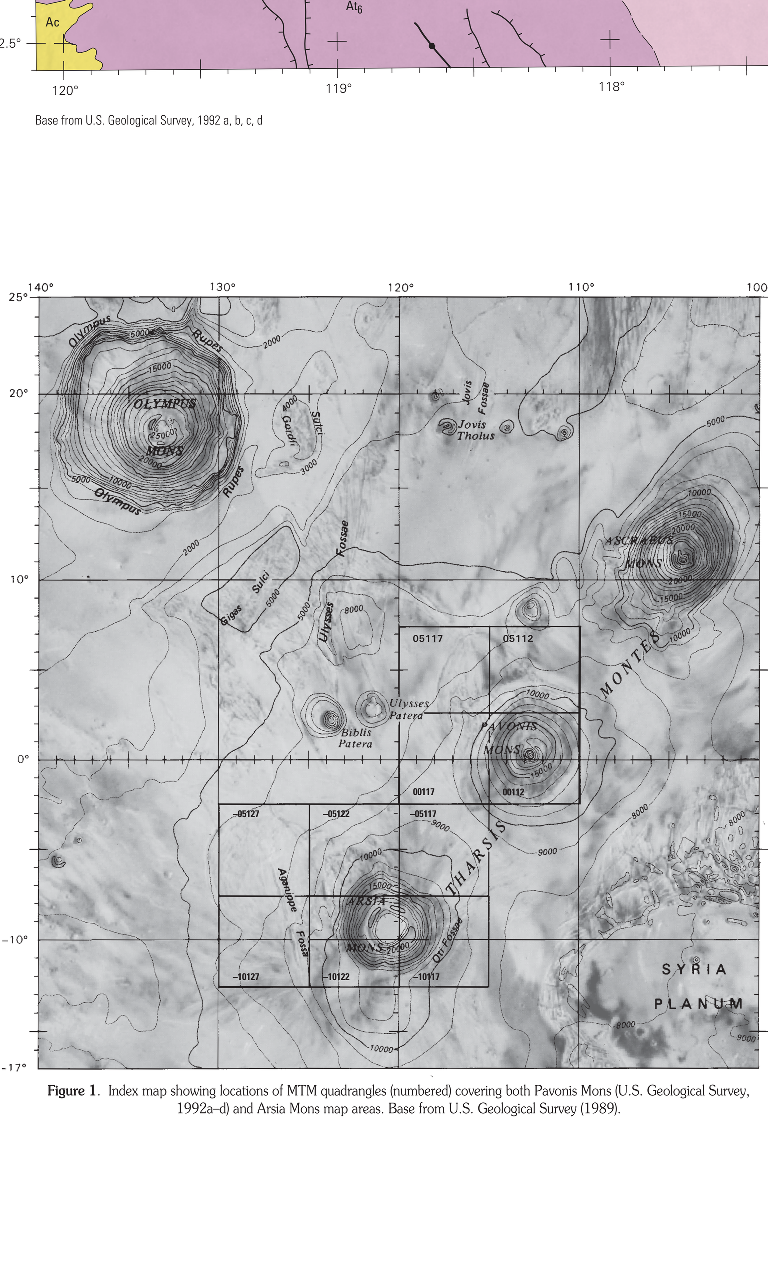


Figure 1. Index map showing locations of MTM quadrangles (numbered) covering both Pavonis Mons (U.S. Geological Survey, 1992a–d) and Arsia Mons map areas. Base from U.S. Geological Survey (1989).

GEOLOGIC MAP OF PAVONIS MONS VOLCANO, MARS

By
David H. Scott, James M. Dohm, and James R. Zimbelman
1998

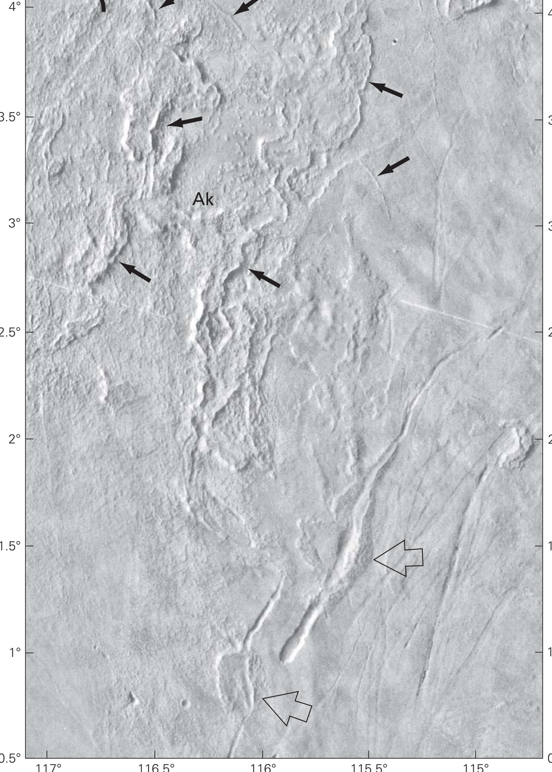
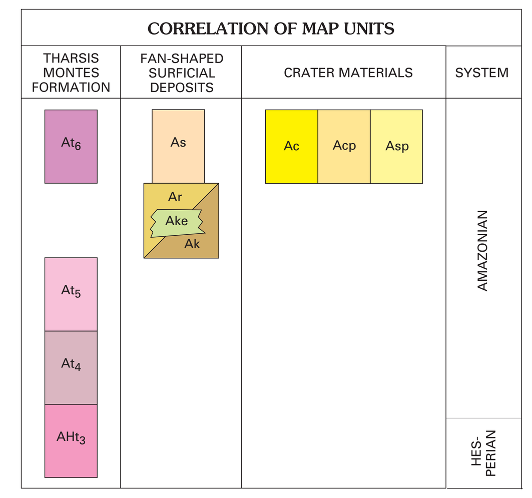


Figure 2. Narrow ridges (curved arrows), interpreted as moraines, mainly occur in ridged facies (Ar) of fan-shaped deposits. Elongate sinuous ridges (straight arrows), interpreted as eskers or margins of lava flows, some originating from possible volcanic constructs (open arrows) along margins of troughs, occur mostly within knobby facies (Ak) of fan-shaped deposits. Enhanced, digital mosaic base of Viking Orbiter images 49B33–49B37 produced by E.M. Lee of the U.S. Geological Survey, 1994, scale 1:502,000.

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

THARSIS MONTES FORMATION

[Includes large volcanic shields and associated lava flows of Arsia Mons, Pavonis Mons, and Ascraeus Mons (Scott and Tanaka, 1986). Members are difficult to distinguish on 1:500,000-scale maps, but at smaller scales they can be broadly separated by crater counts]

At_6 **Member 6**—Smooth, fresh-appearing, overlapping lava flows erupted from central caldera and fissures on flanks of Pavonis Mons; faulted in places. Overlies or embays knobby and ridged units of fan-shaped deposits; stratigraphic position with respect to smooth facies uncertain but probably about same age

At_5 **Member 5**—Resembles member 6 on lower quality images—boundaries indistinguishable in places; better images show prominent lava flow lobes and relatively rougher surface than member 6. Secondary craters from Poynting impact crater superposed on member 5. Directly underlies ridged and knobby facies of fan-shaped materials

At_4 **Member 4**—Forms smooth appearing, highly faulted central shield of Pavonis Mons; fissures and faults mainly concentric to summit caldera with fewer following structural trend of Tharsis Montes. Directly underlies members 5 and 6 and knobby and smooth facies of fan-shaped deposits

AHt_3 **Member 3**—Forms deeply eroded, rough-surfaced lava flows; minor occurrence relative to its areal extent at Arsia Mons. Directly underlies or embayed by members 4 and 6

FAN-SHAPED SURFICIAL DEPOSITS

As **Smooth facies**—Smooth-surfaced material occupies low areas in ridged and knobby facies; sparsely lineated compared to similar appearing facies at Arsia Mons. Low-relief streamlined hills and groups of hills in unit aligned nearly normal to outer margin of fan-shaped deposits and to transverse ridge systems in ridged facies. *Interpretation*: Ash-flow tuffs or lahars embay and partly bury ridged and knobby facies; streamlined hills are drumlins having long axes oriented parallel to direction of glacier movement. Partly fills the complex of fissures and collapse pits on the northeast flank of the volcano

Ar **Ridged facies**—Occurs mostly around outer, lower margin of fan-shaped deposits; characterized by rib-like closely spaced, transverse, parallel ridges many kilometers long. Streamlined hills more prominent and abundant than in smooth facies. Overlaps member 5 of Tharsis Montes Formation. *Interpretation*: Recessional moraines transverse to margin of glacier; drumlins formed by ice movement before onset of recessional phase

Ake **Elongate ridged material**—Elongate, irregular deposits forming rough, sinuous ridges interspersed with knobby and ridged facies. *Interpretation*: Eskers formed by deposition of sedimentary material beneath or within a wasting ice sheet; alternatively, the margins of unique lava flows originating on the lower western flank

Ak **Knobby facies**—Forms large hills and hummocky terrains containing long, irregular, sinuous to linear ridges many kilometers long; interspersed with ridged facies in places. Overlaps members 4 and 5 of Tharsis Montes Formation but underlies member 6 in places. *Interpretation*: Rugged, hilly material containing eskers and recessional moraines in places; represents landforms developed beneath the wastage zone of a disintegrating ice sheet

CRATER MATERIALS

[Impact craters less than about 3 km rim crest diameter are not mapped]

Ac **Material of fresh appearing craters**—All craters in map area have rim crest diameters <5 km diameter; includes ejecta deposits extending as much as one crater diameter from rim crest

Acp **Rim material of Poynting Crater**—Forms rugged to faintly lineated ejecta on outer rim of crater; secondary craters common. Crater rim crest (~80 km diameter) north of map area

Asp **Secondary crater material from Poynting Crater**—Occurs as elongate depressions and overlapping crater chains oriented radial to Poynting; formed by ejecta from Poynting. Overlies member 5 and knobby facies

Contact—Dashed where approximately located

Fault or graben—Dashed where partly buried. Bar and ball on downthrown side

Narrow ridge—Interpreted as moraine

Wrinkle ridge

Narrow trough

Depression—Dashed where partly buried; interpreted to result from collapse. Forms contact in places

Lava flow front—Dashed where approximately located; forms contact in places

Small dome—Interpreted as volcanic; age uncertain. Queried where uncertain

Irregular mound—Age and origin uncertain

Lineation—In smooth facies. Probably a flow line

Elongate hill—Interpreted as drumlin

Caldera

Crater rim crest

Buried crater rim—Showing crest

INTRODUCTION

The geologic map shows lava flows and fan-shaped deposits on Pavonis Mons, the central of three large shield volcanoes (Arsia, Pavonis, and Ascraeus Montes) that form the Tharsis Montes volcanic chain. The volcanoes lie along the crest of a regional northeast-trending rise that extends more than 3,000 km across the western equatorial region of Mars (fig. 1). The volcanic history of Pavonis Mons is similar to that of other volcanoes in the western equatorial region of Mars (Scott and others, 1981a–c; Scott and Tanaka, 1981, 1986; Zimbelman and Edgett, 1992). Previous geologic mapping of this region (Scott and others, 1981a–c; Scott and Tanaka, 1981, 1986) shows six major lava flows that were extruded from the Tharsis volcanoes during the Early Hesperian to Late Amazonian Epochs; four of these lava flow members are present in the map area. On the northwest flank of Pavonis Mons, broad, lobate, fan-shaped deposits form a surficial cover similar to other fan-shaped deposits on the northwest flanks of Arsia, Ascraeus, and (to a lesser degree) Olympus Montes. Similar to those of Arsia Mons, the fan-shaped deposits of Pavonis Mons consist of several facies whose origins are attributed to glaciation, mass wasting, and pyroclastic volcanism origins.

The present map was compiled originally using four Viking 1:500,000-scale photomosaic bases (fig. 1). Then, to show more clearly the regional relations, the maps were reduced to 1:1,000,000 scale and combined on one map sheet. Image quality is generally poor throughout the map area, especially on the west flank of Pavonis Mons, even though most images have a resolution of about 75 m per pixel.

The purpose of the large-scale (1:500,000) mapping was to study the morphology and stratigraphy of the fan-shaped materials on Pavonis Mons for comparison with those on Arsia Mons (Scott and Zimbelman, 1995) and to determine whether they have similar origins and ages. The geologic units were mapped, dated, and interpreted more accurately using the larger scale than was possible on smaller scale 1:2,000,000 (Scott and others, 1981a–c; Scott and Tanaka, 1981) and 1:15,000,000 (Scott and Tanaka, 1986) maps. Map units generally correspond to those on the geologic map of the western equatorial region of Mars (Scott and Tanaka, 1986) and to units on the map of Arsia Mons (Scott and Zimbelman, 1995).

GEOLOGIC AND PHYSIOGRAPHIC SETTING

The map area (fig. 1) lies along the martian equator in the Tharsis southeast (MC–9 SE; U.S. Geological Survey, 1991a) and southwest (MC–9 SW; U.S. Geological Survey, 1991b) and Phoenicis Lacus northeast (MC–17 NE; U.S. Geological Survey, 1986a) and northwest (MC–17 NW; U.S. Geological Survey, 1986b) quadrangles of Mars. The summit of Pavonis Mons is about 18,000 m above datum (U.S. Geological Survey, 1989) and is several kilometers lower in elevation than Arsia and Ascraeus Montes, the two neighboring volcanoes. The central caldera of Pavonis Mons is about 45 km in diameter; it is nested within a larger (~95 km diameter), partly closed older depression whose rim has been buried on the southwest by young lava flows. The upper part of the shield has an average slope of about 4.5° between the summit and the 10,000-m-contour elevation (U.S. Geological Survey, 1989). Lava flows and fan-shaped deposits on Pavonis Mons are probably about the same age as those on Arsia and Ascraeus Montes (Scott and Tanaka, 1986), but crater frequency estimations are not very reliable because of the relatively small areas covered by some of the rock units. However, regional stratigraphic relations and crater density determinations covering larger areas (Scott and Tanaka, 1986; Tanaka and others, 1988), as well as counts of small craters on individual volcanic constructs (Plescia and Saunders, 1979; Neukum and Hiller, 1981), indicate that the volcanoes of Tharsis Montes were active throughout the Hesperian and Amazonian Periods.

STRATIGRAPHY

Young lava flows and fan-shaped deposits of possible glacial and volcanic origin on Pavonis Mons are similar to those on Arsia Mons (Scott and Zimbelman, 1995); older lava flows of Early Hesperian age have not been recognized on Pavonis Mons. Fan-shaped deposits cover a large area on the northwest flank of Pavonis Mons, like the more extensive deposits on the western flank of Arsia Mons (Scott and Zimbelman, 1995). The deposits northwest of both volcanoes are confined to the restricted elevation between 6 and 11 km (Zimbelman and Edgett, 1992), which may be related to climatologic factors governing the stability or availability of ice or other volatiles. The fan-shaped deposits of both Arsia and Pavonis Montes consist of three major facies: (1) hummocky and hilly material (unit Ak), (2) an outer faintly ridged deposit (unit Ar), and (3) smooth material (unit As) that is faintly lineated in a few places and appears to overlie all other units with which it is in contact.

AMAZONIAN–HESPERIAN SYSTEMS

Rough-surface material on the west flank of the shield resembles in part lava flows of member 3 (unit AHt_3) of intermediate age on Arsia Mons; this unit is tentatively assigned the same stratigraphic position and unit designation and is queried on the map where stratigraphic position is uncertain. Member 3 is the oldest member of the Tharsis Montes Formation present on Pavonis Mons. Because of the poor image quality, however, boundary relations with adjacent lava flows are based solely on weak morphological evidence.

AMAZONIAN SYSTEM

All three of the Amazonian-age members of the Tharsis Montes Formation are present on Pavonis Mons. The three material units that make up the fan-shaped deposits on Arsia Mons are also present, but some significant differences suggest more glacial activity and ice movement may have occurred at Pavonis than at Arsia Mons, where the postulated ice cap cover apparently was essentially stationary.

The lowermost lava flows of the Amazonian System, member 4 (unit At_4), were extruded from fissures and faults in the crestal area of the volcano and probably from the summit caldera, where it is overlain by a thin mantle of younger volcanics, member 6 (unit At_6). The relatively smooth surface of member 4 is cut by faults and grabens concentric to the shield structure, similar to its counterpart on Arsia Mons (Scott and Zimbelman, 1995); it is queried on the map where stratigraphic position is uncertain. Member 5 (unit At_5) and member 6 overlie member 4 on the southern flank of Pavonis Mons; boundaries between these materials are ill-defined in places and are approximately located. Member 5 is the most aerially extensive volcanic unit exposed on Tharsis Montes (Scott and Tanaka, 1986); the sources for these lava flows are no longer visible, but the flows must have issued from the many systems of faults and fissures associated with the Tharsis rise (Scott and Dohm, 1990). Aside from a thin mantle around the shield summit, the youngest lava flows of member 6 cover the floor of the caldera and, like those on Arsia, have been extruded from fissures and collapse pits on the northeast and southwest sides of the volcano (Scott and Tanaka, 1986; Zimbelman and Edgett, 1992; Scott and Zimbelman, 1995). The complex system of fissures, collapse pits, and faults on the northeast flank may have been episodically active throughout much of the volcano's life.

The fan-shaped lobe of material deposited on the northwest slope of Pavonis Mons covers an area of about 6×10^4 km^2, or about one-half the area of the deposits on the western slope of Arsia Mons. Knobby facies (unit Ak) forms most of the fan-shaped deposit and consists of dense concentrations of small (~100 m to 1 km across) circular to irregularly shaped hills; rough surfaced, large sinuous ridges (unit Ake) are most abundant in the knobby material. These large ridges (fig. 2) are prominent in the southwestern part of the fan-shaped material, where they occur near the northern extensions of some long (20–100 km) depressions that may have vented subsurface water beneath an ice sheet to form eskers, or may have been the sites of late effusive (and pyroclastic?) volcanism (Zimbelman and Edgett, 1992). No sediments appear to have been deposited beyond the margin of the fan-shaped lobe. The knobby unit reaches an elevation of about 10 km (U.S. Geological Survey, 1989) on the northwest flank of Pavonis Mons where it is in contact with lava flows (member 4) that constitute the main part of the volcanic shield.

The ridged facies (unit Ar) occurs within a narrow band along the outer margin of the fan-shaped deposits and is characterized by an assemblage of narrow, parallel, concentric ridges interspersed in places with the small hills; in places, albedo contrasts in underlying materials (lava flows) are visible and indicate that the unit is very thin. Locally, the small hills in the ridged unit grade into knobby facies, but more commonly a noticeable increase in the sizes of hills and hummocks occurs at, or near, their common boundary.

Many hills within the ridged facies, particularly in the northwestern part of the map area, have oval and streamlined shapes similar to drumlins shaped by the flow of ice. Their shape and long axis direction suggest that ice movement was toward the north-northwest; this direction is also consistent with the overall elongate appearance of the fan-shaped deposit as well as with the orientation of some elongate sinuous ridges (unit Ake) as much as 100 km long. The elongate sinuous ridges are interpreted to be eskers (consistent with the discussion above), pyroclastic flows (probably basaltic rather than silicic) that may have emanated from large grabens on the lower west flank of the volcano (fig. 2; Zimbelman and Edgett, 1992), or debris flows. In places, streamlined, coalesced groups of hills have lengths of several kilometers and also may represent eskers interspersed in a drumlin field. Alternatively, the hills may be aligned hummocks on a lava or debris flow, or possibly wind-faceted yardangs in friable materials, resulting from the tremendous downslope winds predicted for all of Tharsis Montes (Lee and others, 1982; Magalhaes and Gierasch, 1982).

Smooth facies (unit As) occurs as broad featureless plains within both the ridged and knobby units and may exist as smooth floor deposits in parts of the fissures and collapse depressions on the northeast flank of the volcano. It bears some resemblance to the smooth, arcuately lineated material on Arsia Mons (Zimbelman and Edgett, 1992; Scott and Zimbelman, 1995) and also appears to overlie both the ridged and knobby facies of the fan-shaped deposits. However, lineations within the smooth facies on Pavonis Mons are rare, and lobate flow fronts characteristic of lava flows (as in members of the Tharsis Montes Formation) are not visible.

ORIGIN OF FAN-SHAPED DEPOSITS ON PAVONIS MONS

The interpreted origins for the deposits that form large, lobate fans on the northwest flanks of both Arsia and Pavonis Montes are generally the same (see Scott and Zimbelman, 1995) but with some minor but important differences. The ridged facies at Pavonis Mons, as at Arsia Mons, probably consists of glacial drift deposited along the margins of an ice sheet during successive stages in its ablation, downwasting, and retreat. Very little material appears to have been deposited between the moraines where albedo contrasts are visible in lava flows of member 5 that underlie the ridged facies. Unlike the large obstructions at Arsia Mons that appear to have deflected the ridge lineaments (possibly indicating mass movement), no large obstacles are recognizable at Pavonis that predate emplacement of the ridged material. However, downslope movement of ice is indicated by many aligned streamlined mounds and hills resembling terrestrial drumlin fields. These features were not evident at Arsia Mons nor were the large irregular ridges that are prominent in the knobby facies at Pavonis Mons, which may be eskers.

The ridged and knobby facies are intermixed in places along their common boundary. Although some ridges extend as a series of aligned hills into the knobby material, the two units are morphologically distinct. Both facies are similar to types of depositional landforms described by Sugden and John (1976) that develop beneath the wastage zone of a disintegrating ice sheet just after reaching its maximum extent. In their model, the ridged outer facies is composed of till in the form of many concentric terminal moraines formed during recession of ice. Inside this area moraines are superseded by ice disintegration features that include rough, undulating, hummocky terrain and a few ridges with preferred orientations; eskers also become more prominent in this zone and several possible eskers are identified on our map as elongate ridged material. Scarps or detachment surfaces indicating landsliding are not evident on the Pavonis shield.

Smooth material overlies the ridged and knobby facies and, as on Arsia Mons, may consist of pyroclastic material (Zimbelman and Edgett, 1992; Scott and Zimbelman, 1995). However, the smooth facies on Pavonis Mons does not show the many closely spaced flow lineations that are visible in this facies on Arsia Mons. Though the large depressions on the northeast flank of Pavonis Mons contain smooth plains materials that are interpreted to be smooth facies, the strong relation between the smooth facies of Arsia Mons and their probable source vents, the large fault-bounded depressions, is not present on Pavonis Mons.

Although some differences in morphology exist among fan-shaped materials on Pavonis and Arsia Montes, their overall similarity, stratigraphy, and position on the two volcanic shields suggest a common origin. Aside from possible mass movement of material by landsliding at Arsia Mons, two main processes, glacial and volcanic, can account for the emplacement of fan-shaped materials at both volcanoes.

GEOLOGIC SUMMARY

Volcanism in Tharsis Montes began during the Hesperian Period and continued throughout the Amazonian Period. Most of the lava flows and associated materials exposed at Pavonis Mons are relatively young (Amazonian) and of more limited extent than those around the other two large volcanoes (Arsia and Ascraeus Montes) in the Tharsis chain. The oldest lava flows on Pavonis Mons are tentatively identified as member 3 of the Tharsis Montes Formation; they were erupted during the Late Hesperian–Early Amazonian epochs and are exposed in relatively small areas on the volcano. Lower Amazonian lava flows cover most of the shield of Pavonis Mons. This period of volcanic activity was probably associated with uplift, rifting, and reactivation of the central structure, as shown by the abundance of concentric faults and grabens in member 4 of the formation; several faults are almost completely covered by member 5 lava flows, the last large eruptive episode at Pavonis Mons that occurred during the Middle Amazonian. The youngest lava flows, of Late Amazonian age, are relatively limited in extent; they issued from a complex of faults and fissures on the northeast and southwest flanks of the volcano and also occupy the central caldera. These flows were concurrent with, or closely followed, the emplacement of the fan-shaped deposits on the northwest side of Pavonis Mons.

The fan-shaped deposits consist of three major facies with distinct morphologies. Although the facies are intermixed and partly gradational in places, evidence suggests that they originated by different processes. Ridged material most likely formed as recessional moraines along the outer margins of an ice sheet during successive stages in its retreat; knobby material is interpreted to consist of fluvioglacial and drift deposits largely produced as subice disintegration features; the smooth unit probably was emplaced as pyroclastic materials, similar to ash-flow tuffs, or possibly as lahars during final stages in the volcanic activity on Pavonis Mons.

REFERENCES CITED

Lee, S.W., Thomas, P.C., and Veverka, J., 1982, Wind streaks in Tharsis and Elysium: Implications for sediment transport by slope winds: Journal of Geophysical Research, v. 87, p. 10,025–10,041.

Magalhaes, J., and Gierasch, P., 1982, A model of martian slope winds: Implications for eolian transport: Journal of Geophysical Research, v. 87, p. 9975–9984.

Neukum, G., and Hiller, K., 1981, Martian ages: Journal of Geophysical Research, v. 86, p. 3097–3121.

Plescia, J.B., and Saunders, R.S., 1979, The chronology of the martian volcanoes, *in* Lunar and Planetary Science Conference, 10th, Houston, March 19–23, 1979, Proceedings: Houston, Lunar and Planetary Institute, p. 2841–2859.

Scott, D.H., and Dohm, J.M., 1990, Chronology and global distribution of fault and ridge systems on Mars, *in* Lunar and Planetary Science Conference, 20th, Houston, March 13–17, 1989, Proceedings: Houston, Lunar and Planetary Institute, p. 487–501.

Scott, D.H., Schaber, G.G., Horstman, K.C., Dial, A.L., Jr., and Tanaka, K.L., 1981a, Map showing lava flows in the southwest part of the Tharsis quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1268, scale 1:2,000,000.

———1981b, Map showing lava flows in the northwest part of the Phoenicis Lacus quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1272, scale 1:2,000,000.

Scott, D.H., Schaber, G.G., and Tanaka, K.L., 1981c, Map showing lava flows in the southeast part of the Tharsis quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1269, scale 1:2,000,000.

Scott, D.H., and Tanaka, K.L., 1981, Map showing lava flows in the northeast part of the Phoenicis Lacus quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1277, scale 1:2,000,000.

———1986, Geologic map of the western equatorial region of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1082, scale 1:15,000,000.

Scott, D.H., and Zimbelman, J.R., 1995, Geologic map of Arsia Mons volcano, Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–2480, scale 1:1,000,000.

Sugden, D.E., and John, B.S., 1976, Glaciers and landscape, a geomorphological approach: New York, John Wiley, 376 p.

Tanaka, K.L., Isbell, N.K., Scott, D.H., Greeley, Ronald, and Guest, J.E., 1988, The resurfacing history of Mars: A synthesis of digitized, Viking-based geology, *in* Lunar and Planetary Science Conference, 18th, Houston, March 16–20, 1987, Proceedings: Houston, Lunar and Planetary Institute, p. 665–678.

U.S. Geological Survey, 1986a, Topographic map of the Phoenicis Lacus northeast quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1689, scale 1:2,000,000.

———1986b, Topographic map of the Phoenicis Lacus northwest quadrangle of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–1711, scale 1:2,000,000.

———1989, Topographic maps of the western, eastern equatorial, and polar regions of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–2030, scale 1:15,000,000.

———1991a, Topographic map of the Tharsis southeast quadrangle (MC–9 SE) of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–2112, scale 1:2,000,000.

———1991b, Topographic map of the Tharsis southwest quadrangle (MC–9 SW) of Mars: U.S. Geological Survey Miscellaneous Investigations Series Map I–2113, scale 1:2,000,000.

———1992a, Controlled photomosaic of part of the Pavonis Mons region of Mars [MTM 00117]: U.S. Geological Survey Miscellaneous Investigations Series Map I–2248, scale 1:500,000.

———1992b, Controlled photomosaic of part of the Pavonis Mons region of Mars [MTM 00112]: U.S. Geological Survey Miscellaneous Investigations Series Map I–2249, scale 1:500,000.

———1992c, Controlled photomosaic of part of the Pavonis Mons region of Mars [MTM 05117]: U.S. Geological Survey Miscellaneous Investigations Series Map I–2250, scale 1:500,000.

———1992d, Controlled photomosaic of part of the Pavonis Mons region of Mars [MTM 05112]: U.S. Geological Survey Miscellaneous Investigations Series Map I–2251, scale 1:500,000.

Zimbelman, J.R., and Edgett, K.S., 1992, The Tharsis Montes, Mars: Comparison of volcanic and modified landforms, *in* Lunar and Planetary Science Conference, 22nd, Houston, March 18–22, 1991, Proceedings: Houston, Lunar and Planetary Institute, p. 31–44.

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