NEW OPPORTUNITIES FOR GEOLOGISTS

by

Philip H. Abelson

*At the close of 1979, the Past President of IUGS looks to the future - with some lucid and constructive observations on the developments that will affect geology in the years ahead, and the tools which will make the profession increasingly more useful and exciting.**

World geology today faces new tasks and challenges. Demands for new sources of energy and raw materials have come at a time when the "easy-to-discover" resources have already been found. Geologists must probe more avidly and effectively than ever before to find means of discovering hitherto hidden reserves of oil, gas, and mineral deposits.

Fortunately, a large number of tools have been created, or will soon become available, that will enable geologists to obtain the kinds of information they need to aid them in these discoveries and in attaining a better understanding of the earth and the processes that have brought it to its present state.

New Concepts of Ore Formation

A most remarkable recent set of observations by the submersibles *Cyana* and *Alvin* at the East Pacific Rise has provided insight with respect to mechanisms of ore formation. At latitude 21°, fluid with a temperature of 400°C emerges from an undersea ridge. The ridge lies 2500 m beneath the surface and pressure of about 250 atmospheres is above the critical pressure.

Massive sulfide deposits are near the sea floor vents. Elements present include iron, zinc, lead, copper, silver, gold and platinum. If the sulfides were present in quantity on land, the deposit would constitute a very valuable ore body.

It seems evident that very hot sea water under pressure is an effective agent for mobilizing transition elements from silicates, and that sulfides are soluble in the fluid. James Bischoff of the U.S. Geological Survey has already come up with an interesting explanation for what is occurring. He believes that sea water penetrates to a depth of 2 km below the sea floor to the vicinity of magma chamber. There it attains its elevated temperature and is under a pressure of 450 atmospheres. The hot water dissolves some silica and liberates trace metal cations. Sulfide is obtained, in part from reduction of sulfate in sea water by ferrous silicates, and in part from sulfides in basalt.

Bischoff does not mention the important variable pH, which is influenced by the nature of the host rock. At elevated temperatures the pH tends to be lowered, and this would lead to a lower activity of doubly ionized sulfur. In addition, the ionization constants for dissociation of H_2S may be quite different in water, depending on pressure and temperature.

Figure 1. Regional map showing site of dive by the submersible *Alvin* in March, 1979, to explore vents on the East Pacific Rise (Figure courtesy NSF).

Figure 2. Chimney-like feature jetting out superheated (>350°C) water rich in sulfides at a depth of 2700 m on the East Pacific Rise. (Photo courtesy R.D. Ballard, Woods Hole Oceanographic Institution).

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Thus, there is much we still do not know about the mechanisms involved. Information obtained at the East Pacific Rise is not directly transferable to ore formation involving, for example, granitic rocks. However, the observation that hot water under pressure is a remarkable solvent opens the door to new concepts of ore formation.

We can expect that other explanations will be offered for the sea bottom sulfides at the East Pacific Rise. We can look forward to intensive interaction between field observations and laboratory experiments and to further crucial discoveries by observers on *Cyana* and *Alvin*. In consequence, within a few years, a markedly improved understanding of ore-forming processes should be attained.

Figure 3. Ore grade sample containing zinc, copper, and silver sulphides dredged from flank of the ridge. (Photo courtesy R.D. Ballard, Woods Hole Oceanographic Institution).

Deep Sea Drilling

During the past twelve years, the *Glomar Challenger* has probed much of the ocean floors outside the Arctic (see EPISODES, v. 1979, No. 1, p. 3-6; v. 1978, No. 4, p. 3-8). Some 750 holes have been drilled at 500 sites. All sediments examined have been no older than Jurassic. The younger rocks have been found at the mid-ocean ridges and older ones distant from them. The Deep Sea Drilling Program has made many other discoveries. While a tremendous success, it has been forced to avoid some important areas, particularly ocean margins where sediments are likely to contain gas and oil.

A proposal is now being considered by the U.S.A. to equip an existing larger ship with risers and blowout preventers. This ship would have the capability of reaching depths 11 000 m below sea level. The length of the riser would be 4000 m. Since the ocean margins contain about half of the world's volume of sedimentary rocks, the renovated ship - the *Glomar Explorer* - could be expected to provide information leading to development of important petroleum reserves.

One function of the drilling ship would be to provide "ground truth" that would interact very favourably with new and future powerful tools of seismic exploration. Another potential result of the exploration would be discovery of ore deposits. Studies of the ocean margins could be expected to provide valuable insights to geologists concerning the origin and evolution of continents.

Drilling would not be confined to the margins. The ship would have the capability of drilling deep into the floor of the oceans. It would also be expected to examine the ocean ridges and to obtain from them more information about mechanisms of ore formation.

Probing the Continental Crust

Until a few years ago, knowledge about the subsurface geology of the U.S.A. was limited largely to information obtained in drilling for oil in sedimentary basins. But during the last few years a program has been supported that is

probing the earth to a depth of 30 to 70 km. The equipment being used was originally developed by Continental Oil Company for oil exploration. A group of university scientists, led by Professor Jack Oliver of Cornell University, has applied it to deeper strata.

The equipment is designed to observe reflected sound waves with frequencies of 8 to 40 hertz. An array of 96 stations, each with 24 geophones, forms the observing network. The data thus obtained are processed by computers. The consortium of universities called Cocorp has made nine major traverses of important geological features, such as the uplift of Wind River in Wyoming, U.S.A.

A most important advance has been made in studies of the eastern U.S.A. In 1978, Cocorp completed a traverse extending from the valley and ridge province of Tennessee to the contact between the piedmont and coastal plain in Georgia. The results proved the presence of sedimentary rocks beneath crystalline rocks. These observations, together with some made by the U.S. Geological Survey, show that there has been large-scale overthrusting of Paleozoic continental margin of the proto-Atlantic. Overthrusting may have been 260 km horizontally. Apparently, the overthrusting has involved a very large area and the sediments that have been covered are a potential source of substantial amounts of natural gas.

Microelectronics and Instrumentation

In the past year, during visits to 16 leading U.S. industrial research and development laboratories (including IBM, Bell Laboratories, General Electric, Texas Instruments, Hewlett Packard, and Xerox), I was shown advances in microelectronics and instrumentation, some of which have not yet been publicly announced. New and more powerful tools will become available for all branches of the earth sciences.

Basically, there is a continuing and rapid increase in capabilities for computation and information storage. In addition, far more efficient methods of design and fabrication of special microelectronic circuits have been created. These new types of circuits are being used in conjunction with instrumentation to give it enhanced capabilities.

For example, one model of a spectrophotometer is capable of measuring the entire spectrum from 2000 to 8000 angstroms in one second. The equipment includes a microcomputer with a memory that can store known spectra and compare them to the absorption caused by a complex mixture of elements. Results are stored in the computer but can be displayed on a screen or printed out. This equipment will become especially useful in the analysis of trace elements.

New development and procedures in reflection seismometry equipment, as demonstrated at the Geophysical Services, Inc. Company, incorporate advances in microelectronics and in computational capabilities. The number of geophone groups being used in one recording spread for some applications have expanded to as many as 1024, and as many as 3000 are being contemplated within the next few years.

In addition to a larger number of geophones, closely spaced traverses are used to obtain a spatial sampling sufficiently dense to permit the imaging of subsurface strata in three dimensions. The three-dimensional information can then be displayed on arbitrarily selected vertical or horizontal planes through the subsurface. These displays can be viewed on screens or on a variety of paper or film representations. Using such procedures, one can obtain greatly improved resolution and information about the nature of the different strata.

The massive amount of data generated in this three-dimensional approach is processed by computers with enormous computational capabilities. A rapidly emerging technology is the use of seismic data to construct logs containing much of the lithologic information derived from logs obtained from wells. Through the additional structural resolution obtained from the three-dimensional system, coupled with the litho-

logic information from seismic logs, it is possible to make a major improvement in the ability to distinguish between gas-sand, sand-oil, shale, limestone and other lithologic interfaces.

An item in the *Oil and Gas Journal* for August 6 of this year gives a practical example of the power of the new equipment. The article describes the development of a gas field in the Gulf of Siam that contains 1.3 trillion cubic feet proved, 5.9 trillion proved and probable. The field is in a hinge line area characterized by complex faulting which controls hydrocarbon entrapment. The concessions involved had previously been owned and explored by Tenneco and British Petroleum. Using older methods of seismic exploration, they had failed to discover the reserves. The new three-dimensional methods of exploration involved towing a marine cable with 48 geophone groups on lines spaced at 100 m intervals.

Following processing of the information, four wells were drilled with 100 percent success. The first well flowed at a rate of 62 million cubic feet per day, with 1129 barrels per day of condensate. Other wells cut faults within 20 feet of predicted depths and flowed nearly comparable amounts of gas and condensate. The owners of the concession are sufficiently confident in the seismic data to feel that they can proceed with planning the development of the field with a minimum of further exploratory wells.

The usefulness of this type of equipment will not be confined to exploration for oil and gas. R.J. Graebner of Geophysical Services, Inc. is naturally enthusiastic about additional applications of the three-dimensional equipment. He believes that it will have important roles in both coal and mineral exploration and development.

Remote Sensing Equipment

Looking still further into the future, one can predict increases in new capabilities of equipment used to obtain remote sensing imagery (in addition to side-looking radar and Landsat satellites). The Landsat-D satellite scheduled for late 1981 will include spectral bands centred near 2.2 and 1.6 microns in addition to the channels used earlier. The 2.2 micron spectral bands will facilitate mapping of limonite-bearing rocks and a group of hydroxyl-bearing minerals commonly associated with hydrothermal alterations.

A spectroradiometer is to be flown on the second space shuttle flight to determine the optimum spectral bands in the 0.4 to 2.5 micron region for geological studies. A total of ten spectral bands is included.

Another opportunity involves the use of thermal infrared techniques employing sensors for 8 to 14 micron radiation. One looks at diurnal heating and cooling. From the spectral emissivity, one can distinguish silicate from nonsilicate rocks, and among silicate rocks.

Information Storage and Retrieval

Improvements in information storage and retrieval will come as a most welcome development to geologists as to all scientists. We are faced with an enormous proliferation of facts and literature. The quantity is so great as to be disheartening. Yet it constitutes an enormous resource if it can be selectively retrieved and presented. Developments are occurring that portend a revolution in data analysis and retrieval.

In the U.S.A., a number of organizations, both governmental and commercial, are tending to place vast quantities of

information in electronic storage. To use *Science* magazine as an example - a company recently approached management with a proposal to store the complete text of the magazine, beginning with issues going back four years. The magazine is itself a user of electronically stored material: a computer terminal allows one to tap into the world's biomedical literature (the compiler of which is the National Library of Medicine) and to quickly locate desired material through use of key words. This system is similar to GEOREF and others that may be more familiar to geologists.

Some earth scientists are very enthusiastic about the potential usefulness of applying electronic storage and retrieval to geology. Consider, for example, the problems faced by a scientist wishing to make comparisons of the chemical analyses of rocks. A tremendous amount of information exists, but the more than 100 000 analyses are scattered among thousands of journals. Even if the information were gathered together and printed in books, it would take a sizeable shelf to handle all the data - rock type, location, age, mineralogy, methods of analysis, trace elements, and other pertinent information. The data bank, in short, would be unmanageable.

But if all the information were stored in an electronic memory, a computer could then be used to do any kind of sorting of the analyses. For example, one could ask the computer to prepare a list of all Miocene basalts possessing three percent or more titanium, and the like. Preparation of this new information resource is just beginning. The work involved will require the efforts of many people in many countries. It is fitting, therefore, that an effort in this direction has been undertaken by a project under the International Geological Correlation Programme; headed by Dr. F. Chayes, the project is devoted to the design and generation of a world data base for igneous petrology.

Another potential tool, although some distance still from achievement, is the capability of placing the world's geological maps in electronic storage. All the technology for accomplishing the deed and for subsequent display of coloured maps on video screens exists now. Hard copies could be obtained from the stored information.

One of the advantages of electronic storage of information is the relatively instantaneous availability of a selected piece of information, whether that be a map or a chemical analysis. The major advantage, though, lies in the ease and speed with which one can sort the data and, if desired, make comparisons among selected classes of data or other kinds of manipulations.

Another consideration is the fact that the costs of memory storage and computation have been decreasing rapidly, and prospects are good for a continuation of this trend. As interested earth scientists become more proficient with computers, they will develop improved methods of making the cogent kinds of data more readily available.

The above-mentioned are only a few of the developments that will affect geology in the years ahead. The methods by which geologists examine the earth will increase to include new tools. Particularly helpful will be opportunities to see the crust in three dimensions and the development of new knowledge concerning ocean margins, the genesis of ore deposits, and the evolution of continents. As geologists help to fill the great needs of society, they will also enjoy participating in some of these exciting opportunities at the frontiers of scientific knowledge.

ABOUT THE AUTHOR: Editor of *Science*, a leading American scientific weekly, author of *Energy for Tomorrow* (1975), editor of *Researches in Geochemistry* (Vol. 1 - 1959, Vol. 2 - 1967), *Energy: Use, Conservation, and Supply* (1974), *Food: Politics, Economics, Nutrition and Research* (1975), Dr. Philip H. Abelson is a well-known international authority in a number of scientific fields (see EPISODES, v. 1979, No. 2, pp. 39-40 for biographical profile). President of IUGS from 1972 to 1976, Dr. Abelson has also served as President of the American Geophysical Union and Chairman of the U.S. National Committee for IUGG. At present, he is Chairman of both the Bio-Energy Council and the Geophysical Research Board of the U.S. National Research Council.