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JOHN VERHOOGEN
1912–1993

A Biographical Memoir by
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Biographical Memoir

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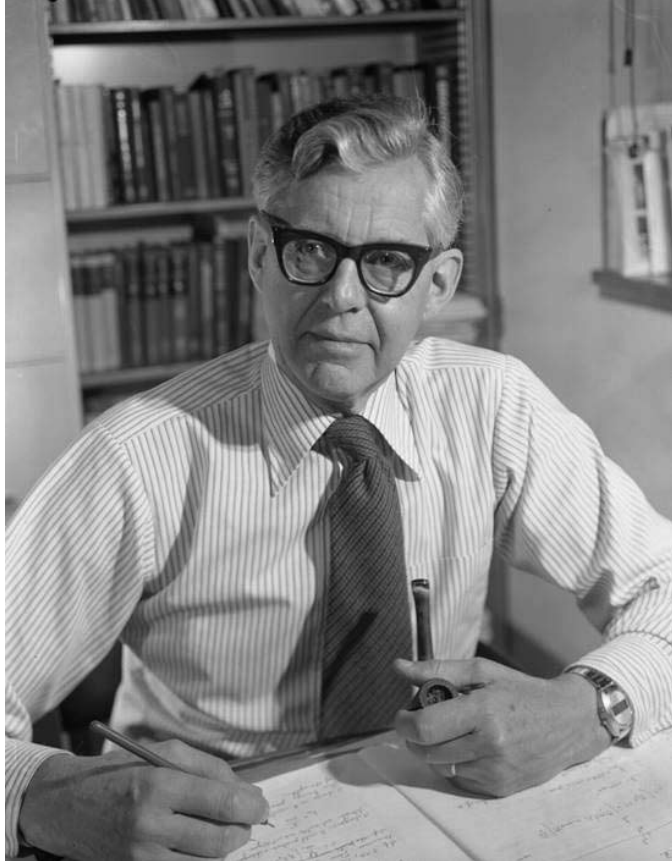


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John Vachon

JOHN VERHOOGEN

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BY PETER L. OLSON

JOHAN VERHOOGEN WAS AMONG the leading Earth scientists of the 20th century and was influential in the development of the modern view of a dynamic Earth's interior. His career spanned more than 50 years on three continents in three professions: engineering, geology, and geophysics. Through his research, teaching, mentoring, and his books Verhoogen inspired a generation of scientists to use fundamental physics and chemistry for unlocking the secrets of Earth.

Verhoogen was born in Brussels, Belgium, in 1912 into a middle-class, professionally oriented family that placed high values on education, learning, and active living. At age 17 while in high school he became afflicted with asymmetrical spinal poliomyelitis, a disease that was rampant in Europe at the time. Although his polio symptoms would progressively limit and ultimately curtail his physical mobility, it is fortunate that initially they were not so severe as to deter him from pursuing a career in the geological sciences, including field studies in remote parts of Africa.

In 1933 Verhoogen graduated from the University of Brussels with a degree in mining engineering. He earned another degree in engineering geology from the University of Liege in 1934 and a Ph.D. in geology from Stanford University in 1936. His Ph.D. degree program was somewhat

unusual. Officially Aaron Waters at Stanford served as his thesis supervisor, but he spent most of his time working with Howel Williams at the University of California, Berkeley, on the eruption history of Mount St. Helens volcano (1937). This was Verhoogen's first experience in the United States, and evidently the perception of greater freedom and opportunity had a profound and lasting influence on him; a decade later he would move with his family to California, where he spent the rest of his life.

Verhoogen's initial major research accomplishment was to observe the famous 1938-1940 eruption of Nyamuragira, Africa's most active volcano, in what is now the Democratic Republic of Congo. He spent a total of nearly 10 months perched on the caldera rim of Nyamuragira at nearly 3000 meters elevation. In addition to daily eruption observations, he carefully assembled a detailed set of measurements including pyrometric lava temperatures, spectroscopic gas compositions, and local magnetic field measurements, a far more diverse dataset than was standard in volcanology at the time. From this data he identified nitrogen bands with anomalous energies and concluded that nitrogen was a newly released phase that had acquired its excess energy where it was formed at depth in the magma system. By combining measurements of the size of orifices with determinations of the velocity of escape to give estimates of the amount of emitted gas (essentially the same technique used to estimate discharge from the BP New Horizons oil well leak in the Gulf of Mexico in 2010), Verhoogen discovered the Nyamuragira lava is in fact undersaturated in volatiles, containing less than 1 percent gas by weight. This in turn led him to propose some revolutionary ideas about the mechanics of volcanic eruptions (1948). He inferred that gas discharge does not play a major role in the mechanics of the Nyamuragira eruption activity or the circulation of its lava lake. These interpretations were

contrary to the views of the time but consistent with another observation, that Nyamuragira magmas have very low viscosity by virtue of their low silica content.

Nyamuragira volcano is still in the news today, and ironically perhaps, we now know that its gas emissions are very significant, although for reasons other than magma dynamics. Hazardous fumaroles of CO₂, locally called *mazukues*, still emanate from flows erupted in 1938-1940 and are reputed to be the sources of elephant and other large animal asphyxiation events. We also now know that time-averaged SO₂ emission rates at Nyamuragira are comparable to Kilauea in Hawaii and its eruptive CO₂ flux is probably several times larger still (Carn and Bluth, 2003), but neither of these gas fluxes were determined in 1938.

News of the invasion of Belgium in May 1940 brought a sudden end to his volcano observations, and Verhoogen spent the remainder of World War II (1940-1946) mostly in the Belgian Congo, procuring strategic minerals for the Allied cause. Toward the end of this period a letter arrived from seismologist Perry Byerly, then chair of the Geology Department at UC Berkeley, offering Verhoogen a junior faculty position. On route from Belgium to California, Verhoogen stopped at the Gulf Research Laboratory in Pittsburgh, in part to learn the views of industry scientists on the future of geophysics. They emphasized to Verhoogen the need for geophysics students to become more proficient in the fundamentals of chemistry, physics, and mathematics. Asked for a concrete example, they suggested that being able to understand Harold Jeffrey's influential but somewhat arcane treatise *The Earth* (Jeffreys, 1924, and later editions) would be an ideal benchmark for students.

The path from geology or engineering into geophysics was not very well established in that era. As a student Verhoogen was mostly interested in geochemistry, particularly

the chemistry of sediments. His interest in geophysics grew incrementally, but can be traced back to his African field experience, which convinced him that igneous processes and volcanism were indisputable evidence for large-scale flow deep in Earth's interior. He also became convinced that the thermal evolution of Earth is controlled by heat transfer associated with convective motions in the deep interior. Greatly impressed by Arthur Eddington's *Internal Constitutions of Stars* (Eddington, 1926), Verhoogen was nevertheless infuriated that astronomers could know the temperature of stars many light years away, and yet here on Earth we hardly knew the temperature 20 kilometers beneath the surface.

Partly because of his global perspective, Verhoogen was an early and vigorous supporter of Alfred Wegener's theory of continental drift, which put him at odds with the prevailing attitude in geology departments at most American universities at that time. Verhoogen later confided another reason for his support of continental drift: his professors at Liege were strongly opposed to it. Although an academic traditionalist in many respects, Verhoogen nevertheless relished being provocative, especially on hotly debated subjects.

Upon his arrival at UC Berkeley, Verhoogen began a life-long quest to bring thermodynamics and fluid mechanics to bear on the interpretation of dynamic processes inside Earth. He began by applying thermodynamics and fluid mechanics to the formation of igneous rocks. His first significant publication in this arena with the title *Thermodynamics of a Magmatic Gas Phase* (1949) established thermodynamic principles underlying many of the important processes in gas-charged magmatic systems, including the equilibrium compositions of magmatic gas phases, deposition from the gas phase, controls on the vapor pressure over a cooling magma, distillation, vesiculation, and crystallization of indifferent states. Only very limited amounts of experimental thermodynamic

data were available at that time, but since then a vast effort has gone into constructing thermodynamic databases for the purposes of exploring many of the processes identified by Verhoogen decades earlier (Nicholls, 2000).

Verhoogen contributed to the early development of geochronology, and he also played a crucial role in the revolutionary discovery of polarity reversals of the ancient geomagnetic field. During the 1950s, physicist John Reynolds was busy experimenting with different types of mass spectrometers capable of measuring the relative abundances of isotopes lighter than uranium or lead. These new spectrometers were first applied to the potassium-argon system, the isotope system that quickly became standard for dating rocks of all ages, in particular, relatively young volcanic rocks. Verhoogen provided Reynolds with a steady stream of volcanic rock samples from around the globe for age determination. About that same time Verhoogen and his graduate students and postdocs began a wide-ranging and long-lasting investigation into the magnetic properties of rocks and minerals, with particular attention to questions of whether the geomagnetic field had spontaneously reversed its polarity, and whether this phenomenon and other instabilities of the geomagnetic pole would provide evidence for continental drift.

Fifty years earlier, around 1905, physicists Bernard Brunhes and P. L. Mercanton had suggested that reversed remanant magnetism discovered in some volcanic rocks might correspond to polarity reversals of the main geomagnetic field. A decade later Motonari Matuyama found additional evidence in the form of reversely magnetized rocks in Japan older than 10,000 years, and shortly thereafter Jan Hospers found still more reversely magnetized volcanic rocks in Iceland. Verhoogen took up this question with postdoctoral fellow Ian McDougall along with graduate students Allan Cox, Richard Doell, and Brent Dalrymple to determine whether rever-

sals were geomagnetic or due to self-reversal in the rocks. Initially Verhoogen favored the self-reversal interpretation. However, Allan Cox in particular, after analyzing hundreds of volcanic samples from the Snake River Plain and elsewhere, found coherent reversal patterns that seemed could be rationalized only by having the geomagnetic field itself reverse. It turned out that the key instrumental development was the potassium-argon dating methods for determining the absolute age of these relatively young volcanic rocks. Eventually these discoveries led to the development of the geomagnetic polarity timescale, and they firmly established that the geomagnetic field had indeed reversed its polarity many times in the past. The geomagnetic polarity timescale later proved to be crucial for quantifying the rates and directions of sea-floor spreading and for determining the relative motions of lithosphere plates.

From the 1950s through the early 1960s a group of young researchers, including Richard Doell and William Fyfe, used Verhoogen's laboratory to construct novel types of magnetometers based on instrument designs by John Graham, Patrick Blackett, and Keith Runcorn and other early experimentalists for the purpose of measuring magnetic directions preserved in rocks. Verhoogen apparently showed limited interest in perfecting these instruments, however. One story begins with his students pleading with him to visit the rock magnetism laboratory that his research grants were supporting. Verhoogen finally gave in, took the short version of the tour, and then abruptly declared it was time for coffee. Accurate or not, this story illustrates the fact that Verhoogen was never deeply involved in technology development nor was he interested in data collection for its own sake. He was keenly interested in experimental results but only so far as their implications for fundamental science questions.

As his postpolio syndromes increasingly took their toll and began to seriously restrict his physical abilities Verhoogen's research steadily evolved from observational toward more theoretical topics. Perhaps his most broad-based and lasting research came to fruition during this period—his quantitative thermodynamic treatment of the genesis of igneous rocks. His approach combined the energetics of crystallization with considerations of the thermal environment of the deep crust and upper mantle where magmas originate. In collaboration with F. J. Turner he published in 1951 the landmark text *Igneous and Metamorphic Petrology*. This and subsequent revisions (the later edition is entitled *Igneous Petrology*, with I. S. E. Carmichael and F. J. Turner [1974]) proved to be the most widely used and influential works on this subject in their time. These treatises highlight Verhoogen's theoretical insights and mathematical abilities, his willingness to engage the most fundamental geological problems, and his visionary knack for anticipating future directions by incorporating the physics of convection, crystallization, liquid and gas dynamics, and other basic processes into igneous and metamorphic petrology.

One interesting and prescient outgrowth of Verhoogen's investigation of igneous rock genesis was his early recognition that Earth's central metallic core is similar to crustal magma bodies in several important respects. This view represented a whole new perspective on the evolution of the core. Verhoogen reasoned that, because Earth as a whole is cooling, the solid inner core must be growing by crystallization of the molten outer core. He realized that crystallization at the inner-core and outer-core boundary provides a large source of energy through latent heat release and other effects associated with the solidification. The molten outer core is solidifying from the bottom up (resulting in the solid inner core) due to the pressure dependence of its melting

point, rather than inward from all sides as occurs in a crustal magma chamber. However, bottom-up solidification means that the latent heat release at the inner-outer core boundary can power thermal convection in the outer core. In 1961 he calculated the latent heat release associated with inner-core solidification and concluded it would indeed drive thermal convection in the outer core and, furthermore, could be a source of energy for generating Earth's magnetic field through dynamo action in the electrically conducting fluid outer core. Subsequent investigations by S. Braginsky (1963), George Backus (1975), and David Gubbins and others (1979) developed these concepts further, adding an important ingredient to the model: the gravitational potential energy supplied by chemical differentiation at the crystallizing inner-outer core boundary. Solidification of the central inner core is now the favored mechanism for powering the geodynamo, and it has also been proposed for the dynamos in other planets.

Verhoogen's investigation of the energy budget of Earth's interior culminated in a monograph titled *Energetics of the Earth*, published by the National Academy of Sciences (1980), which combined material from four lectures he delivered as recipient of the Arthur L. Day Lectureship. In his 1980 monograph Verhoogen systematically analyzed the various energy sources available in the solid silicate mantle for driving plate motions, and he also analyzed the various energy sources available in the core for maintaining the geodynamo, including inner-core solidification, heat loss to the mantle, and more speculatively, radioactive heat sources in the outer core. In an address to the National Academy of Sciences, Verhoogen expressed his fundamental optimism in the following way: "Perhaps the greatest step forward since the discovery of radioactivity has been the recognition of convection as the dominant mode of heat and mass transfer

in most of the mantle and core. Here at long last is something to hang onto.”

John Verhoogen was an inspirational teacher, famous for the clarity, insight, and organization of his lectures and seminars. He spoke with an extraordinary lucidity and command of details. Students would exit from his classes in awe of his clear, concise accounts of how Earth works. He seemed equally at home discussing basic Earth science concepts with future poets as debating Earth science controversies with his colleagues. Although he was extraordinarily articulate, his effectiveness as a teacher came primarily through dedicated hard work and advance preparation. Near the end of his career he confided that he had spent more than half of his working hours just preparing for lectures and seminars, an astonishing revelation perhaps, coming from an active scientist at a major research university. Because he was generous with his time and open with his ideas, he successfully mentored a large number of graduate students, many going on to leadership positions in geology and geophysics. He had an especially sharp sense of humor, most often expressed in his amusing anecdotes involving famous people he had known.

Numerous awards and honors came his way. He was a fellow of the Royal Astronomical Society, American Geophysical Union, Geological Society of America, American Academy of Arts and Sciences, and a member of the National Academy of Sciences (elected 1956). Other recognitions included two Guggenheim fellowships, the Day Medal of the Geological Society of America, and the Dumont Medal of the Geological Society of Belgium. He served in several leadership capacities within large science organizations, including four years as vice president of the International Association of Volcanology and Chemistry of the Earth's Interior. Despite his difficulties in traveling he remained active in national and international science organizations until his retirement in 1976.

Away from science John Verhoogen was a rather private person in spite of his commanding presence. He was married to the late Ilse Goldenschmidt, a native of Austria. Together they enjoyed the company of their four children and numerous grandchildren during quiet summers at Ilse's family home Schloss Erla, a rambling, ancient structure with a village church attached to one end and expansive views up and down the valley of the Danube. He read widely in his spare time, and was an avid swimmer throughout his life.

John Verhoogen, a truly pioneering figure in Earth sciences, died in Berkeley, California, on November 8, 1993.

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