



FIGURE 1. Index map of the Tharsis volcanic province showing quadrangle locations. The number preceded by 1 refers to folio 1:2,000,000 geologic map.

INTRODUCTION

The systematic mapping of lava flow units in the Tharsis region has been compiled into a series of 16 maps at 1:2,000,000 scale. This work provides information on the sources and areal extent of the lava flows, on their eruptive sequences and relative ages, and on relations between the flows and geologic structure in the largest volcanic province on Mars. Some of the maps were made from controlled Viking photomosaics published as quarter quadrangles in the Atlas of Mars Photomosaic Series (U.S. Geological Survey, 1979) and tied to the Viking control net. Where these photomosaics were not available, larger scale catalog photomosaics tied to the Mariner 9 control net were used. These maps were subsequently reduced to the 1:2,000,000 scale, but slight discrepancies may occur in places between features referred to coordinates on the two types of bases.

Mariner 9 orbital images of the region show a few major flow units, mapped around Olympus Mons by Carr (1975) and by Morris and Dwyer (1978), around Arsia Mons by Mursky, Dial and Strobel (1978), and around Alba Patera by Wise (1979). However, flow lobes characteristic of individual lava extrusions were difficult to recognize on the wide-angle A-camera frames used for geologic mapping. With the acquisition of moderate- and high-resolution pictures from the Viking mission, numerous individual lava flows in the Tharsis region were identified and mapped in detail over large areas (Schaber and others, 1978; Scott and others, 1979). Although the geologic investigation was mostly directed toward the mapping of lava flows and the determination of their eruptive sequences, structural features such as faults, fractures, and the basal scarp around Olympus Mons were also mapped and dated relative to the flow units. In this way a sequence of tectonic episodes was determined in conjunction with the major volcanic events.

The Tharsis volcanic province as defined in this study covers some 18 million square kilometers. It is approximately rectangular, extending from lat 40° S to lat 45° N between long 30° and long 155° (fig. 1). Within this province occur the four largest and youngest volcanoes on Mars: Olympus Mons, Arsia Mons, Pavonis Mons, and Ascraeus Mons; the latter three collectively form the large elevated area named the Tharsis Montes. Older major physiographic and structural features are Alba Patera, an ancient low-relief volcano of great size; Achernis Fossae, thought to be a volcanic cone structure, possibly similar to Alba Patera, but older; and Syria Planum, a very large domical uplift southeast of the Tharsis Montes.

The relative ages of major eruptive sequences were determined mainly by their stratigraphic relations and by morphology of the flows. Crater counts on the various units were made to verify these age relations and to obtain some degree of correlation between flows in widely separated areas where relative relations could not be established. Crater-frequency distributions were calculated from crater counts on moderate-resolution (180-200 m/pixel) frames. In general, counts were made only within units having bounding surfaces defined by standard photogeologic techniques. Craters with subdued or modified morphologies possibly indicative of preflow origins were not counted. Sources of error in crater counts included variations in cloud cover, sun-illumination angle, and resolution in images of different scales. Statistically valid data were obtained by counting within large areas of individual flows or geologic units; these areas range from about 36,000 km² to 176,500 km². All units have been assigned to the main time-stratigraphic systems on the 1:25,000,000-scale map of Mars (Scott and Carr, 1978). Differences between these assignments and those on the small-scale map of the planet reflect revisions introduced by the detailed mapping.

REMARKS

Martian lava flows are similar in morphology to those on Earth and the Moon. They commonly exhibit overlapping, lobate, and crenulated margins and occur chiefly as sheet flows or as channel- and tube-fed flows (Carr and others, 1977). Sheet flows are more common on the plains and on the lower, more gentle slopes of volcanoes. Their surfaces appear flat and smooth at structural resolution, but at high resolution they exhibit concentric ridge-and-ridge patterns superimposed to flow margins. Channel and tube flows are more prevalent on the steeper slopes around volcanoes such as Ceratulus Mons and Arsia Mons, but also occur on relatively low-relief surfaces at Alba Patera and Ceratulus Mons. Younger flows have rougher textures than older ones that have been smoothed and mantled to various degrees by eolian deposits. The martian flows, like those on Earth, originated from the central vents of volcanoes or from radial fissures on their flanks, or from fissures in plains areas far removed from the volcanic edifices. Of the 24 major lava-flow sequences mapped in the Tharsis region of Mars, 13 emanated mostly from two large source volcanoes, Olympus Mons and Arsia Mons. The youngest recognized flows were extruded from vents in the Tharsis region, but also from the summit areas of the Tharsis volcanoes. The oldest flows erupted from calderas and associated fissures in widely separated localities at Alba Patera (40° N, 110° E) and Syria Planum (15° S, 100° E), respectively, a large ancient shield volcano and a high-elevation but low-relief dome of regional importance.

STRATIGRAPHY

Basement and Nonvolcanic Units
Basement rocks (unit HNH) are undivided. They consist of both rough and smooth, highly fractured terrain; hilly and cratered material; and cratered plateau and cratered plains materials that form a large part of the ancient martian highlands (Scott and Carr, 1978). They occur mostly as relatively large blocks embayed and partly buried by various flows. Around the periphery of Olympus Mons, however, these older rocks may be exposed in the basal scarp and as self-bled blocks protruding above the lava flows in places. Some of this material may also represent segments of overlapping aureoles that formerly covered the present site of this volcano and Olympus Mons that predates the basal

scarp. However, these various units cannot be separately distinguished in such small areas, and most exposed parts of the scarp complex have been mapped as basement material.
Channel and flood-plain deposits and large accumulations of eolian material have been mapped in a few places. They have been relatively dated—stratigraphically and by crater counts—with respect to the Tharsis lava flows and contribute information on climate in the evolutionary history of the region. Landslides are common around the large volcanoes in the Tharsis region. They occur along and below the basal scarp on the west side of Olympus Mons and on the northwest flanks of Arsia, Pavonis, and Ascraeus Mons. Although the slide material is undivided on the lava flows, it consists chiefly of two end members: 1) rough, blocky rockfalls and rockslides near a dissected area that grade downslope into 2) debris- or mudflow deposits that form thin lobate tongues with many narrow ridges concentric to the outward flow front. These deposits at Arsia Mons and Pavonis Mons are older than flows from the central area of these volcanoes but overlap slightly older flows on their flanks.

Tharsis Lava Flows

The major flow units are grouped very generally into broad relative-age categories. The eruptive sequence appears to have been continuous throughout the volcanic history of the region. Crater densities cited below are the number of craters larger than 1 km in diameter normalized to an area of 1 million km².

Older Flows: Alba Patera, Syria Planum, and the Aureoles of Olympus Mons. The flows from Alba Patera and Syria Planum have the highest crater densities, ranging from about 1800 for the youngest to 3200 for the oldest flows at each location. These figures are roughly comparable to those of younger and older lunar maria at the Apollo 11 and 12 sites respectively (Neukam and Wise, 1976). Estimates of the absolute ages of these and other flows vary widely, however, because of inherent uncertainties in the models postulated for martian integrated flux curves used to establish correlations between crater frequency and geologic age (Neukam and Wise, 1976; Hartmann, 1977; Soderholm, 1977).

The younger flows from Alba Patera partly bury some of the radial and concentric fault systems that transect the older lavas. This burial is particularly noticeable within and around the calderas at the crest of the ancient volcano where the late and waning eruptive stages yielded decreasing volumes of lava. The older flows from Alba Patera embay the highly dissected terrain around the east edge of Achernis Fossae in the Diacra quadrangle (MC-2SE). These lavas also might have penetrated the arcuate central part of this volcano-tectonic structure where they may have been overlapped by very young lava flows of the Olympus plains and possibly also by the oldest aureole unit surrounding Olympus Mons.

At Syria Planum in the Phoenix Lacus quadrangle (MC-17SE), the younger flows also occur near the crest of the structural dome. They probably issued from a partly buried calderalike depression from fissures subsequently obliterated by the numerous flows. These lavas also appear to have buried many of the faults and fractures associated with or preceding channel development along Noctis Labyrinthus. The older flows of Syria Planum embay and partly bury the landforms and faults of Claritas Fossae but are transected by some of the more recent faults. No contacts can be clearly distinguished between the older and younger flow units at either Syria Planum or Alba Patera. The mapped boundaries are speculative and are based mostly on slight variations in morphology as well as crater densities. The aureoles of grooved and ridged terrain surrounding Olympus Mons are classified with the older group of flows. Their relative ages with respect to most other flow units in the Tharsis region can be only broadly determined. Stratigraphic relations clearly show that the aureoles are overlapped by the flows of Olympus plains and the postscarp extrusives of Olympus Mons. There is some evidence, but less certain, that the aureole deposits may be overlapped in places (MC-9SW) by the Tharsis Montes flows. Craters are of little value as age determinants because the ridged and grooved surfaces of the aureoles promote rapid denudation of crater forms by mass wasting; their crater densities are anomalously low, for example, compared with younger adjacent flows that bury the aureoles in places. Morphologically, the aureoles seem to be older than most flows in the Tharsis region. On the basis of stratigraphic evidence and morphology, the aureole units of Olympus Mons are provisionally placed just above the Alba Patera and Syria Planum lavas in the eruptive sequence.

Flows of Intermediate Age: Tharsis Montes, Alba Patera, and Ceratulus Fossae. This group of lava flows has the greatest range in crater densities—from about 450 to 1970, overlapping slightly with those in the older category. Many of the flow units originated from Arsia Mons (fig. 1) and are exposed from the upper to the lower slopes of the volcano. These flows show the greatest diversity in surface characteristics as well as in relative ages. The lower, older flow around Arsia Mons are more subdued by erosion and eolian mantles than the younger and generally higher units. It is not known if this condition applies to higher elevations and residual thermal and tectonic temperatures decrease rapidly and are possibly indicative of fine particulate dust blankets (Kieffer and others, 1977). The most extensive lavas mapped from Tharsis Montes are relatively featureless and homogenous. They represent flows originating from Arsia Mons, Pavonis Mons, and Ascraeus Mons cannot be recognized. Crater counts indicate that they are approximately the same age and they are mapped as a single unit (Atm). The most recent volcanic activity at Alba Patera has occurred within the broad, relatively flat, summit area. Flows from within and around the caldera have buried many fissures developed from earlier eruptions.

The Ceratulus Fossae flows originated from the complex fracture systems of that region and subsequently buried many of the fissures from which they were extruded. They extend southwesterly from their source area across the lava flows from Alba Patera and embay part of the highland terrain

between Olympus Mons and Tharsis Montes. Some may have erupted from fissures in this highland region. They are overlapped, in turn, by younger flows from Tharsis Montes and from Olympus plains.

Younger Flows: Olympus Mons, Olympus Plains, and the Volcanoes of Tharsis Montes—Crater densities for this group of extrusives range from about 90 to 350. They originated from the flanks and summit of Olympus Mons, from fissures in the plains east of the volcano, and from the central areas of Arsia, Pavonis, and Ascraeus Mons. Stratigraphic relations are clearly defined between the flows of Olympus Mons and those of the adjacent plains. These plains partly enclose Olympus Mons on the east within a topographically low area between the volcano and its aureole deposits. To the west of Olympus Mons no evidence exists of well-defined young flow fronts. Prescarp flows in this area are either buried by eolian material or are so deeply eroded as to be unrecognizable. Postscarp lava flows either did not occur on the west side of Olympus Mons or were of such small volume that they were unable to surmount the upturned edges of the scarp. Boundaries between pre- and postscarp flow units on Olympus Mons are not distinct. Crater counts indicate that two slightly different age groups may be present, but the validity of the data is limited by difficulties in selecting representative areas for each unit and errors inherent in distinguishing between small impact and indistinguishable craters on the flanks of a volcano. Evidence that prescarp lava flows exist is shown in places by flow lines sharply truncated at the scarp and by exposures of more mature surfaces in windows along its raised edge. Alternatively, vertical displacements producing the basal scarp around Olympus Mons may have occurred episodically. Intermittent lava flows down the flanks of the volcano throughout the interval of scarp formation could result in the present configuration of prescarp and postscarp flows in different places.

Flows from near the summits of Arsia Mons, Pavonis Mons, and Ascraeus Mons are among the youngest in the Tharsis region. They appear to be relatively thin, with smooth surfaces and indistinct flow fronts; their boundaries with older flows are difficult to define. These lava flows originated from large fractures and fissures along northeast-southwest faults transecting the central areas of the Tharsis Montes volcanoes.

STRUCTURE

Tectonism, as expressed by fractures and faults, culminated before the bulk of the lava flows in the Tharsis region were extruded. It did not cease altogether, however, but continued with diminishing intensity into the period of the youngest flows (Scott and Tanaka, 1980). Early episodes of major faulting were responsible for the highly disrupted surfaces at Claritas, Achernis, Ceratulus, and Memnonis Fossae. Faulting continued in these areas at lesser scales and also at Alba Patera, on the Olympus plains, and on the flanks of Arsia Mons. The density of faults associated with individual flows, like crater density, reflects their relative ages. A summary of tectonic episodes as they relate to major volcanic events is shown in the Correlation of Map Units.

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