# Meteoroids and Impact Craters

*Henry Spall*

"And meteors fright the fixed stars of heaven."
*Richard II,* William Shakespeare

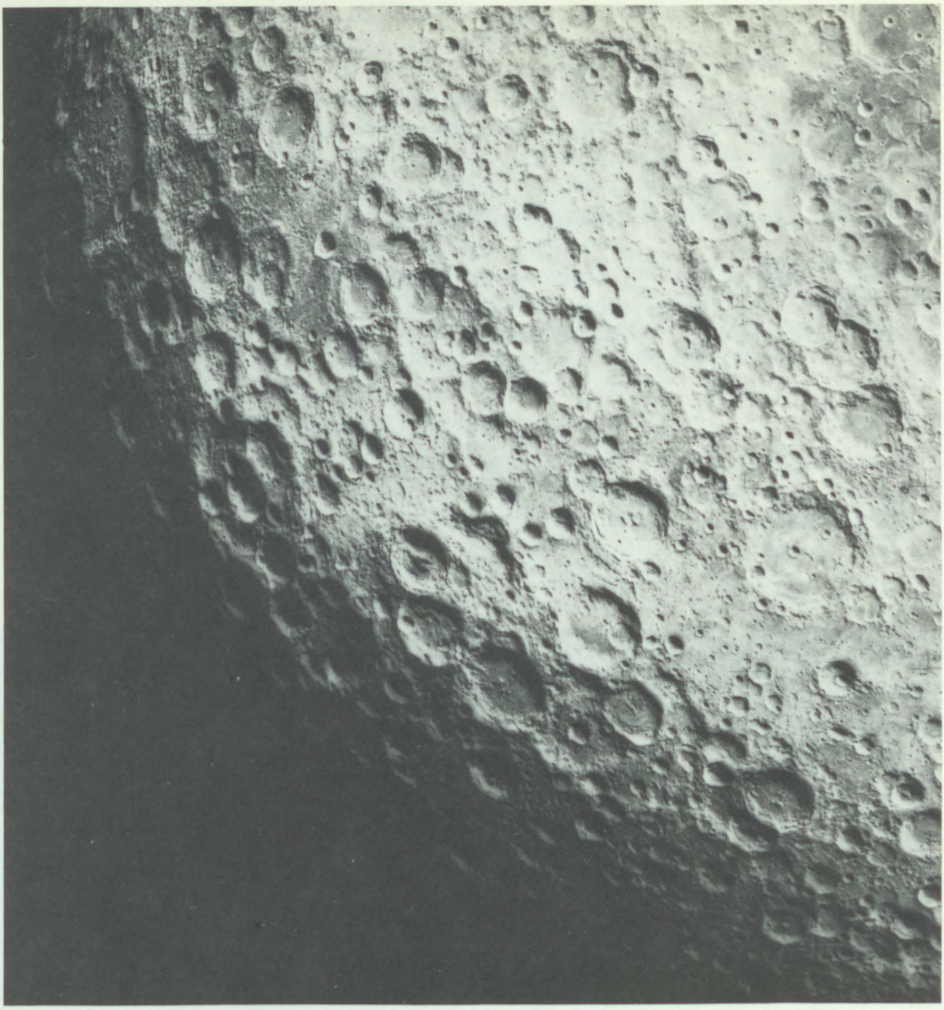
On a clear night scores of meteoroids streak across the sky. They leave light paths we call meteors or shooting stars as the Earth is showered with debris from distant parts of the solar system. When these meteoroids hit the Earth (as meteorites) they range in size from pebbles to the 34 ton Ahnighito meteorite that the American explorer Admiral Robert Peary discovered in Greenland. The unique importance of meteorites is that they have an extra-terrestrial origin and can provide us with direct evidence on the make-up of the solar system. They also give us clues to the origin of the solar system because they formed about 4.6 billion years ago at about the time the planets formed.

Many meteoroids are associated with comets; as a comet travels around the sun it leaves a trail of debris behind it and it is this debris which produces meteor showers. Other meteoroids come from the asteroid belt, a zone between Mars and Jupiter filled with thousands of dwarf worlds that failed to coalesce into planets.

## Three Types of Meteorites

*Iron meteorites* are the most easily recognized meteorite although they represent only a small proportion of those that fall to the Earth. Iron meteorites are not pure iron but also contain nickel, sulfur, carbon and traces of cobalt, and chromium. Although such meteorites are themselves not from Earth, they provide evidence about the composition of the Earth's metallic core.

*Stony meteorites* are the most common type of meteorite, comprising more than 90% of all falls. They are made up of small spheres of silicate minerals in a fine-grained matrix, rather like raisins in a cake. The spheres are known as chondrules and the meteorites themselves are called chondrites. The chemical composition of most chondrites is similar to that of peridotite, the main rock type in the Earth's mantle. One of the most important and intriguing varieties of chondrite is the carbonaceous chondrite; this type



*View of the heavily-cratered lunar highlands area; this is the most ancient area of the Moon and preserves a record of intense bombardment 4.5 billion years ago.*

***Asteroids***

-are minor planets with diameters of half a mile on up to a few hundred miles. They are thought to be either remnants of a planet that disintegrated early in the life of the solar system or celestial material that never quite coalesced into a planet. About 1700 of these asteroids have been named or numbered. The majority are in elliptical orbits around the sun in a belt between the planets Mars and Jupiter. Occasionally the orbit of an asteroid is changed, perhaps by the gravitational effect of nearby Jupiter, so that the asteroid is sent closer to the sun and the inner planets, including Earth.

Some sixty asteroids have been observed to be out of this main belt and are in Earth-crossing orbits; the likelihood of a collision, however, is remote. It is believed that meteorites may be small fragments of asteroids which were broken up by collisions in space.

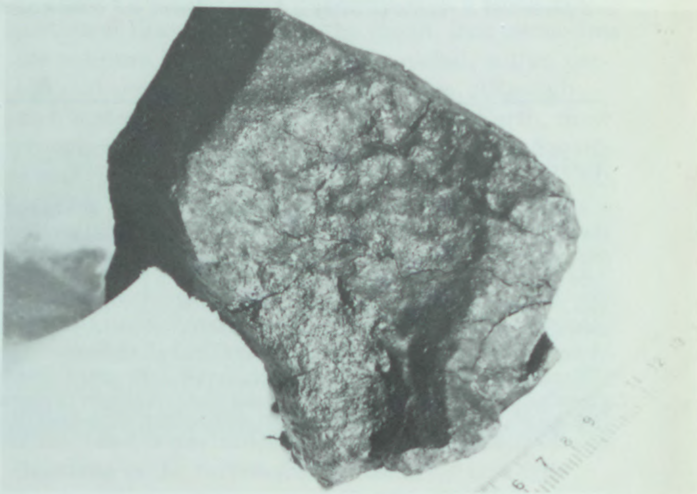
contains significant amounts of carbon compounds of the type believed to have been precursors to life on Earth.

The third kind of meteorites are the *stony irons,* which are mixtures of iron and silicate minerals; they are quite rare.

## Meteorite Falls

Much of this meteoritic material arrives unnoticed on the Earth. There are probably about 500 major falls each year, and most of these accumulate on the ocean floors. By far the best hunting ground is in Antarctica where meteorites falling onto the ice surface over the centuries have been carried along by the great Antarctic ice sheet and are concentrated in areas where the glaciers ablate. Weathering processes in the Antarctic take very much longer than in other parts of the world; meteorites that fall in the deep snow are therefore protected and preserved for great lengths of time. They are easy to spot for there are no other rocks in the upper part of the ice sheet.

*A meteorite on the ice surface at Allan Hills (background), Victoria Land, Antarctica. Photos by Keizo Yanai.*



Meteoroids enter the Earth's atmosphere with very high speeds. The smaller meteoroids are slowed by drag with the atmosphere and the resulting frictional heating means that many of them burn up completely. For those that do reach the Earth's surface, the atmospheric braking effect slows down the meteorites so effectively that they rarely do much more than bury themselves a few inches deep into the surface.

Not so with the larger meteorites. Really large bodies are hardly slowed at all, and the end result is an impact on the Earth's surface at near cosmic velocities that produce a deep impact crater.

## Impact Craters

The most spectacular of these surface impacts is Meteor Crater in Arizona, which is 600 feet deep and 3/4 mile across. It was formed some 50,000 years ago by impact of an iron meteorite considered to be about 150 feet across, weighing about 300,000 tons and traveling in excess of 10 miles per second. The impact occurred on flat-lying sedimentary rocks. David J. Roddy of the U.S. Geological Survey in Flagstaff, Arizona has calculated that approximately 190 million tons of rock were ejected during the event to form a blanket around the crater that is as thick as 75 feet. The cratering mechanism and the effect of the impact on rocks of the nearby desert have been worked out in careful detail by Gene Shoemaker and Susan Kieffer of the U.S. Geological Survey in Flagstaff, Arizona. The sequence of events for the formation of Meteor Crater is shown diagrammatically on page 89. While meteoritic material can still be found at Meteor Crater, most of the meteorite was probably melted during the impact. The chances of such an encounter with the Earth are about once every 25,000 to 100,000 years.

The number of impact craters that we can find now on the Earth's surface is surprisingly small—especially when compared with the Moon where impact cratering is the principal geological process. One of the reasons that impact craters are a curiosity on Earth is that they are constantly being erased by the Earth's very active agents of erosion—water and wind. Impact cratering is, however, a key geologic agent on the other terrestrial planets—Mercury, Mars and Venus; during the early evolution of these planetary surfaces, impact cratering rivalled volcanism as the most important geologic process.

## Further reading

Francis, Peter, 1982, The Planets. Penguin Books. 411 p.

## Gene Shoemaker:

"Picture yourself standing about 20 miles from here about 50,000 years ago. Out of the southeast, a nickel-iron asteroid about 150 feet across is hurtling towards the Earth. As it plunges into the atmosphere it forms a brilliant meteor which grows brighter and brighter, and finally, becomes much brighter than the sun. In fact, it grows so bright that you will be on the verge of being scorched.

At that point, the meteorite strikes the ground and its sends a shock wave with pressures of millions of atmospheres down into the rock and back up into the meteorite. The meteorite burrows into the ground like a hydraulic jet forcing the rock aside, flattening, and then being deflected and thrown back out again.

From the moment that the meteorite strikes, a spray of shock-melted meteorite and vaporized meteorite, and melted and vaporized rock, squirts out at high velocity, a velocity of several miles per second. The spray continues to rise and forms a plume that grows bigger and bigger. Finally, the plume becomes about 4,000 feet across at the base and by that time, the top of the plume of material ejected is extending miles up into the atmosphere. Most of the atmosphere has been blown away by the shock wave made by the meteorite.

The first thing that will happen to you after being nearly scorched is that you will hear the shock wave in the atmosphere itself and it will come like a horrendous clap of thunder. In fact, it will be strong enough to bowl you over even at 20 miles.

The plume, meanwhile, continues to grow. Finally it turns into an enormous black cloud of dust which will punch up through the atmosphere like the mushroom cloud from a nuclear explosion."

From the NOVA television program *The Asteroid and the Dinosaur,* produced by WGBH Educational Foundation, and reproduced by permission.

*Close-up view of Meteor Crater. Photograph by David Roddy and K. Zeller.*

***Sequence of events worked out by Gene Shoemaker for the formation of Meteor Crater, Arizona***

*1. Meteorite approaches the ground at 10 miles per second.*

*2. Meteorite enters the ground, compressing and fusing the rocks ahead of it. Shock effects in the meteorite reach its back side.*

*3. A rarefaction wave is reflected back through the meteorite, and the meteorite is decompressed, but still moves ahead at about 3 miles per second into the ground. Most of energy has been transferred to a shell of compressed, fused rock ahead of the meteorite.*

*4. Compressed slug of fused rock and trailing meteorite are deflected laterally along the path of penetration. The meteorite itself becomes the liner of a temporary cavity.*

*5. The shock wave propagates away from the cavity, the cavity expands, and fused and strongly-shocked rock and meteoritic material are shot out in the moving mass behind the shock front.*

*6. A shell of breccia (mixed fragments) and dispersed fused rock and meteoritic material is formed around the cavity. The shock is reflected as a rarefaction wave from the surface of the ground, and momentum is trapped in material above cavity.*

*7. The shock and reflected rarefaction waves reach a limit at which the sedimentary beds of the Earth's surface will be overturned. Material behind the rarefaction wave is thrown out along ballistic trajectories.*

*8. Fragments thrown out of the crater maintain approximate relative positions except for material thrown to a great height. The shell of breccia with mixed meteoritic material and fused rock is sheared out along walls of crater; the upper part of the mixed breccia is ejected.*

*9. Fragments thrown out along low trajectories land and become stacked in an order* ***inverted*** *from the order in which they were ejected. Mixed breccia fragments along the walls of the crater slump back toward the center of the crater. Fragments thrown to a great height shower down to form a layer of mixed debris.*