

# Geophysics—an overview

The practitioners of this rich and varied field, which transcends the boundaries dividing scientific disciplines and national interests, have a unique opportunity to serve society.

Athelstan F. Spilhaus Jr

Understanding the Earth and its environment in space is a broad challenge that has been accepted by a variety of physicists, chemists, mathematicians, engineers, geologists and biologists. While many of these studied aspects of geophysics at the graduate level, many others became geophysicists without being conscious of the transition. A physicist studying phase equilibria at high pressure learns one day that he is working with materials possibly similar to the composition of the interior of the Earth. As he works with geologists and geophysicists to develop models of what we have not yet sampled, he is continuously drawn by the fascination of Earth's secrets into a total commitment to geoscience, a commitment that will not change his tools or methods of research but will necessitate constant interaction with colleagues, in a variety of disciplines, who are addressing themselves to parts of the solution for the same problem. This need for collaboration among individuals, among disciplines and among countries is a fundamental characteristic of geophysics that in a sense sets it above the basic sciences and gives it a unique flavor of excitement through accomplishment even when progress appears stalled.

Drawing the line between those who are geophysicists and those who are not is at best difficult, as geophysicists are found in industrial and government positions and in university departments of all descriptions. A physicist may be trying to understand convective flow

within the Earth, the dynamics of the Earth's magnetosphere, or the emission of decimeter radiation from Jupiter. A chemist may be analyzing natural waters for pollutants, developing a crystal structure, or using isotopic distributions to determine the age of a rock. One mathematician may be developing models for the gravitational field of the Earth derived from satellite orbits or laser ranging to the Moon, while another applies himself to understanding oceanic or atmospheric circulation. They are all working in geophysics, and as the need for understanding the Earth—on which we must live for the foreseeable future—becomes more apparent to the public, many more will become involved in basic geophysical research; further legions will aid in the collection and evaluation of the data that will be necessary for maintaining adequate standards of air and water quality, for giving adequate warning of impending natural disasters, and for assisting in the identification and rational exploitation of our planet's natural resources.

The common threads that draw geophysicists together exist not in spite of the disciplinary diversity of geophysics but because of it. The small projects requiring multidisciplinary approaches are a microcosm of what is required to approach planetary-scale problems, in which the efforts of a myriad of individuals may combine. One excellent example of such a problem is earthquake prediction and control, discussed in detail later in this issue. Seismologists are at the heart of this work, principally because they have over many years collected data that can now yield new information. These

data are used by geodesists who relate occurrences to earth tides and polar wobble, by physicists and geologists who are interested in the mechanisms of rock failure or are studying the magnetic and electrical properties of rocks, hydrologists who are told that large dams may be the cause of microseismic activity, and even by oceanographers who must predict the arrival time and size of the tsunamis that occasionally accompany Pacific quakes.

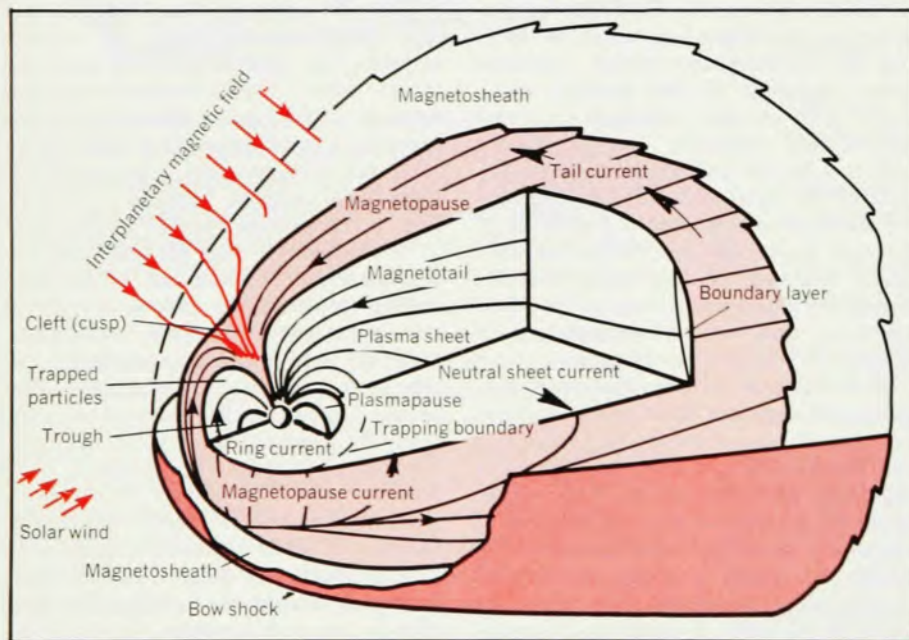
## The upper mantle and plate tectonics

The very nature of the problems facing geophysicists, such as understanding the dynamics of the behavior of the "solid" Earth, demands a global outlook. The Upper Mantle Program provides a good example of how geologists and geophysicists from many nations have worked together. The vision of the eminent Soviet geophysicist V. V. Belousov and his personal enthusiasm for international cooperation among geoscientists played a critical role in the events that led to the planning of this program and continued throughout the life of the project. Belousov served as chairman of both the planning committee and the committee that coordinated the project; Leon Knopoff of UCLA served with him as secretary-general of these committees. By dint of their personal efforts, with the support of many others from countries around the world, they were able to move a program involving almost 50 countries during the late 1950's and early 1960's, when US and Soviet scientists were frantically competing in space and when diplomatic relations between the two nations suffered some of their most spectacular

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Specialized and frequently expensive equipment is required for field work. Here geologist Harrison H. Schmitt is working beside a large boulder near the Taurus-Littrow landing site of the Apollo-17 mission to the Moon's surface. (NASA photo).



**Solar wind.** The effect of low-energy electrons and protons flowing past the Earth is to produce a bow shock and a transition region called the "magnetosheath" around the magnetosphere. It is beginning to appear that the solar-wind particles gain access into the magnetosphere through the clefts in the dayside magnetopause where the high-latitude magnetic-field lines are swept back into the magnetotail and thence to the plasma sheet, the immediate source of auroral particles. (From W. J. Heikkila, EOS 54, 1973.)

peaks and valleys of recent times.

At the conclusion of the Upper Mantle Program earth sciences had reached the crest of a revolution sparked by the development of the plate-tectonics model. With the momentum of this revolution a new international program, the Geodynamics Project, has been launched, a project directed toward defining the dynamics and dynamic history of the Earth and studying how they relate to processes described by the basic plate-tectonics model.

The birth and progress of the concept of plate tectonics embodies much of what I have said about the nature of geophysics. This concept was born from the synthesis of observations made largely by two groups: *marine geologists and geophysicists*, who have devoted their lives to determining the structure of the ocean floor and its interface with the continents (the continental margins), and *seismologists*, who are able to provide insight into the movements of the Earth's crust and upper mantle through the study of earthquakes. The elegant synthesis that led to the plate-tectonics model is so persuasive that it has spread through diverse disciplines to capture the attention of specialists who, ten years ago, very few would have predicted would ever be working together.

In this model the outer shell of the Earth's crust is conceived as being composed of a few very large plates that diverge at ocean ridges, where new material is rising, and converge along island arcs and seismically active continental margins, where plate material is underthrust and consumed. (See figure 2 in the article by Gerald Schubert and Orson Anderson, page 30.) As a documentation of the history of these movements proceeds, and while efforts are made to measure present-day movements and explain them, attention is also directed to the development of a satisfactory dynamic model of the Earth's interior that will provide the driving force for plate movements and perhaps explain magnetic-pole reversals and other related phenomena.

As is true of much of the research of geophysicists, this area promises to lay the foundation for enormous societal benefits. We are now looking forward to a firm understanding of the mechanisms that result in a large fraction of earthquakes and to a better understanding of volcanoes and other concentrations of geothermal energy that are the surface clues to the dynamic process we are trying to model. The knowledge to be gained also promises to lead to areas related to mineral and hydrocarbon exploration. A recent National Academy of Sciences-National Research Council report<sup>1</sup> makes easy and excellent reading for those who

want to pursue in greater depth some of the most promising opportunities for research in the solid-earth sciences.

### New directions, new challenges

That geophysicists recognize the value of common paths among their disciplines and the need to work with those in other sciences, and that they are continually seeking these common grounds, is borne witness to by their professional relationships—not only in the laboratory but also in their national scientific societies and international organizations. The American Geophysical Union is their principal scientific society. In many ways the activities of AGU are analogous to those of the American Physical Society. Large meetings and voluminous archival journals (with monstrous page charges) are common characteristics. But one of the AGU journals, *Water Resources Research*, has transcended the simple publication of archival material. This journal was established ten years ago to draw together the physical scientists and social scientists interested in water resources. The coeditors of the journal are an economist and a geologist, and through their example many geophysicists have been led to think in new directions and to consider their responsibility for providing sound principles on which public decisions can be based. Society's confrontation with the realization that the natural resources of Earth are indeed limited, which is presently emphasized by the energy crunch and its attendant problems, can be ameliorated only by the work of engineers and social scientists who are able to build on the foundations set by earth and space scientists. No discipline of geophysics escapes the responsibility of addressing the problems of our society. While much of the fundamental work in many of these areas has already been done, much still remains. However, in the short term the real challenge, one that again emphasizes the interface with new areas—treading the unfamiliar halls of the social scientists and working closely with the engineers—is the transfer of the science from the archival journal into operating systems.

Formerly, ambitious expeditions were mounted for studying the magnetic field, collecting data on ocean circulation, and mapping the geology of remote areas; today the cooperative programs undertaken by geophysicists are often no less ambitious. The Apollo lunar program, affectionately dubbed "the great field trip in the sky," is perhaps the best parallel to these earlier enterprises and at the same time the best-known example of such monumental efforts. Before the advent of the airplane, geophysicists participating in many worldwide expe-



Moisture-searching radar is used at the National Center for Atmospheric Research to find hail-producing storms as part of the North-East Colorado Hail Experiment. (NCAR photo.)

ditions used sailing ships as transport and generally spent years away from home. Today a ship such as the *Glo-mar Challenger*, which is equipped for deep drilling on the ocean floor, may likewise be scheduled to cruise for several years, but there are many legs to the cruise and new complements of scientists join the ship at one port and leave at the next. Land-based operations, such as the continuing research in the Antarctic, are well equipped; meteorologists use highly instrumented advanced aircraft and satellites to probe the atmosphere. Much of the effort of these projects is still what might be called exploration and mapping, but geophysics is entering a new stage in its development and one can see a shift in emphasis from exploration and mapping to the development and testing of unifying hypotheses. Some expeditions are now being undertaken with the primary objective of testing a specific aspect of one of these hypotheses. But the cost of field research is high, much repetitive mapping of time-dependent features is necessary and many unexplored areas and new parameters must be explored. There is considerable excitement in adding small pieces to the puzzle that will eventually give us a picture of the Earth and how it behaves.

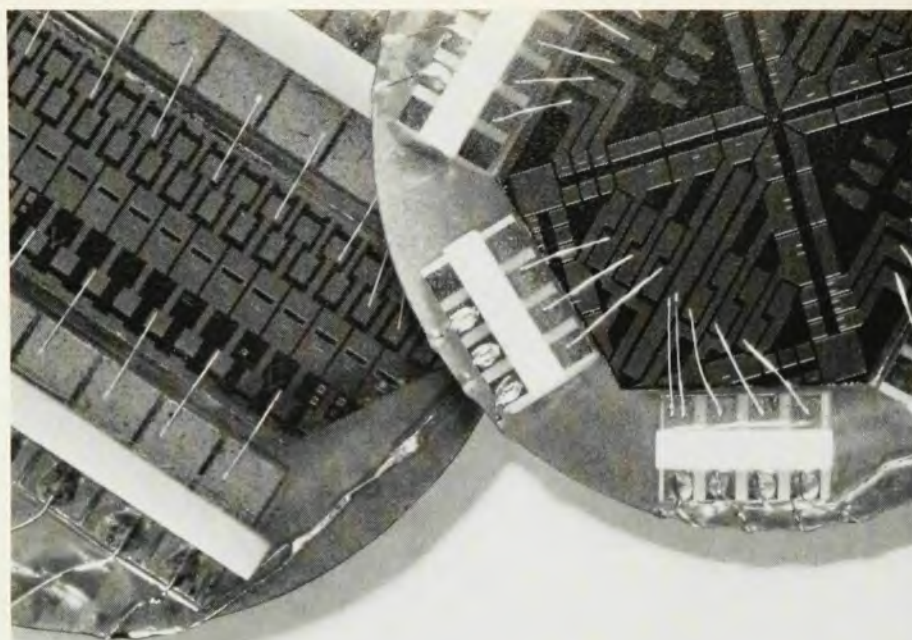
### International exchange of data

These pieces of the puzzle are in the form of data that have been collected by individuals throughout the world and, although not unique to geophysics, the international exchange of scientific data is perhaps better developed in the geophysical disciplines than in any others. There is a long

history of the publication of expeditionary results; more recently international data centers have been developed. Usually, three discipline-oriented world data centers are established, one within the United States, a second in the Soviet Union, and a third in another country. Diplomats will tell you that this sort of collaboration requires good international relationships, but geophysicists will tell you that in their experience the good international relationships frequently follow the friendly relationships developed within the scientific community.

However, the international exchange of data in geophysics is sometimes hampered by both real and imagined military objectives. In the obvious direct relationships between most areas of geophysics and "defense" efforts lies the historical basis for the federal government's overwhelming share in the funding of geophysical research in the US; this relationship perhaps explains why geophysical research is funded today to the order of magnitude that it is. Much of the present-day oceanographic establishment can be traced to roots in naval research, and much of what is done today by oceanographers is done by or for the Navy. Although work funded by naval interests no longer represents the overwhelming proportion of ocean research, it is clear that almost anything done in the field of oceanography has some military application. Analogous situations are found in meteorology for both air and sea operations, in geodesy (missile targeting), and in seismology (nuclear-test detection).

It is easy to see how the connection between basic geophysical research and



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defense could cause difficulties for disciplines that are dependent on maintaining excellent international relations. Among geophysicists worldwide, it appears easy to balance the open (but unstated) recognition of the impossibility of doing geophysical research that cannot be related to military applications against both the immediate and long-term benefits that society will derive from this research. Coupled with the pragmatic recognition that the military is in the best position to provide the logistic support required for large-scale experiments and the political realities of obtaining funding for research, this line of thinking has led to the evolution of a tacit acceptance by military partners and has deprived geophysicists of the agonizing appraisals of the relevance of their activities that many other scientists have gone through.

## Our uncontrolled environment

The satisfactions that can be drawn from the challenges of a career in geophysics are diverse; people on whose research the saving of life depends, people who live in an exciting environment of truly international science, laboratory types, field types, theoreticians, most of them with a toe in the other fellow's business, all comprise the community of geophysicists that I have been discussing.

But I have left out perhaps the most important challenge of geophysics, that of doing science in an uncontrolled environment. Massive experiments go awry because of vagaries in the weather, meanderings of currents, and occurrences of earthquakes or solar flares. These hazards are routinely taken into account in the planning of research. The predictability of the environment poses a greater problem, a paradoxical one, when the time comes to analyze the results. If the natural course of a hurricane is not known precisely, how can the effects of a seeding experiment be assessed? Any attempts to modify other natural phenomena from earthquakes to the reflectivity of the ionosphere present similar dilemmas, which sustain this exciting dimension of geophysics.

In the final analysis we geophysicists, whether admiring a green flash at sunset from the bridge of a research vessel, an auroral display at a northern rocket-launch site or the stark dignity of a new cinder cone in Central America, cannot escape a sense of awe at having the world for our laboratory and nature performing our experiments.

## Reference

1. US Geodynamics Committee, *US Program for the Geodynamics Project—Scope and Objectives*, National Academy of Sciences, Washington, D.C. (1973). □