Barclay Kamb

1931–2011

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
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NATIONAL ACADEMY OF SCIENCES

WALTER BARCLAY **KAMB**

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By Hermann Engelhardt

Walter Barclay Kamb's seminal work on the crystallographic structures of all the known high-pressure ice phases, his bold field observations—complemented by creative theoretical analyses—of the critical processes controlling the fast flow of glaciers and ice streams, and his vast contributions to the scientific literature set a high bar for his fellow glaciological researchers.

Barclay was "dual-threat" in that he had the theoretician's mathematical mind and the experimentalist's sense of practicality. He could operate comfortably in the realm of quantitative models, in the laboratory, and in the field. To these assets, he added the stamina, hardiness, and organizational skills of an explorer.

Born in San Jose, California, Barclay grew up in the San Francisco Bay area and in the Southern California city of Pasadena. He was a child prodigy who absorbed enormous amounts of virtually every kind of knowledge, but showed special skill in mathematics. At age 14, Barclay applied for admission to the California Institute of Technology (Caltech), but given the large influx of veterans returning from World War II, the university's admissions office suggested that he wait a year before enrolling. Wasting no time, Barclay promptly registered at the Pasadena City College, where he took courses in geology, physics, and mathematics, among other subjects.

When he entered Caltech in 1948, Barclay majored in physics but also followed his interest in geology, taking the famous geology and glaciology courses taught by Bob Sharp, with whom he developed a lifelong friendship. By the time Barclay graduated with highest honors in 1952, his intellectual prowess was already legendary on the Caltech campus. He was urged to stay on for graduate studies in physics, along with his good friend Ron Shreve.

But after a year in physics, and a good deal of prodding from Sharp, Barclay and Ron decided to transfer from physics to geology for their Ph.D. studies. Still, Barclay continued to regard himself as a physicist, and he religiously attended the physics department seminars. He was especially drawn to the lectures of Richard Feynman, who taught physics in an unconventional and captivating way.

But moving to the Geology Division allowed Barclay to combine his academic pursuits with his passion for the outdoors. He especially enjoyed both the spectacular scenery and exploring the geologic formations of the American southwest. Working in geology piqued his interest in investigating the atomic structure of the region's minerals, and he did his doctoral thesis on the structure of the complex mineral zunyite, with the Chemistry Division's Linus Pauling as his advisor.

After leaving his mark in three Divisions—Physics, Geology, and Chemistry—Barclay was offered several choices when he finished his Ph.D. Sharp won him over again—Barclay accepted an appointment as assistant professor of geology in 1956. But Pauling did not let go of him either. He put Barclay to work unraveling the beautiful crystalline structures of the many different high-pressure phases of ice—Ice II to Ice IX (except Ice IV, which was added later). Pauling believed that these ice structures, held together by hydrogen bonds, were crucial for understanding the nature of such bonds. Extraordinary skills would be required for the effort, as it encompassed the production of single crystals of these ice phases and working with them at liquid-nitrogen temperatures in the goniometer stage of the X-ray machine. But Barclay possessed such skills, and he excelled.

In 1968, he presented his findings at the First International Symposium on the Physics of Ice, held in Munich, Germany. This event introduced Barclay to the community of ice physicists and glaciologists, and after that debut he contributed to most international forums for these professions. Barclay ultimately received the highest award in the field of glaciology—the Seligman Crystal, conferred by the International Glaciological Society—and he was also honored with the Mineralogical Society of America Award.

Recognizing Barclay as his best student ever, Pauling took steps to keep him at Caltech, going as far as instigating a relationship between Barclay and Pauling's only (and beautiful) daughter Linda. Pauling proceeded to hire Linda as a lab assistant—never mind that her academic interests lay elsewhere, mostly in the fine arts—and then asked Barclay to help her develop X-ray photos in the darkroom. Something indeed developed—in 1957, the two were married. Their union produced four sons—Barclay (Barky), Alexander (Sasha), Anthony, and Linus—who they introduced to the joys of backpacking in the nearby San Gabriel Mountains and the southwest national parks. Barclay, Sr., regularly organized backpacking trips along the John Muir Trail in the high Sierras, and skiing trips to the Pear Lake Hut in Sequoia National Park, for his family and friends.

Barclay was especially attracted to landscapes still covered by glaciers or formed by glacial activity, and he was thrilled when Sharp invited him to apply his knowledge of ice and its properties to glaciers' flow and to the fabric, crystalline metamorphosis, folding, faulting, fracturing, and regelation of glacier ice. The study of glaciers was considered essential to the understanding of geologic processes. Under Sharp's leadership, Blue Glacier in Mt. Olympus National Park in Washington was chosen for special attention, and numerous professors in the Division of Geology and most of its graduate students at the time made the pilgrimage to this picturesque high-mountain glacier.

Kamb on Blue Glacier, WA Olympic Park, hot-point drilling in ice fall, 1962.

Barclay soon took over the project, and with his friend Ron he started drilling boreholes to the bed of the ice using thermoelectric hot points, meanwhile building many novel instruments to study the ice's internal deformation. Taking photos from the base of the glacier and studying basal conditions became Barclay's core interest and focal point. At the same time, the researchers set up an extensive array of stakes on the glacier surface, to be surveyed from stations on the lateral moraines.

Barclay was a master surveyor who treated his Wild theodolite like a baby. Early on, he also saw Blue Glacier as an instrument for monitoring climate change. Every year a marker was posted at the terminus to measure the retreat of the ice. As new striations on exposed rock surfaces came into view, they were meticulously recorded with the aid of a cache of equipment and camping gear that Barclay kept well hidden under a pile of rocks on the left lateral moraine for 10 years. These Blue Glacier studies established him as a leading glaciologist who catapulted the field into the forefront of modern environmental sciences.

After Blue Glacier, and after his discovery of the elusive metastable Ice IV crystalline structure, Barclay initiated a sequence of glaciological projects—each one bigger than the last—leading to many influential papers that helped change the scope of glaciology. Because the key to understanding fast glacier flow lies at the bottom of the ice, the key tool of trade was a hot-water ice drill, built in the Caltech machine shops, that grew over the years from a small 200 m deep device to a more powerful 1600 m one. With the hot-water drill, access boreholes reaching the bed of the glaciers could be drilled in a short time to accommodate borehole instruments, most of which were also designed and built in-house at Caltech.

Kamb surveying on surging Variegated Glacier, Alaska, 1983.

The Variegated Glacier project in Alaska near Yakutat was the first detailed study of a galloping, or surging, glacier during its active period. The glacier increased its speed to over 300 times normal, to a maximum of 65 m per day, with high-pitched ice quakes and new crevasses opening overnight under the sleeping tents and drilling platform. The drilling revealed the pivotal contribution of water storage, the basal lubrication by water at high pressure, and the total reorganization of the basal hydraulic system of the glacier. The ice accumulation of 20 years was swept through the valley in just three months.

The Variegated was extensively surveyed even at night, when lights at the stakes on the glacier were remotely activated by pushing a radio button. Barclay called it his Christmas tree. And it took the nerve of a Barclay to see such a project through; it was undoubtedly not without risks.

In the same fearless spirit, Barclay took on one of the largest and most active glaciers in Alaska, the Columbia Glacier, a tidewater glacier that flowed directly into the ocean and had a bed well below sea level. It was not only fast flowing, at a speed of 9 m per day, but also was starting to catastrophically retreat into its fjord at a rate of 1 km per year. Barclay recognized the last chance to extract the secrets of a most powerful river of ice.

The Columbia Glacier was huge—6 km wide, 1 km deep, and several hundred km long—and its surface was heavily jumbled with crevasses, huge ice blocks, séracs, and icy pinnacles, often next to deep chasms and gaping holes. It took many hours of helicopter circling to find a suitable spot where a drilling camp could be established, and it was necessary for people to step out of the hovering helicopter onto the slippery uneven ice surface. Given this need, Barclay hired experienced ice climbers who regarded the mounting of icefalls as all part of a day's work. Small platforms were hewn from the ice with ice axes to accommodate the drilling equipment and the living tents, ladders were used to bridge over the abysses between the separate perches, and in this process not one false step could be tolerated. The equipment and supplies were then delivered in sling loads dropped from the helicopter.

Kamb drilling on Columbia Glacier, Alaska. The drill stem got caught and bent at the hard bed because the fast-moving glacier was sliding over it.

Again, the phenomenon of basal sliding as the main contribution to fast glacier motion was demonstrated in detail. The high basal water pressure at or near the ice overburden pressure kept the glacier afloat and well lubricated at the bed. The boreholes were 900–1000 m deep. The glacier rumbled along again at a speed 100 times that expected from internal deformation of the ice alone. As a result, big chunks of ice—treacherous icebergs—were calving off the ice cliffs at the terminus into the ocean and menacing the oil tankers plowing their way from Valdez to the Gulf of Alaska. A few years later, these drill sites were gone and most of the tidewater part of Columbia Glacier became open ocean.

The Columbia Glacier Project had another purpose. It served as a credible place for testing a hot-water drilling system capable of rapidly penetrating to substantial depths. It also created a pool of field assistants who were hardened, experienced, and highly motivated.

After that project, Barclay was ready for his biggest adventure—to study the basal conditions of the biggest glaciers on Earth, the fast-moving Antarctic ice streams. The Antarctic Project, which lasted from 1988 to 2001, led to many new discoveries and a series of seminal papers published in *Science*, *Nature*, and other distinguished journals. For example, Barclay's team established that the ice streams draining the West Antarctic ice sheet have the combined characteristics of surge glaciers and tidewater glaciers.

These ice streams move fast by sliding over their beds, which are lubricated by water at high pressure. The geothermal flux is elevated. In samples of basal till, volcanic rocks of volcanic origin are present, thereby pointing to volcanic activity in the interior. The till also contains an abundance of diatoms, showing that West Antarctica was an open ocean in the recent Pleistocene; when CO_2 concentrations in the atmosphere were much lower than today. Barclay's results could not speak louder and clearer that climate change must be taken seriously and reversed responsibly. Otherwise, the decay of West Antarctica is a possibility, with the catastrophic consequence of a sea-level rise of 6 m.

In recognition of his important contributions to Antarctic glaciology, the central ice stream flowing into the Ross Ice Shelf was named the Kamb Ice Stream, formerly only known as Ice Stream C.

Most of the borehole instruments used in Barclay's work on glaciers and ice streams were designed by him and built in-house at Caltech because commercial versions could not meet his stringent requirements. Moreover, because Barclay did not like black boxes, he needed to understand every detail of his instruments down to the tiniest screw. His character required that every experiment was thoroughly planned, every procedure meticulously thought through. Such standards applied as well to his professional communications, and no grant proposal or paper that Barclay wrote was ever rejected.

As the reader might suspect, Barclay had an enormous impact on his students and colleagues. He mentored a small but very successful group of graduate students, some of whom became influential glaciologists themselves. At meetings and seminars—or in virtually *any* conversation, whether with students and colleagues or with people from the broader community—Barclay would pose penetrating questions aimed at the very center of the topic. As a result, during the last several decades there were not many students of glaciology, or professionals in his field all over the world, who did not have their thinking reshaped by interactions with Barclay. Thus his work is cited in almost every important glaciological paper.

Kamb with team on Bindschadler Ice Stream (formerly Ice Stream D), hot-water drilling camp, 1998/99. Barclay in back right.

Barclay's influence was especially great at his home institution of Caltech, where he was admired for his breadth and depth of knowledge, friendliness, and physical stamina and ruggedness. He tended to be informal, but effective. Once he appeared a little late to a meeting of Caltech's Board of Trustees, having come directly from a field trip. Unshaven and still in his field outfit, including dusty boots, he stood in stark contrast to the distinguished members in their elegant business attire. And while they had arrived in sparkling Mercedes, BMWs, and Porsches, Barclay stepped out of his ancient beat-up carryall Continental truck. But he immediately picked up the conversation and contributed to the deliberations.

Among the diverse activities for which Barclay was known: sleeping in a tent in the middle of Antarctica for three months; leading a group of geology students to a place called Devils Punch Bowl, and teaching them, around a campfire under the stars, about some of the most convoluted geological processes; trekking along the Muir Trail with gear and food for 10 days; playing Chopin on his grand piano at home, but when on the glaciers playing dance pieces and folk songs on a set of harmonicas; reciting the poems of Robert Service, especially the ballad "The Cremation of Sam McGee;" imbibing his favorite drink (water) and next-to-favorite (buttermilk), but also savoring the rich bouquet of a fine Pinot Noir from his own vineyard; digging up his compost and planting a vegetable garden; riding his old heavy steel bike to work at Caltech and back home up a steep road to his ranch above Pasadena in the San Gabriel Mountain foothills; repairing his truck and bike or resolving any malfunction around the house; talking to people in the machine shops as well with the well-educated, influential, or powerful; unceremoniously popping a homemade sandwich for lunch at his desk, or eating with students at the Chandler Cafeteria (also known as the Greasy Spoon), or indulging, when called for, in fine dining at the elegant Caltech faculty club (the Athenaeum) at a roundtable with Nobel laureates; caring for the environment by picking up trash anywhere, putting up the first solar collectors on his roof, living green long before everyone else; and busying himself most of all with his beloved pastimes of studying and writing.

In addition to Barclay's extraordinary contributions as a scientist and educator, he provided critical leadership and administrative service to Caltech. His 11 years as chairman of the Division of Geological and Planetary Sciences were notable for the same attributes that characterized his approach to science—devotion, generosity, intellect, passion, and fairness. Thus he inspired others and assured the smooth running of a multifaceted entity. When Caltech needed a provost at short notice, president Murph Goldberger turned to Barclay, who then led the academic program of the institute with similar success.

Barclay was also an outstanding fundraiser for the institute's endowment fund. For example, he organized an extravagant river-raft trip through the Grand Canyon for a group of distinguished donors, who happily paid a million dollars each for this thrill-of-a-lifetime experience. Serving as tour guide, Barclay captivated his audience by recounting the history of Earth as exposed in the sedimentary layers from the upper Kaibab Formation down to the Urgestein, Vishnu group, and Zoroaster granite.

The recipient of many honors and distinctions, Barclay was both a Guggenheim Fellow and an Alfred P. Sloan Fellow during his tenure at Caltech. He was a fellow of the Mineralogical Society of America, the Geological Society of America, the American Geophysical Union, the American Association for the Advancement of Science, and the International Glaciological Society. Barclay was a member of the American Academy of Arts and Sciences and the National Academy of Sciences. Over the course of his career he served on countless committees, panels, and commissions that typically involved geosciences, environment, and resources.

Barclay had a rare blend of talents and traits; and he was a polymath without pretense or egotism. His colleagues, friends, and family admired him not only for his analytical brilliance but also for his decency, humility, and physical toughness. Though he never sought power or authority over people, he was a dutiful, fair-minded, and respected leader whom others followed naturally. Few members of the Caltech community have matched Barclay's career in its longevity, accomplishment, service, and impact.

When he died at his home in Pasadena on April 21, 2011, Barclay was Caltech's Barbara and Stanley R. Rawn, Jr., Professor of Geology and Geophysics. He had battled Parkinson's disease for a long time with great dignity.

Even during his last years, slowly climbing down from his peaks of scientific achievements and physical strength, Barclay was resilient, gentle, and graceful. For all who were fortunate enough to know him, he created unforgettable memories and a cherished legacy.

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