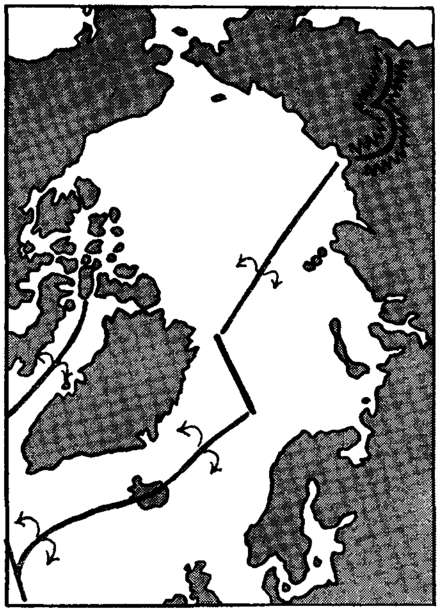
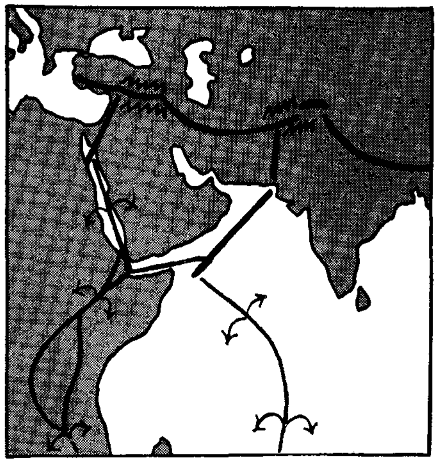




This pair of maps illustrates simply how accordion-like unfolding of Atlantic Ocean floor pushed up mountains in Russian north (left) and Asia (right).

—Maps by J. T. Wilson.

plausible. The existence at a depth of 50 to 400 kilometers of a slightly plastic, white-hot layer, called an asthenosphere, upon which Daly speculated, is now supported by several types of evidence, some of which has been mentioned. W. M. Elsasser, E. Orowan, and D. C. Tozer find flow or convection in a shallow layer to be acceptable, but S. K. Runcorn thinks that the whole mantle convects.

This theory is one form of continental drift, but it is not Wegener's version, for he visualized the continents as rafts moving through the ocean floors like moving ships, while the present concept regards the continents as passive blocks carried about with the ocean floors, like logs frozen in ice. But most of the old arguments in favor of continental drift would still be valid as well as all the new ones.

The magnetic imprinting of the upwelling rocks is the most persuasive evidence for a dynamic earth because the record can be read not only horizontally in terms of both space and time [see sketch, page 48] but in vertical space as well, in corings of sediments taken from the ocean bottoms [see sketch, page 48, and the article, "Were Comets the Midwives at the Birth of Man?", *SR*, May 6]. Other supporting evidence exists, however, in faulting and shearing of the earth's crust; and here again Canadian Professor Wilson has made a decisive contribution to theory. Opening of the Atlantic Ocean without driving great faults across the affected continents seemed impossible until he introduced the flexible geometry of an accordion [see map, page 49]. Only recently a team of scientists from the geochronology laboratories of the University of Sao Paulo, Brazil, and the Massachusetts Institute of Technology proved the practical applicability of his thinking by predicting —from the location of particular ore bodies along the Atlantic coast of Africa —where similar ore deposits would be found along the Atlantic coast of Brazil. Scientists from the Woods Hole Oceanographic Institution on Cape Cod have found fabulously rich mineral deposits in the waters above the mid-ocean rift in the Red Sea, just as Professor Wilson predicted would happen [see page 52]. And studies of the great Alaskan earthquake of Easter 1964 clearly suggest a relationship between the northwestern motion of the Pacific Ocean floor that he pinpointed and the 930-to-1,360-year subsidence of earth's crust that occurred in the Gulf of Alaska before the quake.

—JOHN LEAR,
Science Editor.

CANADA: SCIENTIFIC INNOVATOR

Advice for the Establishment

By J. TUZO WILSON

IT SEEMS trite and obvious to point out that on land, if one can imagine standing on top of the Alps for tens of millions of years, one can visualize that they would have been uplifted beneath one and that they would be worn away still underneath one's feet, but one cannot imagine the mountain heights moving off across Europe, leaving one still standing on the rocks that had formed the peaks. Odd as it seems, this is exactly what we believe to be happening on the ocean floors.

Another way of looking at the same phenomenon is to consider the behavior, during the breakup of Gondwanaland [the original continent that was supposedly centered at the South Pole], of the mid-ocean ridge which lies in the Southern Ocean. The ridge must have expanded away from the coast of Antarctica and moved across the mantle under the centrifugal force of the planet's rotation. Incredible as it may seem, this means that if the Rocky Mountains were part of the mid-ocean ridge system they would not have stayed in Alberta but might have moved across Canada to Ontario or even Quebec since the beginning of the Cretaceous period 140 million years ago.

These quite dissimilar mechanics are the reason why the transform faults of ocean floors [see map, page 49] differ in geometry from the faults studied on continents.

It would appear that relative to the earth as a whole the continents are small crusts which have been differentiated, become rigid (perhaps by dehydration) and which are not at all typical of the earth as a whole in behavior, composition, or history. If we are to view the earth in this perspective, most of our ideas in geology, geophysics, and geochemistry will need some reorientation.

Consider, for example, paleontology. Most paleontologists have considered the problem of continental drift, but they have argued about it for a century and come to such diverse and opposing views that one is forced to conclude that the study of fossils alone is not an adequate way to resolve this problem. Index fossils have provided isochronous markers for comparing the ages of rocks throughout the world. Now it appears that magnetic reversals may be more precise markers and may also be applicable to unfossiliferous rocks. Isotopic studies are providing absolute time scales. If the new techniques can provide exact reconstruction of continents and a better time scale, the whole of paleontology will need reworking. On the other hand, the new methods tell us nothing about ancient life and they are not applicable in all cases and by no means replace paleontology even as a tool.

What attitude one takes depends upon what one wishes to do. If the object is to study ancient life, then the new discoveries will aid paleontology and make it a more useful subject. If, on the other hand, the object is to study the earth, then paleontology appears to

Professor J. Tuzo Wilson is familiar to *SR* readers through his first-hand report on science in Communist China [*SR*, Nov. 8, 1958] during his term as president of the International Union of Geodesy and Geophysics. He numbers among his students Drs. L. W. Morley and R. J. Uffen, both listed in adjacent pages as among Canada's scientific innovators. The text reproduced here was excerpted from Professor Wilson's soup-pot lecture at Expo 67.

be a somewhat less useful tool for that purpose than had been supposed.

Geophysical subjects need a similar scrutiny. If earthquakes are due to steady flow in the mantle, our ideas on their mechanism, especially that of deep earthquakes, need reconsideration. It may be possible to explain the gravity anomalies found over ocean trenches and under the plains of India in a different manner. Maps cf magnetic anomalies will take on new meanings.

In the current discussions, petrology and geochemistry can play a decisive role only if the assumptions underlying the examination of petrogenesis are clear. In the past, geological dogma often tacitly led petrologists to believe that all igneous rocks came from molten magmas, that intrusive rocks remained fixed over their sources, that the mantle was uniform in composition, and that systems were closed so that one could apply laboratory results directly to field observations. If these assumptions are wrong, petrology and geochemistry are not invalidated but their problems are increased. Fortunately, isotopic studies can now be of great help in resolving these harder questions.

Even if one accepted all these novel views, the problems of the geology of a mobile earth would not be resolved. Indeed, they would have just begun, for the history of a mobile earth is quite different from what we have previously supposed. Geography has not remained fixed, but its changes must be plotted and the whole of historical geology requires to be rewritten.

Are none of the present ocean basins older than the Mesozoic era [it began 200 million years ago], as much evidence now suggests? Are all the continents composite? Were parts of North America attached to Europe, to Africa, and to Asia as recently as Cambrian time?

Fundamental to such questions are more general ones. Do convection currents flow steadily at constant rates for long periods, as F. J. Vine and J. R. Heirtzler have contended, or do they stop and start again? Is is likely that the pattern of flow and of mid-ocean ridges, besides moving about steadily, must at long intervals drastically change to new patterns? Could this cause the known alterations in the past distribution of mountain-building? Raymond Hide has raised the question of whether changes in flow patterns in the mantle are related not only to patterns of mountain-building and of drift, but also to rates of reversals of earth's magnetic field.

It is this turmoil of question and divergent answer which constitutes the present revolution and the exciting prospect for great advances in the earth sciences. All of geology, geophysics, and geochemistry will need re-examination for both content and usefulness if mobility is true.

As so often happens when something really new is discovered in science, the Establishment, if we may so describe those larger institutions most closely concerned with the subject, had little to do with it. The petroleum and mining industries paid little attention to the idea of continental drift. Most members of geological surveys and departments of geology and most geophysicists were not expecting any such revolution. In large measure it was expenditures and research related to defense and national prestige which first provided abundant knowledge of those hidden places. Naval research, stimulated by the need to detect and to navigate nuclear submarines, has charted the ocean floors, shown them to be quite unlike continents, and revealed there the largest mountain system on earth: the mid-ocean ridges [see *SR*, July 3, 1965]. Disarmament research, with its need to distinguish between nuclear explosions and natural earthquakes, has provided world-wide networks of greatly improved seismological stations and transformed our knowledge of the earth's interior. Space research is now making comparisons possible between the earth and its moon and between the earth and other planets: Mars, Venus, and Jupiter. The billions of dollars spent on these investigations, in part executed by universities and industry under contract, have provided, with unexpected suddenness, a body of data about the hitherto unknown parts of the earth which is comparable with the bulk of geological data that took so much longer to acquire.

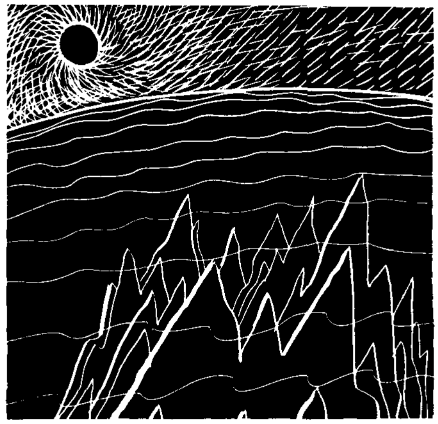
It is impossible to imagine anyone who is not a surgeon removing a brain tumor, or to believe that a supersonic plane could be designed except by aeronautical engineers. On the other hand, mines and oil pools have often been discovered without the help of geologists or geophysicists. This is a measure of the difficulty of our subject and of our ineffectiveness in dealing with it. Since industry has always reserved its greatest rewards and highest praise for successful prospectors and oil-finders, it is not surprising that geologists and geophysicists have not always had all the support they wished. Perhaps the new discoveries will change that situation.

If the continents are indeed composite and have been built or broken apart since petroleum was first deposited, our ideas about basins and about source areas of sedimentary rocks will need revision. The largest effects are to be expected in offshore oil basins. J. Barrell and C. Schuchert envisioned great offshore borderlands where now there is ocean. Such ideas may have been right after all.

The movements of continents may explain the opening or shutting of basins so that the rocks in them changed from marine, to continental, to evaporite conditions. Thus Y. Belmonte, P. Hirtz, and R. Wenger have suggested that the salt domes and oil deposits of Gabon in Africa and of the opposite coast of Brazil were formed when those continents started to break and the sea first entered the rift between them in mid-Cretaceous time. Continental drift may explain why the Texas basin seems to have been cut off in Permian time and why the Gulf of Mexico seems to have opened as a small evaporite basin during Jurassic time and, hence, why there may be salt domes on its floor under 12,000 feet of water.

In mining, the discovery of a proper theory of the earth could have far-reaching effects. According to present ideas, it is very difficult to explain why ore bodies are few while apparently equally favorable structures and host-rocks are abundant. In the continents, some great structures are rich in ores, others are barren. For example, the Urals, the line through Northern Manitoba, and that through Sudbury and Cobalt are rich, but the suture in New England, proposed to represent a former closure of the Atlantic Ocean, appears to be barren.

Some companies and some universities are alert to the need to make a more fundamental approach and to mix geology and geophysics together, but if the prospects raised in this paper are true the need is greater and should be carried further than has been generally appreciated.



Confirmation from Afar

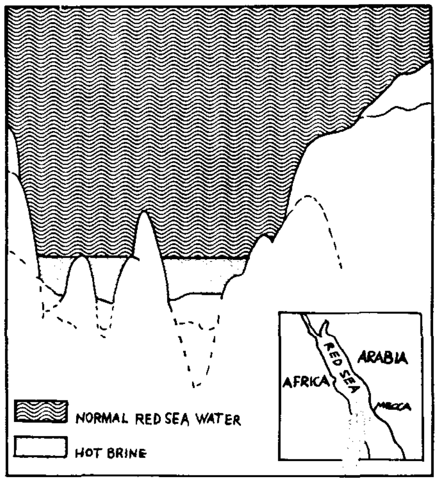
PRINCIPALLY, this report has to do with the discovery and scientific evaluation of hot brines and heavy metal deposits recently found by the efforts of British, German, and American research vessels in isolated deeps of the Red Sea. Geographically, these deeps are located equidistant between Arabia and Africa, near Mecca. The hot brines in the deeps occur below a depth of about 2,000 meters [6,500 feet] in three pools which have been named *Atlantis, Chain* and *Discovery* after the research vessels that discovered them. The largest hot water pool is contained in the Atlantis Deep, which covers an area of approximately 30 square miles, and has waters with a temperature as high as 56 degrees Centigrade [133 degrees Fahrenheit] and is in places 200 meters thick.

Such hot waters are termed brines to set them apart from normal Red Sea water. As the term brine indicates, the waters are highly saline, containing about ten times as much salt as is commonly dissolved in the oceans. The waters are reducing, as evidenced by the lack of free dissolved oxygen and the presence of traces of hydrogen sulfide. Furthermore, they are acidic, and of course hot, at least by the standards of a water-filled bathtub. In contrast, average Red Sea water has a salinity close to that of normal sea water, it is alkaline, oxidizing, and cold relative to our chosen bathtub standard.

The differences listed so far explain why the two water bodies, the Red Sea above and the hot brine below, are physically separated. The temperature and salinity differences cause convection currents, which keep the heavy brine constantly in slow circulation and close to the bottom of the sea.

Aside from these typical brine properties, the waters contain heavy metals. As a matter of fact, some heavy metals may reach concentrations as high as 50,000 times the amounts commonly observed in the ocean. Metals of special interest include iron, manganese, zinc, lead, copper, silver, and gold.

Probably man has never seen a more colorful sedimentary product emerge from the depths of the sea than the 4 meter x 15 centimeter x 15 centimeter square-box cores collected on the *Chain* cruise in fall 1966. The individual layers are well-defined, even down to layers of less than one millimeter thickness. The color variation is fantastic; all shades of white, black, red, green, blue, or yellow can be observed. Perhaps some of the more colorful Indian sand paintings and Mexican rugs faintly match these sediments in the variation and intensity of their colors.



—*Oceanus.*

Cross section of Red Sea bottom soundings shows hot brines suspended under normal sea water. Compare this map with smaller of two maps on page 50.

THE chemical and mineralogical examination of the sediments is quite revealing. After accounting for the interstitial water and the water-soluble salts, the residue is approximately 90 per cent of heavy metal oxides and sulfides, of which the most abundant are those of iron, manganese, zinc, and copper. Although we have penetrated into the metal ooze only about 10 meters, the seismic record suggests that the thickness of the beds might be more than 100 meters in places.

Dr. F. T. Manheim, of the Woods Hole branch of the U.S. Geological Survey, informs us that according to his estimates the heavy metal deposits in the Red Sea offer an ore potential of about 130 million tons, representing a value of $1.5 billion due to the concentration of copper, zinc, silver, and gold. The dollar value of iron and manganese is not included in this calculation.

Dr. Manheim's $1.5 billion figure is rather conservative because it is only based on the Atlantis Deep area, and because a thickness of only 10 meters for the ore body has been assumed. Yet the value of this metal-bearing sediment would exceed the total mined ore of the Coeur d'Alene district in Idaho since mining began there in the 1870s.

An unanswered question is the origin of the salts, the heat, and, last but not least, the metals. Isotope studies done by Dr. H. Craig, of the Scripps Institution of Oceanography, and at our laboratories, reveal that the source of the hot brines most likely is the Red Sea. The metals, on the other hand, probably are derived from more interior sources of the earth and are linked with the hydrothermal, magmatic, and tectonic events of the region.

IT is speculated that tectonism and rifting has opened migration paths for the passage of ascending ore solutions and descending Red Sea waters. On their way up or down, both waters have leached out rock formations. For example, the Red Sea waters have become saturated with salts from evaporitic beds through which they migrated whereas the chemically aggressive hot waters, due to their carbon dioxide and hydrogen sulfide content, may have picked up some of the metals from deeper rock formations.

The high heat flow in the sediments, which may amount to as much as 2 degrees C. per meter depth of burial, can act as a convenient heat source for the slowly percolating brew. Occasional discharge of hot brines into the open ocean, as evidenced by intensively colored heavy metal layers in sediments outside the hot area, can be regarded as the best guarantee for the continuous supply of metals, salt, and heat.

That the waters have been preserved at all is mainly due to the intrinsic morphological and geological setting in this area. We feel, however, that this phenomenon of hydrothermal solutions is not restricted to the Red Sea but is a common feature in all those parts of the world where rift activities presently are displayed. Areas of high heat flow, such as the East Pacific Rise, should thus be more carefully examined for heavy metal anomalies.

Students of hydrothemal mineral deposits and Precambrian iron formations may find in the Red Sea hot brine area a recent counterpart of the ancient ore formation processes. In studying the environmental conditions under which the Red Sea minerals presently are laid down, one may gain insight on the origin of hydrothermal ore deposits and on the conditions in the primordial sea at the time Precambrian iron formations (such as those in the Great Lakes region of the United States) originated.

—E. T. DEGENS and D. A. ROSS
in *Oceanus.*

Oceanus is the journal of the Woods Hole Oceanographic Institution. The above excerpt from it will be part of a book scheduled for publication in 1968 by Springer Verlag, New York.