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The Evolution of Geosciences at Scripps

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Immediately following World War II, the faculty and research staff at Scripps Institution of Oceanography, under the leadership of Director Roger Revelle, began to grow quickly to meet the new challenges of work beyond the immediate continental margin of southern California. By 1950, the geosciences group included, in geology, Revelle, Milton N. Bramlette, Francis P. Shepard, Fred B Phleger, and Douglas L. Inman; in geophysics, Carl H. Eckart, Walter H. Munk, and Russell W. Raitt; and in geochemistry, Edward D. Goldberg. Two geologists from the Naval Electronics Laboratory, Robert S. Dietz and Henry W. Menard, held appointments as lecturers.

The hallmark of Scripps research in the geosciences has been, from the beginning, cooperation among scientists with different special interests in designing and carrying out broadly based research programs so as to make the most effective use of Scripps ships. The various professorial and research titles were and are still treated as equivalent. Many scientists in the Research Series hold appointments as lecturers so they may participate in course instruction and in guidance of doctoral students. We are not a hierarchy, but a company of scholars.

In the following sketch of the evolution of the geosciences at Scripps since 1950, the contributions of individual Scripps scientists had to be greatly abbreviated, especially for those who have been here for decades, with only highlights mentioned. People who were here for only a few years and have long ago gone elsewhere are not included in this brief review.

The 1950s

At the beginning of the 1950s, Revelle, eager to launch the institution further into the truly oceanic realm, organized, with the cooperation of the Naval Electronics Laboratory, the MidPac Expedition whose main objective was to study the set of submerged flat-topped volcanic seamounts—guyots—noted in wartime surveys (Figures 1 and 2). Besides Revelle, Raitt, and Menard, the expedition included a doctoral candidate from Stanford University, Edwin L. Hamilton, whose 1956 publication summarizes the expedition findings. They documented an enormous set of undersea chains of guyots and connecting ridges, some 2,500 km long. From the guyot summits, at depths of about 1,500 m, the expedition dredged shallow-water Cretaceous fossils, about 100–120 million years old, thereby demonstrating not only substantial subsidence of the volcanic foundations, but showing also that these volcanoes could not be ancient Precambrian features, the ruling theory of the time for the permanence of ocean basins and continents. In short, they found that the oceans must be relatively young. The implications of this finding drove the science of marine geology to seek a mechanism to explain this youthfulness, leading finally, 15 years later, to the theory of seafloor spreading and plate tectonics.

During the 1950s, Scripps was under the academic jurisdiction of the University of California, Los Angeles Academic Senate. Courses were offered, both at the undergraduate and graduate level, although all students were in fact doctoral students. Two degrees were offered: oceanography and marine biology. The "big four" undergraduate courses (Physical Oceanography, Submarine Geology, Biology of the Sea, and Chemistry of Sea Water), which most students were urged to take, assured an integrated approach to oceanography. Most students were expected to participate in seagoing expeditions in order to learn how to make observations at sea while making effective use of research vessels. The emphasis was always to involve the students early on in the research enterprise of the institution. Recognizing the special strengths of the geology group at Scripps in the early 1950s, the Research Committee of the American Petroleum Institute awarded the institution a contract (API-51) to study the continental shelf of the Gulf of Mexico—a major repository of oil and gas. The purpose of the project was to understand the dynamics of sediment transport and deposition on the shelf, which would serve as a guide to continental margin sedimentation in general. The project was later expanded to include the Gulf of California. In 1956, Tjeerd Van Andel, a broadly experienced sedimentologist, was recruited to help manage API-51, which engaged the attention of Phleger and Shepard as well as a host of graduate students and post-doctoral students for nearly a decade.

Throughout the 1950s, Scripps, largely funded by the Office of Naval Research (ONR), continued to mount major oceanographic expeditions with important geoscience components, criss-crossing the Pacific to obtain cores, especially of older Cenozoic sediments

Figure 1. Scripps graduate student Arthur E. Maxwell with temperature probe during the MidPac Expedition.

Figure 2. Artist's conception of the Mid-Pacific Mountains if the Pacific Ocean were drained away. Painting was commissioned by Edwin L. Hamilton of the U.S. Navy Electronics Laboratory.

that lay close to the seafloor. These cores could be dated by the team of micropaleontologists that had assembled at Scripps: Bramlette (calcareous nannofossils), Phleger and Parker (foraminifers), and William Riedel (radiolarians), who was later joined by Annika Sanfilippo. At this time, Gustaf Arrhenius, who had studied the equatorial pelagic sediments from the Swedish Deep Sea Expedition, posed the question of whether the alternations of more and less calcareous layers reflected glacial-interglacial changes in surface productivity in deep-water carbonate dissolution. At Scripps, Arrhenius turned his attention to the origin of the manganese nodules and minor minerals in pelagic sediments. Fisher focused on the deep-sea trenches that rim the Pacific, not merely charting their depths but dredging basement rocks from their steep seaward slopes. The expeditions outlined the great East Pacific Rise that extends from near the mouth of the Gulf of California southward in a great arc that exits the Pacific between Australia and Antarctica, and documented its high heat flow. Other expeditions under Menard's leadership mapped out some of the major tectonic fracture zones that extend for thousands of kilometers outward from the East Pacific Rise. Seismic refraction studies by Raitt had established the thickness of oceanic crust above the mantle to be generally less than about 7.5 km. Thus, the major elements of plate tectonics were being charted to the extent that when the magnetic picture was added, the plate tectonic theory could be applied.

That magnetic picture was in fact being put together by a group from Scripps, working with the newly perfected flux-gate magnetometer devised by Victor Vacquier, who had joined Scripps in 1958. His associates, Ronald Mason and Art Raff, made a very detailed magnetic survey of a part of the northeast Pacific off Oregon and Washington, delineating a startling pattern of parallel magnetic anomalies, offset by fracture zones. Similar surveys by the British in the North Atlantic showed similar lineations and clear symmetry in a pattern across the Mid-Atlantic Ridge, a symmetry present in the Pacific data set, but unrecognized at first. The two data sets, when taken together with new data on the age of reversals of the earth's magnetic field in lavas on Iceland and Hawaii, formed the foundations of the theory of seafloor spreading. The magnetic data,

***Figure 3.** Scripps geoscientist Robert Fisher with Captain Lumanaw of the Naval Hydrographic Service aboard R/V* Argo.

combined with evidence of zones of shallow earthquakes concentrated along the East Pacific Rise and the Mid-Atlantic Ridge, and of zones of deep earthquakes concentrated at the oceanic trenches, led to the hypothesis of plate tectonics.

Beginning in the late 1950s, as the new San Diego campus of the University of California was beginning to develop, the Department of Earth Sciences was organized and housed at Scripps, and consisted of a subset of Scripps faculty members with both undergraduate and graduate teaching responsibilities. New faculty were recruited and graduate students enrolled. The experiment lasted only a half-dozen years before the fledgling department was dissolved and its members melded, along with Oceanography and Marine Biology Departments, into a single Department of Scripps, still offering three doctoral degrees. The undergraduate program was continued as an earth science specialization in the Departments of Chemistry and Physics, taught by Scripps faculty. In more recent years, an earth sciences undergraduate major was restored.

Among the faculty recruited for earth sciences were several geochemists and igneous petrologists, who substantially expanded Scripps's efforts to understand the nature of the oceanic crust and volcanoes in and around the ocean basins. Albert and Celeste Engel, on the basis of their chemical analyses of crustal rocks newly dredged from the deep Pacific, Atlantic, and Indian oceans, showed the astonishing uniformity in the composition of these rocks—mid-ocean ridge basalts (MORB)—in contrast to the enormous compositional variety in rocks from volcanic islands, suggesting a global uniformity in processes of ocean crustal formation. The research on trenches and island arcs initiated by Fisher was expanded by James Hawkins, who has worked on the petrologic and tectonic development of backarc basins.

The 1960s

During the first half of the 1960s, Scripps scientists and ships were heavily engaged in the exploration of the Indian Ocean, as part of the multinational Indian Ocean Expedition. Three major cruises, Lusiad, Dodo, and Monsoon, coordinated by Fisher, and using both *Horizon* and a newly acquired converted Navy salvage vessel, *Argo*, spent nearly two years gathering geological, geochemical, and geophysical data in what had been previously virtually unknown territory (Figure 3). Joseph Curray began his own studies in the Indian Ocean in the '70s, focusing on the very thick sediments of the Bengal deep-sea fan, which houses much of the debris from the erosion of the Himalayas. These studies led him to a general synthesis of the plate tectonic history of the collision between the Indian subcontinent and Asia, which raised the Himalayas and Tibetan Plateau.

During the late 1960s, the largest earth science project ever realized, the Deep Sea Drilling Project (DSDP), got under way, with the prime contract going to Scripps. It was originally Project Mohole, an attempt

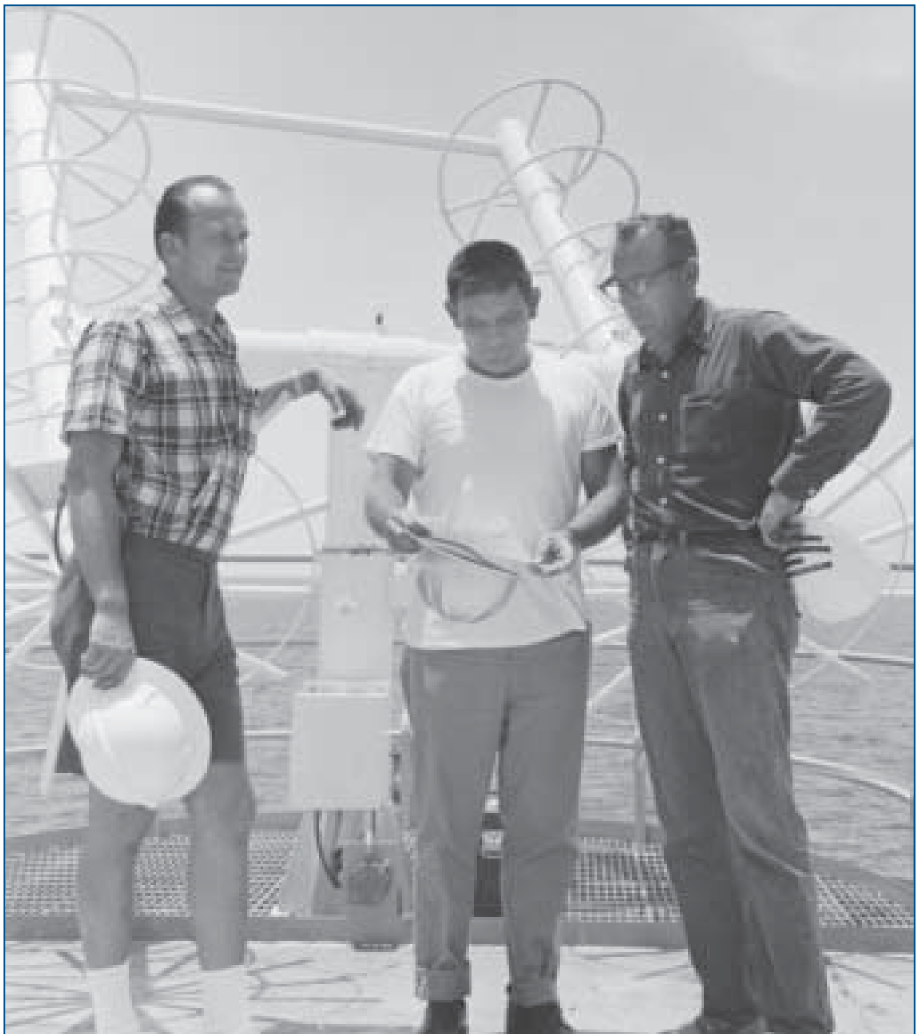

Figure 4. Left to right, Melvin N.A. Peterson, DSDP chief scientist; Kenneth E. Brunot, DSDP project manager; and William A. Nierenberg, Scripps Institution of Oceanography director and DSDP principal investigator.

to drill through the ocean crust (5 km of water and 5 km of basalt) to the major seismic discontinuity believed to mark the top of the earth's mantle. Mohole fell victim to insurmountable technical and political problems, later transformed into the 18-month DSDP with the goal of coring through the sediments on the ocean floor, dating all the layers and testing the seafloor spreading hypothesis based on magnetic data that predicted the age of the basaltic basement beneath the magnetic anomalies. Scripps set about acquiring a drill vessel (*Glomar Challenger*) and an experienced drilling contractor (Global Marine, Inc.), and recruited staff scientists, engineers, and technicians. Scripps mineralogist Mel Peterson was appointed chief scientist (Figure 4). Choosing of drill targets was left to a multi-institutional advisory structure (the Joint Oceanographic Institutions for Deep Earth Sampling), and financing came from the National Science Foundation (NSF).

After 18 months the success of the project was indisputable, and continues to this day, under other titles, 45 years later. Scripps managed the project for about 15 years, an interval during which, as a result of drilling knowledge of the ocean floor and its history increased by an order of magnitude. Seafloor spreading was proved, paleoceanography invented, paleontologic dating of sediments refined to ±20,000 years (from about ±1 million years), the upper few km of oceanic crust sampled, and both passive and active continental margins explored with the drill. Into the drilled holes went downhole observatories, measuring temperature, seismic activity and fluid flow. Scripps scientists participated from the outset, often as cochief scientists and continue to utilize the newer drill ship, *JOIDES Resolution*, today most two-month drilling legs have at least one Scripps scientist aboard.

The drilling results, combined with data from cores taken on conventional expeditions, have been exploited by a group of Scripps paleoceanographers interested in understanding conditions in oceans of the past: temperature, oxygen and carbonate-dissolution profiles, circulation patterns, biogeography, and productivity. Wolf Berger has led in this program, and more recent recruits, Chris Charles and Richard Norris, have significantly broadened these efforts.

From the 1970s Onward

From the 1970s onward, geosciences expanded and diversified rapidly, especially in geochemistry. Miriam Kastner established a laboratory in experimental low-temperature geochemistry, successfully investigating the origin of chert, dolomite, and, most recently, the formation and long-term fate of gas hydrates. Ray Weiss developed deep-sea instrument packages for long-term monitoring of chemical fluxes, and now is exploiting methane as a tracer for water masses. Harmon Craig advanced his pioneering work on stable isotopes of oxygen and carbon, and developed a broad-ranging study of the helium isotope Helium-3, which he hypothesized was brought to the earth's surface by narrow plumes arising from near the core-mantle boundary. David Hilton is studying the gases vented from volcanoes, especially carbon dioxide and neon. J.

Douglas Macdougall, Gunter W. Lugmair, and Alexander Shukolyukov have studied the composition and origin of lunar and meteoritic materials by using isotopic methods, and Macdougall has applied these techniques to the study of oceanic volcanic rocks. Devendra Lal, a nuclear geophysicist, has been using natural nuclear processes to understand physical and chemical processes (e.g., dating of exposed surfaces by using the radioisotopic products of cosmic-ray bombardment). Two Scripps geoscientists, Martin Wahlen and Jeff Severinghaus, have been using ice cores from Greenland and Antarctica to study annual changes in temperature and atmospheric composition over past millennia.

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The research interests of the geochemists from early on have had strong environmental significance. Charles D. Keeling has for more than 40 years monitored with great precision and accuracy the steep rise in the atmospheric greenhouse gas carbon dioxide. Additionally, Ed Goldberg, besides his definitive studies on the distribution of clay minerals on the ocean floor, has led in studies of various potentially toxic compounds being dumped into the sea.

Regional problems of topical importance have been the focus of work by James W. Hawkins, who is engaged in long-term tectonic and petrologic studies of the western Pacific island arcs, backarc basins, and oceanic islands, and by Pat Castillo, who has worked on the petrology of both oceanic basalts on seamounts and plateaus, and on the rocks of island arcs, especially in the Philippines. Hubert H. Staudigel (now at the Cecil H. and Ida M. Green Institute of Geophysics and Planetary Physics [IGPP] at Scripps) has worked on the petrology of volcanic seamounts and islands. I have undertaken other seamount studies in an attempt to understand the origin of Mesozoic guyots (the old Midpac problems) and the origin of seamount chains (mantle plumes vs. stress-induced cracks). I have also put years of effort into comparative studies between oceanic pelagic sediments drilled and cored in the actual oceans and Mesozoic pelagic sediments exposed in the Alps. I am currently finishing studies of the origin of modern atolls and of barrier reefs, emphasizing the role of dissolution during sea-level lowstands in creating lagoons. Jacqueline Mamerickx systematically exploited the network of soundings to construct a set of bathymetric charts covering the entire Pacific and to interpret the morphology of the seafloor in terms of plate tectonics. Neal Driscoll has focused his efforts mainly on the sedimentology and stratigraphy of continental margin sediments, as part of his overall studies of the sedimentary source-to-sink system. Jeremy Jackson, who studied the reefs and shallow-water fauna of the Neogene in the Caribbean for many years while at the Smithsonian Smithsonian Tropical Research Institute in Panama, has been studying the precipitous drop in the abundance of large (mainly edible) marine animals in the Caribbean since the arrival of the first Europeans.

Seismology has a long history at Scripps, beginning with Raitt's work in the 1950s. Much of this earlier work was housed in the Geosciences Research Division (GRD), but in past few decades some GRD scientists have moved to IGPP (including John A. Orcutt and James Brune. Leroy Dorman's research interests are in the seismic structure of the seafloor, using ocean-bottom seismometers (OBS) of his own design. Kevin Brown, whose interest is in fluid flow in sediments and rocks, has exploited Dorman's OBS units by attaching flowmeters to them that monitor flow into and out of the seabed. He has devised ways to measure hydrologic conditions in drill holes, aiming toward understanding the so-called seismogenic zone in subduction zones. John Sclater has continued his long-term investigations of heat flow through the ocean floor and plate tectonics in the Indian Ocean.

Earth magnetism/paleomagnetism has been a growing discipline at Scripps in recent years. Steven C. Cande has used magnetic anomaly patterns to help unravel the plate tectonic history of a large part of the southwestern Pacific and has also discovered that the small-scale "tiny wiggles" in magnetic profiles correlate from one place to another. He and Jeffrey Gee have shown that they are very probably due to variations in magnetic intensity. Lisa Tauxe's interest in the behavior of the geomagnetic field has led her and Gee to make detailed investigations of paleointensities and of the magnetic behavior of minerals under changing conditions.

Since the 1970s, two developments have changed the way Scripps geoscientists use ships. From 1995 to about 1980, while ONR and NSF were both providing substantial ship-time money, we were able to organize long, integrated expeditions on Scripps ships, with Scripps people on every leg. The precipitous drop in ONR support, beginning in the 1980s, and the emphasis by NSF on highly focused, short (one month) self-contained expeditions, when added to the scheduling flexibility introduced by the national coordination of ships' schedules and tracks (through University-National Oceanographic Laboratory System), has meant that in some years Scripps vessels have full schedules, but no Scripps scientists. Meanwhile Scripps people are using other institutions' ships, including, of course, the drilling ship. The former degree of institutional unity and coordination is diminished if not lost, and although Scripps "Ancient Mariners" may get nostalgic, excellent science still gets done.