Oceanography: Geochemical Tracers Offer New Insight

Generations of oceanographers have collected samples of seawater and analyzed its chemical constituents, a process that has gradually led to the identification of oceanic regions vaguely characterized by such features as high salinity or low oxygen content. But the sporadic nature of these investigations has not yielded a very complete picture of the chemical patterns within the world oceans. Still less is known about how these patterns are controlled by physical and biological processes such as currents, turbulent mixing, and planktonic life cycles.

This state of affairs is now rapidly changing, however. A huge, systematic sampling effort, known as the Geochemical Ocean Sections (Geosecs) program, has produced an unprecedented body of new information on nearly 40 major and minor constituents of seawater. In addition to their intrinsic geochemical interest, these data are already proving the usefulness of geochemical tracers for studying circulation patterns and mixing processes within the oceans—including the fate of radioactive and chemical pollutants of human origin. The data also promise to help unravel many aspects of the ocean's biological cycles.

The scale of the effort can be gauged by the more than 7000 separate water samples collected from the Atlantic Ocean alone—from 50 depths at 110 stations along a largely north-south track extending from the Arctic to Antarctica. Similar collections have been made in the Pacific and are to get under way next winter in the Indian Ocean. At the heart of the program is the most sophisticated sampling system ever devised for oceanography. Rosettes of 30-liter bottles are lowered into the ocean on a frame that also carries instruments to measure temperature, pressure, salinity, dissolved oxygen content, and particulate content. Signals from these instruments are telemetered to the ship continuously during the descending leg of a cast and the resulting profiles displayed on a control console. During the ascending leg, the chief scientist aboard triggers the collecting bottles at the depths that best sample the features of the water column displayed in the profiles. The system, developed by Arnold Bainbridge of Scripps Institution of Oceanography, has been criticized by some oceanographers as too elaborate, but most Geosecs participants believe it is a major improvement over the old technique of sampling "blind" at predetermined depths. In any event, the procedure yields an extremely detailed knowledge of the hydrographic context from which each sample was obtained.

The samples themselves are analyzed in automated shipboard laboratories and later in university laboratories for some 23 chemical species, for 15 isotopic species, and for the amount and types of particulate matter. By standardizing analytical procedures, the Geosecs investigators appear to have achieved a degree of consistency from sample to sample not usually found in oceanographic data. In addition, the analytical effort set some new records for precision; ^{14}C concentrations, for example, were determined to within about 0.5 percent, more than twice the accuracy of most previous measurements. Portions of each sample from Geosecs are also placed in repositories for future studies.

The results from the Atlantic and Pacific expeditions (which took place in 1972 and 1973, respectively) have only been widely available in the last 6 months, but already it is clear that the data will have a major impact on oceanographic research. For example, pollution of the oceans with man-made substances is an increasingly serious problem, but little is known about how rapidly the process might proceed or where the effects will be felt first. Present circulation models or even the extensive data gathered by current meters are not yet adequate to unravel oceanic mixing patterns. Now Geosecs measurements of the distribution of the radioactive isotope tritium, a heavy form of hydrogen, have provided the first large-scale empirical picture of the results of the mixing process—in effect, showing how an atmospheric pollutant that is washed out of the air by rainfall ultimately penetrates the oceans.

The tritium was produced by the atmospheric testing of nuclear weapons by the United States and the Soviet Union in the 1950's and early 1960's. Within a few years, the tritium for this inadvertent geochemical experiment, in the form of tritiated water, had reached the ocean surface waters. Extremely sensitive measurements of tritium made by H. Gote Östlund and his co-workers at the University of Miami during Geosecs have enabled the investigators to plot the extent to which this isotope has penetrated the deep ocean, giving a snapshot of the mixing process about 10 years after it began (Fig. 1). Östlund's results show that the mixing process is extremely rapid and that, in the northernmost parts of the North Atlantic, the tritium "dye" has already reached the oceanic bottom waters: this rapid descent is believed to be due to the sinking of cold, saline surface water from the Greenland and Norwegian seas. Östlund believes that the plot also predicts the path and rate of spreading for most other man-made pollutants, since they are predominately released to the environment in the Northern Hemisphere.

Tritium has a radioactive half-life of 12 years, so this particular tracer will not be indefinitely available, but there are a variety of longer-lived, naturally occurring radioactive isotopes in seawater. Indeed, the power of the geochemical approach to understanding circulation patterns and other physical processes within the oceans stems from the complementary use of both radioactive and stable tracers. Deep ocean waters, for example, can be characterized by their salinity and their concentrations of other stable species. Highly saline bottom waters flow toward the equator from the North Atlantic and the Antarctic region of the South Atlantic. The path of these abyssal or deep ocean currents and the extent of their mixing with waters of different origins can be determined from stable chemical tracers that serve, in effect, as indicators of the source of a particular body of water. Radioactive tracers, on the other hand, serve as nuclear time clocks for the circulation and mixing patterns, indicating the rate of flow and thus providing a time scale for circulation patterns. Water in the deep ocean, for example, may require 500 years or more to make a complete circuit of a circulation pattern, a rate too slow to measure by direct means but possible to measure geochemically.

Carbon-14, for example, is produced in the atmosphere by cosmic rays and gradually mixed into the oceans. With a half-life of 5700 years it is what marine geochemists consider a key tracer for determining how long water in the deep ocean has been isolated from the surface. The ^{14}C concentrations allow investigators to map the "aging" of deep water that is formed as cold surface waters in the North and South Atlantic sink and spread out along the ocean floors, gradually mixing upward into the waters above. Exactly how the deep waters eventually return to the surface is not yet known, but geochemists have high hopes

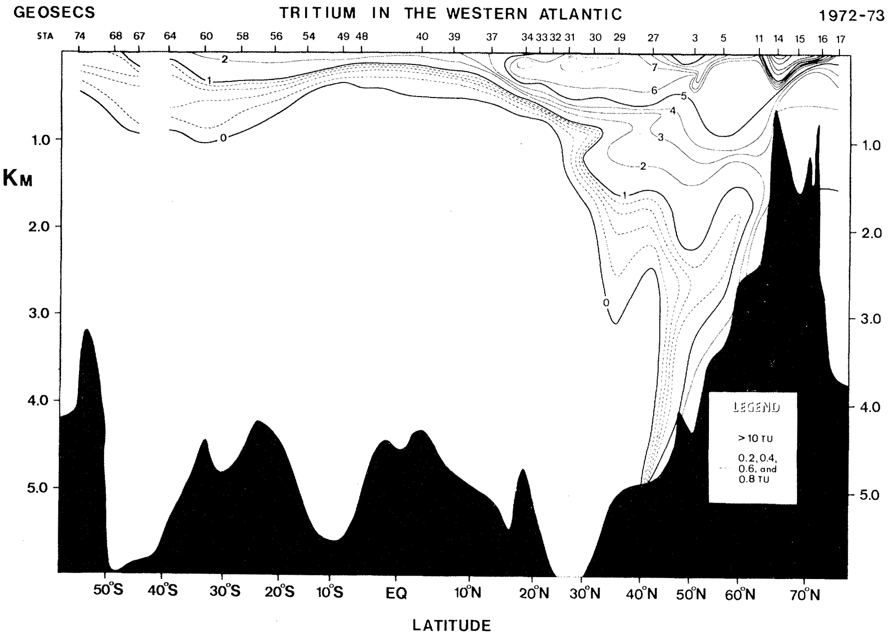

Fig. 1. Tritium profiles in the Atlantic Ocean, indicating the extent to which bomb-produced material has penetrated the deep ocean over a period of about 10 years. The dark area represents the relief of the sea floor. [Source: H. Gote Östlund, University of Miami]

that the ^{14}C will help to elucidate the circulation pattern. The data analyzed so far seem to confirm what was suspected earlier, that the Pacific Ocean has no source of "new" bottom water within its basin but is instead supplied by a complex abyssal current with water formed in the South Atlantic near Antarctica; the ^{14}C concentrations in the deep Pacific are correspondingly lower than in the Atlantic, indicating "older" water.

The ^{14}C data will also be crucial to resolving a debate now under way among physical oceanographers as to the magnitude of the deep ocean flows. The question is whether the deep waters follow a pattern roughly similar to that of the wind-driven surface waters (many oceanographers now suspect that they do) and whether the volumes of water being circulated are also comparable, as some have suggested. Indeed, the Geosecs results seem likely to promote a closer collaboration between physical and chemical oceanographers, heretofore very disparate groups. George Veronis of Yale, one physical oceanographer who has begun to make use of the Geosecs results in his circulation models, describes them as "an unparalleled set of data."

Studies with radioactive tracers are also indicating the nature of turbulent mixing processes near the sea floor. J. L. Sarmiento of Lamont-Doherty Geological Observatory and his colleagues obtained vertical profiles of ^{222}Rn (with a half-life of 3.824 days) and ^{228}Ra (half-life, 5.72 years) accompanied by hydrographic data in the Atlantic and Pacific on Geosecs cruises. Both isotopes originate in the sediments and mix upward into the water column, so that the resulting profiles are the result of the (known) rate of radioactive decay and of turbulent mixing. The model that best explains the results, Sarmiento finds, is one in which the strength of the turbulent mixing varies inversely with the gradient of the density of the seawater; the more constant the density with depth, the stronger the mixing. The result is the more surprising for its simplicity, given the often complex theoretical formulations used to model turbulence. The investigators believe that this relationship may be widely applicable to deep ocean mixing processes.

New insight into circulation and mixing patterns may also help to explain the distribution of geochemical species. Derek Spencer, a geochemist at Woods Hole Oceanographic Institute, has proposed that the major horizontal circulation patterns or gyres rapidly mix the water within them but exchange water much more slowly across their boundaries. This, he believes, accounts for what appear to be relatively uniform concentrations of several chemical species found within gyres and strong gradients at their edges.

Nutrients have not been thought useful as tracers for circulation patterns because they are taken up in the biological cycle and hence are not conserved. Wallace Broecker of Lamont-Doherty has proposed, however, that a composite indicator consisting of nine times the nitrate concentration plus the dissolved oxygen concentration does remain nearly constant in a given body of water regardless of biological activity. The rationale is that nearly nine moles of nitrate are produced for each mole of oxygen consumed during respiration by marine microfauna. He and others have used this composite indicator, in combination with salinity and temperature, to characterize deep ocean water from different sources and hence to deduce the composite origins of water masses.

Broecker also points out that Geosecs measurements of alkalinity and dissolved inorganic carbon will permit oceanographers to calculate how rapidly CO_2 interacts with sea floor sediments—thus determining the time scale of the oceanic sink for this growing atmospheric constituent.

In addition to their impact on the knowledge of physical processes, the Geosecs investigators expect to be able to contribute new information about biological cycles in the oceans. Many nutrients and other chemical species, for example, are taken up by growing organisms near the sea surface and then recycled as the particulate remains of the organisms dissolve while falling to the sea floor. Other chemical constituents of marine biomatter are recycled, if at all, only after they are released through chemical reactions within the sediments.

It turns out, Geosecs investigators say, that the small particulates normally collected in the ocean do not account for much of the flux of matter toward the sea floor. Instead, large, rapidly settling particles such as fecal pellets from zooplankton are now thought to be more important. Additional information on the settling process has been obtained by Devendra Lal and his co-workers at the Physical Research Laboratory, Navrangpura, India. They have used bomb-produced radioactive isotopes that have been incorporated in the particles to measure settling rates for particulate matter of different types. Knowledge of the distribution of nutrients and trace elements within the water column and of the key role of particulates is helping to unravel the processes that control the return of nutrients to the sea surface, which in turn controls the biological productivity of the oceans.

In some instances it is the removal rather than the return of an element to the ocean that is of interest, and here also particulate matter appears to play an important role. Radium found in seawater decays into ^{210}Pb and ^{228}Th. Geosecs investigators have discovered that these daughter isotopes are somehow removed from the deep ocean. The exact process is not yet known, but the data seem to indicate that these heavy metals are scavenged and removed by particulate matter, a process that has been established for copper. Since disposing of nuclear reactor wastes at sea may release quantities of thorium and lead, among other radioactive isotopes, the effectiveness of these presumably biological mechanisms is of no little interest.

In proposing the Geosecs program, marine geochemists held out the idea of establishing a baseline against which man-made changes in the global environment could be measured. Unexpectedly, shipboard measurements of atmospheric nitrous oxide (N_2O) concentrations made during Geosecs cruises and some earlier measurements of the gas 10 years ago in the Pacific have shown the value of a baseline and of a sample bank for later analysis. Nitrous oxide is produced in soil and in the surface layers of the oceans and destroyed in the stratosphere, where it is also the main moderator of ozone. Several scientists concerned with threats to the ozone layer have suspected that widespread use of fertilizers was accelerating N_2O production in the soil. Harmon Craig and Ray Weiss of Scripps compared the recent samples with those collected earlier by the late William Dowd of Scripps and found that average concentrations for equivalent sites in the Pacific had increased by about 4 parts per billion in a decade—a rate that they project would cause a 7.4 percent increase in atmospheric N_2O and a corresponding 1 percent decrease in ozone by the year 2000 and a far more serious effect thereafter. Craig proposes, however, that at least half of the increase in N_2O is probably due to combustion of coal and oil in electric power plants, not fertilizer use. Whatever the source, the result appears to be the first definite indication of a long-term increase in atmospheric N_2O.

Another Geosecs result has proved of interest to solid earth geochemists. Craig and his co-workers found concentrations of the helium isotope ^3He in the Pacific Ocean in excess of the amount expected from its atmospheric abundance relative to ^4He, the more abundant isotope. The excess ^3He was most concentrated in the eastern equatorial Pacific above the East Pacific Rise, where new oceanic crust is being formed by sea-floor spreading. J. E. Lupton and Craig subsequently found that basalts from the Rise are also enriched in ^3He, an indication that the oceanic ^3He is primordial—part of the earth's initial endowment and not of recent atmospheric origin. They conclude that the earth has not completed its internal evolution and is still outgassing, injecting helium from the mantle into the deep Pacific from the crests of the mid-ocean ridges.

What has been obtained from the Geosecs project so far is only preliminary; study of the massive amount of data has just begun. Broecker believes that the data will dominate efforts to understand ocean circulation and mixing processes for the next decade. In any case, it is likely that the increasing sophistication of geochemical research in the oceans will be productive in ways not yet knowable and perhaps vital to managing an increasingly crowded planet.

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The Aging Heart: Changes in Function and Response to Drugs

Most studies of heart disease have been concerned with heart disease in those under 65—the so-called "premature" heart disease. This emphasis is understandable both because premature heart disease strikes people who are more likely to be economically productive and because it usually is more shocking to see a younger than an older person die or become disabled. But the fact remains that most heart disease occurs among people aged 65 or older. Heart disease is so common among old people that it accounts for more than 40 percent of the deaths in this age group.

Heart disease in old people may have different causes and require different treatment than premature heart disease. The changes in the heart that come with age are likely to affect its susceptibility to damage and its response to drugs. In order to determine the degree to which conclusions from data on premature heart disease can be generalized to older people, investigators are studying the epidemiology of heart disease in the elderly and the biochemical changes that occur in the aging heart.

It would be desirable to study the effects of aging on the cardiovascular system by recording physiological changes that occur in members of a group of people as they relate to their chances of dying from heart disease over the course of their adult lives. This is not often done because it is expensive and because people tend to drop out of long-term studies. Thus, only a few studies of this type are being conducted.

One of the most successful long-term studies began in 1949, when the U.S. Public Health Service began recruiting about 6000 people between the ages of 30 and 59 from the town of Framingham, Massachusetts. This continuing investigation is providing some insights into the effects of risk factors for heart disease on people of all ages, including those over the age of 65.

This is the ninth in a series of Research News articles examining recent developments in research on heart disease.

According to William Kannel, who directs the Framingham study, some major risk factors in younger people do not seem to affect the elderly. Serum cholesterol concentrations and cigarette smoking, for example, are not good predictors of heart attacks or strokes in the elderly. (Smoking is associated with the development of lung cancer and emphysema in the elderly, however.) And diabetes seems to have less effect on old men than young, although it does predispose old women to develop heart disease. Kannel says that the best predictors of heart disease in old people are hypertension, electrocardiogram findings, high-density lipoproteins (which are associated with lowered risks) and, in women, diabetes. He emphasizes that, contrary to a widespread belief, hypertension is as much a threat to the old as to the young. The lower an old person's blood pressure, the lower his or her risk of developing heart disease. (Old women with low blood pressure, Kannel says, are "practically immortal.")

Since risk factors for heart disease in the young may not be risk factors for the elderly, not all research on the causes of premature heart disease may be applicable to heart disease in old people. In order to understand the genesis of heart disease in the elderly, it is helpful to know both the biochemical and the physiological changes that occur with age. An emphasis on studies of both physiology and biochemistry is the thrust of research at the National Institute of Aging (NIA) in Baltimore, where investigators are now beginning to piece together a picture of changes in the aging heart.

One of the most striking physiological changes that occurs with age is a decline in the heart's ability to respond to stress. This decline, first reported as early as 1929, has been confirmed by numerous investigators. During the stress of exercise, heart rate and blood flow increase, but the magnitude of these increases is smaller in older than in younger people.

James Conway of Imperial Chemicals in Cheshire, England, and his associates find that these age differences in re-