# PAST AND FUTURE EVOLUTION OF MARINE GEOLOGY

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ABSTRACT: An attempt is made to understand some of the ways that marine geology developed during the past 50 years, essentially the working lifespan of an active but venerable scientist. This interpretation is aided by comparing marine geology with the development of land geology during a longer period, and by attempting to understand the relative roles of science and technology in the field of marine geology. Excursions from simple straight-line advance for all geology (and also for other fields) are provided by the unexpected appearances of broad generalizations, or paradigms, that commonly are developed by a few scientists and opposed by many, at least for a time. These sudden advances await the accumulation of critical masses of knowledge that, in turn, depend upon exceptional opportunities, partly in the form of adequate funding and partly by transfer of technology. These unusual circumstances make accurate prediction of future advances in maring geology (and in other scientific and technical fields) unreliable but still worthy of thought.

## INTRODUCTION

This short essay is intended to provide a general statement concerning the development of marine geology during the past 50 years. This period lies within the time frame of our teacher and colleague, Francis P. Shepard, who worked and published in geology from 1922 until his death in 1985 at the age of 87. Much of the progress made in our field during this time was due to the development and use of new technology. Technology was not one of Frans' strong points; indeed, it generally was best to keep him away from the switches and buttons, but he always knew the value of new technology even though he hated to part with his beloved sextant.

## SCIENCE AND TECHNOLOGY IN MARINE GEOLOGY

When one thinks of evolution or progress in a field of science, one should be careful to recognize the difference between technology and science. According to Webster's dictionary (Gove, 1976), a scientist is a person who has "accumulated and accepted knowledge that has been systematized and formulated with reference to the discovery of general truths or the operation of general laws"; has "ability to state problems, to frame questions, so that the technicians can make the machines yield facts that are significant." A technician is a person "who has learned the practical technical details and special techniques of an occupation."

Technology develops through invention and improvement of devices and/or techniques that enable a scientist to obtain new kinds or quantities of data that can be used to improve solutions of old problems or investigations of new ones. Among such devices that have become available and have been widely used by marine geologists since 1950 are satellites. Their passage provides accurate ship positions far from shore, their imagery yields color or absorption characteristics from which chlorophyll and suspended-sediment concentrations can be derived, and cloud cover from which weather maps can be created to guide shipboard operations. Radar altimetry from satellites can be used to measure sea-surface topography from which both gravity and ocean-floor topography can be inferred. Additionally, satellite measurements can be used for determination of precise geographical positions to permit direct measurements of movements of continents and islands by seafloor spreading. The rates and directions of movements so obtained should increase our knowledge of plate tectonics beyond the limits provided by geology alone.

New devices have been developed for use on surface ships to continuously record and produce real-time charts of the bottom topography by means of multiple sounding arrays and near-horizontal side-scanners to survey broad areas of the ocean floor. Topographic details on a finer scale can be provided by many improvements in underwater photography and television, and by direct human observation in submersibles, or by television in remotely operated vehicles (ROVs) capable of reaching any ocean depth. Regional surveys of general stratigraphy and structure of sediments and rocks beneath the ocean floor can be made through seismic reflection and refraction, magnetic signature and intensity, and gravity. More detailed information about materials beneath the ocean floor comes from drilling into the bottom to recover cores that are nearly continuous and have penetrations exceeding 2 km. New coring devices, such as a hydraulic piston corer used within the drill string, have increased sample recovery and reduced core disturbance. Drilling can be sited very accurately using dynamic positioning of the ship drilling platform, and very deep samples can be obtained by means of re-entering the bore holes after replacing worn bits. Boreholes can also be re-entered for insertion of seismic and other sensors.

There is a vague and uncertain boundary between the invention and use of these new technologies and the study of data obtained by new methods. In general, many devices and most methods have been adapted from previous usage for solving non-marine problems rather than being invented specifically for the ocean. Perhaps the best example of such methods is the use of computers to store, retrieve, process, and plot data of all kinds. Another method is the making and use of various radiometric measurements to determine the ages of sediments, fossils, and rocks from the ocean floor. Another is the analysis of trace elements and stable isotopes to determine sources, paths, and fates of water masses, organisms, sediments, and rocks. Other methods, also extrapolated from previous use on land, are techniques for plotting seismic stratigraphy, dating sediments and rocks by magnetic reversals, and determining their latitudes of deposition.

These and other new technologies and methods represent great advances over the relatively simple tools that were invented and built by oceanographers during earlier decades. Most are produced by skilled technicians whose in-

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terests do not include interpretation of the results in terms of oceanic processes or history. The ideal match is a partnership between technicians having knowledge of materials, electronics, and computers and scientists having knowledge of the ocean and its waters, organisms, topography, or bottom and sub-bottom materials. Nevertheless, the devices, methods, and interpretations of recent results have reached new levels not even dreamed about 50 years ago. Scientists who did not live through these years of accelerating progress can scarcely visualize the change any more than a young child can imagine a world without television.

The main point here is that 50 years ago one could visualize and make only small improvements in then-existing corers, sediment traps, echo sounders, current meters, and other devices. We were unable to leap the gap between then-existing and present methods of measurements before the invention of devices for one field and their spread or adaptation to other fields. Geologists could and did imagine new kinds of information that they could use from application of geophysics (the big geologic hammer) and drilling of deep holes in the ocean floor, but probably it is beyond human mentality to conceive of quantum jumps as large as those within the past 50 years in terms of new concepts and geologic problems that came into focus from the new data. This limitation equally means that we probably cannot imagine the geologic problems that will be at the front 50 years from now anymore than we can visualize the devices and methods that will be available then to solve those problems.

## PAST PROGRESS IN MARINE GEOLOGY

Some interesting comments about the state of geology existing in 1904 and its possible subsequent evolution came from lectures by prominent geologists and geophysicists at the International Congress of Arts and Science, St. Louis, and a farewell lecture by E. Suess in Austria the same year. The presidential address by I. C. Russell (1904) pointed out that previous studies of physiography had largely been exploratory and geographical in nature and that most terminology was inexact. He visualized that future studies would be concentrated in definite areas (such as the ice-covered Arctic and Antarctic regions) and directed toward investigations of specific problems (such as the work of wind, streams, glaciers, waves and currents). Oceanography was a newly developing branch of physiography in combination with geology and biology.

C. R. van Hise (1904) pointed out that chemistry and physics were the elementary sciences and that astronomy, biology and geology were applied (derivative) sciences. During previous decades and centuries, many interpretations of astronomy, biology and geology were laughable to contemporary chemists and physicists. The future progress of geology would require better grounding of geologists in chemistry and physics. G. F. Becker (1904), a geophysicist, briefly outlined past development of knowledge about the Earth's interior based upon now-obsolete hypotheses of origin and age. For improved understanding, he stated the need to concentrate upon better measurements of seismology, magnetics and thermal structure to improve knowledge of magmas, ore deposits, petroleum, glacial climates, weathering, erosion and geologic ages. Eduard Suess (1904) outlined the development of structural and other geological disciplines during his long professorship in Austria, pointing out that many problems remained to be investigated. These four eminent scientists with their many contributions to 19th-Century geology fully expected much further progress in understanding the origin, composition and history of the Earth during the 20th Century, but they had no way of knowing the many means of obtaining the necessary information that would be provided by technicians and the goals to be outlined by scientific generalizations during that century.

Interpretation of results in marine geology, as in all other fields of science, spans a wide range of levels. Fifty years ago marine geologists were more concerned with questions of what and where (descriptive) than with when and how (genetic). As a result, their reach was limited largely to areal distribution patterns of topography, rock types and sediment grain sizes. Later, their questions concerned dates of formation or deposition, geologic processes, changing structure and topography, and prediction of evolutionary changes.

About 1860, a major generalization, or paradigm, was developed by Charles Darwin on the basis of his observations of marine and land plants and animals—the evolution of life forms by natural selection. Only about 25 years ago, a similarly broad generalization was made by a few marine geologists—the concept of plate tectonics, a considerably modified form of the earlier continental-drift hypothesis. Each generalization aroused both opposition and broad approval by other scientists, with much effort spent upon testing, understanding, and extending the general concepts.

At present, perhaps the major concern of marine geologists is the relation of regional changes of topography and sediments to world-wide tectonics and their control of plate movements. Already, one can visualize that an important means for understanding both marine and land geology is via integration of regional geologic features with the plate-tectonic history of the world. We are only beginning to see that plate movements in one ocean are reflected in volcanism and mountain folding within other oceans, by rifting of distant continents, by differences in stratigraphy, and by changes of climates and, thus, changing environments for habitation and migration patterns of both marine and land plants and animals. On a more local scale, we can begin to see how plate movements have controlled the distributions of igneous, sedimentary and metamorphic rocks and their changes during Earth history. Plate movements also control topographic patterns of mountain ranges and flat plains on both ocean floor and continents as well as their subsequent alteration by erosion, burial and renewed tectonism. On a more immediately practical level, the plate movements yield information concerning the potential distributions of important mineral deposits and the processes that form such deposits.

Another paradigm, but one still in its early stages of testing, is that of asteroid or large meteorite impact on the Earth—notably one about 65 Ma probably following several earlier impacts. These impacts appear to have produced massive explosions that threw large volumes of dust into the atmosphere, blocking light from the sun, cooling the air, and considerably reducing photosynthesis or growth of plants. As a result, many species of plants and animals became extinct. It is these concurring extinctions that led to the impact concept. Broad generalizations such as these are the apex of scientific investigation, but they are few in number and are built upon many lesser generalizations and discoveries that, during decades or centuries, expanded and combined as knowledge increased. Such hard questions are being addressed by scientists using whatever tools can be adapted or developed by or in collaboration with qualified technicians.

### FUNDING

The question immediately arises about what can be done to promote the synthesis of scientific observations and numerous small generalizations into the few and broader paradigms. It is easier to understand how to increase the invention of devices and methods: primarily by the provision of money and opportunity for study, experiment and information transfer from other fields of active study. A major source of such funding has been the military branches of governments through efforts to obtain strategic and tactical advantage. Frequently, the scientific gains have been indirect by-products. Examples are Captain James Cook's observations aboard H.M.S. *Endeavour* and *Resolution* during territorial surveys of 1769–1779, Darwin's time aboard H.M.S. *Beagle* during 1831–1836, and work by many scientists on material collected by H.M.S. *Challenger* during her epic voyage of 1873–1876. Important scientific results came not just from British naval ships but also were produced during voyages of naval vessels from France, Italy, Germany, Russia, Japan and a few others. In the United States and the Soviet Union, much was learned about the ocean during post-World War II expeditions aboard navy ships and aboard university ships funded by the Office of Naval Research and its Soviet parallel. To a certain extent, the value and timeliness of the findings aboard navy ships have been limited by some secrecy imposed in the name of military advantage.

Another major source of ship funds has been government agencies of non-military intent such as the U.S. National Science Foundation that, among other programs, sponsored the Deep Sea Drilling Program and now the Ocean Drilling Program, and extensive ocean-wide surveys conducted in the name of the International Decade of Ocean Exploration. The National Aeronautics and Space Administration and the National Oceanic and Atmospheric Administration enhanced the use and development of Earth-circling satellites and promoted shipboard and submersible operations. Universities have provided facilities and graduate students from their various departments, and oceanographic institutions are supported through Federal and some State agencies via research contracts and grants. Two Federal agencies have conducted considerable oceanic research using primarily their own staffs and ships: the U.S. Geological Survey and the U.S. Coast and Geodetic Survey (which later became part of the National Oceanic and Atmospheric Aministration).

Industry also had a large role in marine geology through its efforts to find and produce offshore oil, gas and other ocean-floor minerals. Several major oil companies made extensive geophysical surveys in all oceans aboard their own or chartered exploratory ships as well as conducting stratigraphic programs for their drilling ships and platforms. More local surveys have been made by companies for possible mining of sand and other minerals and by coastal cities for disposal of their sewage and other wastes. In contrast, the lesser developed countries of the world have provided few measurements (rarely even useful tide-guage recordings) and essentially no generalizations about the oceans because of inadequate education levels, other more pressing interests, and financial limitations. Education of selected individuals from lesser developed countries at universities within industrialized nations is an important step for enhancing interest and scientific contributions from those countries, but efforts can be lost when the trained individuals choose not to return to their own countries. Moreover, it appears that a disproportionate effort is made by lesser developed countries to train lawyers (rather than scientists) to obtain some benefits from increased knowledge of ocean resources.

The funds from navies and other other government agencies, university and industry sources in the industrialized nations of the world have provided billions of dollars for shipboard and laboratory studies of oceanic data. However, these sources appear to have been little used for finding and funding the few scientists who develop the broadest generalizations or paradigms. Perhaps this gap reflects the difficulty in identifying the scientists most likely to make such advances, but it may be due to the uncertainty of obtaining broad generalizations from those who are given funds. Perhaps those who are responsible for allocating research funds frequently feel safer if the funds are used for collection of new data. This suggests that a likely source of broad new concepts lies with those scientists who happen to have large, earned, inherited, or pension incomes—an uncertain and unreliable means of promoting science.

### THE FUTURE

Accurate prediction of future scientific problems and of technological advances may be even more difficult to make now than in the past because the extent of present knowledge is so much broader. One may be less able now than earlier to identify successfully the parts of this knowledge that are most likely to serve as the bases for major further advances. It is relatively easy and certain to predict more and better methods of geophysical measurements to better understand the composition and structure of the Earth during the near future. But can we afterward successfully combine these measurements and abundant new dates of events into a comprehensive structural, stratigraphic and physiographic history of the Earth? What and how can we learn about the shapes and characteristics of previous generations of now-vanished oceans and their waters? The evolution of the present oceans has provided clues to the evolution and migration of both marine and land plants and animals; can we find similar clues to the more ancient past within geology and without a time machine? Before many decades have passed, we ought to be able to integrate the changes in Earth structure and stratigraphy with seafloor spreading during the past 200 million years; can we somehow extend that knowledge several billion years earlier?

A better understanding of these past relations should aid in predicting the future of the Earth, its climate, and its plant and animal populations. Will the glaciers remaining from the late Cenozoic finally melt and drown many coasts, or will a renewed advance of ice displace populations? Many answers relevent to humans are in the realm of politics, but cannot predictions from geology modify or supplant political forces? Examples could be in the form of increased coastal erosion, more severe earthquakes, more active volcanism, larger tsunamis, or more asteroid impacts—all of which are even now being studied and evaluated. Are humans more likely to annihilate themselves by bad practices in gathering, farming, hunting, herding, and mining on land and ocean than by military activity, especially during peak times of natural disaster?

Answers appear to be unclear, because great need for knowledge sometimes may inspire greater effort and greater success in obtaining and using knowledge. This need may produce unpredictable successes just as the steady accumulation of knowledge may reach a critical mass that allows rapid understanding and synthesis for a time. Such factors as urgent need, critical mass of knowledge, and unusual terrestrial and extraterrestrial events strew the path of a would-be predictor of science and technology with many unexpected hazards and opportunities. So, for the present, let's just agree that the future of marine geology is likely to be even more interesting and eventful than the past and not try to predict just how it will come about.

## SUMMARY

Progress in marine geology during the past 50 years has been enormous. Emphasis is placed here upon the general trend from data collection, synthesis of data, and relation of results to other kinds of knowledge (from the adjacent land as well as from the entire Earth), and to final development of broad generalizations, or paradigms. A great debt is owed by marine geologists to the many sources of funding that have permitted the adaptation of devices from other fields and the invention of others to improve and speed the collection and interpretation of data that are basic to the later generalizations. Rapid development of these devices and methods during the past 50 years means that if we could visualize the devices and methods to be used fifty years hence, we probably would find them to be at least as different from present devices and methods as the present ones are different from those employed 50 years ago. New sources of data doubtlessly will provide the bases for new generalizations that are now unattainable or even totally unexpected. Clearly, technology and science are twin driving mechanisms, technology providing new kinds of data for science, and science providing needs for new kinds of technical data. This essentially is the same as the question of whether necessity is the mother of invention, or whether invention is the mother of necessity. The mix of scientists and technicians must be present in a culture to yield research and applications, perhaps helping to explain why science (in terms of numbers of publications and development of paradigms) has developed faster in nations that participated in the Industrial Revolution than in most other nations.

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