POSSIBLE CINDER CONES NEAR THE SUMMIT OF PAVONIS MONS, MARS.
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Introduction. In 1979, Wood [1] mentioned the existence of a possible cinder cone near the summit of Pavonis Mons, and he estimated its dimensions. Examination of medium resolution Viking photographs has revealed four additional candidate cinder cones in the summit region. Pavonis Mons has been largely overlooked in the literature concerning the late-stage volcanic activity of the Tharsis volcanoes; and no cones have been found on the other Tharsis Montes [2,3]. The presence of possible cinder cones near the summit implies that volatile-rich pyroclastic activity occurred late in the evolution of Pavonis Mons.

Setting. The summit region of Pavonis Mons (Fig. 1) was photographed at moderate to high resolution (50 to 75 m/pixel) by both Mariner 9 and Viking 1. The summit is about 18 km above the martian datum [4,5], and has two conspicuous features: a 45 km-diameter caldera and, off-set to the northeast, an 85 km-diameter depression [6-9]. The caldera is about 4 to 5 km deep [4,5,10]; and the walls have numerous vertical, parallel ridges and grooves which are attributed to mass wasting and aeolian modification [11,12]. The caldera floor appears smooth and featureless with the exception of two 500 m-diameter craters. The large depression is bounded by inward-facing arcuate scarps in the west, and both an inward- and outward-facing scarp in the east. There is no surface expression of the southeastern rim of the depression. Six mare-type wrinkle ridges oriented radial to the caldera occur within the depression, none occur within 5 km of the caldera rim, but three of them extend up to 12 km beyond the depression rim. The depression apparently formed before the caldera; and the wrinkle ridges formed before or concurrently with the depression [13]. The wrinkle ridges likely formed by compression [14-16], the depression likely formed by volcanotectonic collapse [9].

Cones and Mounds. Five cones or mounds, labeled "c" in Fig. 1, occur within 5 km of the caldera rim. The best example is a cone with a pit at its summit which occurs on the volcanic shield along the edge of a fissure, about 3.5 km west of the caldera rim. This cone, originally identified by Wood [1], is best seen in an oblique-view photograph from Mariner 9 (DAS S5685959). It is also visible in Viking 1 images 210A32 and 210A34. To the north of this cone there is an irregular, rough-textured, raised-relief landform (labeled "m" in Fig. 1) which is bisected by a fissure. Two mounds, approximately elliptical in shape, occur along fissures north of the caldera rim between the rim and the southern end of a wrinkle ridge in the 85 km depression; one of these features appears to have a summit crater. Two additional features, circular mounds with summit pits, are visible near the limits of resolution in Viking frame 210A34; they occur in the large depression about 15 km east of the elliptical mounds and about 5 km north of the caldera rim.

Interpretations and Discussion. The five cones and the irregular, rough-textured landform are considered to be volcanic constructs, because of their occurrence on a volcano and their proximity to both the caldera and to fissures in the summit region. Wood [1] interpreted the cone seen in the Mariner 9 image as a possible cinder cone with a basal diameter of ~1.1 km, a crater diameter ~0.45 km, and a height of ~0.07 km. Although Wood did not plot this cone [fig. 6 of 1], with these dimensions the cone plots within the cinder cone "field" of Wood's crater diameter/basal diameter diagram for monogenetic volcanoes [13].

Alternative explanations for the cones are: (1) They could be small effusive volcanoes, such as the chain of low shields in the Arsia Mons caldera [17]; or (2) they could be volcanic domes. Short of obtaining very high resolution photographs or thermal infrared measurements, there is no conclusive test to demonstrate that any of the five cones/mounds are cinder cones. One test for the presence of cinders is to look for very high resolution thermal infrared data, which might indicate the presence of cinders because thermal inertia correlates with grain size under martian atmospheric conditions [eg. 19]. The highest resolution thermal infrared data from the Viking Infrared Thermal Mapper (IRTM) did not indicate the presence of surficial deposits with grain sizes larger than ~0.1 mm (silt-sized) on the Pavonis Mons shield [19]. However, the spot sizes for these data were about 3 to 5 km, while the cones are smaller, about 1 to 3 km.

If the cones are cinder cones, then they indicate that pyroclastic activity occurred on Pavonis Mons. Since they appear to be associated with fissures emanating from the caldera, they might post-date the caldera collapse, and would suggest that the last summit volcanic activity involved volatile-rich magmas [eg. 20]. Cinder cones form from short-lived strombolian eruptions, usually resulting from eruption of a low-viscosity magma through a narrow fissure or conduit [21]. The fact that these landforms do not resemble the low-profile, several km-wide cinder cone shapes predicted for Mars by McGlone et al. [22] might be explained by their use of terrestrial values for ejecta volumes, escape angles, and velocities.

The possible presence of cinder cones on Pavonis Mons distinguishes it from the other Tharsis volcanoes. Olympus, Arsia, and Ascracteae Montes were photographed at higher resolutions by the Viking Orbiters, yet detailed studies of these volcanoes reveal no cinder cones or other evidence for pyroclastic volcanism [2,3]. It should be noted that the Hawaiian basaltic shield volcanoes have numerous cinder cones on them [eg. 23]; suggesting that Pavonis Mons has had a similar evolution.

The cone-shaped landforms near the summit of Pavonis Mons are the most likely candidate cinder cones yet identified on Mars, because they occur on a volcano and they occur in the vicinity of a caldera, as do many of the Hawaiian cinder cones. Possible cinder cones have also been identified on Elysium Mons.
Numerous cone-shaped features with summit pits have been identified elsewhere on Mars [eg. 25-27], but their volcanic associations are questionable due to the lack of a definite volcanic context.


Figure 1. Sketch map of the summit region of Pavonis Mons. Mare-type ridges are shaded. The five cone-shaped features are labeled "c", and are interpreted as possible cinder cones. Feature (m) is interpreted to be a volcanic extrusion which post-dates the caldera. The units labeled are: (cf)= caldera floor, (s)= wall-slip material, (cw)= caldera walls. Sketch is centered at 0.8°N, 112.7°W; the map base included Viking 1 images 210A 33-36.