Eugene M. Shoemaker

1928-1997

BIOGRAPHICAL *Memoirs*

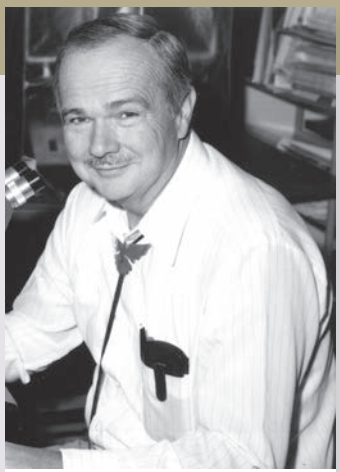
A Biographical Memoir by
Susan W. Kieffer

NATIONAL ACADEMY OF SCIENCES

EUGENE M. **SHOEMAKER**

April 28, 1928–July 18, 1997

Elected to the NAS, 1980



Photograph by Carolyn Shoemaker.

Eugene M. Shoemaker, a leading light of the United States Geological Survey, died on July 18, 1997, in a tragic motoring accident near Alice Springs, Australia. Gene was doing what he loved most—studying meteorite impact craters in the field with his wife of 46 years, Carolyn (Spellman) Shoemaker. Carolyn was badly injured in the accident but recovered. Gene is survived by his three children, Christine Woodard, Linda Salazar, and Patrick Shoemaker. On July 31, 1999, some of his ashes were taken to the Moon on the Lunar Prospector space probe, and to this date he is the only person whose remains have been laid to rest on the Moon. The brass casing of his memorial capsule bears a quotation from Shakespeare's Romeo and Juliet:

> *And, when he shall die*
> *Take him and cut him out in little stars*
> *And he will make the face of heaven so fine*
> *That all the world will be in love with night*
> *And pay no worship to the garish sun.*

By Susan W. Kieffer

Gene's enquiring mind spanned an unusually large range of scientific disciplines—petrology, astronomy, stratigraphy, field geology, volcanology, impact dynamics, and paleomagnetism, to name a few. From his work, whole new fields of shock metamorphic studies, impact crater modeling, and stratigraphic relations on planetary bodies evolved. Among Gene's many accomplishments were the development of the concepts of dating planetary surfaces from the statistics of the size distributions and numbers of impact craters, training astronauts, starting a sky survey for Earth-orbit-crossing asteroids, pioneering the idea that sudden catastrophic changes can arise from meteorite impacts, and discovering, with Carolyn and colleague David Levy, Comet Shoemaker-Levy 9, which impacted Jupiter in 1994.

Early life

Gene was born in Los Angeles to Muriel May (nee Scott), a teacher, and George Estel Shoemaker, both from Nebraska. His father worked variously as a farmer, teacher, movie grip, and coach during Gene's youth, and the family moved between Los Angeles, Buffalo, New York and several spots in Wyoming. His father, a farmer at heart and in practice, hated living in New York and Buffalo, and his mother hated life in a cabin in Wyoming where George had obtained a job at a Depression-era Civilian Conservation Corps camp as an education director. Their compromise was that Muriel would take the children and teach at Buffalo's School of Practice during the school year and return to Wyoming for the summers. As David Levy described in his book *Shoemaker by Levy*, Gene inherited a swashbuckler aspect from his father and a perfectionist aspect and drawing skills from his mother.

Gene's interest in rocks arose in Buffalo, where the Buffalo Museum of Science had developed a pioneering program of science education, including offerings in the evenings and Saturday-morning courses for students in the primary grades. He entered the School of Practice in fourth grade, quickly becoming an avid collector of minerals, was taking high-school-level evening courses within a year, and taught himself about the Devonian fossils that occur in abundance in western New York State.

In 1942 the family moved to Los Angeles, where Gene attended Fairfax Senior High School, which he finished in three years. There he played violin in the school orchestra, excelled in gymnastics, and got a summer job as an apprentice lapidary after his first year in the school. His parents worried that he might skip college to become a professional lapidary!

Gene never considered going to college anywhere but the California Institute of Technology (Caltech), and he enrolled there in 1944 at the age of 16. He was embedded among mature students heading off to serve in World War II who needed science and technology training as fast as possible, an environment in which his ambition, drive, and enquiring mind thrived. He received his bachelor's degree at age 19 and only a year later completed his M.Sc., studying the petrology of Precambrian metamorphic rocks in northern New Mexico.

In 1948, at the age of 20, he was hired by the U.S. Geological Survey, an organization with which he remained at least partly associated for the rest of his life. His first work for the USGS involved searching for uranium deposits in Colorado and Utah. At the

Gene at the bottom of Meteor Crater.
(Photo by USGS Astrogeology.)

time, the dawn of the nuclear age, little was known about the location of uranium deposits in the United States. As David Levy recounted, it was on Gene's 20th birthday, while he was on the Colorado Plateau looking for uranium, that he looked up at the Moon and thought,

I want to go there! I want to be one of the first people on the Moon. Why will we go to the Moon? To explore it, of course! And who is the best person to do that? A geologist, of course! I took the first fork that went to the Moon that morning.

In 1950 Gene embarked on work for a Ph.D. at Princeton University, intending to continue his study of metamorphic petrology, but this plan was interrupted when the USGS again sent him out in the field, this time leading him to investigate volcanic processes, for it was in the eroded vents of ancient volcanoes that uranium deposits were often located (1956, 1962). His explorations were concentrated in the Hopi Buttes of northern Arizona, fortuitously close to Meteor Crater.(This site is also known as Barringer Crater, named after entrepreneur and mining engineer Daniel Barringer, who in 1891 postulated that it had been created by the impact of an iron-containing meteorite. About the same time, G. K. Gilbert, chief geologist of the USGS, examined the crater and declared that it was the result of an explosion of volcanic steam. The majority of scientists at the time—and for many decades thereafter—rejected Barrington's theory in favor of Gilbert's.) When Gene first visited Meteor Crater, there was still some disagreement over its origin, but

what he saw led him toward the view that both it and the craters on the moon were due to meteorite impacts.

Gene loved to be in the field mapping. It was almost incidental to him that he developed the theoretical concepts for interpretation of impact by drawing on analogies between chemical and nuclear explosions and impact processes. With E. C. T. Chao and B. M. Madsen he was the first to discover the natural occurrence of coesite, a high pressure polymorph of silicon dioxide (SiO_2), at Meteor Crater. Because coesite only forms at high-pressure and had never been found in a volcanic environment the case for a meteorite impact was won. Shoemaker and Chao subsequently solved the controversy about the origin of the Ries Basin in Germany by finding coesite in the rocks there as well. Their theoretical concepts, petrologic discoveries, and careful field mapping in the 1950s and '60s paved the way for the acceptance of meteorite impact as an important geological process on Earth. Decades later these discoveries and concepts became crucially important in the unfolding of ideas about why species like dinosaurs disappeared at the boundary between the Cretaceous and Tertiary Eras about 65 million years ago—the so-called K/T extinctions.

Aiming for the Moon at an early age

In 1956 Gene tried to interest the USGS in constructing a geological map of the Moon. Because of the Cold War priority on finding plutonium, the Survey instead kept him at work in the field, where he studied craters formed by small nuclear-test explosions under the Yucca Flats in Nevada. These studies led him to compare Meteor Crater with those nuclear explosions, and it was in this work that Gene did his seminal research on the mechanics of meteorite impacts.

Gene received his doctorate from Princeton in 1960 with his dissertation on Meteor Crater. Also, his 1956 paper with Robert Hackman, "Stratigraphic Basis for a Lunar Time Scale," was a landmark in deciphering the history of the moon. With this paper, his early work in applying the methods of geology, rather than those of physics and astronomy, to the planets, and his lifelong quest to quantify the rain of asteroids and comets onto the Earth, Gene in effect stole the planets from the astronomers and gave them to the geologists.

In 1961 he took a leading role in four separate projects: establishing the astrogeology program of the USGS, the study of the new science of astrogeology, the Surveyor and Ranger missions to the moon, and the training of astronauts. Through these initiatives

Gene in spacesuit during astronaut training. (Photo by USGS Astrogeology.)

he created an alliance between NASA and the USGS in which geologic techniques are used to interpret remote sensing data. That alliance is still robust and thriving in the second decade of the 21st century. Gene's comprehensive knowledge of lunar surface processes and the lunar regolith provided a geologic framework to the early observations of the lunar surface, and as the Apollo missions progressed, his influence never waned.

His dream of going to the Moon himself was stifled in 1963 when he was diagnosed as having Addison's disease, a condition that disqualified him from becoming an astronaut. Instead, when the USGS Astrogeology Center was founded in Flagstaff in 1965, he was appointed its Chief Scientist and organized the geological activities planned for the lunar landings.

I first met Gene in 1966, when he had a dual relationship with the USGS and Caltech. Like many in my entering graduate class of planetary scientists that year, I came out of a physics/math background with little or no exposure to geology. Gene was teaching astrogeology and I signed up for his course, which dealt with meteorite impact dynamics. He also led a spring field trip down the San Juan River, where we were exposed to rocks, river running, and Mule Ear diatreme—a crater caused by the explosive contact of magma with ground water. What a way to get introduced to geology and river running, both becoming passions of mine that lasted throughout my career! I decided that I wanted to work with him, and so asked him if there were any efforts of his that I could get involved with during the summer.

He invited me to come to Flagstaff and, in what I was to discover was a pattern, decided the day I arrived that the very next day he had time to take me up to southern Utah in a remote area near the new Canyonlands National Park to work on a problem that he'd had in his pocket awhile. His idea was that the structures in the south end of Canyonlands might be an analogue for the then poorly understood Basin and Range Province—a

After following Gene across Elephant Hill on my first day in a USGS Jeep, I must have looked a bit green, because he looked at me and said, "Haven't you ever driven a four-wheel drive before?" "No," I confessed..., "you never asked..."

vast region running south-southeast from southeastern Oregon and southern Idaho into western Mexico and characterized by narrow, parallel mountain ranges separated by arid lowlands. He, Carolyn, and family piled into a USGS Jeep, got me a second one, and off we went to Utah. We went not only into Canyonlands, but all the way through it and out the south end into the wilds managed by the Bureau of Land Management.

A major barrier to entering the wilds of Canyonlands is Elephant Hill, described by the National Park Service as "one of the most technical four-wheel-drive roads in Utah… [It] presents drivers…with steep grades, loose rock, stair-step drops, tight turns and tricky backing." After following Gene across Elephant Hill on my first day in a USGS Jeep, I must have looked a bit green, because he looked at me and said, "Haven't you ever driven a four-wheel drive before?" "No," I confessed…, "you never asked…"

This was typical Gene, optimistic that people could do anything if they just set their mind to it. After a brief trip down into one of the low valleys, a graben, and a quick lesson on how to winch the jeep back out, Gene and his family left the next day, leaving me, who had never camped, to secure the problem that we had brought a four person USGS tent, but no tent stakes. It was July, the temperature was 110° by 10:00 in the morning, a mountain lion and I mutually terrorized each other, chipmunks ate all the labels off my canned foods, and the nearest water was two hours away back over Elephant Hill. Moab, a one-lane cow town where I could get supplies, was another two hours away. Bob Sharp (The chairman of the Caltech Division of Geological and Planetary Sciences) never forgave Gene for sticking me out there alone, but I could never thank Gene enough for the wonderful adventure and for the confidence that he showed in my ability to survive and grapple with a complicated geological problem.

I ended up doing a Ph.D. dissertation based on the shocked porous Coconino sandstone from Meteor Crater. My initial efforts were theoretical, using the primitive computers of the time to model one-dimensional plates of quartz impacting each other across one-dimensional pores. When I described this to Gene, he said, "If you're going to do that, you

better look at some real shocked rocks." He handed me thin sections and showed me how to use a petrographic microscope. The instant result: I relegated computer calculations to an appendix in my dissertation. With that simple comment about looking at the real rocks, he instilled in me a lifelong commitment to combining my theoretical work with laboratory and fieldwork. When I would grumble that the world was too complicated, he'd let out that boisterous laugh of his and say, "That's what's so great about it!!"

Gene's early involvement in the unmanned Ranger and Surveyor programs evolved into scientific leadership in the manned Apollo program. His lunar studies culminated in 1994 when, as science team-leader of Project Clementine, he led the acquisition of new photographs of the lunar south-pole region, previously poorly documented.

Gene at Meteor Crater.
(Photo by USGS Astrogeology.)

Gene trained many geologists and astronauts along the "Astronaut Trail" around the rim and down into the bowels of Meteor Crater. He chaired the National Academy of Sciences committee that selected Harrison "Jack" Schmitt as the first scientist-astronaut to go to the moon.

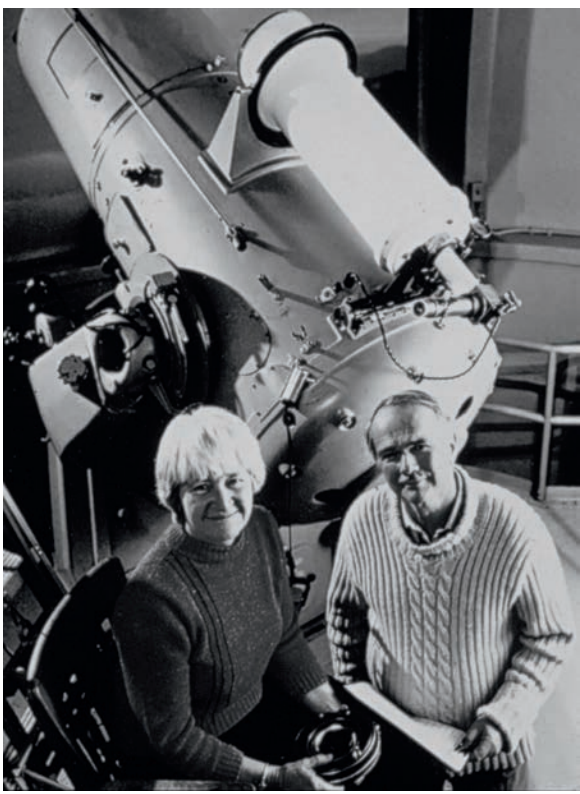
Gene unraveled the geologic history of many parts of the southwestern United States, particularly in Arizona. He loved the Hopi Buttes, Meteor Crater, Upheaval Dome (Utah), and Grand Canyon country. More than 50 years after his careful mapping and interpretation of the processes of eruption of the diatremes of Hopi Buttes was published with Carl H. Roach and Frank M. Byers, that paper still provides the basic model and field data for our understanding of these features and their relatives, the diamond-bearing kimberlites. He introduced many of us to the geology of the Southwest on river-rafting trips down the San Juan and Colorado to explore the rocks, to teach us about the rates

of processes revealed in the side-canyons, and to educate us in the history of exploration of the region. His desire to understand and document the geology of the Southwest led him with Don Elston to the establishment of a major paleomagnetic facility at Flagstaff, a laboratory to measure the magnetic properties of rocks. These properties can give the age of rocks and information about their geologic history. The lab operated from 1970 to 1991.

Applying geologic principles to other moons

In 1969 Gene returned full-time to Caltech as a professor of geology and served for three years as chairman of the Division of Geological and Planetary Sciences. Until he retired from the professorship in 1985 he divided his time between Pasadena and Flagstaff. He continued to maintain an office in the USGS Astrogeology Center in Flagstaff after his formal retirement in 1993, while at the same time taking up a position at the Lowell Observatory.

Shortly after he settled in at Caltech, Gene became interested in extending his geological knowledge of the formation and distribution of terrestrial and lunar impact craters to the study of the astronomical objects that formed them. With Eleanor Helin, a planetary scientist at Caltech, he developed a plan to search for such objects—in this instance, the Apollo asteroids—with the 0.46 m. Schmidt telescope at Caltech's Palomar Observatory. This search program had its first success in July 1973 and, with the help of a number of students and of collaborations using other Schmidt telescopes, was soon significantly augmenting the rather meager knowledge that had been accrued on these objects during the previous four decades.



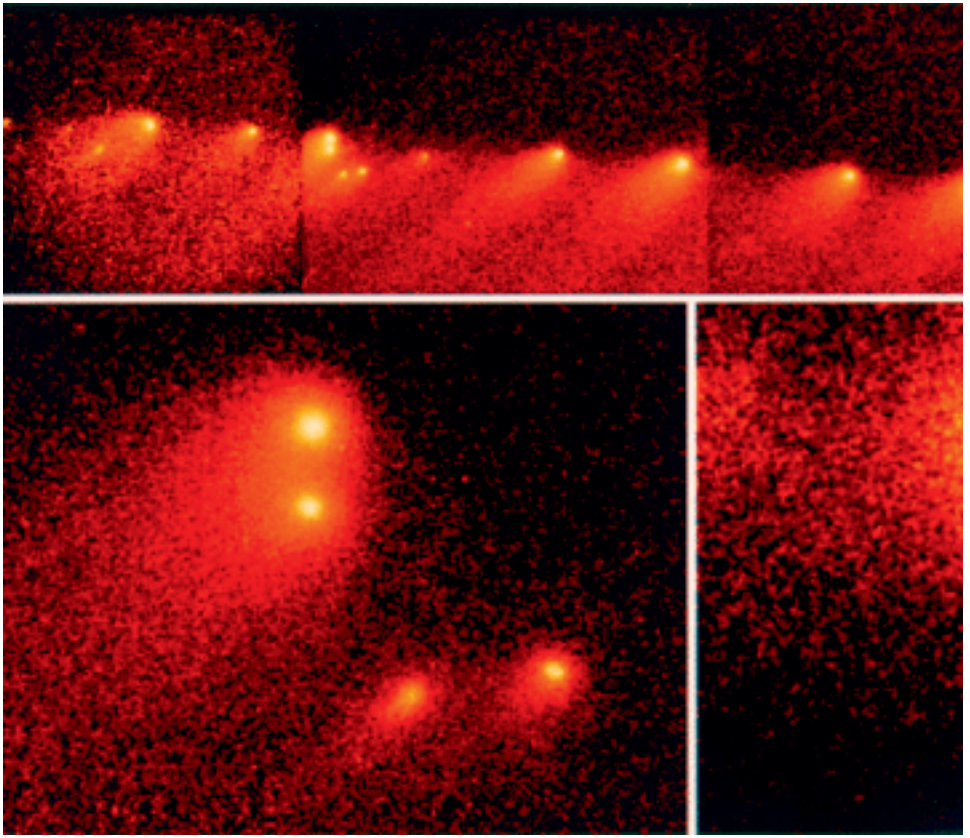
Carolyn and Gene at Palomar telescope. (Photo by USGS Astrogeology.)

Gene applied his creative but disciplined imagination to propose interpretations of phenomena on other planets never seen in our terrestrial experience before the age of space exploration. He was a key member of the team that proposed that the plumes on Io, a satellite of Jupiter, were geysers and volcanoes venting from sulfur and sulfur dioxide reservoirs. He was on the team that proposed that the plumes on Triton, a satellite of Neptune, could be degassing nitrogen from a solid-state greenhouse of nitrogen ice, and he was involved in many projects interpreting the geology of both the rocky and icy satellites. No sizable body in the Solar System escaped his observant eyes, and every piece of data was integrated into his constantly evolving vision of the origin and evolution of the Solar System, its planets, and their satellites. *

After the three Shoemaker children were grown up and on their own, Carolyn became increasingly involved with measuring images from the Palomar films and became a major partner with Gene in the Palomar Asteroid and Comet Survey (PACS) to search for comets starting in the 1980s. In 1983 the couple discovered the first of the record 32 comets associated with their name; they found more than 800 asteroids, as well. By the 1990s, electronic charge-coupled devices would enable surveys to find many more objects faster and more efficiently, but by the time PACS ended in 1994, Gene, Carolyn and colleagues had uncovered 40 of the known Amor, Apollo, and Aten asteroids. There are now 417 of these objects known. A few months before the Shoemaker program was terminated came its "defining moment." Gene and Carolyn were working with the astronomer David Levy, and they all received the thrill of their lifetimes when some 20 components of Comet Shoemaker-Levy 9 at crashed into the planet Jupiter.

This discovery was announced in the *International Astronomical Union Circular 5725*:

> *Cometary images have been discovered by C. S. Shoemaker, E. M. Shoemaker, and D. H. Levy on films obtained with the 0.46 m. Schmidt telescope at Palomar. The appearance was most unusual in that the comet appeared as a dense, linear bar ~1' long and oriented roughly east-west; no central condensation was observable, but a fainter, wispy 'tail' extended north of the bar and to the west. The object was confirmed two nights later in Spacewatch CCD scans by J. V. Scotti, who described the nuclear region as a long narrow train ~47" in length and ~11" in width, aligned along p.a. 30-260. At least five discernible condensations were visible within the train, the brightest being ~14" from the southwestern end. Dust trails extended ....*



Comet Shoemaker-Levy 9 in pieces as it approaches Jupiter in July 1992.
(Photo by NASA/JPL.)

Shoemaker Impact Crater, Australia.
(Photo taken from space by USGS Landsat program.)

The pieces of the comet impacted Jupiter from July 16 through July 22, 1994, and 20 years later, observers still see evidence of the impact in the form of water vapor in the upper atmosphere of Jupiter.

Though retired, Gene continued his quest to investigate meteorite impact craters on Earth, especially in Australia. It was there that Gene was killed, and Carolyn severely injured, in a head-on collision with a truck. Gene died as he had lived, active to the hilt. In honor of the work that Gene and Carolyn did in Australia, the impact structure formerly known as the Teague Ring was renamed Shoemaker Crater. It is a deeply eroded remnant of an impact crater, with a diameter of about 100 km.

His legacy

Two of the greatest paradigm shifts in the 20th century were the discoveries of plate tectonics and its processes and the role of meteorite impacts in upsetting the slow pace of geological processes. Gene, with his students and colleagues, played a major role in the latter.

Everyone who knew Gene was affected by his enthusiasm and energy. In addition to his scientific legacy, there are the memories that those of us who knew him will always treasure: of the warm, twinkling humanness, the unfailingly generous spirit, the intellectual honesty, the romance and love in his eyes for Carolyn, and the unflagging enthusiasm for life and its unfolding. Even now, as I write this 17 years after his death, I know many for whom his magic lives on in their hearts.*

There have been many memorial testaments to Gene, and I selected one here that I think conveys his spirit as well as his science. "The Man Passing by on his way to the Moon" was written and performed by Bevan French on the occasion of Gene's retirement from the USGS. It was published in the November/December 1997 issue of *Planetary Report* (17:14), a few months after his death:

The Man Passing by on his Way to the Moon

Verse 1:
He was born in a basin that's now called L. A.
He decided quite early that he wouldn't stay.
The Moon shone down on him, there were rocks all around,
And in that combination, his life's work was found.

He'd lie in his cradle and smile at his mother,
With a hammer in one hand and a rock in the other.
And late in the evening you might hear him croon,
"I'm just passing by on my way to the Moon."

Chorus:
He's done coesite and stishovite and asteroids and dinosaurs,
He's discovered the craters with which Earth is strewn.
He's done missions and committees and management and bureaucrats;
All the things that you do on your way to the Moon.

Verse 2:
He started with field work like all Survey hands,
But salt and uranium were not in his plans.
It was Meteor Crater and all of its kin
That changed our whole view of the world that we're in.

Then he hooked up with NASA and worked with Apollo,
'Cause where astronauts went, geologists could follow.
And in conference or meeting he'd sing the same tune,
"I'm just passing by on my way to the Moon."

Chorus:
He's done coesite and stishovite and asteroids and dinosaurs,
He's discovered the craters with which Earth is strewn.
And all these catastrophes are non-Uniformitarian;
That's what you learn on your way to the Moon.

Verse 3:
So to all young geologists who are new on the scene,
If you want to do well, take your lessons from Gene.
Stay close to your field work, but leave your mind free,
And don't sit at home when there are new worlds to see.

For the young are not finished with the worlds that we know.
They've heard all our stories, and they're eager to go.
It won't be next August, or the following June,
But one day they'll pass by on their way to the Moon.

Chorus:

He's done Ranger and Surveyor and Voyager and Clementine.
He's explored and he's taught, and he won't slow down soon.
For in spite of committees and all of those bureaucrats,
There'll be folks passing by on their way to the Moon.

Reprise:

That's not bad for a man on his way to the Moon.

ACKNOWLEDGEMENTS

* **Disclaimer**

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The text of Bevan French's song "*The Man Passing by on his way to the Moon"* appeared originally in *Planetary Report*: 17:14 and is reprinted here with permission of both Bevan French and The Planetary Society.

An excellent biography of Gene is Shoemaker by Levy—*The Man Who Made an Impact.* David H. Levy, Princeton University Press, 2002. I have drawn heavily from this excellent source.

HONORS AND AWARDS

Gene's many honors included:

Wetherill Medal of the Franklin Institute,1965 (co-recipient with Ed Chao)

Honorary Ph.D., Arizona State College (now Northern Arizona University,) 1965

Arthur S. Fleming Award, 1966

NASA Medal for Exceptional Scientific Achievement, 1967

Honorary Ph.D., Temple University, 1967

U.S. Department of the Interior Honor Award for Meritorious Service, 1973

National Academy of Sciences, elected, 1980

U.S. Department of the Interior Distinguished Service Award, 1980

Arthur L. Day Medal of the Geological Society of America, 1982

G. K. Gilbert Award of the Geological Society of America,1983

Rieser Kulturpreis, 1983 (co-recipient with E. C. T. Chao and Richard Dehm)

Barringer Award of the Meteoritical Society, 1984

Kuiper Prize of the American Astronomical Society, 1984

Honorary Ph.D., University of Arizona, 1984

Leonard Medal of the Meteoritical Society, 1985

Distinguished Alumnus Award, California Institute of Technology, 1986

Bowie Medal of the American Geophysical Union, 1996

Rittenhouse Medal of the Rittenhouse Astronomical Society, 1988 (co-recipient with C. S. Shoemaker)

U.S. National Medal of Science, 1992

Whipple Award of the American Geophysical Union, 1993

Fellow, American Academy of Arts and Sciences, 1993

Fellow, Geological Society of America, Mineralogical Society of America, and American Geophysical Union

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