Obituary

Eugene M. Shoemaker (1928–97)

Founder of the scientific study of impact cratering

Eugene Shoemaker, who died on 18 July, founded the scientific study of planetary impact cratering on the Earth, Moon, planets and their satellites, as well as pioneering surveys of near-Earth asteroids and comets, often in collaboration with his wife Carolyn. His most important scientific legacy was recognizing how pervasive the impact cratering process was in the early Solar System.

Shoemaker was born in Los Angeles, and received his undergraduate degree at Caltech at the age of 19. A year later, in 1948, the Cold War had directed geological exploration activity in the United States towards identifying uranium deposits in Colorado and Utah. Shoemaker joined this effort as an employee of the US Geological Survey (USGS). But while studying the volcanic rocks of the southwest, Shoemaker became interested in the question of whether the craters on the Moon were volcanic or caused by impacts of asteroids and comets (a question that was only finally answered upon the return of lunar samples by the Apollo programme). After his first visit to Meteor Crater, Arizona, in 1952, he became convinced that both it and lunar craters had been formed by impacts.

In 1956, Shoemaker was assigned to map craters formed by nuclear explosions at the Nevada test site. He discovered that the nuclear craters and Meteor Crater had the same overturned flap with inverted stratigraphy, ejected from the craters, and that these craters had transiently been deeper cavities, partly filled by fall-back ejecta. This work, described in his PhD thesis (1960) and in *The Planets* (ed. G. Kuiper, Univ. Chicago Press, 1962), first defined many features of the impact process.

After 1960, when the NASA planetary programme was first organized, Shoemaker took a lead in establishing the Astrogeology Branch of the USGS. He led projects to map craters on the Moon, both from telescopes on the Earth and from a series of lunar spacecraft: Ranger, Surveyor, Lunar Orbiter and Apollo. With Voyager, Shoemaker also helped map the heavily cratered solid satellites of the outer planets — Jupiter, Saturn, Neptune and Uranus.

The Apollo programme was an especially trying experience for Shoemaker, as he wanted to be the first astronaut–geologist to map the Moon. Unfortunately, the discovery that he suffered from Addison's disease precluded this adventure. "Damn, I wanted to go to the Moon; instead I am chairing the Astronaut Selection Committee," he remarked. He had a leading role in astronaut training and directed the Apollo 11 and 12 astronauts from NASA's Houston Control Center.

But he was at least able to carry on studying impact structures on Earth, always accompanied by Carolyn. His enthusiasm and observant eye for both the big picture and tiny details of the geology made a field trip with Shoemaker memorable — and his adventurous spirit resulted in his getting more vehicles stuck in ditches and mud than any geologist of his generation.

Cratering is an especially important process on airless worlds such as the Moon and asteroids. Along with Donald Gault, Shoemaker first conceived the idea that highly cratered surfaces on airless objects should be covered by a layer of impact ejecta, which he named a 'regolith'. And he was among the first to recognize that by measuring the relationship between crater density and diameter, the age of a planetary surface could be inferred. For example, the heavily cratered anorthosite highlands of the Moon were shown to be more than four billion years old, whereas the youngest basalt *mare* units are only 2.5 billion years old.

In 1972, Eleanor Helin and Shoemaker began a programme to search for Earth and near-Earth asteroids using a 0.46-m Schmidt telescope camera at Palomar Mountain. In the 25 years that they, and later, Carolyn, laboured with their 1930s equipment, they discovered some 140 of the known 417 Amor, Apollo and Aten (near-Earth) asteroids. Also, some 32 comets were discovered that carried the Shoemaker name.

To confirm the impact origin of craters, Shoemaker demonstrated that the size distribution and flux of existing objects that could hit the Earth is closely correlated with the number, size and age distribution of the relatively recent craters found on the Earth and Moon. Shoemaker was the first to use the Palomar near-Earth asteroid survey, along with the Earth's crater density-versus-age relation, to estimate the frequency with which asteroids hit the Earth. He found that the risk to civilization from such impacts is appreciable. The International Spaceguard Survey, which is dedicated to identifying and tracking objects in space that may threaten our future, is a direct product of Gene Shoemaker's pioneering research.

The crowning, and the most famous, achievement of Shoemaker's career was the discovery of the Comet Shoemaker–Levy 9 (SL9) in 1993. With amateur comet-discoverer, David Levy, the Shoemakers obtained a poor image of the broken-up comet on a poor night for observing. The observation was made only because they had some film that had been accidentally pre-exposed, and they decided not to waste it. Two hours later, after Carolyn Shoemaker had noticed what looked like a 'squashed comet' on the still-wet film, a telephone call was made to James Scotti at the University of Arizona Observatory. He certified the result with "Wow, you guys really have a comet!". Later images showed what looked like a 'string of pearls', believed to be fragments of a Jupiter-family comet that was tidally disrupted when passing close to Jupiter in 1992.

Several days later, dynamicists determined the orbit, and discovered that SL9 would hit Jupiter the next year. The spectacular result, in July 1994, was our first observation of a large planetary impact, and graphically demonstrated the routine nature of impact processes in the Solar System. The production of the dark scars from methane and sulphur-derived gases was unexpected, and taken with the lack of such scars from telescopic observations dating back to 1781, supports theories that SL9-type events are rare, occurring only at intervals of 2,000 to 5,000 years.

Eugene Shoemaker died with his field boots on, in an automobile accident in Australia's outback on his way to map a meteorite crater. Carolyn survived the crash.

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