Geophysics and Planetary Science at Caltech

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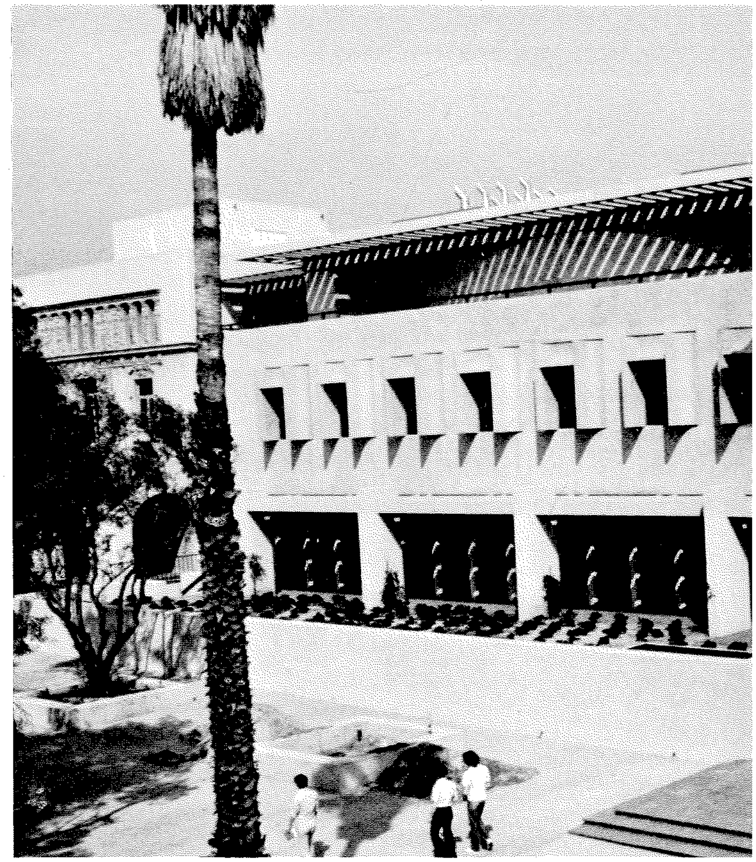


The opening of the Seeley G. Mudd Building of Geophysics and Planetary Science is a notable milestone in the development of the Division of Geological and Planetary Sciences, and is an occasion calling special attention to the research and teaching in geophysics and planetary science at Caltech. This issue of *Engineering and Science* offers a collection of views of these activities, described by faculty members who are taking up their academic residence in the new building.

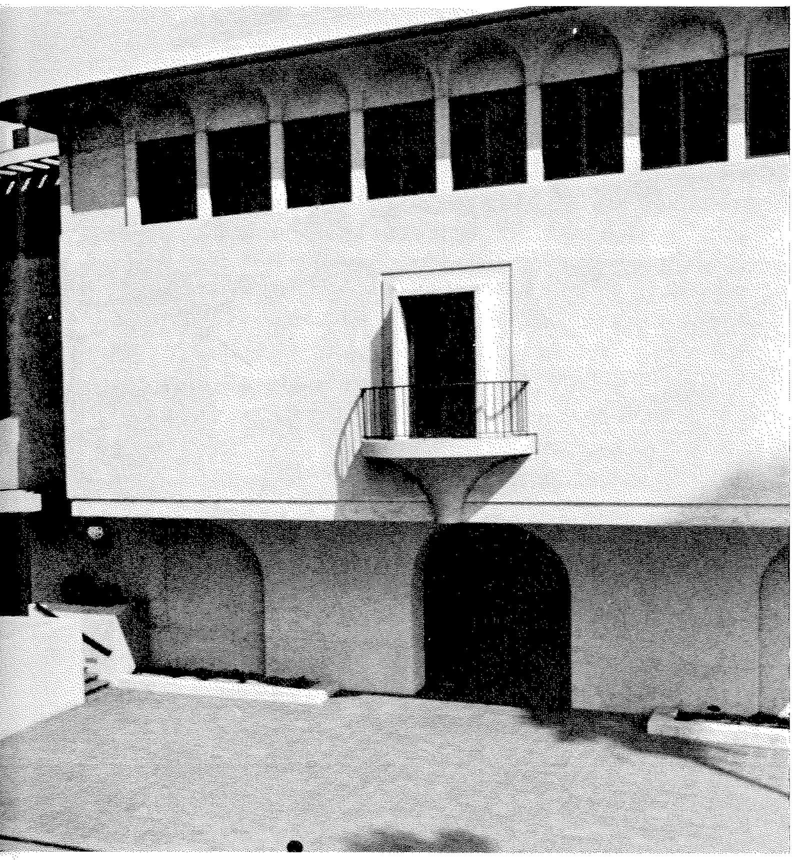
The disciplines of geophysics and planetary science have very different origins and histories at Caltech. In many ways their interests are opposite—geophysics looking inward to the earth's interior, planetary science outward to other worlds. And yet they also have much in common, and their mutual interests are certainly growing.

Geophysics as an academic discipline at Caltech dates from shortly after the inception of the Division of Geology and Paleontology in 1926. It began in earnest with the arrival in 1930 of Caltech's first professor of geophysics, Beno Gutenberg. The subsequent transfer of the Carnegie Institution's Seismological Research Laboratory to Caltech as part of the geology division, and the addition to the faculty of Charles Richter and Hugo Benioff, created a center of seismological research at Caltech that was soon renowned throughout the world.

Although formal courses in geophysics were taught on the campus, the research was conducted from the start at the Seismological Laboratory located in the hills to the west, where the seismographs could be placed on bedrock. This physical separation and a variety of other factors contributed to the development of rather independent traditions, styles, and loyalties among the groups in geophysics and geology. However, several field research projects were carried out jointly by John Buwalda and Beno Gutenberg and their students, notably geophysical explorations of the floor of Yosemite Valley, the Frazier Mountain thrust, and the Beartooth thrust in Wyoming.

The substantially expanded research program in geophysics that developed under the leadership of Frank Press in the fifties, and flowered in the augmented facilities of the Seismological Laboratory at the adjacent Donnelley Building, set the tone and style of seismology as we now know it at Caltech, and cultivated an attractive *esprit de corps* among faculty and graduate students that continues to this day. When at the same time the geology group on campus began to branch out into new research areas with strong emphasis on underlying physics and chemistry—geochemistry, for example—the possibilities for productive interchange between the geology and geophysics groups increased decidedly.

The physical separation continued, but Clarence Allen, whose early base was largely on the campus, pointed the way to closer ties by developing a close association with the Laboratory, and he eventually served two years as its acting director. The attractive research atmosphere and well-developed traditions of the Lab are enthusiastically maintained by its current director, Don Anderson, whose



"South Mudd"—
Caltech's new Seeley G. Mudd Building of Geophysics and Planetary Science flanks the existing Seeley W. Mudd Laboratory of the Geological Sciences—now known as "North Mudd."

broad interests have been instrumental in stimulating a number of new areas of research.

Planetary science is by contrast a very recent addition to the division, reflected in the change of the division's name to its current form in 1970. It grew out of the great scientific development that accompanied the space program. Especially because of its association with JPL, Caltech realized early in this development that it should help to provide the new studies of the solar system with solid academic foundations. The geology division foresaw in the impending growth of information about the planets an opportunity to gain greater insight into the earth, and it believed conversely that our understanding of the earth would be helpful in interpreting new data on the other planets. It therefore began to build a faculty that could pursue planetary science with these possibilities in mind, and that could thus interact fruitfully with the rest of the division.

We did not realize at first how far afield in science this would in fact lead us, or how greatly the scientific bandwidth of the division would be increased. Most of the new faculty members in planetary science have backgrounds, orientations, and interests quite divergent from those traditional in the division, and the boundary line has become somewhat shadowy here between our division and the Division of Physics, Mathematics and Astronomy, where several important kinds of planetary research are also carried out. Nevertheless, our new group in planetary science developed a good rapport with the rest of the division, functioning from the beginning as an integral part of it.

Perhaps this is due partly to the fact that much of the division plunged eagerly into lunar science as the Apollo program unfolded. The external features of the planets, observed from spacecraft, needed to be understood in terms of the internal structure of these bodies, and this opened an important area of common interest between planetary scientists and geophysicists, since ideas and techniques developed for studying the internal structure of the earth could be applied to the planets in general. Another example of common interests is the planned Viking 1975 landing mission to Mars, for which the geophysicists are providing a seismometer that will be able to give positive proof of the internal activity that was deduced by planetary scientists from observations of the planet's surface.

By the mid-sixties it was becoming apparent that research activities in geophysics were overflowing the available space in the Seismological Laboratory, and that development of planetary science was being hampered by insufficient facilities on the campus. At the same time, the disadvantages in the location of the Seismological Laboratory off campus were becoming more keenly felt. The idea of solving these problems and opening up new opportunities for geophysics and planetary science at Caltech by creating a new building on the campus germinated during Robert Sharp's chairmanship of the division and was successfully implemented under the chairmanship of Eugene Shoemaker. Achievement of the new building stems directly from the generosity of several donors. Initiation of the project was made possible by a large gift from the family of Dr. Seeley G. Mudd, long a friend of the Institute, and by a matching grant from the U.S. Department of Health, Education, and Welfare, because of the public-service contributions of the Seismological Laboratory in providing earthquake information.

The Mudd gift was the key to undertaking the project, and the building is named in honor of Dr. Mudd. It gives handsome testimony to the generosity that his family has shown to Caltech over the years, complementing prominently the existing Seeley W. Mudd Laboratory of the Geological Sciences, which has housed a good part of the division since 1938. These two beautiful buildings stand side by side facing Wilson Avenue on the west side of the campus and are connected at two levels. To distinguish them easily by name, we are informally calling the Seeley W. Mudd Laboratory "North Mudd" and the new Seeley G. Mudd Building "South Mudd."

As detailed planning for the new building revealed the many special features needed for the operations of the Seismological Laboratory and planetary science, it became apparent that the project was so extensive and complex that some of them could not be included without additional gifts. We were very fortunate in appealing to the generosity of several donors in support of these special needs: Mrs. Roland W. Lindhurst for the Laboratory of Experimental Geophysics, Mr. Ross McCollum for the Space Photography Library, Mr. Henry Salvatori for the divisional Seminar Room, and the Kresge Foundation for matching funds for these and other special laboratories.

To the donors, the Division of Geological and Planetary Sciences extends its very special thanks. They have made possible the beginning of a new era in the scientific life of the division and the Institute. To the Institute administration and to many of the division faculty who contributed to the project in numerous ways, to the architects who designed the building, and the contractor and workmen who built it—to all of these the division also owes a debt of gratitude. Our debt is especially great to Clarence Allen, who from the beginning and throughout the project carried the prime responsibility on behalf of the faculty for working out an attractive design to meet our numerous special requirements, and for watchfully following it through to completion. Many of the basic concepts in the building, and many novel and pleasing details, are due to his efforts.

What can we expect of geophysics and planetary science in the years to come? We can get an idea from the facilities provided in the new building.

For geophysics, which largely occupies the south wing, there is of course office space for faculty, students, and staff, and in addition an extensive complex of instrument rooms, work room, computers, seismogram library facilities, instrument and machine shops, and a special outfitting area for preparing seismic equipment for the field. The work in these facilities represents the heart of the Seismological Laboratory's operations in monitoring and interpreting earthquake activity in southern California and throughout the world, and in deciphering the internal structure of the earth from the propagation of seismic waves.

Other special laboratories such as the Helen and Roland W. Lindhurst Laboratory of Experimental Geophysics, laser Raman scattering laboratory, high-pressure laboratory, and X-ray laboratory represent new directions of research in geophysics aimed at understanding the properties of rocks and minerals at the high pressures and temperatures of the earth's interior.

The Gutenberg Library and Benioff Conference Room will provide the focal point for the frequent small, informal seminars and scientific "bull sessions," so stimulating to intellectual ferment and new ideas, that are one of the characteristic ingredients of the research atmosphere in the Seismological Laboratory.

For planetary science, which is mostly housed in the north wing, there are comparatively fewer special laboratories in the building because much of the work is theoretical or utilizes observational facilities away from the campus, such as optical and radio telescopes and spacecraft. Many of the observing instruments are developed here, however, so there are special optics and electronics laboratories.

The McCollum Library will house an extensive collection of spacecraft photographs of the planets, and will have special information-retrieval equipment for displaying the photographs and facilitating their selection and study. And a super-clean geochemical laboratory for studies of lead, uranium, and thorium in lunar samples testifies to the mutual interest of planetary scientists and geologists in studying the planetary bodies of the solar system.

For the division as a whole, the new building provides the Salvatori Seminar Room, which will be used as the gathering place for our division-wide seminars. Above all, the building creates a new proximity of geophysics, planetary science, and geology that will encourage increased interaction among them and will, we hope, lead to valuable new joint ventures in research and teaching.

A quick look at the interests of the faculty who are now located in the new building will give a good idea of what geophysics and planetary science at Caltech are all about, and where they are going.

In geophysics we have Professors Clarence Allen, Tom Ahrens, Don Anderson, Charles Archambeau, David Harkrider, Don Helmberger, and Hiroo Kanamori. Allen is an authority on faulting and seismicity throughout the world, and takes the lead in guiding the work of Caltech's network of seismograph stations in southern California. Much of the Lab's extensive work on the mechanism and seismic effects of the 1971 San Fernando earthquake was done under his leadership. He strives to relate the research in seismology to the practical concerns of earthquake engineering, and he is often called upon for expert advice by government agencies.

Ahrens studies the properties of rocks and minerals under ultrahigh-pressure shock waves, in order to understand the interior of the earth and planets. He also uses experimentally produced shock metamorphism as a tool for interpreting shock effects in lunar rocks.

Anderson's broad interests extend from classical seismology to the internal structure, thermal history, and origin of the planets. His theoretical interpretations in combination with Ahrens's experimental work promise to yield a definitive understanding of the phase structure deep within the earth's mantle.

Archambeau, Harkrider, and Helmberger analyze and interpret the propagation of seismic waves in the earth. Archambeau is particularly concerned with the generation of seismic waves by fault motions, with distinguishing between the seismic radiation from earthquakes and explosions, and with the use of finite-element analysis to study tectonic processes.

Harkrider concentrates on the analysis of surface-wave propagation and its coupling with air waves and tsunami waves. He is taking the lead in developing an on-line digital computing system for recognizing automatically the seismic signals from earthquakes the moment they are received at the Lab, and for determining earthquake locations immediately.

Helmberger's attention is focused on interpreting the earth's body waves by sophisticated computational methods that allow the complete wave-form of the seismogram to be generated synthetically and thereby used in deducing the earth's internal structure. He is also using these techniques to understand the strong ground motions that occur near the epicenter of an earthquake.

Kanamori's interests include many aspects of seismology, especially the earth's free oscillations and the structure of the crust and mantle, and also gravity, geothermal heat flow, and high-pressure physics. He is currently studying the possibilities of earthquake prediction, a vitally active field in which Clarence Allen, Don Anderson, and senior research fellow James Whitcomb are also participating. Many of the studies impinge on major questions of continental drift and lithospheric plate motion that are of central interest today in geophysics and, indeed, in the division as a whole.

The group in planetary science consists of Professors Peter Goldreich, Andrew Ingersoll, Duane Muhleman, Bruce Murray, and James Westphal. Goldreich studies the dynamics of planetary systems, particularly the way in which the rotational spins of the planets are coupled to their orbital motions around the sun, the changes in these motions with time, the gravity fields of planets, and the processes by which the planets could grow by accretion from an original solar nebula. He discovered the explanation of how radio emission from Jupiter is modulated by the planet's satellites. He also studies far-flung astrophysical problems such as neutron stars, pulsars (to which he applied earthquake concepts), and interstellar masers.

Ingersoll's primary interest is the dynamics of planetary atmospheres—for example, the motions associated with Jupiter's cloud bands and red spot, and the existence of instabilities in atmospheric motions. He analyzed the "runaway greenhouse" effect in Venus's atmosphere, and he has been active in a scientific controversy over the effect of disturbances in the sun's atmosphere on measurements of the sun's shape (oblateness), which has important implications as a test of the general theory of relativity. He has participated effectively in teaching freshman physics and a joint geology-engineering course in atmospheric science.

Muhleman uses the radio telescopes of Caltech's Owens Valley Radio Observatory to measure radio and microwave emission from the planets, which can be used to infer temperatures at or beneath the planet's surface or in its atmosphere, to estimate the planet's magnetic field, to detect lightning discharges or similar electrical effects (as on Jupiter), and to deduce planetary atmospheric pressures and compositions.

Murray's focus is the use of spacecraft photographs for exploration and interpretation of planetary surfaces. He is playing a leading role in learning about Mars, Venus, and Mercury from the photographs obtained in the Mariner missions.

Westphal is using new techniques of ground-based telescopic observation in infrared and visible light to increase our knowledge of planetary surfaces and atmospheres, and is also applying these powerful techniques to observing pulsars and distant clusters of galaxies.

A number of these topics are discussed by the faculty themselves in the following articles, which give by far the best idea of the flavor and vigor of geophysics and planetary science at Caltech.

What does it all add up to? In geophysics—a vigorous attack on the structure of the earth's interior and on the mechanisms of its internal activity, especially earthquakes. In planetary science—an endeavor to understand the variety of planetary structures and environments in a comprehensive way that will shed light on the evolution of the entire solar system and on the earth in particular. As we begin to pursue these broad and fascinating subjects in the new Seeley G. Mudd Building of Geophysics and Planetary Science, we can be sure, I think, that the research and teaching will more than ever live up to the motto "*labor bonus et multus*" that appears on the division's seal—good work and lots of it! □