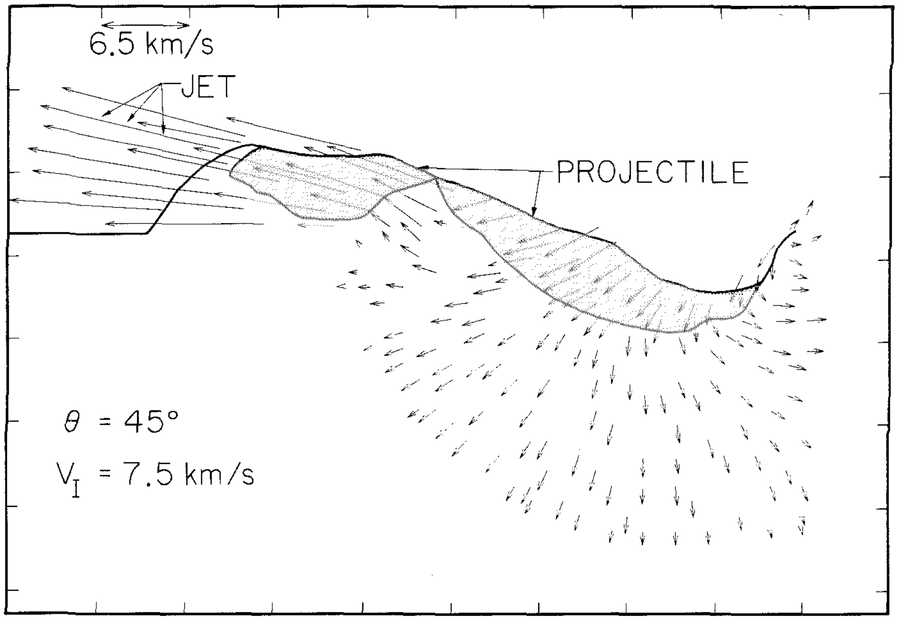
Research in Progress

The Martians Have Landed

BETWEEN 1968 AND 1980 NASA spent $979.1 million on the spectacularly successful Viking program, which sent two unmanned spacecraft to study the planet Mars. It now appears that during all that time at least eight pieces of Mars may have been right here at home. They apparently fell to Earth as meteorites and are currently under intense study by scientists around the world.

Although these meteorites differ significantly from the 10,000 or so others in the world's museums, not all scientists are convinced that they could have come from Mars. It isn't their chemical composition or their age or any of their other characteristics that make researchers reluctant to assign these rocks a Martian origin. Rather, the stumbling block to full scientific acceptance is the question of how they could have left Mars in the first place and how they could have arrived here in such good condition. Recently, however, Thomas J. Ahrens, professor of geophysics, and John D. O'Keefe, visiting associate in planetary science, have devised a scenario which just may convince their skeptical colleagues that these meteorites really did come from Mars.

Except for their relatively pristine condition, everything points to a Martian origin. They all crystallized from molten rock about 1.3 billion years ago, as determined by the ratios of samarium to neodymium, rubidium to strontium, and potassium to argon. The asteroids, source of almost all other meteorites, cooled completely about 4.5 billion years ago, and volcanic activity on the moon ceased about 4.2 billion years ago, so both lunar and asteroidal origins seem to be ruled out. In addition, these meteorites have spent only between 2 and 10 million years in space, as judged by their cosmic ray exposure times. (Meteorites derived from asteroids typically spend far longer times exposed to cosmic rays on their transit to Earth.) And Donald Bogard of the Johnson Space Center has determined that the composition of noble gases trapped in the meteorites is consistent with what we learned about the Martian atmosphere from instruments on the Viking landers.



In this simulated meteorite impact, a spherical object has just hit the Martian surface at 7.5 km/sec and at an angle of 45°. The impact produces a high-velocity jet of hot gas that can lift large boulders into interplanetary space. The arrows point in the direction of motion. Lengths are proportional to velocity.

Together, these putative pieces of Mars are called the "SNC meteorites" after the locations at which three of them were found: Shergotty (India), Nakhla (Egypt), and Chassigny (France). Two others were found in Antarctica and one each in Nigeria, Indiana, and Brazil. The SNC meteorites are members of the achondrite class of igneous meteorites but differ significantly from the eucrites, the most common achondrite type. In composition, some of the SNC meteorites are olivine, some are clinopyroxene and olivine, and the rest are pyroxene and plagioclase. These rocks resemble samples of the crust and upper mantle of the Earth. Their textures show the clear imprint of having cooled from a melt in a gravitational field, one that must have been far stronger than those associated with even the largest asteroids.

But though their chemical and geological characteristics all point to a Martian origin, it's not easy to understand how the SNC meteorites could have left the red planet's surface. Martian escape velocity is 5.05 kilometers per second (11,300 miles per hour), and some process would have had to accelerate large boulders to this speed in order for them to have escaped Martian orbit. At first glance, the most likely mechanism for this would be the impact of a comet or asteroid directly perpendicular to the Martian surface. In response to such an impact, material could have rebounded from Mars at sufficient speed. Unfortunately for this model, however, any such material would have been pulverized, or at the very least thoroughly melted. Some SNC meteorites do show evidence of shock-induced melting, but this melting is not nearly extensive enough to accord with the direct impact model.

Another possibility is that the material ricocheted off Mars after a grazing meteorite impact. Although relatively rare, such impacts are by no means unknown; Mars has more than 170 large elongate craters with characteristic "butterfly" ejecta patterns. But according to Ahrens, this too is an unlikely scenario. "It's a good idea, but it doesn't accelerate materials to high velocities. In fact, it doesn't even produce material that's *molten* at 5 kilometers per second. Although at first blush you might expect it to be a good way of launching material, because you do launch a lot of material preferentially along the direction of impact, the velocity that it's launched at is relatively low."

Ahrens's work involves the study of materials undergoing high-velocity impact. His laboratory, the Helen and Roland Lindhurst Laboratory of Experimental Geophysics, contains two powerful guns capable of accelerating projectiles to high speeds. When the larger of these, a 106-foot-long, 35-ton, light gas gun, is fired, all South Mudd shakes, and a one-ounce plastic and tantalum bullet attains a speed as high as 7 kilometers per second (16,000 miles per hour). According to Ahrens, this apparatus can produce impacts with dynamic pressures as high as any occurring anywhere in the solar system.

Using the data gathered in this way, O'Keefe and Ahrens build "equations of state" that describe the behaviors of various materials under various impact conditions. These equations are then fed into a computer program that, in Ahrens's words, "conserves energy, mass, momentum, motherhood, and apple pie," to simulate the effects of meteorite impacts on the Martian surface.

The results of these simulations suggest that the best way to get material off Mars involves neither perpendicular nor extremely shallow impacts. Rather, material is most likely to be accelerated past escape velocity if the impact angle is between about 25 and 45 degrees from the horizontal. Such impacts vaporize the water, carbon dioxide, and other volatiles trapped in the Martian crust and produce a jet of hot gas that can reach a velocity of 20 kilometers per second. This is sufficient to sweep rocks ranging up to one meter in diameter off the surface of Mars, at speeds greater than 5 kilometers per second, without damaging them in any appreciable way.

Although these rocks escape the Martian gravitational field, says Ahrens, "they probably don't get a high enough velocity to escape the solar system and they go into orbit around the sun. Objects that are launched into somewhat eccentric orbits become perturbed in orbit as a result of the very slight gravitational effects of the planets. Probably most of these objects go into Mars-crossing orbits and, in time, fall back to that planet. But a small number leak out of the zone around Mars and eventually go into Earth-crossing orbits." And a small number of those fall to the ground to be found and puzzled over by terrestrial scientists. □ — *RF*