The origin of the moons of Mars is of great interest because they are the best characterized small bodies in the solar system, they are targets for in situ exploration during the next decade, and many of their physical and dynamical features are enigmatic. Both moons are very dark, irregular bodies of a few tens of km in dimension. Their carbonaceous-like albedo (6%) and low density (1.7 to 2.2 g/cc) (ref. 1), and the fact that Phobos is spiraling in toward Mars (arrival date 5 x 10^7 yr (2)), has suggested that the moons are captured C-type asteroids (3) or perhaps comets (4). Dynamicists (2), however, argue that while Phobos's orbit suggests it may have been captured, the orbit of the outer satellite Deimos is stable with low inclination and near-zero eccentricity, implying that it has not been. Phobos can not have been captured and evolved pass Deimos into its present position without colliding with Deimos. Unfortunately, the dynamical evolution of Phobos seems indeterminate, for Yoder (5) demonstrated that Phobos experienced abrupt changes in e and i when passing through gravitational resonances with Mars, but that the magnitude of the jumps is dependent upon Mars' instantaneous eccentricity and obliquity, which are highly variable. As Burns (2, p. 148) concludes, this removes Phobos "from the realm of deterministic dynamics".

Can the physical properties of Phobos and Deimos (P/D) offer possible clues to their origins? The proposed origins include: planetismals coformed with Mars (3), captured C-type asteroids (6), captured comets (4), and impact-fragmented rubble piles of any of these (7). The proposal that P/D formed at the same time and of the same material as Mars (e.g. planetismals which escaped incorporation into Mars itself) is the refuge of dynamicists who can not explain capture of Phobos. The main problem with this origin is that exhaustive studies of the asteroid belt reveal a strong zonal stratigraphy of asteroid types from S types in the inner asteroid belt to Cs in the outer and Ds at the extreme outer edge (8); no substantial mixing can have occurred. Thus, Mars was not made from carbonaceous asteroid-like material (as many models assume), but rather from material more like the ordinary chondrites (9), and P/D can not be remnants of the martian planetismals.

Hartmann (10), pointing out the similar low albedo surfaces for P/D, Jupiter's outer satellites, Saturn's outermost moon Phoebe, and the majority of outer solar system asteroids, proposed that all were primitive asteroids perturbed into planet-crossing orbits and ultimately captured. P/D's captures would have been facilitated by Mars' early massive extensive atmosphere (6). Hartmann further speculates that Phobos may have had an icy interior, which released volatiles along radial grooves when the crater Stickney was formed, thus accounting for raised rims along some of the grooves. P/D's shape, size, albedo and cratering are all consistent with what is known or inferred about asteroids. The density of Deimos (1.7 + 0.5 g/cc; 1) is less than the inferred density of the C-type asteroid Ceres (2.2 + 1.1 g/cc;
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11), which spectrally matches P/D (12), and the measured densities of CI (2.2-2.3 g/cc) chondrites (13). Phobos' density (2.2 + 0.5 g/cc) matches, however.

A captured comet origin for P/D has apparently never been seriously considered, yet new information about Halley's comet suggests that it may be a strong possibility. The nucleus of Halley is dark (albedo = 4%) and irregular, with dimensions of about 16 x 8 km (14). Apparently there are numerous pits which may form by impact or escape of volatiles. Whipple and Larson (15) infer the existence of curving line sources for gas release on Halley, features which may be similar to the grooves of Phobos. Further- more, the carbonaceous-like albedo and the detection of water (16) are consistent with P/D. The density of Halley's nucleus is still being determined but is likely to be considerably < 1 (H. Zook, pers. comm.). In general, however, comet densities are totally unknown, reflecting more an investigator's bias for comet origins than physical data. Whipple (17) suggested cometary densities in the range 1.0 - 1.5 g/cc.

The physical properties of P/D are most consistent with their ultimate origins as asteroids or comets; both fit the data reasonably well. It is unlikely that P/D are made of the same material as Mars or formed with it. Dynamicists, who accept capture as the favored origin for a menagerie of outer planet satellites - despite their difficulty in explaining exactly how it happened (2, p. 157) - need to re-address the origin of P/D, based on the evidence that capture probably did occur. In addition, evidence from oblique impact craters on Mars suggests that a martian moon much larger than P/D once existed (18). From Schultz and Lutz-Garihan's (18) observation that three distinct families of oblique impact craters exist, I infer that multiple captures, breakups and collisions with Mars may have occurred. Capture may be easy for Mars, but hard for dynamicists.

The origin of the satellites is important to two other groups. Planners for the exploration of P/D should decide what measurements to make in situ to decide if the moons were once asteroids or comets. And meteoriticists should consider the possibility that no matter where P/D formed, they are the most accessible sources for the carbonaceous meteorites that hit the Earth.