tain sign that it is no longer enough just to be a microcircuit producer.

Moreover, there is a blurring of the line between chip makers and equipment manufacturers, in part because of the consumer electronics boom. Companies that made microcircuits for calculators, for example, soon realized that it could be more profitable to make the entire instrument. National and TI, more than other companies, have exemplified this trend, whereas Intel, except for an ill-fated digital watch venture, has stayed aloof from it.

A further blurring of the line comes from those companies making products that use microcircuits, such as defense systems manufacturers who wanted chips so specialized that microelectronics firms would not agree to fashion them. They have developed their own in-house microcircuit fabrication capability. Western Electric and IBM have always made integrated circuits for internal use. (IBM makes about the same number of microcircuits as TI.) Now most major manufacturers of large and minicomputers have the ability to make some of their own components. Among instrument manufacturers, Hewlett-Packard is an outstanding example of a company making its own proprietary chips.

One of the hot topics of debate at recent electronics conferences has been whether the VLSI era of microelectronics will belong to components manufacturers newly become equipment makers or to systems houses that now make their own microcircuits. At the International Electron Devices Meeting, Petritz took the middle road, declaring that there would continue to be a place for both types of businesses, because it is too hard for most companies to be successful in both activities. Some chip companies might survive as independent divisions of larger corporations, however.

It is remarkable that, almost to a man, those in the microelectronics industry do not regard themselves as being in revolutionary times. Ralph Gomory, a vice president at IBM in charge of its Research Division, thinks it may all be a matter of perspective. In his view, technology inches ahead continuously. But new applications can seem to be revolutionary because they appear only when a succession of technical advances suddenly makes possible an application that was previously not feasible. Whatever the case, the changes being worked within the microelectronics industry itself as the VLSI era approaches certainly seem as dramatic as the effects previous generations of microelectronics have already had on society.

One question that has been asked (*Business Week* titled a story last December, "Can Semiconductors Survive Big Business?") is whether the creativity and entrepreneurial drive that characterized the early days of microelectronics can be continued in the new era of giant corporations. It is important that the answer be "yes" because competition from overseas and Japan in particular is becoming formidable. The next article will be on international competition in microelectronics.

—ARTHUR L. ROBINSON

A New Kind of Storm Beneath the Sea

Marine geologists and physical oceanographers are each sorting out their own types of evidence for surprisingly swift currents across the bottom of the deep sea

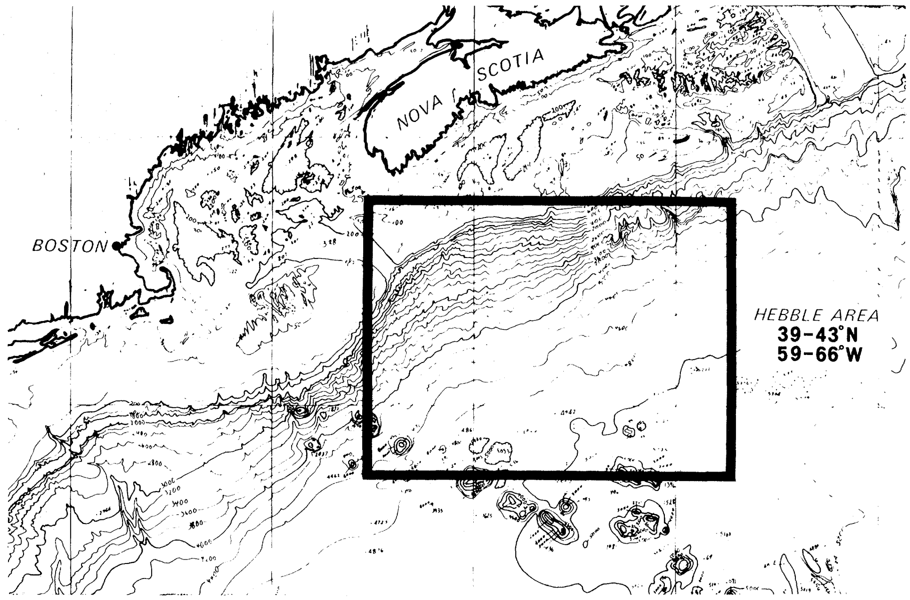
The bottle of water hauled onto the ship's deck from near the sea floor 5000 meters below was strange indeed. Instead of being as crystal clear as bottled springwater, the way most open ocean water is, this sample was muddy—it looked more like river water than seawater. Although researchers had come to this spot south of Nova Scotia last year to study how currents lift clouds of mud off the sea floor, the heavy cloudiness that they found astounded them. Measurements showed that water near the bottom had been muddied with 100 times as much sediment as is found in most parts of the ocean and several times more than had ever been seen before.

All the mud was being kicked up by intermittent currents that were twice as swift as physical oceanographers expected, among the strongest currents ever measured across the deep sea floor. Geological oceanographers, who have been studying ripples in the bottom mud caused by currents, expected high-speed currents because they could not imagine any other cause for the kinds of ripples seen in the bottom sediments. The new observations lend some credence to the geologists' claims of a broad, fast current along the western edge of the deep Atlantic, but detailed observations have covered too short a period to permit firm conclusions. Many researchers would agree at this point with the oceanographer who noted that "we just don't know what's going on down there."

Circumstances are inevitably pushing geological and physical oceanographers toward closer cooperation in the study of the boundary between the sea and the sea floor, but such studies have been some time in coming. As early as 1936, the late Georg Wüst of the Institute of Oceanography at Kiel measured variations in the deep-sea temperature, pressure, and salinity, variations that drive the major ocean currents, and concluded that deep-sea currents were not as sluggish as had been supposed. They probably could, he said, alter the shape of the sea floor and carry sediment great distances. "Geologists were slow to grasp the importance" of Wüst's calculations, according to Charles Hollister, a marine geologist at the Woods Hole Oceanographic Institution on Cape Cod. Further papers by Wüst in the 1950's and personal appeals to individual geologists, such as Hollister and the late Bruce Heezen of Lamont-Doherty Geological Observatory, eventually led to the first studies of the effects of currents on the deep-sea bottom.

But then it was the geologists' turn to goad the physical oceanographers. The latter began to directly measure deep current speeds of 10 to 15 centimeters per second (or about 0.5 kilometer per hour), speeds that had been predicted by Wüst. But the geologists started to suggest, on the basis of photographs of bottom features, that even faster flows must occur over many parts of the ocean. By looking at the types of ripples, the way sediment collects behind obstacles, the shapes of scour marks in the mud, or the smoothness of the bottom, geologists eventually assigned speeds of 40 centimeters per second or more to currents that had never been measured directly. In some cases, the currents described by geologists struck many physical oceanographers as being rather unlikely.

The prime example of this dichotomy of opinion is the apparent existence of two Atlantic western boundary undercurrents—the classical undercurrent proposed by the physical oceanographers and a stronger, deeper current based on the evidence of the geologists. These are casually known among researchers as the "geologists' undercurrent" and the "physical oceanographers' undercurrent." The source for either would be the dense bottom water that spills from the Norwegian Sea over the submarine ridges on either side of Iceland. According to calculations of the sort made by Wüst and a few direct measurements, this water hugs the bottom along the side of the Atlantic basin at depths of 2500 to 4000 meters as it heads south at moderate speeds of 10 to 20 centimeters per second.



The HEBBLE study area in which high-speed currents over the deep sea floor were detected. The area includes the continental shelf in its northwestern corner, the steep continental slope below the shelf (region of closely spaced contour lines), the gently sloping continental rise, and the flat abyssal plain in its southeast corner. The HEBBLE instrument array generally extended along a northwest-southeast line in the south-central portion of the box. The New England Seamounts run across the southwestern corner of the box.

Some geologists, on the other hand, see geologic evidence of a stronger, deeper current across the entire continental rise (the barely sloping apron of sediment below the continental shelf) from a depth of 4000 to 5000 meters. Flowing in the same direction as the classical undercurrent, this undercurrent seems to be strongest, at least off Nova Scotia, between 4800 and 5000 meters where it forms meter-wide, 15-centimeter-high ripples parallel to the current, according to Brian Tucholke of Woods Hole. Tucholke had estimated that such features and the amount of sediment suspended in the bottom water in the area could only result from currents of 40 centimeters per second or more that flowed predominantly to the southwest.

Responding to such claims, some physical oceanographers, including Valentine Worthington of Woods Hole, point out that they are unable to find a likely source of water to supply a steady current at that depth. Others, such as James Luyten also of Woods Hole, wonder whether the bottom features show the typical strength and direction of currents in the area or perhaps reflect an infrequent combination of unusual circumstances.

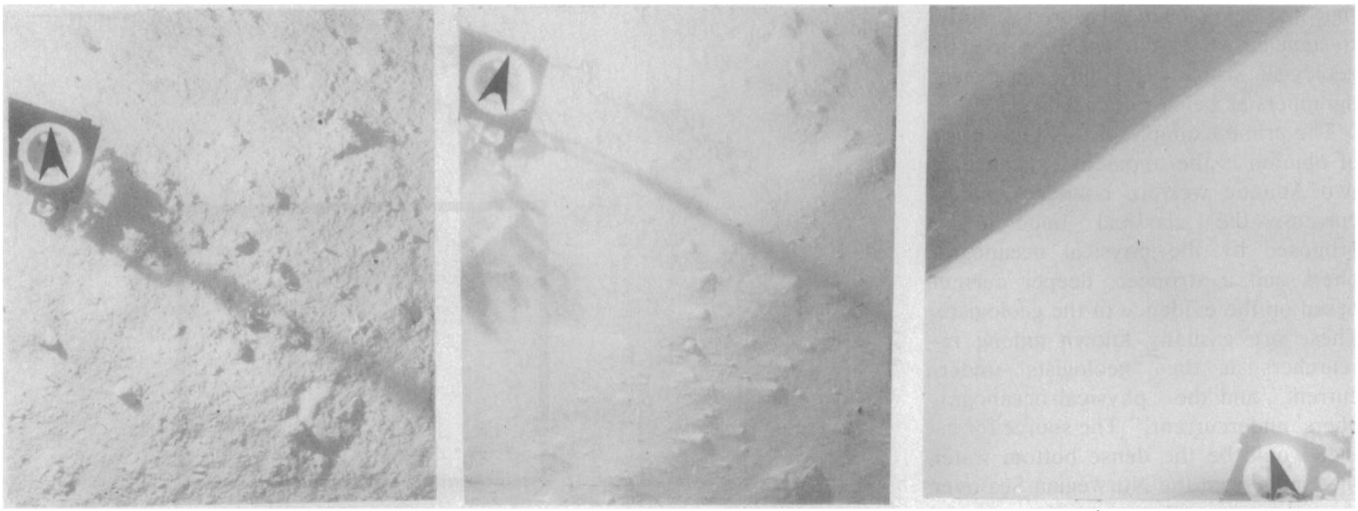
Last year's observations of deep, high-speed currents will not completely resolve these questions because the records so far are for too short a period to make clear what is going on in the unexpectedly complex area chosen for study. The continental rise off Nova Scotia appeared to be a geologically simple area to planners of the High Energy Benthic Boundary Layer Experiment (HEBBLE), an effort intended to study how swift currents and the surface of the sediments interact. Data gathered during two research cruises last year, one in July and one in September, and from instruments left on the bottom between cruises show that the currents in the HEBBLE area surge to high speeds, abate rapidly, and swing through different directions over only a few weeks.

The muddy water samples gave the first clue that the bottom waters of the HEBBLE area are exceptionally energetic. Instead of containing 50 to 100 micrograms of suspended sediment per liter of seawater, which is typical of much of the Atlantic, Pierre Biscaye of Lamont-Doherty found that his muddy samples contained 10,000 to 12,000 micrograms per liter. But Biscaye's results varied from place to place and time to time. The water near the bottom seemed to be more turbid on the deeper part of the rise near depths of 4800 to 5000 meters. In one spot, Biscaye's value of 1000 micrograms per liter had fallen to 50 micrograms per liter a week later.

Ronald Zaneveld of Oregon State University found even more rapid fluctuations when he lowered his transmissometer, an optical instrument that measures the clarity of seawater, to near the bottom in the HEBBLE area. Clean seawater has a transmission value of about 68 percent, but Zaneveld detected unprecedented changes in transmission of 20 percent in an hour and 5 percent in 1 minute. This variability convinced him that currents within 400 meters of the bottom were wafting clouds of sediment along the rise that were much smaller than a kilometer in size.

Several current meters placed on the sea floor recorded equally energetic activity. A 30-meter chain of current meters dubbed the Chandelier, which was intended to float nearly vertically from an anchor on the bottom, heeled over more than 35° when hit by surges of current. Allowing for the odd stance of his instrument, Georges Weatherly of Florida State University estimates that the bottom current climbed from about 20 to 50 centimeters per second and then fell back to 20 centimeters per second during a 5-day period last September. Although the nearby Gulf Stream moves as fast as this at the surface, its speed decreases with depth, as does the speed of most surface currents, and is not thought to extend to the bottom in such deep waters.

In addition to its considerable depth, the variability of the current surge suggests that it was not a part of the classical undercurrent either. At the time of the surge, a string of current meters set on the bottom across the rise by Mary Jo Richardson of Woods Hole measured a modest speed of 18 centimeters per second toward the west at a depth of 4100 meters, as might be expected for the classical undercurrent. At the same time, an instrument at a depth of 4985 meters registered a fairly steady flow of 45 cen-



Bottom photographs in the HEBBLE area showing the effects of three different current speeds. The photograph on the left shows a tranquil scene at a depth of 3804 meters. It appears that any currents in the area have been too weak to affect the delicate features created by burrowing animals. In the center photograph, taken at a depth of 4868 meters, a strong current with an estimated speed of 20 to 40 centimeters per second has smoothed the bottom so that only the more resistant burrowing features remain. These so-called crag-and-tail features indicate that the current flows to the west here. (The arrowheads indicate true north.) On the right, a current estimated to be greater than 40 centimeters per second has created a nearly smooth, featureless surface and a triangular ridge (the sharp, linear feature casting the dark shadow), suggesting that the current flows to the west-southwest here. [Source: Brian Tucholke and Charles Hollister, Woods Hole Oceanographic Institution]

timeters per second to the west-northwest, while the current 50 kilometers away at 5040 meters first surged to the northwest, abated to near stagnation, and then surged to the east at 30 centimeters per second. These observations are "remarkably consistent" with the directions and velocities indicated by the bottom features photographed near each of the meters, according to Tucholke, considering the short observing time.

Instruments left on the bottom between the two cruises last year indirectly recorded other current surges. A transmissometer observed three other periods of extreme murkiness lasting 3 to 5 days each, according to Zaneveld. All of them were more intense than the event observed by the current meters. All had transmissions of less than 20 percent, and one included a transmission of less than 0.01 percent. "That's about as dirty as any water I've seen anywhere," Zaneveld notes, "and that includes estuaries." Even during relatively quiet times, such as during much of August, the variations in turbidity compared with the largest changes seen in much of the rest of the Atlantic.

As HEBBLE researchers begin to draw their data into a coherent picture, they and others are wondering how the deep bottom waters can be stirred with such violence. The western boundary undercurrent, the Gulf Stream, and the ring-like eddies that it spins off (*Science*, 28 October 1977, p. 387) do not seem to be candidates because their currents are not thought to reach the deepest parts of the ocean. It has been hypothesized that a deep circulation passes through the edge of the HEBBLE area, resembling a compact but near-bottom version of the Gulf Stream system. But it would not be sufficient to explain the direction indicated by the bottom features or the speeds of the observed currents, according to Worthington, who originated the idea.

Perhaps the closest comparison that can be made is with equally fast flows observed by Luyten on the continental rise northeast of Cape Hatteras. When he placed current meters beneath the Gulf Stream to find how far it extends toward the bottom, he found that the bottom water was actually sloshing back and forth across the rise. Reaching peak flows of 50 to 60 centimeters per second, the water seemed to be reversing its direction every 25 to 30 days and thus producing no net flow in any direction.

Luyten is not sure what drives such oscillating currents, which apparently occur all along the coast, but he is confident that they are at least indirectly associated with and to some extent driven by the Gulf Stream. This narrow, swift current lying off the U.S. east coast snakes back and forth, throwing off energy in a form that could cause the water over the rise to slosh back and forth with the observed 50- to 60-day period, according to Luyten. Whether the same process could explain the bottom features and currents observed in the HEBBLE area, he is not sure.

Although most physical oceanographers familiar with the problem suspect that the Gulf Stream must be involved, Albert Williams, a physical oceanographer at Woods Hole and a HEBBLE team member, believes that no one on either side has as yet bridged the gap between what the geologists see and what the physical oceanographers can explain. In the case of Luyten's oscillating currents, Williams believes that their general north-south direction up and down the rise could not explain the ripples in the HEBBLE area, which trend toward the west. Current markings on the bottom indicate a consistent flow direction over hundreds of kilometers, Williams points out, but the oscillating currents appear to be less than 50 kilometers wide. The currents in the HEBBLE area also seem to surge and abate more quickly than those to the south, he says. A complicating factor, he and others point out, may be the chain of submerged extinct volcanoes to the south of the HEBBLE area that could alter currents.

The most immediate need is for a record of current speeds and directions longer than the presently available 2-week record. The only current meter left on the bottom between last year's cruises broke down after only a few days. An 8-month record should be in hand after the Triffid instrument array (named for its resemblance to the sci-fi monsters of the same name) is recovered shortly. Then, it should become clearer what the typical, ripple-forming currents are like.—RICHARD A. KERR

Additional Reading

Oceanus **21** (No. 1) (winter 1978), entire issue.