RUSSELL WATSON RAITT

1907 – 1995

BY LAWRENCE A. LAWVER
AND ROBERT M. KIECKHEFER

Russell Watson Raitt with Robert Pepin, Downwind Expedition, 1958.

While far less known to the average American than his close relatives, musician Bonnie Raitt and her father, singer John Raitt, Russ Raitt is renowned in the earth-science community as the father of marine geophysics in the Pacific Ocean. It is hard not to remember Russ as being one-half of Russ and Helen Raitt because Helen had such a remarkable presence in contrast to Russ's self-effacing ways. Russ and Helen first met at South Pasadena High School in their teens; while Russ was out getting his Ph.D., Helen married and had three children. So when Russ and Helen Hill did get together and marry in 1935, Russ acquired an instant family, joined in 1939 by their daughter Martha. Martha proceeded to marry Christopher G. A. Harrison, a Scripps graduate student and now a marine geophysicist at the University of Miami, thereby keeping geophysics in the family. Russ and Helen shared 40 years of a remarkable life together. Part of the Russ and Helen mystique was their home in Scripps Estates Associates (SEA). Helen had been instrumental in the formation of SEA and by good luck drew an early chance to pick their lot. They then hired a California architect who built them an extraordinary redwood and glass house, one of the very few private residences that he designed. Standing at the stove in the kitchen one looked across the far living room to a window that framed a postcard view of La Jolla Cove, while to one's right was the vista from Black's Beach to the San Pedro–Long Beach Harbor hills and several of the offshore islands. Their Ellentown Road home is remembered by all for the fabulous parties, dinners, thesis defense blowouts, and weddings. I (LAL) had

always wondered why the house worked so well for large parties until I found that Helen's design criterion was to be able to entertain 100 people comfortably. Except for Russ's closest colleagues at Scripps, most La Jollans primarily knew Russ socially because he was not a self-promoter. Few of the legions of distinguished people who met Russ at 2424 Ellentown Road could have told you of his many contributions to earth science and marine geophysics but all appreciated him as an extraordinary human being.

Russell Watson Raitt was born in Philadelphia, Pennsylvania, on September 30, 1907. His father was a minister in the United Presbyterian Church, with responsibility for founding new churches all over the United States. In 1921 the family moved to Hollywood where Russ entered high school. He found it much more sophisticated and exciting than the schools he had known before, but his parents decided Hollywood was a den of iniquity and soon moved to South Pasadena, where Russ finished high school. In 1925 he entered the California Institute of Technology, partly because it was gaining a reputation as an excellent school under the new leadership of Robert A. Millikan, but mostly because it was nearby. There he was exposed to many outstanding teachers, such as Ira Bowen for sophomore physics, and Linus Pauling, who supervised Russ's junior year research project. He was graduated in 1929 with a B.S. in physics, traveled in Europe, and then worked for Hercules Powder Company for two years.

Russ returned to Caltech for graduate work in 1931. His doctoral work, under Millikan, a Nobel-laureate physicist, was to measure the radioactive content of a large number of dirt samples collected by Millikan and associates around the world as part of their study of cosmic rays. His Ph.D. dissertation in 1935 was titled: "Direct measurement of alpha particle activities of rocks and determination of thorium" and marked the beginning of his lifelong involvement in the earth sciences. Later in that year Russ joined two Caltech geophysics graduates, Josh Soske and Raymond Peterson, to form the Geophysical Engineering Corporation, a company established to look for oil fields. Their first project was reflection prospecting in the Los Angeles Basin. To interpret their reflection records, Russ had to obtain velocity as a function of depth. He soon discovered that about 1933 Caltech's Beno Gutenberg had shot a long refraction profile across the Los Angeles Basin to measure the depth of alluvial fill. This provided, in Russ's evocative words, "a beautiful profile of the travel time versus distance, which fit quite well to a linear velocity/depth function." The three-man field party also surveyed the Pasadena water basin for depth to the granitic basement, and did refraction prospecting in the San Joaquin Valley.

By 1941, Russ's company was declining, "it had been kind of fun," Russ said, "and I think we pioneered in some ways." With possible naval military actions looming, Russ was an early recruit to the newly formed University of California Division of War Research (UCDWR) laboratory in San Diego. He visited it to talk to its director, Vern O. Knudsen, who was on leave from the UCLA physics department. Russ joined the lab shortly thereafter in the summer of 1941. Helen was delighted with the impending move to San Diego because she enjoyed the beach; prior to marrying Russ she had lived in Hawaii for a time with her three young children.

As an acoustic physicist, Russ used explosives and echo-ranging transducers to measure sound propagation and scattering in the water and reflections from the seafloor, all subjects critical to submarine operations and detection. The only available "ships" to do the

war research work were two yachts, *E. W. Scripps* on loan from the Scripps Institution of Oceanography, and *Jasper,* a war-preempted yacht later part of the Scripps fleet (there renamed *Stranger*). Carl Eckart was a division head at UCDWR for the echo-ranging section to which Russ belonged. Russ found Carl to be a "marvelous scientist ... he had such a wonderful conception of what was important in everything he did."

During 1942, Russ and some of his UCDWR biology colleagues observed the phantom bottom that made the seafloor appear very shallow where it was expected to be quite deep (Eyring, Christensen, and Raitt 1948; Raitt 1948). During the 1930s and early 1940s, this false bottom had been recorded and mapped on fleet nautical charts as shoals or vast tracts of ocean floor inimical to submarine navigation. The trio concluded that this was not an instrument problem, and called it the Deep Scattering Layer because it scattered the sound waves. In June 1945 biologist Martin W. Johnson followed the daily cycle of the Deep Scattering Layer through 24 hours and suggested that the layer was made up of living organisms. Once so recognized, the cartographers had to remove from charts such major entities as "Guardian Bank" west of Costa Rica and the vast "Allaire Bank" southwest of Baja California. Aspects of the collaborative UCDWR research results led to the development of new sonar systems for U. S. submarines and a 1946 reference book, *Principles and Applications of Underwater Sound,* that remain relevant today.

As the UCDWR began to be dismantled during 1945 the Navy Electronics Laboratory (NEL) was established from it. Carl Eckart wanted a university affiliation but he almost gave up because of interminable delays. Russ hung on at the remnants of UCDWR, having chosen not to transfer to NEL and on 1 July 1946, the Marine Physical Laboratory (MPL) of the University of California began operations that continue to this day. Russ as Senior Research Associate, along with Carl Eckart as Director and Professor of Geophysics, Robert W. Young as Research Associate, William C. Kellogg as Research Fellow (i.e., graduate student), and Finn W. Outler as Marine Supervisor were the first scientific staff members of MPL. Almost immediately in 1947, Russ began teaching at Scripps with a course in the principles of underwater sound. In 1948 MPL joined Scripps, instead of the University of California at Berkeley, as Carl Eckart became director of both MPL and Scripps. Russ received a faculty position to be leader of its first seagoing research team, becoming an associate professor at Scripps in 1949 and a professor in 1956.

Russ's first research at MPL was a carryover from the UCDWR days. He analyzed oscillograms of bottom echoes derived from vertical beams of 24-kHz sound. He kept tinkering with the equipment while he gathered more reflection records at sea off San Diego. Using the wartime bottom surveys done by the geological group under Francis P. Shepard for UCDWR, he selected sites of specific seafloor composition—from rock to mud—and analyzed the records for the dependence of echo amplitude and form on bottom type, depth, and topography. By 1948 Russ was able to say that "Observations of the reflection of ultrasonic sound from the sea bottom have been explained reasonably well by the hypothesis that the sound is diffusely scattered from the ocean bottom, or from a layer extending a few feet into the bottom" (MPL Quarterly Report, 1 January-31 March 1948). While many at Scripps may not have been cognizant as to exactly what Russ did, others throughout the world collaborated on the exciting new work. He established cordial contact with a team of

researchers at Cambridge University that included Maurice Hill, Tom Gaskell, and their mentor, Edward (later Sir "Teddy") Bullard.

Early in 1948, Russ began reflection studies using explosives at sea, with the first trip a 12-day voyage to Erben Bank (800 miles west of San Diego). On that operation he recorded 132 shots ranging from 1/2 pound to 5 pounds of TNT. By the middle of 1948 he was doing refraction studies with SOFAR detonators and 50-pound charges of TNT. He quickly learned that hydrophone motion was lessened by trimming the hydrophone at nearly neutral buoyancy at depths of 100 to 200 feet. While developing this technique Russ, ever inventive, found that sturdy Tabasco© bottles were excellent floats for the hydrophones, which typically were denser than water. Although it was certainly within his prerogative as Chief Scientist to commandeer a supply of these bottles, Russ knew that angering the cook was a recipe for a tense cruise. He therefore just asked the cook for the empty bottles, and also then at each meal poured copiously this fiery sauce on everything imaginable, to ensure an adequate bottle supply. The TNT charges were fired from a motor whaleboat—when practical, although weather conditions did not often permit operating in the deep ocean beyond the continental slope (MPL Quarterly Report, 1 April-30 June 1949). For that reason a number of shallow-water profiles were recorded in the lee of islands such as Guadalupe, Cedros, and Islas San Benitos. With the present OSHA requirements it is hard to imagine getting volunteers to light off 50 lb. TNT charges from a small boat or permission of the omnipresent bureaucrats to do such work.

Late in 1948, Scripps acquired *Paolina-T,* a former purse seiner, and Russ began two-ship refraction profiling in the spring of 1949 with *Paolina-T* as the shooter and *PCE(R)-855* of NEL as the receiver. His primary method was to have one vessel, the "shooting ship," position itself about 80 km± from the "receiving ship" and run toward it firing TNT charges underwater: the charges were fired more frequently and were smaller as the distance decreased. The "receiving ship" drifted on station with neutrally buoyant hydrophone arrays deployed at depths of 40-50 m. After passing close to the receiving ship, the shooting ship continued on for a further 60 to 90 km at which normally the first arrivals from the sub-crustal mantle could be established. Russ shifted to a slow-burning time fuse instead of electric detonators for safety reasons, so that the shooting ship could travel at full speed. "It was found quite practicable to record 50 miles of profile, with shots about one mile apart, in an eight hour working day" (MPL Quarterly Report, 1 July-30 September 1949). This method of firing explosives and receiving refractions was used by MPL for more than 30 years, though the 8-hour day soon became around-the-clock operations featuring "things that go boom in the night."

In the seismic experiments of that era, Russ's group tried various ways of measuring reflections from the seafloor. They used hydrophones built by others, and they developed their own. They used the "snake"—a long plastic hose full of spaced hydrophones devised by L. C. Paslay of Dallas, Texas, which Russ thought may have been the first towed seismic array. Too bad for Scripps that they did not patent the towed multichannel seismic streamer, which soon became a mainstay of the oil industry's offshore exploration!

In August 1949 Russ participated in Merle A. Tuve's project to determine the structure of the earth's crust down to tens of kilometers. Tuve's work was sponsored jointly by the Carnegie Institution of Washington and the three-year-old Office of Naval Research.

For this work, Russ relied on his experience as an oil prospector in the 1930s. He fired six charges of 1,200 pounds, six of 2,400 pounds, and one of 600 pounds from *Paolina-T*. The MPL group recorded these shots at 13 ocean stations while Tuve and associates recorded them at many land stations. As part of the same project Russ set up an ocean station to record a quarry blast detonated on 6 August 1949, at Corona (California) that used 156,000 pounds of explosives. This was a huge explosion, but Russ asked, "Why stop here?" Soon he was planning to use nuclear tests at Bikini and Eniwetok as seismic sources.

Russ throwing a charge overboard, Capricorn Expedition, 1952.

By 1950, after testing marine techniques over the seafloor in the nearby continental borderland and off Baja California, Russ was ready to examine the deep Pacific. In 1950 he participated in Scripps's first major, postwar cruise, Midpac—the Mid-Pacific Expedition. He recorded some 1,200 miles of refraction profiles, including a reversed profile inside Kwajalein Lagoon and many reversed profiles inside Bikini Lagoon and on the flanks of the atoll (Raitt 1954). From the open-sea blue-water profiles he was surprised to find the average sediment thickness of the Pacific Ocean basin to be very thin. More detailed analyses revealed a low-velocity layer apparently related to volcanic rocks that was later called Layer 2.

On Capricorn Expedition in 1952–1953 Russ continued his mission to rid the world of surplus World War II explosives. He recorded 2,542 nautical miles of profiles and experimented with larger charges up to 480 pounds of TNT (MPL Quarterly Report; 1 January–31 March 1953). All but four stations reached the Mohorovicic discontinuity (the "Moho"). The observed sediment thickness was surprisingly thin, on the order of only 100 to 200 meters in many cases. In the Tonga Trench the sedimentary fill was at most a few hundred meters, and there the Moho was 10 to 15 kilometers deep; elsewhere it was 5 to 10 kilometers deep. The low-velocity layer was again identified on many of the records (MPL Quarterly Reports; Raitt 1956, Raitt 1957). By using two ships and long shotlines, Russ routinely detected and mapped the distinct velocity demarcations between overlying sediments, the upper basement member (now known to be pillow basalts and dike complexes), the underlying major lower crustal layer (gabbroic plutonics) of nearly uniform sound velocity transmission, and the upper boundary depth and velocity characteristics of the upper mantle itself.

Helen joined Russ at Nukualofa, Tonga, for the later legs of Capricorn Expedition, although she had not set out to do so. She had planned on simply visiting the ship in Fiji and in Tonga but then various delays on the ship's part caused problems. She recounted that trip in a popular account *Exploring the Deep Pacific* (1956, W. W. Norton) which was translated into several languages and sold worldwide. Perhaps the most significant feature of

Helen's voyage on *Spencer F. Baird* was that she accidentally became the first woman to sail on a two-month segment of a long Scripps cruise, thereby easing the way for future female research scientists such as Tanya Atwater. (Rachel Carson had been invited to go on Capricorn but was unable to make it.) Rereading Helen's book describing daily operations reminds us how far we have come since the days of star fixes and redoing ship's track plots for the previous days or even weeks in order to correct navigation errors. The Global Positioning System has changed so much of what we do.

As Capricorn Expedition headed home in early 1953, Russ and colleagues discovered the linearly extensive, anomalously low mantle velocity beneath the crest of the East Pacific Rise south of the equator and, later, to the north. In several expeditions with Robert L. Fisher to Pacific trenches in the 1950s, Russ and George Shor mapped a normal to slightly thickened oceanic igneous crustal structure and upper mantle that deepened beneath the trench axis and under the nearshore flank. Later work in 1960 by this trio confirmed these same observations in the Sunda Trench off Bali and Java. The puzzle pieces were starting to fit together as fundamental clues in the then-emerging picture called "seafloor spreading": thin crust at the ridge crest, later identified as the spreading center, and thickened older crust sliding down the trenches to satisfactorily resolve the "expanding earth" problem. This work evolved as components of the whole plate tectonic revolution, buttressed with the input of the identification of an upward 1,400 km offset of similar marine magnetic anomaly suites (Mason-Raff lineations) north and south of the Murray and Mendocino fracture zones by Victor Vacquier, Art Raff, and Bob Warren (Vacquier et al. 1961).

Russ continued reflection and refraction studies in the Southern California Borderland (Shor and Raitt 1958a, 1958b; Shor, Raitt, and McGowan 1976) and, whenever possible, farther afield in the Pacific Ocean (Raitt, Fisher, and Mason 1955; Fisher and Raitt 1962; Shor, Menard, and Raitt 1971) and eventually into the Indian Ocean (Francis and Raitt 1967). He—and Caltech's George Shor, who had joined MPL to work with Russ in 1953, and engineer Alan C. Jones—tried other kinds of hydrophones, including ones on the bottom, towed streamers, and new techniques. But basically they retained the methods that Russ had devised in his early years because these worked. Over the years others adopted the techniques. Although the instrumentation and procedures were described in two papers (Raitt 1952; Shor 1963), the spread of the methods was mostly through personal contact; by visitors to Scripps, and by people whom Russ talked to abroad and as a visiting geophysicist on their own ships. The methods were adopted first by British and Soviet groups, then by the Japanese, and finally by geophysicists at Lamont-Doherty Geophysical Observatory and Woods Hole in preference to methods they themselves had developed.

A summary of the most important discoveries from these wide-ranging surveys was reported by Russ in *The Sea,* Volume 3 (Raitt 1963): the small thickness of sediment in the ocean basins, and the widespread existence of Layer 2, the material just beneath the unconsolidated sediments, now known to be pillow basalts. Those who did refraction work in the Atlantic Ocean often did not detect Layer 2, and therefore calculated excessive thicknesses for the sedimentary layer. Russ detected Layer 2 early on, and worked to determine its nature. In part he was lucky: Layer 2 was easier to detect in the Pacific because the sediments are thinner on average than in the Atlantic. In part, it was an unexpected

benefit of a quirk in his field procedure. Russ called for the small shots at close range at the shortest time intervals possible; he routinely monitored the quietest hydrophone on a pen-and-ink oscillograph, and thereby obtained detailed data in real time over the very limited range in which Layer 2 appeared as a first arrival. Meanwhile, back in the Atlantic, the researchers who waited to develop each photographic oscillogram before calling for the next shot (the standard procedure in industry) needed longer intervals between shots and so missed Layer 2.

Russ insisted on going to sea with a speaker cabinet, containing a huge woofer, so that he could listen to the low-frequency refractions as they arrived—multimedia monitoring long before the general public knew what "multimedia" was. With this cabinet mounted on the ceiling, the arrivals sounded like rumbles of far-off thunder, followed by the earsplitting crash of the unrefracted sound traveling only through the water.

Helen Raitt on Capricorn Expedition, 1953.

Russ's effective technique could be exasperating at times to the explosives handlers on the shooting ship. After each charge was lit and dropped into the water, the shooter asked, "What size charge do you want next, Russ?" Russ's usual answer was something like "Give me another 10-pounder" or "The refractions are getting weak—better make the next one 20 pounds." More than once, however, he said, "I'm not sure—let's see how the arrivals look for the shot that's in the water." This was a pragmatic course because there was a limited supply of explosives and it was foolish to fire 240 pounds when 120 would do the job. A minute later the charge detonated, and a few seconds after that, the refracted waves arrived on the pen-and-ink recorders. A minute after that, the shooters would repeat their question, "What size charge do you want next, Russ?" And occasionally the answer was, "I'm not sure—what do you have made up?"

Other significant observations by Russell Raitt's team through the years were the remarkable uniformity of sound velocity within each layer of the oceanic crust, the small variations in depth to the mantle in deep-sea areas, and the accidental discovery of the low mantle velocity beneath the East Pacific Rise. Russ's early work in the Southern California Borderland and around Guadalupe Island provided the background for the site selection of the test holes and the location of the Experimental Mohole drilled by *CUSS I* in 1961. From that came finally a sample of Layer 2: stark blue-grey basalt. Raitt and Shor both served on the panel that chose a site near Hawaii for the not-yet-drilled Mohole. The general characteristics of the seismic structure of the ocean floor as summarized by Russ in his article in *The Sea* Volume 3, thin sediments indicating young crust, a seismic velocity for most of the crust unlike that found on the continents, the extreme thinness of the crust compared with continental crust, and uniform velocity from place to place indicating crust that had not undergone complex geological processes, were important factors in the

development of the theory of seafloor spreading. Russ's work was fundamental in gathering the primary data for this seismic model.

In the mid-1960s, Harry Hess, a longtime friend from Princeton, reviewed the Pacific data from off Hawaii and California which Russ had collected. Russ and George Shor were drawn into the puzzling question raised by Harry Hess in 1964: why, in refraction data taken by Raitt and Shor near California and Hawaii, did the velocity of seismic waves within the mantle appear to be faster in an east-west direction than in a north-south one? The term is anisotropy, and measurement of this small difference with any reasonable precision requires an elaborate pattern of shooting and receiving, such that observations are distributed over at least one-half the arc of a circle 30 miles in radius. Returning to the field, Russ and George developed a field protocol using three ships to provide two simultaneous observing points for a single line of shots. With those, they could work with time differences rather than absolute travel times. The definitive experiment that finally proved the existence of anisotropy of seismic velocity in the mantle involved four ships and five telemetering buoys on SHOW Expedition in 1966. The ships were from Scripps, Hawaii, Oregon State, and Wisconsin, and the scientists included Gerald Morris, Russ's graduate student. The SHOW Expedition results clearly demonstrated azimuthal anisotropy in mantle velocities. Later Russ and his associates showed that this condition was probably universal in the Pacific at least, with the high-velocity vector in the direction of seafloor spreading. Others demonstrated theoretically that this could be caused by the alignment of olivine crystals during mantle cooling. The seismic anisotropy work was described by Bob Dietz as "the most important marine geophysical experiment of the decade."

Russ was still pursuing the anisotropy on Scan Expedition in 1969 when he broke his leg while boarding a longboat after a visit on the fabled island of Pitcairn. Gerald Morris completed the scientific program of that expedition after Russ was airlifted to Tahiti (Raitt, Shor, Francis, and Morris 1969). And, as always, the data were catalogued and stored by Duffy McGowan in Sverdrup Hall at Scripps, where Russ could find them after his leg mended. During his career, many of Russ's seismic results were unpublished by him, but he kept such detailed field notes that others were able to use the results to good effect. For instance Spudich and Orcutt (1980) used a line that Russ had shot two decades earlier to delve much further into the petrology and physical properties of the oceanic crust.

The cost of mobilizing four ships to share the same piece of ocean was enormous, but even the cost of employing two ships was high. To stretch research dollars, Russ and other MPL scientists began using various versions of sonobuoys to receive acoustic energy and transmit data back to the shooting ship. Sonobuoys were cheap, especially because Russ and George Shor could persuade the U. S. Navy to give them away for free, permitting two ships' worth of data to be collected by one. A problem with sonobuoys, however, was their limited radio range—they were designed to transmit to airplanes looking for submarines, so their VHF radios only operated within line-of-sight. Obviously longer lines-of-sight were needed, and getting the sonobuoy antenna far above the ocean surface was one way to accomplish this. As if to prove that four ships sharing one patch of ocean was not chaos enough, the MPL crew designed an improved sonobuoy whose launch was a four-ringed circus: (1) a helium balloon to lift the antenna, (2) the sonobuoy, floating in the ocean, (3)

the hydrophone, about 60 meters below sea level, floating neutrally buoyant, and (4) an anchor on the seafloor, to keep the balloon from dragging the buoy across the Pacific Ocean.

In the 1970s, Russell Raitt was a leader in moving the Scripps geophysical community into the digital era. A major project was the creation of a towed hydrophone array, and with the data recorded digitally on a PDP-8 computer, much more detail could be observed in the records, especially in second and third arrivals, whose signals were superimposed on the codas of the easily observed first arrivals. Russ wrote much of the software that manipulated the new data, including programs named TUNE and SKIN. Many a grad student wondered what these names had to do with seismic refraction, until they picked up the deck of IBM punched cards to run them through the IBM-1800 computer. Because Russ's programs were written in FORTRAN, the top card was //FOR followed by the program name. Who says that computer nerds don't enjoy puns?

Dancing during one of the parties at Russ's house included (from left) Martha Stallard, Larry Lawver, Annette Coles, Russ Raitt, and Jehanne Teilhet.

Russ was always modest in his accomplishments. Perhaps because his next door neighbor on Ellentown Road was the world-famous Jonas Salk, he saw no point in name-dropping. One day at the office, associate Helen Kirk had an esoteric question about some technique that Russ had developed. Russ in his usual way bumbled around and said he had a letter in his file somewhere that exactly addressed Helen's question. He pulled it out and handed it to Helen who read, "Dearest Russ:," then text that precisely dealt with Helen's question and the letter was signed, "Fondest regards, Al." Of course, "Al" was Albert Einstein. Russ probably met him at Caltech in the early 1930s, but few at Scripps had known of their friendship.

Besides enjoying going to sea, Russ always loved to travel, and he combined these pleasures at every opportunity, and included many tropical isles in his journeys. Russ and Helen had especially strong ties to Tonga, founding Tofua Press, originally a vehicle for publishing bilingual Tongan/English books and, for many years traveling to and maintaining close friendships with their Tongan friends. Another of Russ's loves was freeform dancing. Following the accident on Pitcairn, his physician suggested that the 62-year-old Russ take up dancing as a rehabilitation exercise. We imagine that the physician was thinking of ballroom dancing, but Russ of course heard "The Monkey," "The Swim," and countless other gyrations that were in vogue among youths one-third his age. Parties (including at least two weddings) at the Raitt home overlooking Black's Beach typically ended in the wee hours of the morning, with Russ wondering why everyone was leaving exhausted.

Helen's death in the spring of 1976 was a shock to the Scripps community. On three days notice, four hundred people showed up at 2424 Ellentown Road to pay tribute to Helen with food, wine, and camaraderie. She would have approved. Despite the loss, Russ continued to be an active scientist, still going to sea. In fact, his next birthday was probably his longest. After a month in the Banda Sea in eastern Indonesia, Leg 8 of the INDOPAC expedition ended in Guam early in the morning of the 30th September 1976. Following the usual rapid unloading of R/V *Thomas Washington*, Russ and most of the rest of the scientific party embarked on the overnight flight to Honolulu. When they arrived, having crossed the dateline, it was still the 30th, and still Russ's birthday, so he remained in Hawaii for a few days to celebrate.

In the 1970s, Russ took a number of extended trips to Florence, Italy, where he stayed in an apartment that Mirella Belshé had inherited from her mother. Russ and Helen's house and garden were filled with Mirella's sculptures and paintings. In Italy it was thought better to let an apartment to a friend than through the open market because once a tenant got into an apartment it was often impossible to get them out even if they stopped paying rent. So while Russ was doing Mirella a favor, he studied art in Florence and became enthralled with the graphics work of Bridget Riley who did color-form minimalist paintings. Russ pioneered—with the help of the Scripps computer facility—writing programs to produce Bridget Riley-esque works of computer art. After he retired he could often be found in the dining area of their fabulous house on the cliffs above the beach producing new works of art using pen plotters. In fact, his art work was one of his most important activities during the last twenty years of his life. Here was a true and meticulous scientist who transformed himself into an artist. Russ left a vast body of pioneering computer art, but just as he was self-effacing in his science he also refused to promote his art, which was some of the very earliest computer generated work.

In the late 1980s and early 1990s, Russ's house again was full of young people. This time Russ was surrounded at his dining room table by his grandson Ewen Harrison, who was attending UCSD, and Ewen's college friends, who all called Russ "Pépe" and loved his awesome rock and roll record collection and his interest and open mindedness about a prodigious number of subjects.

To his graduate students and those of others at MPL as well as to his colleagues at sea and ashore, Russ was a quietly inspiring model of what a richly informed, thoroughly decent scientist should be. Patient and kindly, Russ was a superb tutor and welcomed all questions from inquiring students. On the other hand he was a notoriously uncomfortable lecturer. Every so often, the powers that be at Scripps would insist that he teach a course. It was so clear that he did not want to lecture that it was difficult to sit through his course but if you went to his office with a question, he was a joy to listen to. He shared ideas, explanations, and skills most generously. Modest and painfully slow to publish even spectacular fundamental results, Russ did not seek the "medal and award" track. He welcomed students when approached, but avoided doctoral committee chairmanships. His students included Dick Phillips, who later taught at the University of San Diego, Don Helmberger, now professor at Russ's old school, Caltech, and Gerald Morris, who went on to the Naval Research Lab. He co-chaired the committee of John Orcutt, who became head of the Institute of Geophysics and Planetary Physics and who is still at Scripps. Friendly,

open, of wide curiosity, and with a shyly delightful sense of humor, Russ was welcomed everywhere, including on two early Soviet research cruises in 1971 and 1973. He was a frequent visitor to Teddy Bullard's lab at Madingley Rise and helped establish the "Cambridge Connection" that brought many Cambridge trained scientists, including Sir Teddy himself, to populate the ranks of marine geophysics at Scripps.

Russ passed away in the spring of 1995, at the age of 87. His memorial service at Scripps was attended by many who praised Russ's accomplishments as a scientist, as someone who reached out to the international community, and as a longtime La Jolla citizen. En route to this service, several attendees were startled when the elderly gent driving the shuttle van from the parking lot to Scripps shook hands and said, "Hi, glad you could come to Russ's service ... I'm Jonas Salk." Who else but the modest Russ Raitt, friend of Al Einstein, would have such a world-renowned scientist offer to drive a shuttle van at his memorial service?

In retrospect, to return to those early days at Caltech with his mentor Robert Millikan: three of Russ's fellow graduate students in that physics laboratory later became Nobel laureates. As Bob Fisher (1996) wrote: "Russell Raitt walked with giants, but they were in good company."

Acknowledgments

Much of this review was taken directly from an article by John G. Sclater and Elizabeth Shor that was written for the occasion of Russ's 80th birthday celebration (Shor, E. N., and Ebrahimi, C. L., eds., Marine Geophysics: A Navy Symposium, Marine Physical Laboratory Report No. MPL-U-42/87, Scripps Institution of Oceanography) and is used verbatim with their approval. Some of the material in that article was from a taped conversation among R. Raitt, G. Shor, and E. Shor on 30 October 1984, which is the source of quoted comments by Raitt. The Sclater and Shor article includes a bibliography of Russell Raitt's publications. This article also relies heavily on the memorial Bob Fisher wrote for *EOS* that appeared in v.77, no.47, 19 November 1996. Martha and Christopher Harrison have read and graciously contributed to this article.

References

Eyring, C. F., R. J. Christensen, and R. W. Raitt, 1948. Reverberation in the sea. *Journal of the Acoustical Society of America*, v.20. pp.462-475.

Fisher R. L., 1996. Russell W. Raitt (1907-1995). *EOS*, v.77, no.47. p.467.

Fisher, R. L., and R. W. Raitt, 1962. Topography and structure of the Peru-Chile Trench. *Deep-Sea Research*, v.9. pp.423-443.

Francis, T. J. G., and R. W. Raitt, 1967. Seismic refraction measurements in the southern Indian Ocean. *Journal of Geophysical Research*, v.72. pp.3015-3041.

Hess, H. H., 1962. History of ocean basins. In *Petrologic Studies: A volume to honor A. F. Buddington*, Engel, James, and Leonard (eds.). *Geological Society of America*. pp.599-620.

Raitt, R. W., 1948. Sound scatterers in the sea. *Journal of Marine Research*, v.7. pp.393-409.

Raitt, R. W., 1952. Geophysical measurements. *Symposium on Oceanographic Instrumentation*, Office of Naval Research. pp.70-84.

Raitt, R. W., 1954. Seismic refraction studies of Bikini and Kwajalein atolls. *U.S. Geological Survey Professional Paper 260-K*. pp.507-527.

Raitt, R. W., 1956. Seismic-refraction studies of the Pacific Ocean Basin, part I, Crustal thickness of the central equatorial Pacific. *Bulletin of the Geological Society of America*, v.67. pp.1623-1639.

Raitt, R. W., 1957. Seismic refraction studies of Eniwetok Atoll. *U.S. Geological Survey Professional Paper 260-S*. pp.685-698.

Raitt, R. W., 1963. The crustal rocks, In *The Sea, Ideas and Observations on Progress in the Study of the Seas*, M. N. Hill, (ed.), v.3. Interscience. pp.85-109.

Raitt, R .W., Fisher, R. L., and R. G. Mason, 1955. Tonga Trench. In *Crust of the Earth* (a symposium). A. Poldervaart, (ed.), *Geological Society of America Special Paper 62*. pp.237-254.

Raitt, R. W., G. G. Shor, Jr., T. J. G. Francis, and G. B. Morris, 1969. Anisotropy of the Pacific upper mantle. *Journal of Geophysical Research*, v.74. pp.3095-3109.

Sclater, J. G. and E. N. Shor, 1987. Forty years of oceanic research, and an appreciation of Russell W. Raitt and Victor Vacquier. In *Marine Geophysics: A Navy Symposium*, E. N. Shor and C. L. Ebrahimi (eds.). Marine Physical Laboratory Report No. MPL-U-42/87, Scripps Institution of Oceanography. pp.4-17.

Shor, G. G., Jr., 1963. Refraction and reflection techniques and procedure, In *The Sea, Ideas and Observations on Progress in the Study of the Seas*, M. N. Hill, (ed.), v.3, Interscience. pp.20-38.

Shor, G. G., Jr., H. W. Menard, and R. W. Raitt, 1971. Structure of the Pacific Basin. In *The Sea, Ideas and Observations on the Progress in the Study of the Seas*, A. E. Maxwell (ed.), v.4, part II, Wiley-Interscience. pp.3-27.

Shor, G. G., Jr., and R. W. Raitt. 1958a. Seismic studies in the southern California continental borderland. *Scripps Institution of Oceanography Reference* no.58-78. 19p.

Shor, G. G., Jr., and R. W. Raitt, 1958b. Seismic studies in the southern California continental borderland. *International Geological Congress*, 20th Session, Section 9, 2nd volume. pp.243-259.

Shor, G. G., Jr., R. W. Raitt, and D. D. McGowan, 1976. Seismic refraction studies in the southern California borderland, 1949-1974. *Scripps Institution of Oceanography Reference* no.76-13. 71pp.

Spudich, P. and J. Orcutt, 1980. Petrology and porosity of an oceanic crustal site: Results from wave form modeling of seismic refraction data. *Journal of Geophysical Research*, v.85. pp.1409-1433.

Vacquier, V., A. D. Raff, and R. E. Warren, 1961. Horizontal displacements in the floor of the northeastern Pacific Ocean. *Geological Society of America Bulletin*, v.72. pp.1251-1258.