



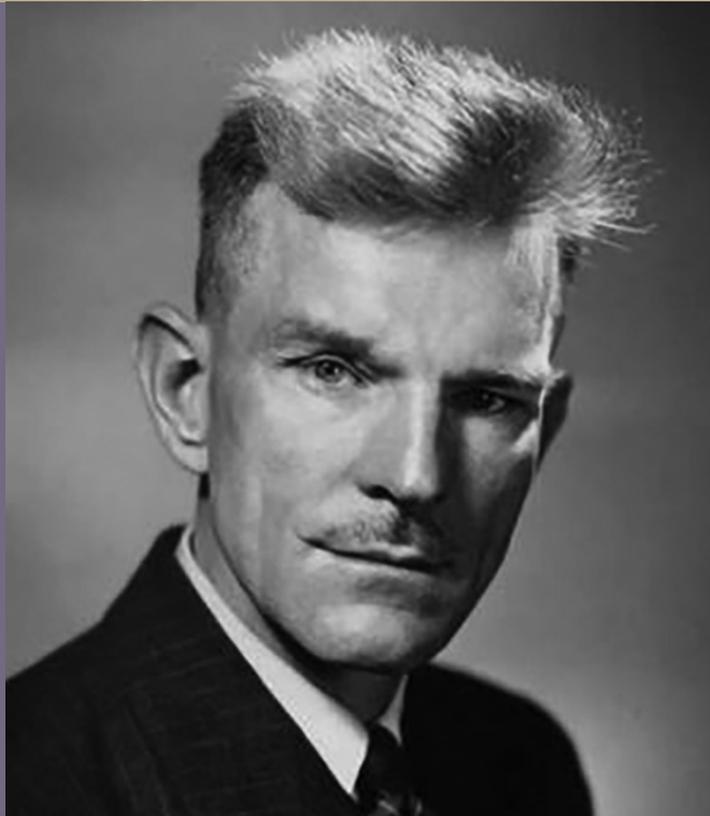
**M. King Hubbert**  
1903-1989

BIOGRAPHICAL

*Memiors*

*A Biographical Memoir by  
Steven E. Ingebritsen and  
Michael Manga*

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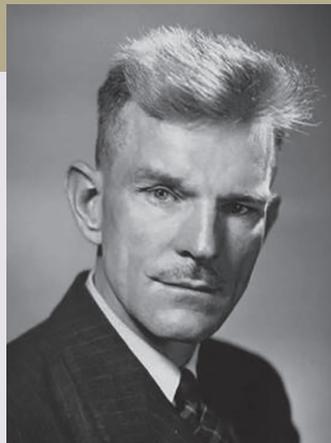
# MARION KING HUBBERT

October 5, 1903 – October 11, 1989

Elected to the NAS, 1955

Marion King Hubbert was a geoscientist best known for his development of the Hubbert Curve, a means of measuring the production rate of petroleum in a given area and for introducing the concept of “peak oil” in 1956. He was a widely sought-after speaker and the author of many seminal scientific papers that elucidate the physical underpinnings of multiple fields of geoscience. He was elected to the National Academy of Sciences (NAS) in 1955 in recognition of his research on geophysical fluid dynamics and hydrocarbon resources.

This bibliographic memoir draws upon previously published work, including a full-length biography, Mason Inman’s *The Oracle of Oil*,<sup>1</sup> and several brief biographical sketches,<sup>2, 3</sup> as well as the lengthy transcripts of nine oral-history interviews done by Ronald E. Doel at Hubbert’s home in Bethesda, Maryland in the year of his passing.<sup>4</sup> The quotes from Hubbert in this memoir all come from these transcripts.\*



By Steven E. Ingebritsen and  
Michael Manga

## Early Life and Education

Marion King Hubbert, son of William Bee and Cora Virginia (Lee) Hubbert, was born in San Saba, Texas, on October 5, 1903, a descendent of settlers who arrived along the San Saba River about 1850. One of seven siblings, Hubbert had two older sisters, three younger brothers, and a youngest sister. As Hubbert recalled, the family “farmed and cultivated land in the creek bottoms. The upland was pasture. We never had a big ranch. We just had a farm with mixed type of land. It was hilly country.” Hubbert’s father also worked intermittently as a farm manager and built embankments for railroads and canals.

Even as a very young child, Hubbert was fascinated by how things work:

*The most advanced technology of the time was the most fascinating. In the early stages that was a blacksmith’s shop. Later on it was steam locomotives or steam tractors for driving the threshing machine....I remember*

*when I saw my first railroad train, my first electric light...[though] I've traveled a thousand miles by covered wagon....I was just fascinated with [freight engines]. Here was this piston rod coming up and a leakage of steam spilling out around the piston rods.... Somebody had told me – one of the workmen, maybe – that if you put a sealed can of water in the fire, that the steam would blow the lid off the can. So I tried it. My mother had a big iron pot for the family wash. She had emptied a can of lye, which had a big friction type top...into this pot. Maybe she was making soap or something, I don't know. I got this can and did what he told me. I put water in it, put the lid back on, put it in the fire, and sure enough, it did blow the lid off. The lid and steaming water hit my younger brother on the hand, and he was screaming and making a lot of fuss....But I was tremendously impressed with the power of this steam. It went right back to those steam locomotives, which I'd never understood a thing about before.*

This incident reportedly occurred in 1908, when the budding experimentalist would have been only five years old. Similarly dramatic experiments later became a hallmark of Hubbert's pedagogy and are featured in his published papers.

Hubbert's childhood opportunities for formal schooling were limited. The family lived well outside of town, and he was often needed for farm work. Both of Hubbert's parents were generally supportive of public education, the availability of which “depended on the available money, and that fluctuated with the town economics.” Hubbert described his parents as “principal leaders in the community in supporting the schools [who would] go to bat on any day in the week for good schools... Still, [t]heir basic education was about 5th grade.”

The personal efforts of Hubbert's mother were essential to his early education:

*We bought a farm...[and my] mother was shocked over the fact that here were all these [neighbor] children growing up...who couldn't read and write. They were illiterate. No schools. Well, she was so incensed by that, that she went to the county seat [where] they had a two weeks training school...and my mother took this school...She got her teacher's license, and went back, cleaned out the old auxiliary buildings next to our house and made a school out of it.*

Hubbert's father's support for education was tempered by a pragmatic attitude towards farm work:

*I practically displaced the farm hand from the age of 10. I worked with horses and plows...and could do a man's work. Then in the summertime you worked like hell all summer, and my father didn't have much of a sense of play. He was a workaholic. You know, you have a rainy day, wouldn't that be great to go fishing? "Boys, don't you think we ought to go down and fix that fence?"*

Hubbert's oldest sister was "my principal member of the family that I could deal with" and served as a valuable conduit to the wider world, particularly during World War I, when she was a clerk in the Signal Corps of the Army in Washington, D.C. From that distant city, she sent her brother a steady stream of technical reading: letters, government documents, and magazines. Hubbert noted,

*She was [seeing] things she'd never seen before – the Smithsonian and the museums and what not...we carried on quite a conversation.... She'd send me all kinds of things to read that I'd never seen or read before.... The Popular Mechanics magazine was my favorite magazine, and was then advertising a volume...from back numbers.... My sister bought that volume for me.*

Local opportunities for education past the eighth grade were limited:

*I finished the 8th grade in this country school....[T]he school term ran from a minimum of four months to a maximum of seven.... When I got out of that, I went away to this private school for a year. At the end of the year, the school folded financially. The postwar Depression of 1921. So at the end of the school year—I was the valedictorian of the class, incidentally—my teachers fudged all the credit they could possibly justify and graduated me from high school. Gave me my high school diploma. One of the credits was a year in agriculture. But I had several years in agriculture!*

*[I]n 1921, before the prices collapsed, [a] teacher talked to me in the summertime and said that he was now the President of [a] junior college, Weatherford College, 30 miles west of Fort Worth. Would I come up? He'd look after my getting jobs and that kind of thing. Actually I had no*

*money but I had a young cow, [a] milk cow. ... I sold her to my father for \$25....They had arrangements whereby anybody who intended to be a preacher could attend without tuition. It turned out that all of the future preachers in the school....were the dumbest men in the student body."*

Hubbert had been "brought up in all of the church dogmas and literature...[and] it never occurred to me to question the authenticity of the Bible." However, at about this time, he recalled, "I found myself beginning to question." His primary focus at Weatherford College became whatever mathematics and science courses were available, but

*[a]t the end of the second year, I was again completely at my rope's end, what do I do now? I had a very low regard for most of the Texas colleges. Football and oil are the principal item of the curriculum....We were approaching the end of the year....I was assistant librarian and at night the library was closed, so it was my private study. After dinner, along about 8 o'clock in the evening, the President dropped in....He said, "What do you want to do next year?" I said I didn't know, I was in a quandary. He said, "Why don't you go to the University of Chicago?" I nearly fainted. I hadn't thought of going beyond the boundaries of Texas. The problem was money. I had to go someplace where I could get a job.*

Naïve in the ways of the world, Hubbert did not know anyone in Chicago, nor did he apply for admission or write any letters in advance. But jobs were hard to come by in Texas, and he reckoned, "by God, [I'll have] the whole city of Chicago to get a job in!"

Hubbert decided to work his way from central Texas to Chicago as a wheat harvester, following the northward progress of the harvest. After arriving at Chicago, he would present his credentials to the dean, gain admission to the university, and find the requisite jobs. Despite his experience with farm labor, Hubbert found the wheat harvest to be "a man-killing operation...working about a twelve, thirteen hour day...sleeping in haystacks." He resolved to "never handle another shovel of wheat, ever" and found a job laying tracks for the Union Pacific Railroad, which

*was just heaven...easy work. You only worked 10 hours a day and you got Sunday off....I grew up handling an axe, so...it didn't take very long to feel completely at home with this spike maul....it gets to be a timed rhythm. You can do that ten hours a day and still feel good....I actually got fat. I weighed 180 pounds when I got off the job. It was great, healthful outdoor exercise.*

Upon presenting himself at the University of Chicago, Hubbert found, unsurprisingly, that his credentials for admission were viewed skeptically:

*[W]hen they looked my credentials over, there was considerable misgiving [about] high school credit and courses from Weatherford College and so on. Essentially they took most of my college credits and used them as entrance credits in lieu of high school. I think I wound up with five college credits out of two years [at Weatherford]....The provision was that if I didn't flunk out, they would reconsider [the Weatherford credits] after a year or so.*

Hubbert still faced the problem of gaining funds for a warm overcoat, tuition, room, and board. He found jobs as a telephone installer, postal clerk, and waiter, “working round the clock,” and began coursework at the University of Chicago during the winter quarter in January 1924.

Inspired by his former Weatherford College teacher Kenneth Luchauer, who had also migrated north to begin his own graduate studies at the University of Chicago, Hubbert intended to focus on chemistry, but rather quickly determined that “the long hours in the chem lab were incompatible with the hours I had to work for sustenance.” He did successfully take “all my college math over, all of it, because I knew it wasn't good enough.” Providentially, Hubbert also elected to take a course in geology during his second quarter at Chicago:

*[T]he reason I was interested in geology at this time was for the history. After all, I know Biblical history. I'd learned that geologists had a different chronology and I wanted to know about it....So I signed up for this geology course, largely to offset the Biblical upbringing that I had....*

*However, [I]t never occurred to me to major in anything. I was actually up there for an education. Then I got called up by the dean one day who said, “You haven't declared your major.” And I said, “I don't want to major in anything.” “Oh, but you've got to. The university rules require it. Not only that, but you have to have a minor.”... So I studied [the college catalog] very carefully, to see what I could major in that would interfere the least with what I was interested in doing anyway. I found a provision in the catalogue for a joint major in geology and physics.*

Hubbert was then assigned a faculty advisor in geology, J. Harlan Bretz. At the time, Bretz was already deeply embroiled in his decades-long (and ultimately successful) battle to convince colleagues that the Channeled Scablands in eastern Washington were created by catastrophic flooding—a hypothesis that challenged the prevailing conservative interpretation based on uniformitarianism.<sup>5</sup> Hubbert would also eventually establish his own reputation as an iconoclast, famous for “solo sorties against ideas entrenched in universities...oil companies and the U.S. Geological Survey.” In fact, his later-in-life home in Bethesda contained a very large painting of Don Quixote, “displayed so prominently that visitors are often taken aback.”<sup>6</sup> It thus seems fitting that Hubbert’s first mentor in geology was another famous iconoclast. Though warned by fellow students that Bretz was “a terrible person,” Hubbert found him to be compatible and helpful, as well as “intellectually exacting.” With help and support from Bretz, Hubbert was able to obtain a series of paid assignments at the University of Chicago and gradually shed his various side jobs.

Having established his academic bona fides at Chicago, Hubbert debated with the Registrar about the admissibility of his high school and Weatherford College credits:

*She had my records spread out, and we started to go over them inch by inch. She was looking over my high school credits. “Now,” she said, “here’s this credit in agriculture”...She said, “You know, these small schools, they just don’t have adequate laboratories”...I said, “Look. I was raised on a farm...I worked on the farm all summer, before school and after school. Do you mean to tell me Chicago students have that much laboratory in agriculture? In the big Chicago high schools?” She had to admit she was licked and allowed the credit.*

This concession allowed Hubbert to obtain a bachelor’s degree from Chicago in June 1926. After a summer job in Texas with Amerada Petroleum, Hubbert embarked upon graduate study at Chicago, although he took a full year off in 1927–1928 to do experimental seismic work in west Texas for Amerada.

Hubbert’s first two published papers both reflect his lifelong habit of critically examining received wisdom—in this case, received wisdom from one of his professors, the distinguished Rollin Chamberlin, who would be elected to the NAS in 1940 for his contributions to structural geology.<sup>7,8</sup> Hubbert greatly admired the work of Rollin Chamberlin’s father, T. C. Chamberlin but thought that Rollin himself was overly “worshipful of his father...couldn’t possibly be critical...[w]hatever his father said was it ... [h]e was mouthing words he didn’t understand.”

Hubbert's first published paper<sup>9</sup> stemmed from a class assignment to review the results from a Geological Society of America (GSA) committee appointed nineteen years earlier to define fault nomenclature.<sup>10</sup> The GSA committee, by definition, consisted of some of the most respected scholars of the time, including Harry Fielding Reid as chair, William Morris Davis, Andrew C. Lawson, and Frederick L. Ransome. Nonetheless, the twenty-two-year-old Hubbert did not hesitate to critique their collective wisdom, finding the committee's result to be

*a hodge-podge if I ever saw one. Every kind of a screwball name for things they could think up, and it was just...god awful. It was a seminar situation. I was given the assignment...of reviewing this GSA paper for the class.... I suggested, why don't we just reduce them down to its elemental, geometrical components? We're dealing with kinematics and geometry. I gave this paper, after having gone through this – just miserable GSA committee report.*

Rollin Chamberlin was so impressed with Hubbert's critical review that he offered to print it, albeit in more temperate language, in the *Journal of Geology*—a journal founded by T. C. Chamberlin and where Rollin Chamberlin himself served as managing editor from 1923–1929 and editor from 1929–1947.

Slightly later, while taking Rollin Chamberlin's course in structural geology, Hubbert became deeply skeptical of a postulated relationship between imposed stresses and observed strains. Withdrawing from classroom debate that threatened to become acrimonious, Hubbert secretly began building an experimental apparatus in the basement, with rigid blocks embedded in marked modeling clay. When Hubbert presented the results to the department's Geology Club, Rollin Chamberlin was present, was "tremendously surprised," and—to his great credit—apologized to Hubbert and generously suggested that his work also be submitted to the *Journal of Geology*. The University of Chicago awarded Hubbert a master's degree in 1928 on the basis of this second published paper.<sup>11</sup> Although both of these earliest papers remain relatively obscure and little-cited compared to his later work, their conceptual underpinnings feature in his later, seminal papers on scale models and the strength of the Earth.<sup>12, 13</sup>

In 1928–1929, Hubbert taught an introductory geology class at the University of Chicago but he recalled that he "began to stew more and more over the fact that [no geophysics] was being given in the geology department" and "concluded that...I could

give a course in geophysics myself.” The department approved such a course for the 1929–1930 academic year. He noted,

*while I was giving it, a man from Columbia University dropped by [T.T. Rade, head of the Columbia School of Mines]...scouting around for somebody to teach geophysics at Columbia. So I invited him in to my lectures [and] was invited to come to Columbia University for an interview....They gave me a job as instructor in geophysics....*

### **Columbia 1931–1941**

With his hard-won expertise in mathematics and classical physics and diverse research interests, Hubbert construed geophysics broadly, as encompassing any application of physical principles and quantitative analysis to geological problems. However,

*the geology departments, Chicago and the rest of them, were almost oblivious to any general notion of geophysics, meaning the physics of the Earth....the average outlook as to what was geophysics, as seen by a geology department, was these various gadgets for finding oil...magnetometers and seismographic instruments.*

Hubbert had limited interest in this facet of geophysics, lacked the requisite instrumentation at Columbia, and “refused to do a trivial problem [but] was working on a whole flock of things.” Nonetheless he spent the summers of 1931–1937 working for the Illinois Geological Survey on an Earth resistivity project in mining areas of southern Illinois. In the late 1930s, this particular work was transferred to the U.S. Geological Survey (USGS), and this event would mark the beginning of Hubbert’s long formal and informal association with the USGS.

On October 3, 1931, Hubbert married Yelena Palinova, a University of Chicago student friend. As described by Hubbert’s biographer, Mason Inman, this seems to have been essentially a marriage of convenience. Palinova had fled Russia during the Bolshevik revolution. Meanwhile, her native region of Latvia had become independent. U.S. immigration officials now wished to deport Yelena, but she was officially stateless, as neither Russia nor Latvia would issue her a passport. Marriage to Hubbert allowed her to continue graduate research on parasitology at Chicago. Hubbert meanwhile returned to New York, where he began dating Miriam Berry, a brilliant medical secretary, in 1935. Hubbert and Palinova divorced in 1936, Miriam divorced her husband in 1937, and

Hubbert and Miriam began presenting themselves as husband and wife in November 1938. “Even if not legal, they considered themselves husband and wife” at that point.<sup>14</sup>

During this period in New York, Hubbert became heavily involved in technocracy, which refers to a system in which decision makers are selected based upon scientific or technical knowledge. Economist Thorsten Veblen (author of *Theory of the Leisure Class*, then recently deceased) was an early American advocate, and interest in technocracy increased as the United States and the world settled into the Great Depression. In 1932, Howard Scott and Hubbert founded Technocracy Incorporated, which argued that engineers should guide the economy into a thermodynamically balanced production cycle. Hubbert was sufficiently devoted to technocracy that, at the end of the decade, determined to leave Columbia, he considered becoming Director of Research at Technocracy Inc. But by that time Hubbert’s interest in technocracy had declined—“I’d come to the conclusion that the thing wasn’t going to accomplish anything I was interested in...[t]he technical part of it simply wasn’t going anywhere”—as had that of the American public, perhaps in part due to the ongoing New Deal.

Throughout his time at Columbia, Hubbert was somewhat frustrated by a mismatch between his own desires and expectations and those of his employer, and he had limited interaction with his colleagues in the geology department:

*I found most of the social contacts with the faculty boring, so I avoided them. [I] was much impressed with...a Belgian who came there in the mid-thirties...by the name of M. I. Biot...first-class...in applied mechanics [but in] the thirties my principal intellectual friends...were in the Geological Survey rather than in Columbia, and I frequently came down to discuss problems...with friends in the Geological Survey.*

Hubbert found the geology department to be insular and its students unprepared for quantitative analysis:

*The geology department...was a watertight little island of its own. They had about 12 professors [and] about 50 graduate students....In order to have students, every course has to be required....They’re just stuffed and crammed with the required geology courses. So...physics, mathematics, chemistry, all that kind of thing as background, they didn’t have. Even if they wanted it...the administration would have been distinctly unfavorable.*

Hubbert himself was able to take advantage of Columbia's strengths in physics and chemistry to further his own education, for instance by taking "an advanced course in very fundamental chemistry, fundamental physical chemistry, and then chemical hydrodynamics" taught by Victor La Mer. And an unexpected assignment to teach an engineering class was a revelation:

*I'd come back from my field work in Illinois and was told that the [professor] who had been giving this course for civil and mining engineers had left, and you're taking over tomorrow!...Well, I never had any students anywhere with that degree of technical training. And I was of course totally unprepared to give this course....So it was kind of tentative, feeling your own way....Well, it worked out very nicely....[W]e got around finally to the part on geological phenomena. So I discussed the thing that I'd had buzzing around in the back of my head since 1931, when I began [studying the Earth's electrical resistivity] in Illinois....I raised the question of what is the basic physical equation analogous to say electricity, with the flow of ground water? For the current obviously it could be either volume rate of flow or mass rate of flow. But what about forces? What about potential function, if there is one? I didn't know the answer to that. As I say, it was a kind of an idle curiosity type thing....So we did the usual thing, we made a guess. We guessed it was pressure. Well, it's easy to show that that was impossible.*

This serendipitous teaching assignment set the stage for one of two massive and lasting contributions to the geoscience literature that Hubbert made at Columbia, namely *The theory of ground-water motion*.<sup>15</sup>

Hubbert's other major contribution to the literature during his decade at Columbia, the *Theory of scale models as applied to the study of geologic structures*, also arose serendipitously.<sup>16</sup>

Hubbert met German structural geologist Hans Cloos in 1933 at the International Geological Congress in Washington, D.C., where Cloos had a large display table exhibiting scale models of geological structures. Hubbert was greatly impressed by the fidelity of these models to geological reality as he knew it and queried him on his work:

*What material did you use? [Cloos] said, "Almost liquid clay." [Hubbert responded] "By God, that's even worse from reality than these other*

*things which we use" [but] that night in [his] hotel room...did a little bit of theoretical work on this, and [concluded] that what Cloos had used had almost exactly the right properties [because of scaling]....Well, it boiled down to this, to take the very simplest case. The mass of a body proportional to its volume, and the volume is proportional to the length. Put this on a scale, so that if you have an original length  $L_1$  and you cut it down to  $L_2$ , the volume will be reduced by a ratio of  $L_1$  over  $L_2$  cubed. And over  $L_1$  cubed. And what about the strength? [T]he forces? The forces will be proportional to the weight, and then the stress will be the weight by area. Well, the weight will be proportional to the volume, which will be  $L$  cubed or the  $\Lambda$  ratio,  $\Lambda$  cubed, and the force will be proportional to that also. But the stress is force per unit area and the area is proportional to  $L$  squared, and so you come out with the stresses proportional to  $\Lambda$ ....Well, if you took a block of rock, say, a thousand kilometers and you reduce it down to a...tabletop of say a meter—well, that would be a thousand kilometers, that would be a millionfold reduction. You'd have to reduce the strength of that material by a million. [T]hat was what Cloos had done....And so for constant density, why it was a valid model theory.*

Having satisfied himself that Cloos' approach was correct, Hubbert set his calculations aside. Then in 1936 he was asked to serve on an interdisciplinary National Research Council committee (geology, physics, chemistry). Hubbert "was struck by the fact that one of the things they had on the agenda was the theory of scale models" and said "Well, I'll take that."

Whereas some of Hubbert's other major contributions would meet with sustained resistance, his theory of scale models met with "Spontaneous immediate acceptance... Never any argument about it." Like many of Hubbert's fundamental contributions, *Theory of scale models*... was lengthy (62 pages in the GSA Bulletin) and developed from first principles, citing work by Newton and Galileo as well as contemporary geoscience researchers. The University of Chicago awarded Hubbert's doctorate in 1937 for this work, which was his first truly influential paper, having been cited 1,165 times as of this writing and 85 years post-publication is still being cited about fifty times per year.

This concept of scaling underpinned his understanding of how the crust deformed, illustrated with the thought problem reproduced in Figure 1. At the time, "among the most perplexing problems in geologic science has been the persistent one of how an earth

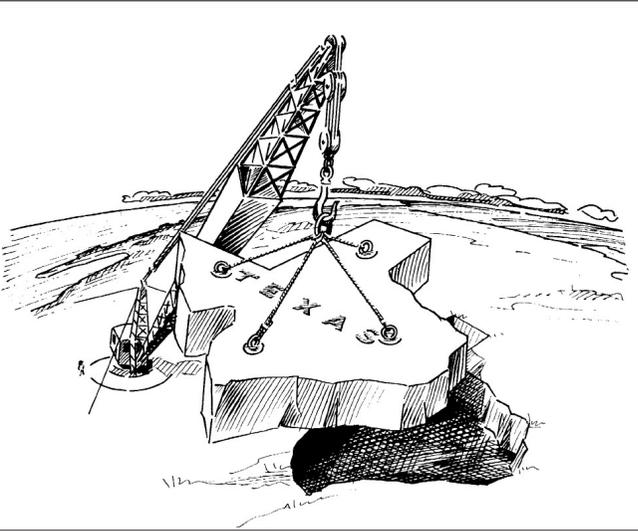


Figure 1: To highlight the importance of scaling, Hubbert presented an illustrative example: “Here we suppose that we are able to quarry as a single block with a thickness roughly one-fifth its width the entire state of Texas, and that we have a quarry crane capable of hoisting it. Let us suppose further that this block is composed of the strongest of rock and, moreover, that it is monolithic and flawless. The question to which we seek an answer is: Will the rock itself be strong enough to permit hoisting in this manner?” After leading readers through the thought experiment and its implications, he concluded “The inescapable conclusion, therefore, is that the good state of Texas is utterly incapable of self-support.” (From Hubbert (1945). Reprinted by permission of the American Association of Petroleum Geologists.)

whose exterior is composed of hard rocks can have undergone repeated deformations as if composed of weak plastic materials.”<sup>17</sup> He summarized “...evidences of rigidity and those of fluidity was not a conflict of data but of thinking” owing to the need to think on the appropriate “scale of geologic space and time.”

Hubbert’s work on groundwater theory, begun casually while teaching engineering, intensified during his final year at Columbia. His interest was spurred by the discovery that a fundamental textbook in petroleum engineering<sup>18</sup> misrepresented Darcy’s law for flow of fluid through a porous medium by invoking flow from higher to lower pressure. He noted, “a fundamental equation of the entire book! But without any understanding, any vestige of understanding, of the physics of it. In the first place the equation was wrong, and [the author] had no understanding of the fact that it was wrong.”

This prompted Hubbert to “write a little paper on this subject” but “all kinds of auxiliary intriguing questions arose,” making the manuscript much longer than originally anticipated. Hubbert had approached Rollin Chamberlin about publication in the *Journal of Geology* when he initially decided to write on this topic, but both Hubbert and Chamberlin were surprised by the eventual length of the manuscript. After some hesitation, and advice from a trusted referee,

Chamberlin nonetheless agreed to publish the 160-page *Theory of ground-water motion*.<sup>19</sup> This contribution, building from first principles, set the emerging discipline of hydrogeology on a firm theoretical foundation, correcting a fundamental misunderstanding of Darcy's law that underpins all of hydrogeology.

Intuitively, one might indeed tend to think of groundwater as flowing from areas of high pressure to areas of low pressure. But this idea is readily debunked by simple experiments such as the one diagramed in Figure 2a, where flow is from  $P = 0$  at point A to  $P > 0$  at point B to  $P = 0$  at point C, or alternatively, by consideration of the pressure distribution in a static column of water ( $P = \rho_w g d$ , where  $d$  is the depth below the water surface), as in Figure 2b.

Groundwater actually flows from areas of high energy to areas of low energy, and the energy state is represented by the hydraulic head (Figure 2b), which Hubbert derived from basic physical principles after declaring with typical asperity that "... to adopt [head] empirically without further investigation would be like reading the length of the mercury column of a thermometer without knowing that temperature was the physical quantity being indicated."

For a constant-density fluid in an isotropic medium, flowlines will be completely dictated by a potential field. That is, they will parallel the gradient vectors of some measure of fluid potential, such as hydraulic head. But Hubbert was careful to point out that such a potential field cannot be defined for variable-density flow,

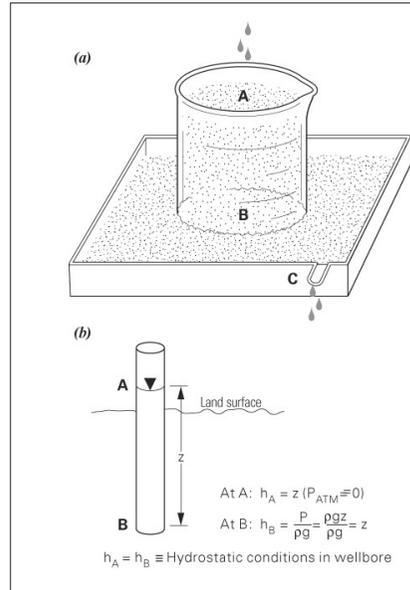


Figure 2: (a) A simple experiment demonstrating that groundwater does not necessarily flow from areas of high pressure to areas of low pressure. Water is added at a steady rate to an open-ended sand-filled column partly embedded in a sand-filled tray. Flow is from point A ( $P = \text{atmospheric} = 0$ ) to point B ( $P > 0$ ) to point C ( $P = 0$ ). (b) Components of hydraulic head ( $h = P/\rho_w g + z$ ) illustrated with reference to a piezometer, a tube that is open to the atmosphere at the top and to groundwater flow at the bottom. The pressure datum ( $P = 0$ ) is taken as atmospheric pressure, and the bottom of the tube is the reference elevation datum where  $z = 0$ . At point A, then,  $h_A = 0 + z = z$ . The pressure at point B is determined by the weight of the overlying column of water,  $\rho_w g z$ , so that  $h_B = \rho_w g z / \rho_w g + 0 = z$ . The relation  $h_A = h_B = z$  defines hydrostatic (nonflowing) conditions within the piezometer tube.

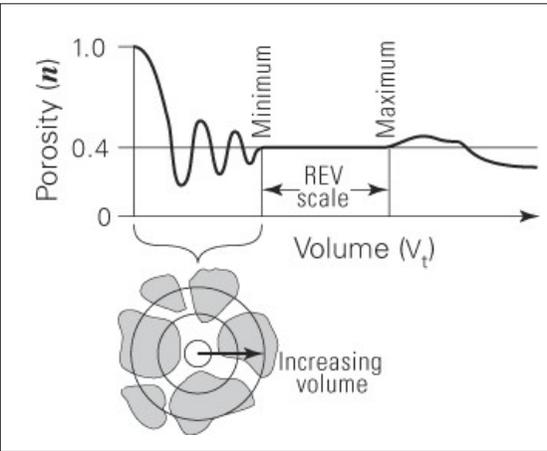


Figure 3: Key hydrogeologic parameters apply at a macroscopic scale such that the porous solid can be viewed as continuous in space. Hubbert (1956a) chose porosity as a visual example, and here porosity ( $n$ ) is depicted as a function of averaging volume. At a particular point ( $V_t \sim 0$ ), the value of  $n$  is either 0 or 1. The computed value of  $n$  stabilizes as it is averaged over progressively larger volumes. (After Hubbert (1956a, his Fig. 5)).

except for the very special case in which lines of equal pressure, temperature, and concentration are parallel. In the general variable-density case, the field of force has a rotational component that tends to cause convective movement; this rotational component can perhaps be regarded as superimposed on the potential field.

Hubbert later demonstrated that Darcy's law, which was empirically derived, can be theoretically derived for a Newtonian fluid by averaging equations of fluid motion known as the Navier-Stokes equations over a representative volume of porous medium (Figure 3), assuming laminar, steady flow or negligible inertial terms.<sup>20</sup>

Hubbert's insights into groundwater motion were slow to be accepted. He referenced this delay at some length in his 1963 GSA Presidential Address, which was published in *Science* magazine,<sup>21</sup> saying in part:

*[The misrepresentation of Darcy's law] might be considered almost a trivial example were it not for the fact that the equation cited was for 25 years the most widely used equation in the petroleum industry. It was used as the basis for nearly all reservoir engineering, for several major physical treatises, and for most of the journal literature in petroleum engineering during that period, and it was accepted, with rarely a dissenting voice, by a technical personnel which was a representative cross section of the output of all the institutions of higher learning in the United States, before it was ruefully discovered that the equation in question was neither physically correct nor a valid statement of a result established a century earlier by a Frenchman named Henry Darcy.*

Hubbert's title was *Are We Retrogressing in Science?* and subtitled "Despite superficial evidence to the contrary, science in the United States is in a state of confusion." The mistreatment of Darcy's law was one example in support of his thesis.

### **Shell Oil, 1943–1964**

Hubbert's next long-term affiliation was with Shell Oil, which he described as "the most productive period of my life." Between Columbia and Shell, from 1941–1943, Hubbert was briefly employed at the Board of Economic Warfare, where he was "senior analyst in mineral resources...working principally with mineral resources around the world of military interest." But despite Hubbert's interest in resources, he became "fairly disgusted" with approaches that he viewed as corrupt and politicized. He was thus receptive to an unsolicited job offer from the Shell Technology Center in Houston, Texas, in 1943.

Hubbert came to Shell just before his fortieth birthday, which was "actually a very tight situation, because Shell had a corporate rule of not hiring anybody over the age of 40. I got in by about three weeks before the critical date." Hubbert felt "very much on probation" but "fortunately [management] left me alone enough, so I could work like hell and did." As Hubbert's stature and reputation within the organization grew, he was increasingly able to exercise influence, guide research programs, and resume contributing to the open literature.

In 1945, Shell management authorized construction of a greatly enlarged Houston research laboratory devoted to both exploration and production. Hubbert became associate director and, whereas Shell had traditionally been "very leery about publication [the laboratory] adopted a liberal policy of publishing everything...after it had had its initial use by the company." The laboratory "hired [people] entirely interchangeable with university professors" and also developed long-term relationships with expert consultants such as Hubbert's Columbia colleague M.I. Biot, "who worked with us until after I left." Geophysics and geomechanics were important emphases at the Houston laboratory. When Shell eventually began to reduce research expenditures in the mid-1960s, roughly coincident with Hubbert's departure, the geophysics group at Shell became the founding core of a large and respected program at Texas A&M University: "Shell was about to disband this group; secondly A&M was able to get some money and make a bid for them [and] moved it lock, stock, and barrel over to A&M."

Soon after coming to Shell, Hubbert reinvigorated the internal technical-training program, spurred in part by finding that many of the company's technical staff were still

in thrall to ideas about fluid flow that he thought he had disproven in his *Theory of ground-water motion*: “I came in with this background of groundwater motion and... found that the Shell engineers were still talking about fluid flowing from high to lower pressure.”

At Shell, as at many organizations that house a (generally small) research function tied to a (generally larger) operation program, there was potential for disconnect and misunderstanding. Throughout his tenure there, Hubbert tried hard to communicate research findings and activities to the operational program. He developed compelling experimental demonstrations, having long found it necessary to “use the Galileo technique; it required a demonstration [because] limited...to verbal arguments...you could spend the rest of your life and get nowhere.... You get around that problem with an experiment which contradicts one line of argument, and demonstrates another.”

Hubbert’s seminal publications during his two decades at Shell included work on the hydrodynamic entrapment of petroleum,<sup>22</sup> hydraulic fracturing,<sup>23</sup> thrust faulting,<sup>24, 25</sup> and resource depletion.<sup>26</sup>

### Hydrodynamic Entrapment

Because the comprehensive *Theory of groundwater motion* included multiphase flow,<sup>27</sup> Hubbert’s work on *entrapment of petroleum under hydrodynamic conditions* was a natural outgrowth.<sup>28</sup> His concept of impelling force (Fig. 4a) provides a useful way of visualizing the net forces acting on each fluid. The impelling force is the negative of the gradient in fluid potential, so it is a vector quantity that defines the direction in which an element of fluid will tend to migrate. Its derivation omits capillary effects, assuming that these are approximately isotropic except near lithologic contacts. Figure 4b shows the impelling forces acting on elements of water, oil, and gas in a hypothetical hydrodynamic envi-

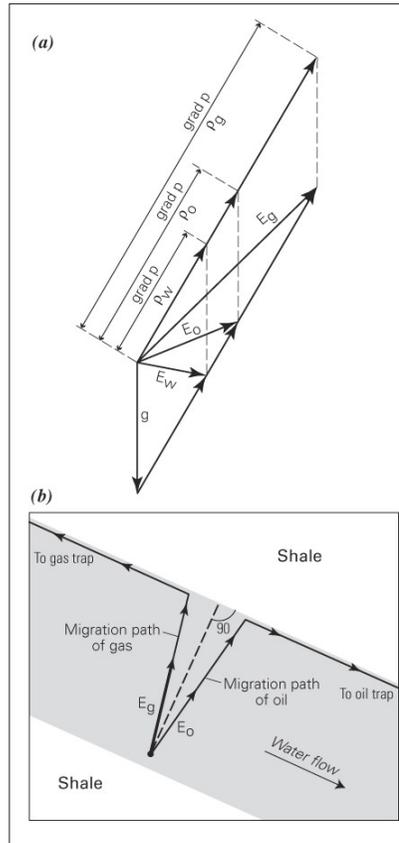


Figure 4: (a) Impelling forces on water, oil, and gas in a hydrodynamic environment. (b) Divergent migration of oil and gas in a hydrodynamic environment. (From Hubbert (1953), reprinted by permission of the American Association of Petroleum Geologists.)

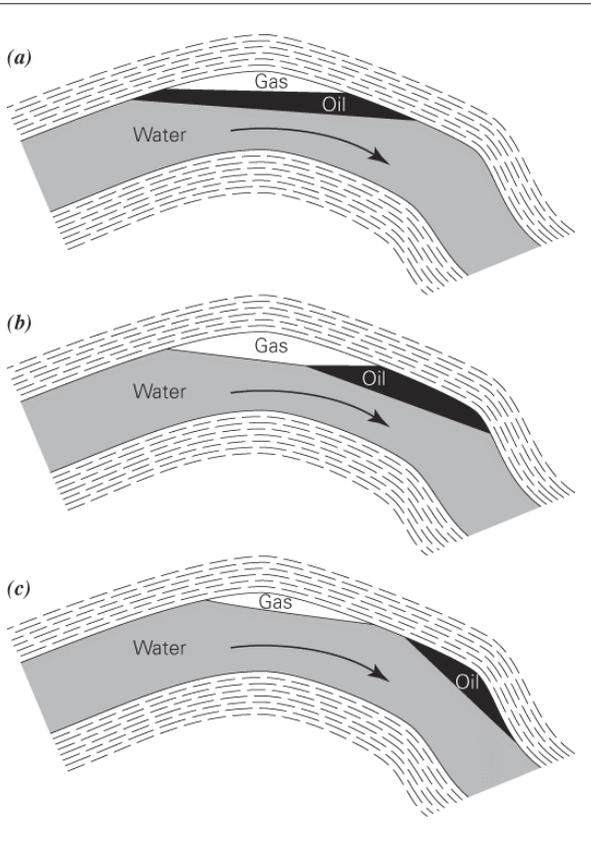


Figure 5: Oil and gas accumulations in a hydrodynamic environment. In (a), gas is entirely underlain by oil; in (b), gas is partly underlain by oil; and in (c), the gas and oil traps are entirely separated. The progression from (a) to (c) is due to increasing “hydrodynamic tilt” and can be interpreted either in terms of an increasing horizontal pressure gradient (increasingly vigorous groundwater flow) or in terms of varying hydrocarbon densities (i.e., the difference between  $\rho_w$  and  $\rho_o$  decreases from (a) to (c)). (From Hubbert (1953), reprinted by permission of the American Association of Petroleum Geologists.)

ronment. Downdip flow of groundwater in a confined aquifer follows the dip-parallel vector  $E_w$ . The less dense oil and gas both migrate to the top of the aquifer, but the relative angles of  $E_o$  and  $E_g$  are such that oil migrates downdip, whereas gas migrates updip.

Hydrodynamic forces can affect the geometry of even the simplest structural trap. Under hydrodynamic conditions, large-scale (noncapillary) oil-water interfaces will dip in the direction of groundwater flow, according to

$$\frac{dz}{dx} \propto \left( \frac{\rho_w}{\rho_w - \rho_o} \right) \left( \frac{dP}{dx} \right),$$

where  $dz/dx$  is the slope of the interface and  $dP/dx$  is the horizontal fluid-pressure gradient. The significance of this “hydrodynamic tilt” can readily be illustrated in the context of anticlinal structures (Figure 5), which constitute some of the more obvious oil and gas traps under both hydrostatic and hydrodynamic conditions. If the horizontal pressure gradient is sufficiently small, each of the impelling-force vectors ( $E_w$ ,  $E_o$ , and  $E_g$ ) will be nearly vertical, and the equilibrium distribution of fluids within an anticline will be approximately governed by vertical density

segregation (Fig. 5a). As the lateral pressure gradient increases, so does the tilt of the oil-water interface (Figs. 5a-c). The anticlinal structure can serve as an effective oil trap only where its own dip exceeds the tilt of the interface. In general, entrapment can be related to minimum fluid potentials for hydrocarbons, mechanical screening by pore-size reduction, and capillary-pressure barriers.

As described by Hubbert, “A minority literature...from 1909 into the 1930s<sup>29</sup> had developed a “hydraulic theory” in which “the flow of water was...an essential condition for oil and gas migration”, but “by the mid-1930s geologic thinking had reverted largely to the premises of hydrostatics.” Hubbert employed both theory and flow-box experiments with colored alcohol and water to fully demonstrate hydrodynamic entrapment. After circulating the results widely within Shell, Hubbert “demanded the privilege of writing a paper on my work on this thing.” Publication triggered widespread interest at oil companies, universities, and at the USGS, and “immediately there was a request...to go on a distinguished lecture tour.”

### Hydraulic Fracturing

The term hydraulic fracturing (also “hydrofracturing” and now popularly “fracking”) has been used since at least the late 1940s to describe the common oil-well stimulation practice of pumping fluid into a well at high pressures in order to fracture the formation and increase its permeability.

Hubbert was drawn to this problem by a debate within Shell’s production department:

*[H]ere we’ve had this hydraulic fracturing going on now for about seven years or so...with thousands of cases already, and yet there’s still the overwhelming view is that these fractures are horizontal. So we needed to know, are they horizontal or are they vertical?*

The work was done in close collaboration with Stanford University student David Willis:

*[W]hen I was giving these lectures out of Stanford...this young Willis, one of the graduate students...I was so impressed with the boy [I told the Dean] “Look, I’m not out here recruiting, but I am so impressed with this young man Willis, and I could use a personal research assistant.”*

Hubbert and Willis showed that in a normal-faulting environment the greatest principal stress,  $\sigma_1$ , is vertical, and hydraulic fracturing will occur in (sub)vertical planes that are orthogonal to the least principal stress,  $\sigma_3$  (Fig. 6). In a reverse- or thrust-faulting envi-

ronment,  $\sigma_1$  is close to horizontal, and horizontal or subhorizontal fracturing will indeed tend to occur at fluid pressures close to the total overburden pressure.<sup>30</sup>

Finding that their initial “theoretical argument was having no effect whatever” among production crews where “[t]hey were sure absolutely that they were making horizontal fractures...and no amount of theoretical argument would make any dent in them,” Hubbert asked Willis to develop a convincing experimental demonstration. They injected a plaster of paris slurry into layered gelatin under laterally controlled stresses, and this demonstration “had a magical effect. It made Christians out of these people. And within a week they were sending in field confirmation.”

The physical understandings developed in his *Mechanics of hydraulic fracturing* article underlie the revolution in “unconventional” oil and gas (UCOG) production that occurred much later, in the early twenty-first century.<sup>31</sup> Copious recent citations of *Mechanics of hydraulic fracturing* reflect in part the growth in UCOG, as well as the associated increase in induced seismicity in the U.S. midcontinent, where similar physical processes promote slip on faults. *Mechanics of hydraulic fracturing* has been cited 2,646 times as of this writing, including about 150 times per year over the past decade, and seems soon-destined to overtake *Role of fluid pressure in overthrust faulting: I...* as Hubbert’s most-cited paper.

### Thrust Faulting

Hubbert and W.W. Rubey introduced the concept of fault movement produced by Mohr-Coulomb failure of a fluid-saturated geologic medium.<sup>32,33</sup> They focused specifically on overthrust faulting and aimed at resolving the mechanical problem of moving very long fault blocks over nearly horizontal surfaces. Without consideration of pore-fluid pressures, such movement appears to be precluded by the limited strength of the overthrust block and/or the large frictional resistance to low-angle sliding.

Hubbert’s interest in thrust faulting was awakened during a Shell-sponsored field trip through the Alps, where he observed, “older rocks thrust over on a gently inclined

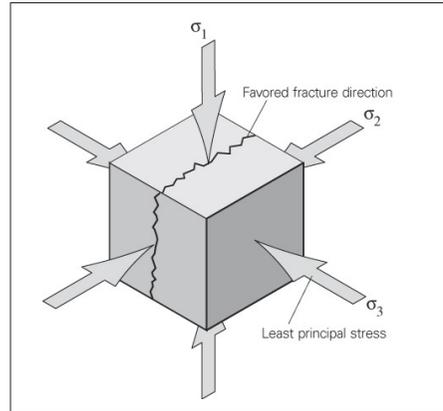


Figure 6: Stress element showing preferred plane of fracture orthogonal to the least principal stress  $\sigma_3$ . (After Hubbert and Willis (1957).)

surface [with] no perceptible significant deformation in the rocks either above or below, although there may have been if you'd examined it more carefully." He immediately inferred the important role of fluid pressure.

Shortly thereafter, Hubbert recalled,

*[W.W. Rubey and] his wife and I had dinner at the Cosmos Club. He spent the entire dinner hour quizzing me about the reality of these abnormal pressures in the Gulf Coast and elsewhere, and I said, "Yes, they're real." And finally he said, "The reason I'm interested in it is, I have an idea that may have something to do with thrust faults." [Rubey had been] working his way toward the notion that the water pressure might have something to do with [thrust faulting]. Well, we were both embarrassed. It was kind of an awkward situation. And then I kind of outlined what my own thinking on this thing had been and he briefly mentioned, he'd asked [O. E.] Meinzer, head of the groundwater people [at the USGS], some questions about it.*

After checking with his supervisor at Shell, Hubbert said that he "propositioned [Rubey] on this thing [as] a ready-made situation for collaboration."

The comprehensive studies of thrust faulting by Hubbert and Rubey<sup>33,34</sup> applied Terzaghi's 1925 concept of effective stress to the problem of faulting.<sup>35</sup> In thrust faulting, part of the brittle crust is thrust over adjacent crust at a low dip angle, typically 0 to 30°. In the thrust belts associated with continental collisions (such as the Himalaya, Alps, and Appalachia), the upper crust is thickened by displacements on a series of thrust faults. Thrust faulting is also important in the creation and thickening of accretionary prisms where oceanic crust is subducted. Individual thrust sheets can extend over hundreds of kilometers, as in the Alps or the southern Appalachians of the United States. Even such large blocks seem to have maintained much of their structural integrity while moving.

Without consideration of fluid-pressure effects, there is no satisfactory mechanical explanation for the low-angle thrusting and/or sliding of large, thin, relatively intact sheets of rock. If one assumes that a "dry" rock sheet is moved by a horizontal force, its own strength can readily be shown to be insufficient to withstand the required force, even if a fairly low value is assumed for the coefficient of friction along the fault plane.<sup>36</sup> That is, the sheet would deform internally before sliding. If one assumes that the movement is produced by gravitational sliding, the strength of the sheet ceases to be a consideration, but a rather large slope (~30°) is required to initiate movement (Fig. 7). Field relations

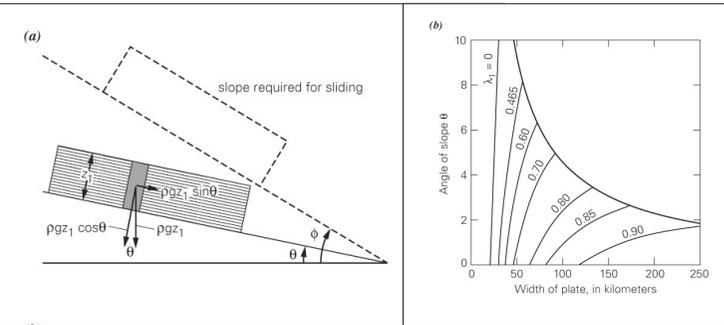


Figure 7: (a) Normal and shear stresses on the base of a block inclined at angle  $\theta$ , and angle  $\phi$  required for sliding. Hubbert and Rubey (1959) pointed out that tests of both rocks and unconsolidated materials consistently give angles of internal friction  $\phi \sim 30^\circ$  and that this is also the mean angle of sliding friction of rock on rock. Thus the angle of tilt of the surface must be raised to about  $30^\circ$  – or fluid pressure increased – for the block to slide. From Hubbert and Rubey (1959). (b) Width of plate that can be pushed downslope for various values of slope angle  $\theta$  and fluid pressure/overburden pressure ratio  $\lambda$ , assuming “intermediate” values for the crushing strength of the plate and the coefficient of friction. The bold curve truncating the labeled curves represents a total relief of 8 km. (From Rubey and Hubbert (1959). Reprinted by permission of Geological Society of America.)

a geologic medium) is identical with that for a completely enclosed solid immersed in liquid. They proceeded to show that, given elevated fluid pressures, very large blocks can move along arbitrarily small slopes (Fig. 7). Hubbert and Rubey further noted the common occurrence of elevated (>hydrostatic) fluid pressures in sedimentary basins and that tectonic compression can also cause elevated fluid pressures, citing as examples the Andean and Himalayan foothills and oil fields in Iran, Trinidad, and Burma.

Hubbert and Rubey include one of Hubbert’s best-known experimental demonstrations. When lecturing on the topic, as illustrated in Figure 8, Hubbert would sometimes set up an inclined plane at the front of the lecture hall. At the beginning of the lecture, Hubbert would ostentatiously drain a can of beer, remarking on how cold it was. He would then place the can upside down on the inclined plane. At some point in the lecture, the can would slide down the plane. The mechanism? As the air in the can

generally preclude such slopes.

The greatest principal stress  $\sigma_1$  is horizontal in reverse- or thrust-faulting environments. The least principal stress  $\sigma_3$  is vertical, and (sub)horizontal failures will occur when the fluid pressure approaches the total overburden pressure. Thus, the concept of effective stress, which Hubbert and Rubey derived from direct application of Archimedes’ principle of buoyancy, affords a viable mechanism for reducing the frictional resistance to overthrusting. Hubbert and Rubey showed that the result for a porous solid (for example,

warmed, the air expanded and pressure increased, lowering the effective stress. The work on thrust faulting was immediately well-received. Hubbert and Rubey<sup>37</sup> remains Hubbert's most-cited paper as of this writing (2,677 citations) and continues to be cited about ninety times a year over last ten years.

### Peak Oil

Today M. King Hubbert is best known outside

the geoscience community for his ideas about "Peak Oil"—a concept reflecting the fact that we are rapidly consuming a finite geologic legacy and that production must eventually peak and decline. For a petroleum-dependent world, the timing and magnitude of this peak are of acute interest. As we turn to this topic, however, it is worth noting that Hubbert's election to the NAS in 1955 reflects his contributions to fundamental geophysics, rather than his resource forecasts. Hubbert's election to the NAS preceded his first prediction of "Peak Oil," which was presented to the American Petroleum Institute (API) in 1956. The API presentation and associated paper<sup>38</sup> immediately attracted attention and controversy both within the oil industry and, thanks to widespread media coverage, among politicians and the broader public.

During the 1950s, Hubbert's primary scientific focus had gradually shifted from fundamental geophysics to mineral and energy resources. This reflects a long-standing and growing interest, rather than an abrupt shift. In 1926, Hubbert had taken a required University of Chicago course in economic geology—a topic that he "hadn't the slightest interest in"—from departmental Chair Edson Bastin, who Hubbert viewed as "a little bit on the dull side and not too bright." Unexpectedly, he found it to be "one of the most revolutionary courses I ever had in my life." Hubbert's subsequent work with the technocracy movement, his wartime service with the Board of Economic Warfare, and his familiarity with Shell's own strategic perspective all contributed to an abiding interest in the significance of Earth resources in human affairs.<sup>39,40,41</sup>

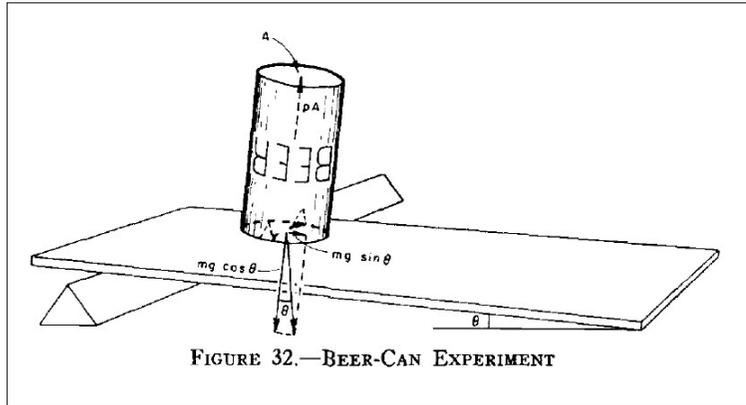


FIGURE 32.—BEER-CAN EXPERIMENT

Figure 8: The beer can experiment used to illustrate how fluid pressure enables motion along a very low angle surface. (From Hubbert and Rubey, 1959).

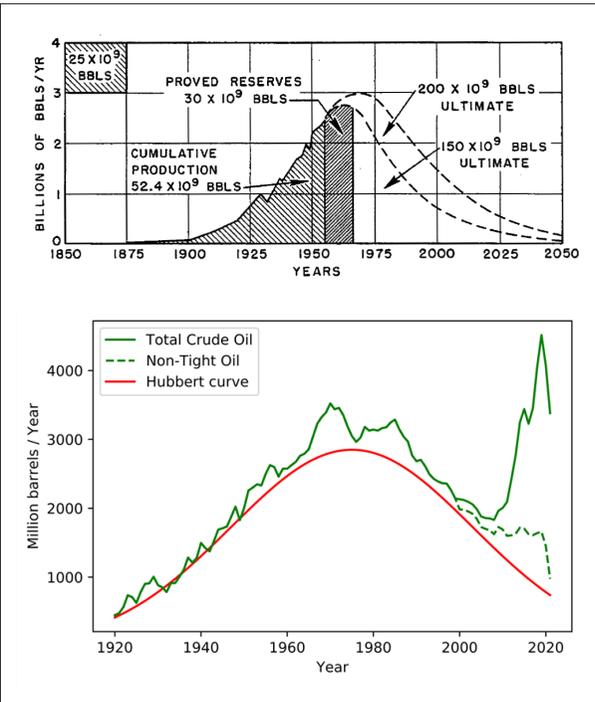


Figure 9: (a) Projected U.S. crude-oil production (Hubbert, 1956b) based on initial reserves of 150 and 200 billion barrels and (b) Hubbert (1956b) forecast curves superimposed on actual U.S. crude-oil production 1920-2021. In (b), 'Non-Tight Oil' refers to oil produced by conventional methods and the difference between 'Total Crude Oil' and 'Not-Tight Oil' after about the year 2000 owes to hydraulic fracturing of low-permeability ('tight'), formerly unproductive rocks ([https://en.wikipedia.org/wiki/Peak\\_oil#/media/File:OilProduction-TightTotalHubbert-dec2021.svg](https://en.wikipedia.org/wiki/Peak_oil#/media/File:OilProduction-TightTotalHubbert-dec2021.svg)).

In his 1956 API presentation and associated paper,<sup>42</sup> Hubbert was arguably the first to explicitly predict the brevity of the fossil-fuel era. He predicted that United States oil production would peak in 1970—a prediction widely disbelieved at the time but soon proven essentially correct. Hubbert quantified his prediction by means of what has become known as the Hubbert curve or Hubbert's peak (Fig. 9a). (Though critical discussion at the time sometimes referred instead to Hubbert's pimple.)

The Hubbert curve closely resembles the shape of the probability density function of the normal distribution (that is, the "bell curve") but is actually the derivative of the logistic curve. It was proposed as a model of the rate of petroleum extraction, with the rate of oil production determined by the rate of new oil-well discovery.

With the help of Martha Lou Broussard (then Martha Shirley), Hubbert regularly updated his peak-oil predictions based on the newest available data. Broussard was the first woman geology graduate from Rice University and, as she recalls in Inman,<sup>43</sup> "[m]ost companies wouldn't hire a woman

researcher, and when they did they were treated as inferior....Hubbert wasn't prejudiced against women, however. He didn't care as long as I could do the math." She recalled,

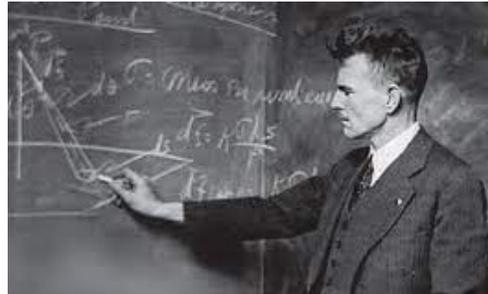
*I had the privilege of working under Hubbert as my very first job for a*

*very long six years. This was during his last years at the Shell Research Lab here in Houston (Shell Development Co.). Each year when API was to announce the Petroleum Reserves, I would travel to Washington in order to receive them that day and return to Houston to do the math of the new log-normal curve. There was always a big argument in the business section of the newspapers with the President of Humble Oil (now Exxon-Mobil) making an announcement that there had always been oil and always would be oil.<sup>44</sup>*

Although Broussard and Hubbert did repeated updates, even Hubbert's very first peak-oil predictions for the United States proved quite accurate. Superimposing these earliest predications (Fig. 9a) on actual U.S. oil production (Fig. 9b) reveals that they were quite good for about half a century,<sup>45</sup> roughly 1956–2006, accurately predicting both the timing (~1970) and magnitude of the U.S. peak (~3 billion barrels/day). After that point in time, technological advances in hydrofracturing and drilling began to drive an unprecedented increase in U.S. production. Rather ironically, Hubbert himself, working with his student David Willis, had long ago helped to elucidate the physical basis for the hydrofracturing revolution in “unconventional” oil and gas (UCOG) production that occurred in the early twenty-first century and unexpectedly reestablished the United States as the world's top oil-producing country.

### **U.S. Geological Survey 1964–1976**

After attaining an age and length of tenure such that he was eligible for a full pension from Shell, Hubbert sought other opportunities. Shell had a longstanding arrangement with Stanford University that enabled Hubbert to spend part of each year teaching at Stanford, and there was some expectation that Hubbert would now choose to reside at Stanford full time. There was also interest at the California Institute of Technology (Caltech), the University of California, Los Angeles, and the University of California, Berkeley. Further, there was longstanding interest at the USGS, which had been wooing Hubbert since 1957, when he was offered one of the two “supergrade” positions that the agency had just been allocated. At that time, Hubbert's friend and collaborator W.W. Rubey was to be offered the other supergrade position. Hubbert declined this initial offer because he was



Hubbert teaching.

still seven years short of pension eligibility at Shell—an important consideration for him and Miriam—and in any event, he noted that “the pay was only about half what I was getting with Shell.”

In 1964, Hubbert did accept an offer from the USGS: “[t]hey didn’t have a grade 18 anymore but they could give me a grade 17 [and] the arrangement was that I would be full time at the Geological Survey, but there was a provision for a leave of absence without pay...and at Stanford then...I was a full professor with tenure.”

Hubbert unexpectedly chose to relocate to USGS headquarters in Washington, D.C., rather than the USGS Menlo Park facility, which is near Stanford and Berkeley; he made the decision “so I would be where I could have possibly some influence.” Personal considerations had dissuaded him from seriously considering the options in the Los Angeles area:

*[T]he foul climate [pollution] there, I was very scared of it [and] I’ve got more relatives, more family in the LA area than any other place in the United States, and my family is a pretty clannish group. They do an awful lot of family socializing...at somebody’s house [and] I don’t like to do that kind of thing. I mean, once a year or something of the sort, but not every few weeks....I was very, very leery about getting involved in a situation where I was surrounded by relatives....*

Hubbert’s decade-plus at the USGS was marked by intermittent conflict between him and the senior management of the agency, particularly Vincent McKelvey, who served as USGS director from 1971–1978. Hubbert’s perspective on this conflict is discussed in detail in Inman’s biography of Hubbert and in Hubbert’s oral-history interviews with Ronald E. Doel, and we will treat the disagreement only briefly here.

It is not entirely clear what Hubbert was expected to work on at the USGS; perhaps senior management expected continued work on fundamental geophysical problems, along the lines of Hubbert and Rubey.<sup>46</sup> In fact, Hubbert’s title at the USGS was, “I think...Research Geophysicist, to be working on structural geological problems” and he found upon arrival that “there’d been a little politics behind the scene to try to keep me out of oil and gas and things of that sort.” But by this time Hubbert’s primary interests had in fact become energy- and mineral-resource assessment, nuclear-waste disposal, and other issues that today might be grouped under the umbrella of “sustainability.” His stature and visibility were such that he was continually invited to lecture and teach on these topics, serve on high-level advisory committees, and even testify before Congress.

Though he did so as a USGS employee, these invitations were rarely routed through USGS management, and he sometimes expressed views that were at odds with official agency positions.

The USGS historically has been a flexible bureaucracy, allowing broad latitude to its scientists.<sup>47</sup> Nonetheless, on some high-visibility issues, it strives for internal consensus. During the period of the Hubbert-McKelvey rift, which overlapped with the early 1970s energy crisis, the assessment of petroleum reserves was perhaps the most visible issue that the agency faced. The official USGS position on U.S. oil and gas reserves—and McKelvey's own view—was much more cornucopian than that of Hubbert. And Hubbert, of course, refused to be part of what he viewed as a flawed consensus. Hubbert believed that, as a result, USGS management aimed to stifle, censor, and eventually fire him.<sup>48,49</sup> By the mid-1970s the official USGS estimates did appear to be grossly optimistic, which contributed to McKelvey's eventual resignation in 1978.

With benefit of a half-century of hindsight, the conflict between Hubbert and USGS management seems inevitable. We note that both of the primary parties to the dispute were respected by their peers at the time and remain well-regarded today. In fact, the largest building at the USGS campus in Menlo Park is named for Vincent McKelvey, and that same facility hosted a (M. King) Hubbert Quorum on hydrogeology from 1993–2019.

USGS employees at the time were aware of the conflict and sometimes found humor in it. As described by Hubbert's biographer Mason Inman,

*The controversy gave the Geological Survey's Pick and Hammer Club a much juicier target than usual for its annual satirical skits....In the April 1975 show, one skit described "Vincible McWelldry, The Top Gasser" and "Em King Blubbert" called the "oracle" of groundwater and "all moving liquids." As McWelldry and Blubbert engaged in long-winded debate, roustabouts brought a wind turbine on to the stage, and [a geologist, likely representing Betty Miller] announced "Gentleman, if you'll just continue your argument indefinitely, and face the fan, there'll be no more energy crisis."*

## Scientific and Personal Philosophy

M. King Hubbert emerges from history as nearly entirely consumed by scientific exploration and related matters of science and public policy. He had no children, no passionate hobbies, and no religious belief. Hubbert's long series of oral-history interviews with Ronald E. Doel concludes with a question about life philosophy to which he responds:

*[A] simple rational view, discerned from the organisms in the earth and their impressions. As a famous physiologist from Chicago, Antone J. Carson, head of the Physiology Department, used to shock his audiences with, "One of these days, I'm going to be a long time dead." Like the dinosaurs, here today, gone tomorrow.*

Despite his challenging and uncompromising personality, Hubbert sustained a lifelong devoted partnership with Miriam and lifelong friendships with colleagues such as Deversy Crombie (Chicago), Hewitt Dix (CalTech), James Gilluly (USGS), Beno Gutenberg (CalTech), Bill Haley (Syracuse), Arpad Nadai (Gottingen U.), Wallace Pratt (Humble Oil), W.W. Rubey (USGS), and Ray Walters (Standard Oil). Even in late middle age, after his retirement from Shell, Hubbert's services were sought by elite universities as well as the USGS. He was awarded most of the top prizes in the geosciences, including the GSA's Day Medal (1954), election to the National Academy of Sciences (1955), the GSA Penrose Medal (1973), the Vetlesen Prize (1981), and the Cresson Medal (1981) and in 1962 was elected president of the GSA. Throughout his career he remained highly sought-after as a teacher, lecturer, and member of high-level advisory committees.

Hubbert held strong and vigorously expressed views about the practice and philosophy of science. On the most pragmatic level, his repeated failures to convince colleagues of the correctness of his ideas via purely theoretical arguments—and likely his own personal inclinations—made him a creative experimentalist, convinced of the both the intrinsic and heuristic value of laboratory-scale experimentation. We have described several examples in this biographical memoir, starting with the 1908 steam-explosion experiment by the then-five-year-old Hubbert; many more examples can be found in the 565 pages of oral-history interviews by Ronald E. Doel, an extraordinary resource for any biographer.

In *Is being quantitative sufficient?*, Hubbert described how, for the first decade-plus of his scientific career, he believed wholeheartedly in the credo of his "Patron Saint" Lord

Kelvin, namely that if a “science dealt with qualitative nonnumerical relationships, it was in a primitive state of development; if it...employed the methods of mathematical analysis, it was in a more advanced stage.”<sup>50</sup> Throughout his career, he advocated passionately for the importance of providing quantitative training for geology students, arguing that “...physics of the earth . . . is of vital concern to the students of geology—‘the science of the earth’.”<sup>51</sup>

But he eventually came to realize that “[y]ou could make an ass of yourself mathematically and quantitatively just as well as by any other method.” After all, Hubbert reflected, Kelvin himself, working under false assumptions, had derived a mathematically precise but erroneous age for the Earth, whereas contemporary geologists like Darwin, working from qualitative inferences, had derived more accurate estimates. Hubbert also returned again to one of his favorite examples, erroneous groundwater flow laws, devoting ten pages to this topic under the heading “Negative aspects of quantification in geology.”<sup>52</sup>

Hubbert’s extraordinary GSA Presidential Address, reprinted in its entirety in *Science* magazine,<sup>53</sup> did not confine itself to geology, but was rather a passionate critique of the entire U.S. science enterprise, concluding that “[d]espite the large amount of superficial evidence to the contrary, the present state of science in the United States is one of considerable confusion...we appear to have lost sight of our intellectual foundations.” Hubbert began his argument with the fundamentals, citing confusion of units in the *American Institute of Physics Handbook*: “how was it possible for three professors of physics to have compiled...such a conglomeration of units[!] Granted that such a list was compiled and submitted to the editors in manuscript form, how was it possible that it was not rejected by the referees and editors?” After touching yet again on his familiar bugaboo of Darcy’s law (the misrepresentation thereof), Hubbert proceeded to review the major physics textbooks currently in use and speculate that “it is possible that students within recent decades have not learned classical physics, and that now those same students have become authors of textbooks.” Hubbert then decries the current mode of government funding of university research which has made “the universities...large centers of applied research [such that] a very large premium is thus placed upon the promoter, or the ‘empire builder,’ at the expense of the true scientist and the scholar [which] strongly favors the opportunist capable of grinding out scientific trivialities in large numbers.” Hubbert disliked the emerging paradigm that “any scientific enterprise of broader scope than an individual ‘specialty’ can only be carried out through the cooperation of teams representing the various ‘specialties’ involved” and claims that “thinking is peculiarly an individual enterprise.”

With benefit of sixty years of hindsight, the views expressed by Hubbert seem overly pessimistic. Inspired in part by Sputnik and a global competition with the Soviet Union, the U.S. science enterprise was expanding and accelerating in the early 1960s. And many of its subsequent successes have arisen from so-called “big science” that relies on large, interdisciplinary teams of scientists and engineers. Hubbert himself, despite his long-term association with large organizations such as Shell and the USGS, epitomized “small science” performed by highly motivated individuals and their immediate associates. This is reflected in his publications, largely single-author papers with only a handful having a coauthor. Other elements of his early-1960s philosophy seem prescient:

*[T]he problems confronting the human race today are such that a widespread knowledge of science is essential if they are to be dealt with effectively....[I]t is urgent that our universities again become institutions of learning, and that we provide for them a more orderly form of support... that competent teaching in universities again be accorded the respect that its importance demands, and that the curriculum be revised to make it not only possible but mandatory for students to receive a working knowledge of the fundamental principles of science.*

\* Unless otherwise indicated, all quotes in this memoir are from this collection of transcripts. The voluminous (104 ft3) M. King Hubbert collection at the American Heritage Center, University of Wyoming (<http://archiveswest.orbiscascade.org/ark:/80444/xv742552>) includes correspondence, lectures and class notes, publications and reprints, research notes and subject files, glass negatives, maps and charts, and other artifacts.

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