crater-forming bodies must have been greater early in lunar history than at present to account for the heavily cratered highland regions of the moon. Radiometric dates for lunar samples established beyond all doubt, however, that the bulk of the craters were neither old enough to have been due to the initial accretion of the moon nor young enough to be due to the small flux of meteorites that now intersects that earth-moon system.

Very few rocks dated earlier than about 4.0 billion years ago have been found on the lunar surface, testimony to the intensity of the bombardment up to that time, and yet the flux decreased so dramatically that the younger maria, formed around 3.3 billion years ago, are only very sparsely scored with craters. Thus the exploration of the moon has not shed much light on the first 0.5 billion years of the solar system, at least in the sense that was originally expected. So thoroughly has the early history of the moon been obliterated that the bombardment flux prior to 4.0 billion years ago is in some dispute. Some investigators believe that the flux peaked at about that time, producing a lunar cataclysm, while others think in terms of a series of bombardments since the moon's formation 4.6 billion years ago.

Because no samples of the martian or mercurian surfaces are available, a definite chronology for these planets is lacking. The best estimates of the cratering history, however, suggest that the pattern of bombardment has been much the same—intense and rapidly decreasing—and that the absolute magnitude of the flux has not differed by more than a factor of 2 from that observed on the moon.

It thus seems likely that an intense exchange of matter throughout the solar system and the resultant bombardment of the newly formed planets—what one geophysicist describes as "the tail of a cataclysm that was the birth of a solar system"—was an inescapable feature of the early solar system, including the earth. This conclusion has led to a renewed appreciation and examination of violent, collisional processes and their role in the solar system. One implication is that cratering was an important geomorphological process in the first 600 million years of planetary bodies, determining some of the topography and the physical features of surface rock. By one estimate, for example, as many as 25 projectiles of the size that created the huge Imbrium crater on the moon may have struck earth during this period. It was, initially, a surprise to many investigators to find that the rocks in the lunar highlands (the older regions of the lunar surface) were predominantly breccias, complex assemblages of materials heated and

Early Ideas about the Solar System and the Planets

In the history of astronomical ideas, it seems that the primitive concepts about the origin of the solar system have endured, but early ideas about the individual planets were often erroneous.

Laplace is often credited with the idea that the sun and the planets evolved out of a single nebula. In 1796 with knowledge that nebulas were common in the galaxy, after the Orion nebula was discovered in 1655, Laplace hypothesized that the gravitational and centrifugal forces in a contracting cloud could produce rings that would break up into lumps—like the present solar system. Laplace's theory was unpopular, however, because the sun contains practically all the mass and practically none of the angular momentum of the solar system. Many dualistic theories of the sun and planets were proposed, such as the idea by the French naturalist Buffon that a huge comet hit the sun obliquely and left behind enough matter to form the planets, but the dualistic theories have been discarded.

Prior to the 20th century, telescope observations were more often visual than photographic, and the sketches observers drew of their sightings were sometimes painfully faulty, especially when they drew the face of Mars. The period after Schiaparelli's "discovery" of canals in 1877 is surely an embarrassing epoch for American science, when a number of Americans but few British scientists believed the report of canals, and for many years it gave planetary astronomy a bad name. Not only did the foremost expositor of canals, Percival Lowell, draw intricate grids of intersecting fine lines (the intersections were said to be oases built to utilize water that the canals carried from polar caps to more temperate regions), but he reported to see "twinning" of canals. In his book *Mars* (1895) Lowell proudly stated that the steady air at Flagstaff, Arizona, was the reason astronomers at his observatory saw canals, while others did not.

The canals were not the only details of Mars that Lowell assessed wrongly. The Mariner 9 spacecraft observations strikingly refute Lowell's contentions that "Mars has few mountains worthy of the name," and that "Mars is blissfully destitute of weather." But Lowell did correctly note that the polar caps diminish seasonally, though he incorrectly reasoned that they were composed of frozen water instead of carbon dioxide. Lowell presaged the current controversy over Mars beautifully when he said that "In more ways than one, it is in that great glistening white patch [the polar cap] that our water problem takes its rise."

Although the moon was easier to observe, it was not much better understood in the 19th century than Mars. In *The Moon*, a classic work in 1885, Nasmyth and Carpenter did a very careful study of lunar craters and came to the conclusion that they originated from volcanic activity rather than the impacts of falling debris, as now understood. The authors likened the lunar surface about the crater Theophilus to the region around Naples, Italy, and found no insurmountable difficulty in describing the 78-mile diameter crater Petavius as a volcanic caldera. Nasmyth and Carpenter thought that the heat for melting came from the accretion of the moon—an idea that is quite appealing now.

Not all the misconceptions about the nature of the planets date to the 1890's. In successive decades of the 20th century, well-respected scientists have proposed the surface of Venus to be a carboniferous swamp, a windswept desert, or a planetary oil field. Desert may still be a good description, but as recently as 1955 Menzel and Whipple published the opinion that Venus is covered by a water ocean, which would of course be carbonated by the atmosphere of the planet.—W.D.M.