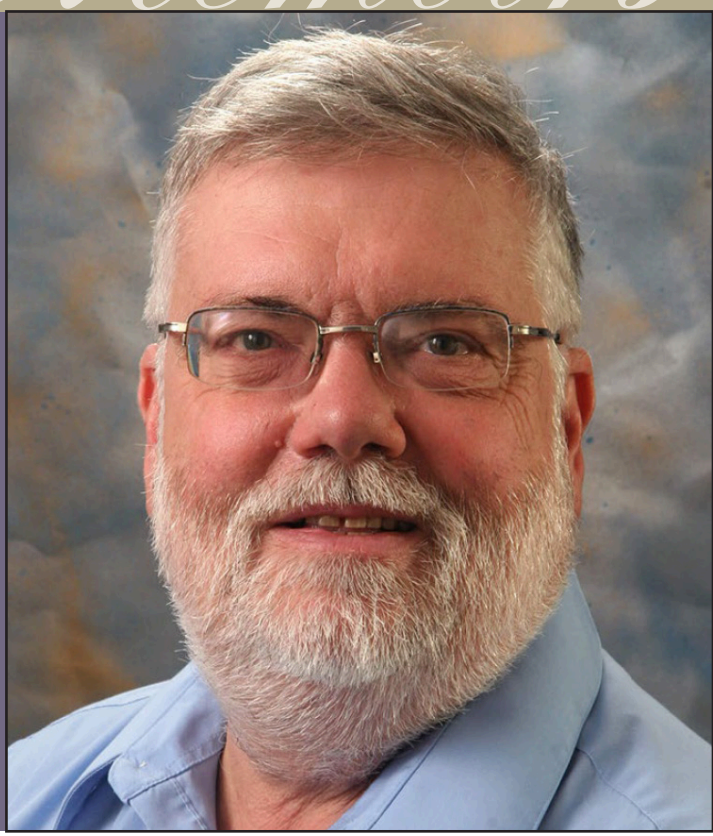
Henry J. Melosh

1947–2020

BIOGRAPHICAL *Memoirs*



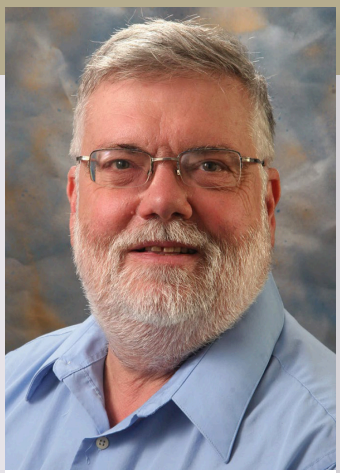
A Biographical Memoir by
Francis Nimmo
and Bill McKinnon

NATIONAL ACADEMY OF SCIENCES

HENRY JAY **MELOSH**

June 23, 1947–September 11, 2020

Elected to the NAS, 2003



By Francis Nimmo and Bill McKinnon

H. Jay Melosh was a planetary physicist best known for his elucidation of the physics and consequences of hypervelocity impacts. These included quantifying the effects of the dinosaur-killing impact on Earth and the ability of impacts to transfer unshocked material from one planet to another. The latter led to an interest in how organisms might be transmitted from planet to planet (panspermia). His expertise was summarized in a book-length monograph that, thirty years later, remains a bible for impact modelers. Jay was also deeply interested in planetary tectonics, being the first to explain how processes such as spin-down could produce global patterns of faults. He proposed the mechanism of acoustic fluidization, a still somewhat controversial process that has been implicated in large landslides, impact crater modification, and fault ruptures. Jay was an exceptional mentor of students, many of whom are now leaders in their fields, and led a famous series of geological field trips. His infectious enthusiasm for his subject and the rigor with which he scrutinized all ideas made him an unmistakable force in planetary sciences.

Early Years

Henry J. Melosh IV was born on June 23, 1947, in Patterson, New Jersey (Figure 1). His father, Henry "Hank" Melosh III, was an electrical engineer, and his mother was Eleanor Frances Wilde Melosh. As a child, his interests included ham radio (he was a life-long practitioner), fishing (the family had a cottage on a lake) and rocketry. After one particular launch blew out all the windows of his local school, he was relocated to a boarding school in New Hampshire but continued his experiments. Jay, as he was universally known, was never a great respecter of authority, and his early enthusiasm for explosions evidently never left him.

Following family tradition, Jay attended Princeton University, where he studied physics from 1965–1969 (Figure 2). This led to Ph.D. studies in particle physics at the Cali-

Figure 1 -Henry Jay Melosh at one month with his father Henry and mother Eleanor in Ridgewood, New Jersey, 1947.

fornia Institute of Technology (Caltech) with Nobel laureate Murray Gell-Mann, during which he spent time at the European Organization for Nuclear Research (CERN) and the Fermi Institute in Chicago. The paper arising from his 1973 thesis, which examined the relationship between current and constituent quarks, is still referred to as the source of the "Melosh transformation" and remains Jay's most-cited first-author paper.[1]

At Caltech, something unexpected happened. Perhaps because of a latent interest in geology—undoubtedly amplified by his summer glaciology field work with Barclay Kamb—and perhaps because of dissatisfaction with the state of particle physics, Jay decided to switch fields and start thinking about planetary science. It was a good time and place to do so: the results of the Apollo program were still being digested, and Caltech was at the forefront of the nascent field of lunar geology (the astronauts having been trained in geology by Eugene Shoemaker and Lee Silver, among others). Following a stint at Caltech as an instructor, Jay was hired as an assistant professor in the Division of Geological and Planetary Sciences there in 1976.

Figure 2 -Matriculation photo from Princeton.

Jay and Barclay wrote a paper on glaciological observations they had made, but it was never submitted because the answers didn't jibe with Barclay's conception of how glaciers worked. Jay had a similar trust in his own intuition. He was also famous for always signing his reviews, even as a junior person reviewing a senior person's work—a risky proposition, but one that exemplified Jay's concept of how science should proceed.

During his time at Caltech, Jay began to study several problems that were to occupy him for the rest of his career. His next paper after the Melosh transformation was on lunar "mascons,"[2] then recently discovered and unexpected positive gravity anomalies associated with large craters.

He initiated a seminal series of papers on the global tectonic consequences of changes in planetary shape, through despinning, orbital recession, or true polar wander. His first paper on this topic[3] contains a tongue-in-cheek acknowledgement to the Los Angeles County Superior Court for providing office space—he wrote the paper while doing jury duty! He introduced the idea of acoustic fluidization, whereby vibration-driven particle interactions reduce the effective friction of granular materials.[4] And he also wrote his first papers on impact crater processes, the topic with which he is most indelibly associated.[5,6]

Shortly after receiving a promotion to associate professor in 1979, Jay left Caltech and moved with his young family (first wife Penny, children Nicholas and Gregory, and dog Rigel) to what is now Stony Brook University. During this period he continued to develop, with Arthur Raefsky, a finite-element viscoelastic deformation model (TEKTON),[7] which was used by many groups to investigate various Earth and planetary processes over the next couple of decades. In keeping with his philosophy of open collaboration, Jay made the source code available to others upon request (and challenged users to find bugs in it!).

The University of Arizona

In 1982, Jay left Stony Brook for the University of Arizona (UofA), at the time the institution with the largest concentration of planetary faculty in the country. He was to stay there for the next twenty-seven years, ultimately becoming a Regents Professor with a joint appointment in the Lunar & Planetary Laboratory and the Department of Geoscience. It was during this period that Jay really established his dominance in the field of impact physics.

One issue of particular interest was whether certain meteorites could have come from Mars. Jay was initially highly skeptical of this idea, because it was hard to understand why these meteorites showed little evidence of shock, and was vocal in saying so at conferences. But as the evidence mounted, he reconsidered and found a mechanism—spallation—by which near-surface materials can be launched at high velocities without experiencing extreme pressures.[8]

A natural progression of this idea was to consider whether life could be transmitted from one planet to another by this process—the idea of panspermia. Such an idea was not necessarily regarded as a respectable scientific hypothesis, but Jay was unperturbed and proceeded to champion the idea vigorously, even extending the idea to the transfer of life between stellar systems.[9] He overcame objections that any micro-organisms would be destroyed by

the impact shock by dipping bullets in a petri dish of *D. radiodurans* bacteria and having an undergraduate fire them at a steel wall! His lectures on panspermia were often titled "Are We All Martians?" Jay frequently had a touch of the showman about him.

A second issue was the consequences of large impacts, which received an important intellectual boost from the 1984 Conference on the Origin of the Moon in Kona, Hawaii. Jay wrote a still-valuable monograph on the thermal effects of such impacts[10] and also considered the likely consequences for core formation and magma ocean generation. He also became interested in the interactions between impacts and atmospheres, partly inspired by the impact scars and ejecta on Venus revealed by the Magellan mission. One memorable publication showed how the dinosaur-killing impact on Earth would have heated the entire atmosphere to broiling point.[11] Jay originally wanted to title this paper "Broiled Alive," but the editors objected. In at least one public talk on the subject, he placed a couple of plastic dinosaurs in a toaster oven and had some younger audience members monitor their demise.

Jay was also deeply concerned with developing accurate equations of the state of planetary materials, descriptions of which underpin all impact codes. Much of the work on these equations of state was initially classified and carried out at Sandia National Laboratories in New Mexico. Jay was influential in helping move some of this knowledge into the public domain, and published improvements on existing equations.[12]

In 1989, Jay collected all his accumulated impact knowledge into the book *Impact Cratering: A Geologic Process*. It became an instant classic and is still unsurpassed thirty years later. Despite the breadth of material and depth of insight displayed, the book is actually remarkably short, surely one reason for its success. The second edition is being finished right now by two of Jay's former students and will undoubtedly be one of Jay's more enduring legacies.

By the late 1990s, computers had become fast enough to perform 3D, rather than 2D, impact simulations. Working with his student Elisabetta Pierazzo, Jay wrote a whole series of important papers on how various aspects of cratering mechanics changed as the impact angle changed.[13] Whereas some crater characteristics were relatively insensitive to the impact angle, others, such as melt production and atmospheric loss, are more strongly affected.

Unlike many theoreticians, Jay was a great believer in the importance of geological observations in general, and field trips in particular. The UofA field trips that Jay ran

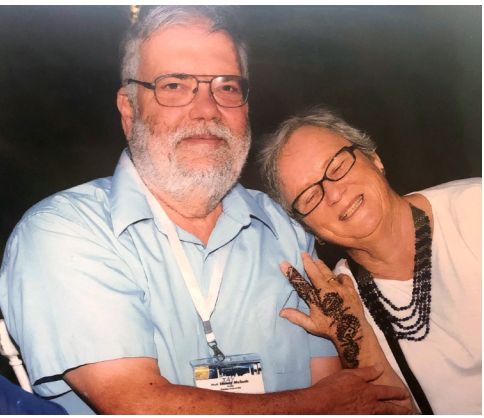


Figure 3 -Jay and Ellen.

are legendary and form the basis of many of his students' best stories. Some collateral damage was inflicted on the long-suffering departmental vans, but the camaraderie and Socratic scientific discussions formed an indelible impression. A recent survey of graduate alumni of the planetary curriculum revealed that many viewed Jay's field trips as their most valuable learning experience. Some noted that Jay used to walk around banging a frying pan to wake everyone up.

In general, Jay worked most closely with his students, rather than with more senior collaborators. One exception is his series of papers with Boris Ivanov, a Russian impact expert. This collaboration reflects Jay's long-term interest in and admiration for Russia: he had stories of "smuggling in" information about plate tectonics (at that time not widely accepted behind the Iron Curtain) during the Cold War, and on at least one occasion being interrogated in a van by a group of KGB agents before being summarily expelled from the country.

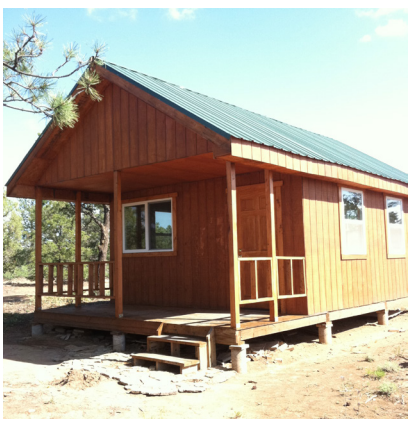


Figure 4 -Jay and Ellen's self-constructed New Mexico cabin.

On the occasions when he did work with senior authors, Jay often picked people with very different backgrounds. His "broiled alive" paper included a co-author from the U.S. Forest Service, and he worked with comet expert Mike Belton to help investigate the geological effects of fluidized flows on those bodies.[14]

During his time at UofA, Jay met and married his third wife, Ellen Germann in 2002. (Figure 3). Ellen aided and abetted Jay in his non-science activities: for instance, the couple built a cabin in New Mexico entirely by themselves (Figure 4), using a high school text as a guide. This

construction effort was probably aided by the fact that Jay was an expert woodworker who sold his products at local craft fairs.

Spacecraft Missions

Although Jay was a pre-eminent theoretician, his papers were often based on spacecraft observations, and in the 2000s he became deeply involved in a pair of spacecraft missions.

The first was Deep Impact, a mission to determine the internal characteristics of a comet by firing a projectile at it. Jay's job was to predict what was likely to be observed as the spacecraft flew by. This was a non-trivial task, given the large uncertainties in the comet's properties, but it was a vital one because it determined exactly what observations should be made. The flyby, carried out in 2005, was a great success, but the impact crater itself was not imaged. Fortunately, a "retired" spacecraft (Stardust-NExT) was available to be redirected and found what was most likely the expected spacecraft-made crater.[15]

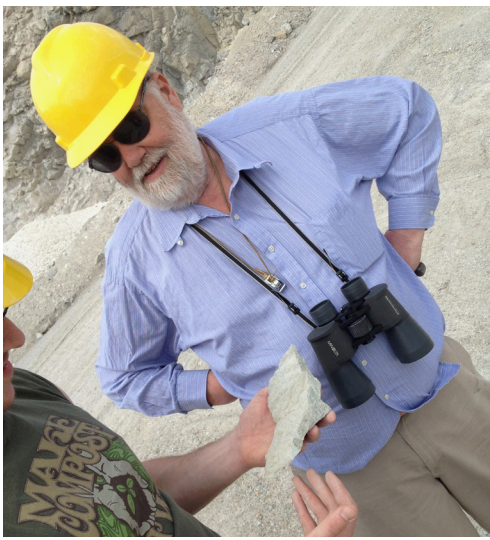


Figure 5 -Jay standing inside the central peak of Kentland impact crater, 2014.

The second mission was GRAIL (Gravity Recovery and Interior Laboratory), which produced exquisite maps of the Moon's gravity. This gave Jay an opportunity to follow up on his long-standing interest in mascons. Using a combination of impact models and finite-element viscoelastic codes, Jay and his colleagues were finally able to demonstrate how mascons formed, some forty-five years after they were first discovered.[16]

Purdue University

In 2009, Jay moved from Arizona to Purdue University in Indiana. He had been offered the once-in-a-lifetime opportunity of starting up a planetary science group from scratch and was ready for a new challenge. He threw himself into this work with his characteristic energy, hiring a group of bright young professors and establishing strong connections with aerospace engineers on campus. He also continued the field trip tradition, finding new sites such as the Kentland impact structure (Figure 5) to visit.

Despite the heavy administrative load, Jay found time to complete a second major planetary textbook: *Planetary Surface Processes* (2011). This was based on a long-standing course he taught at UofA and is distinguished by its physical intuition, and the number of anecdotes included. The latter was a deliberate pedagogical strategy of Jay's; as he said, he would frequently meet students "who, after many years, still retain the story, if not the point that it was meant to illustrate!"

A decade after Jay's arrival, the Department of Earth, Atmospheric, and Planetary Sciences at Purdue has roughly ten planetary faculty, making it one of the largest planetary groups in the country. That success is largely down to Jay and will serve as a long-lasting monument to his endeavors. He is commemorated by the H. Jay Melosh Planetary Science Engagement Fund, intended to aid students with expenses to attend scientific meetings.

A Joyful Professor

To Jay, science was simply fun—his enthusiasm and willingness to pursue new ideas to their logical conclusion never wavered. But that enthusiasm was backed by a rigorous, quantitative mindset, and those displaying fuzzy thinking often received short shrift; he held other people (and himself) to the highest scientific standards. Jay could certainly be intimidating—though he mellowed with age—but he was a fervent supporter of his own students, believing that they should be given the latitude to pursue their own inquiries. Such academic freedom was extremely important to him, not least because his own career involved such a radical change in direction. He was an outstanding mentor of graduate (and undergraduate) students: many of his protégés are now themselves leaders in planetary sciences.

Although it might not have been apparent to those faced with one of Jay's characteristically to-the-point science questions, he had a deep reservoir of kindness. He found and shipped back to its young owner a toy car that had been lost, apparently for ever, in the bushes. And he encouraged Ellen's interest in weaving, which meant sharing his house with more than a dozen looms.

Jay was not a believer in giving up easily, either in science or in life. One particularly memorable example began with his purchase of three goats to keep down the weeds in his Arizona yard. Despite the goats' complete lack of interest in eating weeds, the enterprise expanded to include more goats and, ultimately, a cheese- and meat-producing endeavor. Unfortunately, neither product was edible, and the experiment was reluctantly terminated.

Jay received many awards over the course of his career. These included the Barringer Medal from the Meteoritical Society (1999), the G. K. Gilbert Award (for planetary geology) from the Geological Society of America (2001) and the Hess Medal from the American Geophysical Union (2008). He was an active member of the National Academy of Sciences following his election in 2003. He was also a Fellow of the American Association for the Advancement of Science, the American Geophysical Union, the Geological Society of America, and the Meteoritical Society.

By 2020, Jay was in the process of stepping down from Purdue and beginning a well-earned retirement: he and Ellen had already bought a house on Cape Cod, partly to facilitate Jay's sabbatical at the Massachusetts Institute of Technology. Sadly, the pair did not have much time to enjoy this next stage: Jay passed away unexpectedly on September 11, 2020. He is survived by Ellen, his first wife Penny, and sons Nick (a materials scientist at Stanford University) and Greg (a naval aviation tech).

ACKNOWLEDGMENTS

We thank the following people for sharing their memories of Jay: Ellen Germann, Zibi Turtle, Brandon Johnson, Nick Melosh, Carolyn Porco, Erik Asphaug, and Jonathan Lunine.

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