

# Memorial to M. King Hubbert

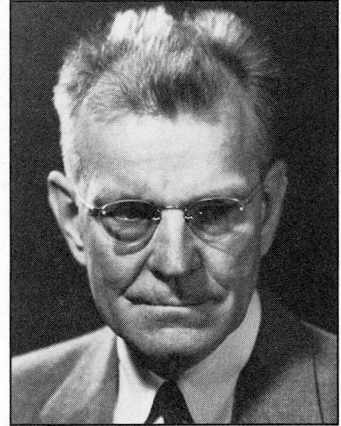
## 1903–1989

DAVID B. DOAN

5635 Bent Branch Road, Bethesda, Maryland 20816

Marion King Hubbert, one of the outstanding geologists and geophysicists of this century, died in his sleep in the early hours of October 11, 1989, as the result of an embolism.

A brilliant geologic thinker, an authority in the reconciliation of geologic thought with the principles of physics, a pioneer in the application of continuum mechanics to problems of tectonics, an expert in the behavior of fluids in porous media, and an innovator in the mathematical prediction of the limits to mineral resources, M. King Hubbert's career was an odyssey of magnificent proportion and productivity. His work encompassed academia, industry, government and, ultimately, independent consulting. He was a member of the National Academy of Sciences and President of the Geological Society of America in 1962.



He was awarded both the Arthur L. Day Medal and the Penrose Medal of the Geological Society of America; fellowship in the American Academy of Arts and Sciences; The Rockefeller Public Service Award from Princeton University; the Elliott Cresson Medal of the Franklin Institute of Philadelphia; the Anthony F. Lucas Gold Medal of the American Institute of Mining, Metallurgical, and Petroleum Engineers; the William Smith Medal of the Geological Society of London; and ultimately the Vetlesen Prize from Columbia University, the highest honor that exists in the earth sciences. He was chairman of the Division of Earth Sciences of the National Research Council from 1963 to 1965. He was instructor of geophysics at Columbia University, professor of geology at Stanford University, and regents professor at the University of California at Berkeley, and was awarded the degree of doctor of science *honoris causa* from Syracuse University and from Indiana State University. He was Distinguished Lecturer of the American Association of Petroleum Geologists in 1945, 1952, and 1973 and elected honorary member in 1974. He was associate editor of that organization's *Bulletin*, and editor of *Geophysics*. He was an honorary life member of the Canadian Society of Petroleum Geologists, and an honorary member of the American Institute of Mining, Metallurgical, and Petroleum Engineers, and elected an honorary life member of the Society of Exploration Geophysicists.

He is survived by his wife, Mrs. Miriam Berry Hubbert of Bethesda, Maryland; two sisters, Mrs. D. Menter Jessup of Los Angeles, California, and Mrs. C. G. Colin of Adrian, Texas; and also by two brothers, Leo D. Hubbert of Torrance, California, and Jack L. Hubbert of Ballinger, Texas.

Born in 1903, King Hubbert spent his early years on a farm in the dusty plain of San Saba County, Texas. His schooling was to some degree catch-as-catch-can, the length of the school year varying between four and seven months according to the progress of farm work. The uncertainty of schooling rankled him; he noted later that his expectations were for something better—to learn, to use his mind. Upon completing two years at Weatherford, a small nearby junior college, he gave up in disappointment and decided to seek further schooling somewhere beyond the confines of his home state. Musing one evening, decades later, he admitted that he literally

dreamed at night of attaining a first-class education. Academic degrees were not important; he craved knowledge, wisdom, and cognizance, particularly in the sciences. The popular press had made much of the formulation of the nuclear model of the atom as well as the special and general theories of relativity. The twentieth century promised nothing if not a new era of science, and King Hubbert wanted to be part of it.

After consultation with the president of Weatherford, King applied to the University of Chicago and was accepted, but had no money to travel to Chicago. He was forced to work his way there, initially following the wheat harvest northward. He put in 13-hour working days under a blistering sun, and nights sleeping in haystacks. At the Kansas border he renounced the wheat harvest, gathered up his modest earnings, and headed for Kansas City in the hope of finding some better form of work. Almost broke, he was hired by Union Pacific to work in Colorado replacing old rails with new, heavier steel track. The air was bracing, the food good, the workday only 10 hours, and there were real bunks to sleep in.

Finally arriving in Chicago in September 1924, he took up residence in a boarding house full of medical students, many of whom he later saw through medical school and internship. Meanwhile, he supported himself working various jobs and entered school. A year later, told by his dean that he would have to select a major subject, King replied that he hadn't intended to major in anything—he was there for an education. Under duress he studied the college catalogue, eventually to find an obscure major in geology and physics, that he believed “made it almost a necessity” to minor in mathematics. Thus was assembled an education that made him one of the most solidly based of earth scientists. F. J. Pettijohn remembers him in the old Chicago days thus: “He turned out to be something of an iconoclast, a sharp critic with an excellent analytical mind and skill in mathematical and physical analysis.... King neither needed nor accepted advice and supervision. He was a very independent individual—a student of nobody.”

After field work with Amerada involving reflection seismology, he returned to Chicago as a teaching assistant and general gadfly, criticizing the accepted methods of teaching earth sciences and pushing ideas about courses in geophysics as a complement to those in geology. In 1930 he published his critical review of isostasy showing that the concept, as invoked, lacked any rigorous analytical foundation. Geodesists tended to make the Spheroid of Reference fit a small part of the geoid in a few places while ignoring how greatly it misfit the remainder of the geoid over most of the planet. Thus “isostasy” was created originally to rationalize differences in gravity measurements that seemed systematically too small over the continents and too great over the oceans. He showed that most geodetic reductions were “indissolubly confused” with assumptions of isostasy in determining the value of gravity on the geoid. Worth reading today, this paper was a harbinger of the quality of work to come.

In 1931 he seized an opportunity to become instructor of geophysics at Columbia University, where again he lobbied strenuously for inclusion of comprehensive physics and math, not to mention geophysics, as part of the standard curriculum in geology. Although well-intentioned, such efforts were not welcomed, and M. King Hubbert was tolerated as something of a crank, getting in the way of the departmental program. Unabashed, he pressed his ideas at Columbia and spent summers with the Illinois State Geological Survey working on resistivity measurements of perched ground-water bodies. In the mid-thirties he met Miriam Berry, from bluegrass Kentucky by way of the University of Wisconsin, who was working for a New York pharmaceutical company. The acquaintance found its way through the Manhattan heyday of George Gershwin and Jerome Kern, recovery from the Depression, trouble in Europe, King's increasing dissatisfaction with his situation at Columbia, and a lifetime nuptial commitment.

By 1937 he saw clearly the chasm separating geology, and especially what passed for geophysics, from the tenets of classical physics. That year he wrote the paper on the theory of scale models that is arguably one of the most seminal published in geology in this century. Using

dimensional analysis, he depicted geometric, kinematic, and dynamic similarity in the application of continuum mechanics to scale modeling of geologic structures. Bypassing the complications of thermodynamic behavior, he concentrated on the relation of length, mass, and time constants of geologic systems being modeled. Scaling laws were derived for a variety of familiar geologic structures and processes.

This paper had several significant consequences. First and foremost, it played a role in the revolution in geologic thought away from immediate observation and direct measurement toward a new prescriptive empiricism in the physics of systems modeling that culminated some 30 years later, with some help from seismology, in the recognition of at least the kinematics of plate tectonics. Second, it (and subsequent comments) persuaded many geology departments that students would gain more from calculus and additional physics courses than they would lose by dropping required courses in descriptive geometry, surveying, blowpipe mineral analysis, and the like.

Not least, and somewhat to the surprise of King Hubbert, the paper was accepted as his Ph.D. dissertation by the University of Chicago faculty, a felicitous outcome that, admittedly, he had not foreseen.

In 1940, near the end of his years at Columbia, he reinvestigated the phenomena originally studied in the 19th century by Henry Darcy, the results of which had become distorted and controversial between practitioners in hydrology and petroleum engineering. After repeating Darcy's original experiments, he published *Theory of Ground-water Motion* that not only verified Darcy's work but included the field equations for the movement of water and other fluids through the permeable media of the earth's crust. He introduced the concept of gravitational potential as perhaps the most fundamental of the state variables governing such fluid movement, and showed once and for all that fluids are not constrained to flow only from higher to lower pressure. This elegant paper made much 20th-century work instantaneously obsolete and re-established the foundation for modern hydrology. By his own admission it infuriated both the hydrologists and the petroleum engineers, who ceased fighting each other to turn on him. Ruefully, but in the belief that his results were physically unimpeachable, he took on all critics in published rebuttals that are themselves models of reasoning and clarity.

By this time he gave up on trying to introduce more physics and math, let alone geophysics, to the geology curriculum at Columbia, noting later that the parting was mutually satisfying to the university and himself. After two years with the World War II Board of Economic Warfare analyzing world mineral resources, he joined Shell Development in 1943 in Houston. Here he reorganized his scale-models paper to a new version published in 1945 as *The Strength of the Earth*, which brought him his first AAPG Distinguished Lectureship and put him in a solid position with Shell. By 1951 King had the title of Consultant, General Geology, and relief from most administrative duties. Charles E. Weaver, of clay-mineral fame, later Director of Geosciences at Georgia Tech, knew King as a source of exacting but helpful information during their days at Shell Development: "I recall going to him one day with a quick question on some element of a research problem, and receiving a well-organized response that occupied most of an hour. He didn't cut corners."

By 1952 he published *Entrapment of Petroleum Under Hydrodynamic Conditions*, an exquisite blockbuster in fluid dynamics showing the basis for differential migration of oil and gas in permeable media and the unexpected inclination of gas-oil-water interfaces arising from the interactions of fluids of unlike densities in a dynamic continuum. This generated "crazy" patterns of entrapment in unclosed subsurface structures; counterintuitive and totally new, it altered the course of petroleum exploration. A second AAPG Distinguished Lectureship followed.

Following this, with David G. Willis, he began a series of investigations of the strength of rock materials and permeating fluids under changing conditions of stress that led to their 1957

paper, *Mechanics of Hydraulic Fracturing*. This showed that if the fluid pressure in a wellbore is increased to exceed the ambient lithostatic stress plus the tensile strength of the rock, the resulting fracture will be oriented perpendicular to the least principal stress, or vertically (rather than horizontally, as previously believed) away from the wellbore for depths greater than 700 to 800 feet in most rocks. This initiated a period of intense development of hydrofracture completion techniques in the petroleum industry that continues today, and led to the recovery of significantly greater quantities of oil and gas.

At about this time came the legendary creeping beer can that led to the Hubbert-Rubey collaboration on the mechanics of overthrust faulting. After a hot day of field work in Wyoming, a quickly emptied beer can, served on a table of almost imperceptible tilt, slowly made its way from one end to the other. Some experiments followed, requiring more and more beer in the interests of science, until it was established that the steel can virtually floated because its bottom rim enclosed a concavity of compressed atmospheric gases. Thus arose the concept of the critical role of pore-fluid pressure in the movement of great thrust sheets for many miles, contrary to the accepted idea of prohibitive coefficients of friction.

King Hubbert's presidential address at the 1962 meetings of the Geological Society of America, *Are We Retrogressing in Science?*, deplored the deterioration in quality of existing physical science texts and teaching, and the mendaciousness of the system for wheedling government contracts. The university system "strongly favors the opportunist capable of grinding out scientific trivialities in large numbers [versus] the true scholar working on ... problems whose solutions may require ... efforts extending over years or even decades." A little straight talk among friends.

Still going strong in 1963, at the time of mandatory retirement from Shell, he became a research geophysicist with the U.S. Geological Survey in Washington, spending one quarter each year teaching at Stanford through 1968, at which time he became professor emeritus of geology and geophysics. During the spring quarter of 1973 he was regents professor of the University of California at Berkeley.

A different side of King Hubbert that began in the old Chicago days was his fascination with the idea of limits to exhaustible resources, primarily metals, but shifting to energy and fuels after World War II. Plotting a rate curve of production against time,  $dQ/dt$ , and allowing maxima of varying shapes, he knew that the curve for a given resource had to return to zero because the integral of the curve could not exceed the total amount of that resource. By sophisticated manipulation of values for discovery rates and changes in established reserves, he was able to predict first in 1948 and more formally in the mid-1950s that production of crude oil in the United States would peak about when it actually did, in 1971. His forecast had caused shock, consternation, and denial in various parts of the petroleum industry. Confirmation of his heretical prediction aroused great interest in the media, particularly the *New York Times*, and established him as an "energy expert," somewhat to his annoyance; he regarded himself as an analytical expert. This kind of work put him on various committees for the National Research Council and the National Academy of Sciences, as well as before congressional committees of both houses as an expert witness. Significantly, he was not of the Malthusian or Club-of-Rome school; he believed that periods of exponential growth were unsustainable but that transition was possible to a future minimum-growth world based on inexhaustible and relatively cheap solar energy.

He retired again in 1976 and became a consultant to the U.S. Geological Survey as well as the world in general, working on various projects mostly having to do with energy systems and resources as well as the movement of fluids in the subsurface. In December 1981, he received the Vetlesen Prize, the premier award in the earth sciences, accurately equated to the Nobel Prize but awarded less often. During the ceremonies, C. Barry Raleigh, Director of the Lamont-

Doherty Geological Observatory, remarked: "Being outspokenly correct when the conventional wisdom would have it otherwise may not win popularity contests, but the vitality and intellectual integrity of men such as King Hubbert are rare and precious qualities. Recognition ... marks our great gratitude and humble respect for all that he has done for our science and for this country."

His last night on earth saw him at the Cosmos Club with his wife and a friend, in great spirits and looking well. Later, he attended to one or two administrative matters before retiring. In the morning he did not awaken.

At King Hubbert's death, there was not a geologist, hydrologist, geophysicist, petroleum engineer, or mineral economist in the entire world who was not deeply in his debt. The intensity of a lifelong commitment to his private notion of education, unusual in itself, led to endless Socratic argument with friends such as Jack Stark, Bill Krumbein, Jim Gilluly, Bill Rubey, and Francis Pettijohn; it led also to his ascendancy as probably the leading generalist in earth-sciences research. Characteristically, his Vetlesen Prize acceptance was devoted to the unification of learning in the physical sciences.

King appreciated argument as the knife welcomes the whetstone, an opportunity to hone his ideas to a cutting edge. He seemed always to have in mind that time is the independent variable, never to be wasted. He gladly used his time to explain involved concepts to others, but could become short with those he thought were wasting his. He had a low tolerance for lack of preparation in presentations at meetings, remarking that it was the perfect way for one person to waste the time of two hundred. His sense of humor, somewhat sardonic, was little short of enormous. He derived hilarious pleasure from caricatures of himself by players in the notorious Washington Pick & Hammer shows that depicted his inability to find his way through the labyrinth of the USGS headquarters at Reston, Virginia. Tastes in music ran to Mozart and Beethoven, but at age 83 he did a wonderful performance of "Yes, We Have No Bananas!" one day while riding to a lecture engagement. His strength, both physically and intellectually, was what helped him get through the early years. He knew where he wanted to go, albeit at a price not many would have been willing to pay.

If art is the perfection of memory, as has been said, then perhaps science is the sublimation of reason. A superb exemplar was the scientific productivity of M. King Hubbert. The ideas he wove into the great skein of geological thought not only illumined the advances of this century but endure as a celebration of reason. Memory may fade through the shifting venues of time, but value is conserved: the work of Marion King Hubbert will be read with technical fascination and deep intellectual satisfaction for years to come.

All honor, then, to the young man from San Saba who ventured alone and traveled far to seek elusive truths in the scheme of things. He succeeded, probably beyond his expectations and, in all likelihood, beyond his dreams.

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