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NOTES ON  
THE JOINT SCRIPPS INSTITUTION OF OCEANOGRAPHY-U. S. NAVY  
ELECTRONICS LABORATORY MID-PACIFIC EXPEDITION

The motor vessel HORIZON of the Scripps Institution, (a converted Navy fleet tug, formerly ATA-180, which after the war was at Bikini during operation CROSSROADS) and the EPCE(R)-857, a 220-foot research vessel assigned to the U. S. Navy Electronics Laboratory have just returned (HORIZON October 28, EPCE(R)-857 on November 3) from an expedition lasting somewhat over three months, to explore the ocean waters and the sea bottom of the eastern central Pacific, between San Diego, the equator, and the Marshall Islands, and extending north as far as  $40^{\circ}$  north latitude. The two ships travelled a total distance of over 29,000 miles, considerably more than the distance around the world at the equator. The ships left San Diego on July 28th in company, proceeded to latitude  $4^{\circ}$  North, longitude  $140^{\circ}$  West and from there to the Hawaiian Islands. They arrived in the Hawaiian Islands on August 23rd. Some repairs were necessary to the EPCE(R)-857, as a result the HORIZON left alone on August 27 and proceeded to conduct scientific investigations in the area southwest of the Hawaiian Islands between 500 and 1,200 miles west of Honolulu. The HORIZON was joined by the Navy vessel on August 16th and the two ships proceeded to Bikini Atoll where they spent a total of some three weeks. They then returned home by separate courses, the HORIZON going north towards Wake Island and then northeast north of Midway Island to the parallel of  $40^{\circ}$  North latitude, along which she returned to a point west of Cape Mendocino and then south along the California coast to San Diego. The EPCE(R)-857 took a different course from Bikini, first going to Kwajalain, thence to Johnston Island, Northeast to Hawaii and home from there.

Some 30 scientific personnel participated in the expedition representing 5 scientific institutions; the Scripps Institution of Oceanography, the Department of Meteorology of the University of California at Los Angeles, the University of Southern California, the United States Geological Survey, and the U. S. Navy Electronics Laboratory. In addition there were some 85 people making up the crews of the two ships, so that there were a total of 115 people participating in the expedition.

A great variety of scientific projects were undertaken. On the first leg of the trip from San Diego to Hawaii meteorologists from U.C.L.A. made over 60 radiosonde observations of the upper air. These observations were made at least twice a day throughout the first month of the expedition. Several of the sounding balloons got above 100,000 feet so that a good deal of data were obtained about conditions in the stratosphere, as well as at the lower levels of the atmosphere with which airplanes and surface craft are primarily concerned. It was found that in this virtually unexplored area, where very few scientific observations of any kind have been taken, the weather is considerably more variable than had previously been supposed. The expedition encountered a series of mild storms at about three day intervals throughout the first part of the trip. These were brought about by a wave motion in the surfaces of equal atmospheric pressure, or isobars, which caused relatively strong winds, a good deal of rain, and a rough sea. Some of these waves in the isobars later developed into tropical storms. Thus we were actually able to observe the birth pangs of atmospheric disturbances which might later turn out to be hurricanes.

The two ships were also concerned with conditions in the ocean waters and particularly with the living things in the upper 400 fathoms. During the war it was discovered that in the day time there is a concentration of animals below the surface of the sea in a series of layers at different depths. This discovery was made by the use of underwater sound. It was found that when a sound is sent out from a ship, an echo is returned from a short distance below the surface even though the bottom is several thousand fathoms deep. In the San Diego area this echo is strongest at about 200 fathoms. At night the echo layer rises to the surface at sunset and goes deeper at dawn. There has been a great deal of interest on the part of many scientists as to the kinds of organisms which may give this echo. Some think they may be giant squid or eels, others that they may be fish of various sizes, still a third group thinks they may be tiny shrimp-like creatures called Euphausiids and a variety of other similar forms. One of the purposes of the expedition was to try to obtain what information we could about these organisms which scatter the sound. This was done by sending sounds of different frequencies into the water and studying the character of the echoes obtained; also by using a large net, designed by Professor Gordon Tucker of San Diego State College, to try to get samples of the animals living far below the surface.

On the trip south to the equator and back to Honolulu it was found that actually there are often as many as 5 or 6 sound-reflecting layers in the water. All of these exhibited a vertical motion correlated with variations in light intensity. For example when it was raining the layers rose nearer the surface, and when the sun was shining the layers went deeper. At sunset the echo sounders recorded a vertical migration up to the sea surface of

part of the organisms making up the layers. However, it was noticed that some of the organisms which scattered the sound did not rise but stayed at the same depth, so that a layer present in the daytime would still be present at night at about the same depth, even though many of the animals in it had risen up to near the surface.

The echo sounder record also showed in the daytime many blobs just below the surface which might be schools of fish or schools of squid. At night, when the ship was hove to in tropical waters, there were often as many as a thousand squid up to 18 inches long around the ship; sometimes there were also hundreds of dolphins (these are the fish dolphin, or so-called dorado; the Hawaiians call them mahi-mahi). These squid and dolphin were attracted to the ship by the presence of small lantern fish and sauries (another kind of pelagic fish) which were in turn attracted by the light we hung overboard from the ship. The squid formed an actual barrier patrol around the ship in many cases so that the little fish never could get near the light. They were eaten as fast as they got within 30 feet of the ship. We were able to spear some of the squid and to open up their stomachs, which were usually found full of fish scales and other fish remains. The dolphin stomachs, on the other hand, were usually nearly empty, so that they apparently were not getting along as well as the squid.

We succeeded in bringing up many deep sea fish with Mr. Tucker's net; some net hauls had as many as a hundred of the queerly shaped hatchet fish with their rows of luminescent organs like portholes along the side.

The scattering layers were found in general to behave in quite a complicated way, and the net impression that the scientists gained was that

the upper layers of the ocean between the surface and 400 fathoms teem with many kind of organisms, many of which give an echo to the sound beam and contribute to the scattering layer on the echo sounding record. These organisms tend at times to be concentrated in layers and at other times to be spread out throughout the entire upper part of the ocean. Most but not all of them rise near the surface at night and go below the surface in the daytime. It was also striking that the amount of life present around the ship at night was very much higher at about 10° North latitude than further north or south.

The Scripps Institution, by the way, is developing a very much larger net to see if it is possible to catch the large creatures that may be present below the surface.

We are now using a net 15 feet across and some 50 feet long, which will be towed at 4 to 5 knots to try to obtain the animals that are able to swim fast enough to escape from smaller nets. We think eventually it may be necessary to go to a net 50 feet or more across. It is notable that in the net we used on the expedition we caught only one fish more than about 3 inches long; this was a snipe eel, a long thin creature some 3 feet long and about 1 inch in diameter with a long pointed bill.

We were also interested in studying the currents near the surface. For this purpose we used a new instrument developed by the Woods Hole Oceanographic Institution called a "jog-log" or "geomagnetic electrokinetograph." This makes it possible for the first time to measure ocean currents from an unanchored ship. It operates on the principle that the motion of the sea water through the earth's magnetic field sets up an electrical current and

this can be measured by trailing 2 electrodes astern of the ship. The instrument is called the jog-log because it only measures the component of the water motion at right angles to the ship's course, so it is necessary to change course at right angles, in other words to jog, whenever one wants to measure the actual direction and speed of the currents. We took such a measurement every two hours almost throughout the entire expedition. Of particular interest were the two sections across the north Pacific from San Diego to a point just north of the equator and from there to Honolulu. We found that in low latitudes the currents are quite fast, up to 2 nautical miles an hour in speed. These were the first actual measurements ever made of currents in low latitudes and gave, as is so often the case, quite a different picture than had previously been deduced from theoretical considerations.

North of about  $10^{\circ}$  North latitude the current flows in general to the west. This is the northern equatorial current; contrary to our expectations we found that instead of flowing due west the northern equatorial current where we were making our observations was flowing pretty much southwest. Below  $10^{\circ}$  North latitude the currents swing around to the south and to the east. This is the region of the equatorial counter-current. It had always been previously supposed that the equatorial counter-current flowed exactly from west to east and again we were quite surprised to find that where we made our measurements the current flows about  $40^{\circ}$  south of east. The direction of motion of the water again swung around south of  $6^{\circ}$  North latitude to the southwest. This is the northern part of the southern equatorial current.

These observations can be explained in two possible ways, both representing essentially a new development in oceanography. Either the equatorial

currents are sinuous, meandering across the ocean much like a meandering river or else there are a series of giant whirls or eddies in the equatorial region, eddies with diameters of a thousand miles or more in which the water proceeds in an elliptual or circular path around the eddy rather than proceeding directly across the ocean as had been formerly supposed. We also measured the temperature, salinity, oxygen and phosphate content of the water and found in accordance with previous observations that at about  $10^{\circ}$  North latitude there is cold water quite close to the surface. The temperature of the surface water is over  $80^{\circ}$  but only 100 feet below the surface the temperature drops to about  $55^{\circ}$ . Further south and north the high temperature water extends eto depths of several hundred feet. This is the explanation of the great abundance of animals in the surface waters of low latitudes. The surface waters are fertilized by the upwelling of deep water along the margins of the equatorial counter-current. Thus, it is possible for a large population of plants to grow there, which in turn feed the animals.

The principal scientific purpose of the expediton was to explore the bottom of the deep Pacific Ocean. This was done using a series of new scientific tools which have been developed in the past 10 or 15 years. Indeed the primary justification for the expedition was the fact that with modern developments in instruments and techniques it is possible to find out a great deal more about the deep sea than has ever been known previously. It may be interesting to list some of these new techniques and instruments. First and most important is the recording echo sounder, which makes it possible to obtain a continuous record of the depth of the sea bottom along a ship's course without ever stopping the ship. This is done by sending a sound pulse down to the bottom and receiving the returned echo with a hydrophone under the ship. The

time required for the echo to return is recorded on a broad tape. The outgoing signals and the echos are very closely spaced and the result is that the echo sounder record draws a profile or cross-section of the depth to the sea bottom along the ship's course. Both ships were equipped with specially adjusted echo-sounders so that they would operate effectively in deep water. Soundings were taken while the ships were underway at normal cruising speed at depths up to more than three miles (3,300 fathoms, or about 20,000 feet).

The second instrumental technique which gives a great deal of valuable information about what lies beneath the sea floor is the seismic refraction method developed in exploration for oil. This involves the use of two ships, one to set off explosive charges below the surface of the ocean, and another with hydrophones suspended in the water to pick up the sounds of the explosion. We made seismic runs out to separations between the two ships of 80 miles or more. Altogether some 35,000 pounds of TNT were exploded and over 1,600 shots were set off during the cruise. We were able to make sections of the thickness of the mud and of the structure of the rocks beneath the sediments for a total distance of about 1,500 miles during the course of the trip. During each seismic "run" charges were dropped at intervals of 1 to 2 miles.

The third new instrumental development is a method of obtaining long cores of bottom muds which was invented and tested by a Swedish scientist named Kullenberg. This consists of a pipe with a piston inside of it, and is, therefore, called the piston corer. The pipe is lowered to the bottom on the end of a steel cable and pushed into the bottom with weights weighing a ton or more. Then the piston is released and pulled upward. The resulting suction forces the pipe into the mud. The Swedes have been successful in using this method to

obtain bottom muds up to 50 feet long. We were not able to obtain cores anywhere near this long, primarily because of troubles with our large dredging winch which made it impossible to put a weight of more than 1,500 pounds on the end of the cable. We did obtain ten cores from 10 to 24 feet long. We also used other types of coring devices and altogether took seventy-five cores of the sea bottom. The total length of the cores obtained during the course of the expedition was about 300 feet.

The fourth new instrumental development was a method of measuring temperature gradients in the bottom mud, and from this to measure the heat flow from the earth's interior. That is, the rate at which the earth is cooling off by conduction of heat through the rocky crust. This involved a complex electronic recording system containing vacuum tubes and small <sup>S 4-1/2</sup> synchronous motors which was lowered to the bottom in a pressure-proof case down to depths where the pressure was more than 7,000 pounds per square inch. Attached to this case is a long spear or probe which was plunged into the bottom mud. This probe contained two thermometers about 8 feet apart which recorded the difference in temperature between a point one foot below the mud surface and a point 9 feet below the surface. This gave us the temperature gradient of the mud to a very high degree of accuracy, less than 1/100 of a degree Fahrenheit. The instrument was developed at the Scripps Institution by James M. Snodgrass, John D. Isaacs and Arthur E. Maxwell of our Special Developments Division.

The fifth instrument which we used to explore the sea floor is not new but has only been used in recent years for geological purposes. This is a dredge made out of chain fastened together with wire and attached to a steel frame or cutting edge. With this dredge it is possible to break off pieces

of rock and hardened sediment from the sea floor, wherever such rock is exposed above the blanket of sediments on the bottom. This dredging up of rocky material from the sea bottom is a rough business because the rock is very strong and doesn't want to be broken. The dredge was suspended from a half-inch steel cable and our objective was to drag it along the bottom until it became stuck on a piece of outcropping rock; then we would maneuver the ship, and try various expedients to break off the rock. Usually we succeeded in breaking it off. Sometimes, however, we were forced to leave the dredge behind when we were unable to free it from the bottom. The dredge was used successfully down to 9,000 feet, about 1,500 fathoms below the sea surface. This, as you can imagine, is a difficult and nerve racking business because the strains on the wire build up to rather alarming proportions. We sometimes got strains of 6 tons or more on the dredging cable.

The sixth technique which we used for exploring the sea bottom is underwater photography; using a special camera developed at the U. S. Navy Electronics Laboratory, we were able to obtain flashlight pictures of the sea bottom at depths of nearly a mile.

Other techniques we applied to the study of the deep sea are methods for separating and counting the numbers of bacteria in the bottom muds and for measuring the dissolved chemical substances in the interstitial waters of the mud.

Perhaps the most far reaching discovery we made was that there exists southwest of the Hawaiian Islands a long narrow mountain range, which we named the Mid-Pacific Mountains. It is more than a thousand miles long, 14,000 feet from the deepest part of the surrounding sea floor to the highest summit

and about 100 miles wide. This is not a completely new discovery as the hydrographic charts of this region have long shown isolated shoal points at depths of 450 to 1,000 fathoms rising above the general level of the sea floor at 2,600 to 3,000 fathoms. What we were able to show, however, was that these shoal points do not represent isolated peaks rising from the deep sea but rather they are the summits of a long, narrow virtually continuous range of mountains. This range is bounded on the south side by a scarp or gently sloping cliff, the slopes of which vary from  $4^{\circ}$  to about  $20^{\circ}$ . The scarp varies in height from 1,200 feet to nearly 12,000 feet. The Mid-Pacific Mountains cross the line of the Hawaiian Islands at Necker Island about halfway between Hawaii and Midway and extend on both sides of the Hawaiian Islands. They extend northeast of Necker Island at least 100 miles and southwest at least 1,000 miles. They make an angle with the Hawaiian chain of  $120^{\circ}$ . We carried out dredgings on six of the peaks in these Mid-Pacific Mountains. Most of these peaks were flat on top as if they had been eroded or abraded by wave action in shallow water, and had since sunk below the surface of the sea down to their present depths of 900 to 1,000 fathoms. We were able to show that these flat-topped peaks were indeed cut by waves because we found rounded pebbles and cobbles of volcanic rock on their summits.

Of even greater interest was the dredging from two of these peaks of limestone, containing numerous shells of clams, snails and sea urchins, and in one case a piece of reef coral bigger than a man's fist. Reef corals only grow in shallow water at depths of not more than 100 to 200 feet and yet this reef coral was found at a depth of 6,000 feet. This can only mean that this summit at the time the coral grew was 6,000 feet shallower relative to sea level than it is now. This particular specimen of reef coral has been

identified as belonging to the genus *Astrocoenia*. It lived some 30 to 40 million years ago during the Eocene or Oligocene period. Shells of large snails were obtained in the same dredge haul but these cannot be given an accurate geologic date nor can we tell so much from them as to the depth at which they grew. The remarkable fact about these dredgings of rounded cobbles and fossils from the sea mounts is that they show that the sea bottom in relatively recent geologic time has been the scene of violent activity, that is there have been great changes in depth. Mountains have been thrust up and have subsided. Previous to the expedition it had generally been thought by geologists that the floor of the deep Pacific has remained virtually static for hundreds of millions of years, perhaps far back in the earth's history before the age where there were any living things at all. In 1947 a paper was written, which has since been widely quoted, which described the existence of many sea mounts in the Pacific with flat tops which were thought to be cut by wave abrasion. The author, Professor H. H. Hess of Princeton University, called these flat-topped sea mounts, *guyots*, after a great French geographer who spent much time at Princeton. However, Professor Hess was under the influence of the widely held theory that the floor of the Pacific has been stable throughout geological time and he therefore proposed that these sea mounts had been formed in pre-Cambrian time or more than 500,000,000 years ago by wave erosion of volcanoes which rose above the sea surface. He then supposed that during the last 500,000,000 years the sea level had slowly risen because the bottom of the ocean was being gradually built up with sediments so that now the sea mounts are from a mile to half a mile below the sea level. He also thought that perhaps the amount of water in the ocean had increased by addition of water from volcanic springs. Undoubtedly the amount of water in the ocean has increased

from additions from volcanoes and undoubtedly the sea floor has been partially filled up with sediments so that the sea level has risen. But our discovery shows that the sea mounts were near the surface far more recently than had previously been supposed, and that they have sunk in such a short time, geologically speaking, that the submergence must be due primarily to a sinking of the sea floor caused by geological convulsions in this area. This result is confirmed by measurements we made of the thickness of sediments in the central Pacific, using seismic refraction techniques. We found that the sediments are from 1,500 to 3,000 feet thick. Thus the thickness of sediments is not sufficient to have raised the sea level enough to submerge the mountains. We also found that a few feet beneath the surface of the sediments in a great many cases there are layers of volcanic ash. These must represent material thrown out of volcanoes during the last few million years and some of the layers must represent volcanic material thrown out since the ice age, perhaps less than 20,000 years ago. There is no uniformity from one core to the next in the ash layers. That is in each core the ash layers are different in thickness and depth from those in other cores so that the ash in different cores must have been thrown out from different volcanoes at different times. This means that there has been a great deal of volcanic activity throughout most of the region traversed by the expedition during comparatively recent geological time.

Beneath the sediments on the sea floor there is a layer of rock with a high velocity for earthquake waves of about 22,000 feet per second. This rock found just below the sediments on the sea floor is probably basalt. The same type of rock is found under the continents at depths of from about 10 to 15 miles and is overlain by a great thickness of granite. On the sea floor the granite layer is absent. The basaltic layer under the ocean floor is

relatively thin, only two to three miles thick, beneath it there is a sudden increase in the sound velocity to about 27,000 feet per second. This zone of sudden increase goes by the wonderfully complicated name of the Mohorovicich discontinuity, after the Polish scientist who first pointed out its existence from a study of earthquake records. It extends all over the world and marks the boundary between the earth's crust, the comparatively light rocks which make up a thin layer on the earth's surface, and the earth's mantle, that is the heavy rocks, high in iron and magnesium, which extend down to the core of the earth at a depth of about 2,000 miles. The core of the earth itself is presumed to be liquid, consisting of molten iron and nickel. This simple picture of the outer layers of the earth superimposed like layers in a cake seems to be particularly characteristic of the region east of the Hawaiian Islands. In the Hawaiian Islands themselves, we found that the lava flows and ash layers of which the islands are composed have a much lower sound velocity, only about 12,000 feet per second, and that this kind of rock lies over the heavier material with a sound velocity of about 22,000 feet per second which in turn overlies the Mohorovicich discontinuity. West of the Hawaiian Islands, in the area of the Mid-Pacific Mountains and further west, we also found rock beneath the sediments similar to that of which the Hawaiian Islands are composed, even at depths of 3,000 fathoms. Thus in this region there is one more layer in the earth's crust than there is east of the Hawaiian Islands. While we are discussing the results of the seismic refraction studies we might proceed to the Marshall Islands area where we made a careful resurvey of the structure of Bikini Atoll and of a flat-topped sea mount which extends out from Bikini Atoll to the northwest. This is called Sylvania Sea Mount after the Navy ship which first surveyed it. It was found during Operation CROSSROADS that Bikini

Atoll consists of a thick layer of skeletons of coral and other animals which surround a volcanic core at depths of several thousand feet. On the Mid-Pacific Expedition we made a similar seismic survey of Kwajalain Atoll, which turns out to be in general similar to Bikini, that is to consist of an enormous pile of calcareous remains of organisms. In other words it is an enormous bone pile overlying volcanic rock. Thus, coral atolls represent the largest structures ever made by living creatures. In comparison the pyramids of Egypt and the Empire State Building are microscopic.

On Sylvania Sea Mount, the flat-topped sea mount northwest of Bikini, we dredged volcanic rock at the surface. Here, then, we have a submerged volcano on top of which a coral atoll did not grow. It is difficult to understand how it happened that when the volcano which underlies Bikini sank beneath the sea surface, coral was able to grow up and build a tremendous atoll on top of it, whereas right next door an atoll was not formed. We did find a few remains of coral on top of Sylvania Sea Mount at a depth of 750 fathoms. We were able to take a photograph of some large coral heads on the sea bottom. These coral heads, like all of the rock on top of the sea mounts, was covered with a thick layer of manganese. Apparently such a layer of manganese is characteristic of all exposed rock surfaces in the deep sea. On top of Sylvania Sea Mount the manganese layer was over 4 inches thick, while on the tops of the sea mounts in the Mid-Pacific Mountains the manganese was only about 2 inches thick. Since there is virtually no dissolved manganese in sea water, it is a puzzle how these thick layers of manganese are built up on rocky surfaces on the sea floor. The manganese actually accumulates in a variety of ways, one of the most typical is in the form of nodules, round rough-surfaced balls and irregularly shaped masses often several inches in diameter, which consist of nearly pure

manganese dioxide. If one cracks open one of the nodules there is always found to be a nucleus of something else, a pebble of volcanic rock, sometimes the ear bone of a whale, sometimes the tooth of a shark. In some cases the teeth are those of sharks which are extinct. In addition to dredging rock from the top of Sylvania Sea Mount, we collected volcanic rock in place on the slopes of Bikini Atoll at a depth of 9,000 feet and found another piece of volcanic rock which might be close to its source at a depth of 6,000 feet. Thus, we have added considerable evidence to the theory first advanced by Charles Darwin nearly a hundred years ago that coral atolls are formed by reefs growing around old volcanoes. As the volcanoes sink beneath the waves the coral keeps up with the subsidence and always remains just at the sea surface so that eventually we have a thickness of several thousand feet of coral and other kinds of bones over the deeply buried volcano. Another bottom photograph taken on top of Sylvania Sea Mount shows ripple marks in the sediments similar to those which exist on a sandy beach. These ripple marks indicate the presence of currents or wave motion even at these great depths, something which was previously not believed possible.

Our measurements of the temperature gradients in the bottom muds showed a surprisingly large gradient, approximately  $1^{\circ}$  Fahrenheit per fifteen feet. That is, the temperature increases with depth in the muds at this rate. This is about five times the rate at which the temperature increases in oil wells or in mines. It is well known that in oil wells a temperature near that of boiling water is reached at a depth of about two miles. But under the sea floor the temperature gradient increases much more rapidly than this. This is a very surprising and significant result because it has always previously been supposed that the increase of temperature observed in continental rocks is due

to the outward flow of heat generated in the earth by radio-activity, and to a lesser extent to heat from the earth's interior which is conducted outwards as the earth cools. (If the heat which is flowing from the earth were due entirely to cooling of the earth's interior the earth could only be some 20,000,000 years old, instead of 2,000,000,000 years old as we know it is.) The rocks underneath the sea floor have always been thought to contain a very small amount of radio active material, so that it was thought that the temperature gradient would be much less than that we actually found. It may be that there is considerably more radio activity than has been supposed in the rocks beneath the sea floor, or that the radio activity extends deeper into the mantle. In fact it may be that even the earth's core has an appreciable amount of radium and uranium in it. This would give rise to convection currents in the molten iron and nickel. Such currents have been suggested as the source of the earth's magnetic field by the British physicist, E. C. Bullard. Another possible explanation of the high temperature gradient is that volcanic activity beneath the sea floor has resulted in heating of the rocks beneath the sedimentary cover and that more heat is being carried off than would be the case if the rocks were solid.

Perhaps one of the most dramatic results of the expedition came from the study of the bacteria in the bottom muds. In muds in the southern California region we find a very high concentration of bacteria right near the surface of the mud and the number of bacteria decreases very rapidly a few feet below the surface. This is because there is considerable food for the bacteria to eat near the surface but as times goes on they eat most of it up and a few feet below the surface there is very little for them to live on and so the number of bacteria decreases very markedly. In the cores which we obtained from the

deep sea, on the other hand, we found about 10,000 bacteria per cubic centimeter near the surface and practically the same number at depths of 10 to 20 feet below the surface. There appears to be very little, if anything, that the bacteria can eat in these deep sea muds, because they are highly oxidized and have a very small content of humus or organic matter. The possibility, therefore, is suggested that the bacteria have existed throughout the time it has taken the sediments to accumulate nearly but not quite in a state of suspended animation. That is, they may have been deposited somewhat like the grains of clay or quartz which make up the bulk of the sediments and have simply remained unchanged, not growing, and metabolizing at a very low rate, literally for millions of years until finally we came along with our coring apparatus, brought them up to the surface and put them into a culture medium, where they started to grow rapidly. Alternatively it is possible that there are small amounts of energy available for the bacteria which are not very well understood and that they have existed throughout the millions of years they have been buried at a very low level of vital activity, just enough to keep them alive during all this time. We found a great variety of types of bacteria in the sediments, some of them having physiological reactions which would make them incapable of actually growing or carrying out their vital functions in that environment. One of these types, for example, are the bacteria which reduce sulfate to hydrogen sulfide in order to obtain their oxygen. These sulfate-reducing bacteria are the kind that produce a bad smell in Mission Bay and San Francisco Bay mud. They cannot flourish in the bottom of the deep sea because the environment is so oxidizing that conditions for the production of hydrogen sulfide do not exist.

The chemical studies of the bottom mud showed that weathering is taking place on the sea floor similar in some respects to the weathering of rocks to agricultural soil that takes place on land. We found that the volcanic ash layers, for example, were very profoundly altered while the interstitial waters of the sediments were relatively acid and highly oxidizing. Also there was a great deal more dissolved silica in the interstitial water, that is the water between the sediment grains than in the overlying sea water. Moreover there was a considerable amount of ferric hydroxide or iron rust in the water. All of these characteristics must be the result of the decomposition of the volcanic ash layers and other sedimentary materials. Evidently this weathering takes place beneath the surface of the bottom sediments. The sediments varied in color from a light buff color to a dark chocolate brown color quite unlike the green, blue and black mud which are collected near shore.

The echo soundings taken on the expedition showed that the topography of the sea floor is very irregular and variable. There are mountainous regions separated by intervening plains or flat areas. We believe that the flat areas are covered by a layer of sediments which has blanketed the underlying rough topography, because there is little if any erosion which could produce flat surfaces beneath the sea. Over a very large part of the sea floor the underlying hills and other topographic irregularities stick through the sedimentary cover and make the bottom surface relatively rough.

The sediments beneath the sea floor were found in many of our cores to be highly stratified, with alternating layers of different kinds of material ranging from oozes composed entirely of the skeletons of one-celled organisms called foraminifera, to very fine-grained muds consisting of clays washed out

from the land and accumulating with extreme slowness on the sea floor. These alternating layers of different kinds of material must reflect in some cases changes in the temperature of the waters near the sea surface. It has been shown in the Atlantic, for example, that since the end of the ice age the oozes consisting of the skeletons of foraminifera have been deposited over a relatively wide area, while during the ice age the water was so cold that these little animals could not exist, and the only sediment that could be laid down was the clay washed out from the land. By studies of cores in the Atlantic it was possible to determine the temperature of the ocean waters for the past several hundred thousand years and it has been found that these temperatures have fluctuated by more than  $10^{\circ}$  during that time. One hundred and sixty thousand years ago, for example, there was a warm spell and two hundred thousand years ago the waters became cold. Somewhat similar changes in ocean temperatures must have taken place in the Pacific and have been partially responsible for the stratification found in the cores. Another process which has helped to bring about this stratification is the slumping or sliding of material which has accumulated on sea mounts. This apparently takes place irregularly and over a rather small area at any one time, so that clean washed sand layers, layers of pebbles, layers of limey ooze and of clay are piled on top of each other as slumping takes place from different places. At some localities in the deep sea we found no sediments at all but only bare rock surfaces, Apparently the bottom currents are sufficiently strong to wash the bottom free of sediments.

The following scientists took part in the expedition: Professor Roger Revelle, Acting Director of the Scripps Institution of Oceanography, was scientific leader of the expedition. Russell W. Raitt, Associate Professor of

Geophysics at the Scripps Institution of Oceanography, was responsible for the seismic measurements, using equipment designed and built by him; he was assisted by Thomas W. Runyan and Daniel K. Gibson of the Scripps Institution staff; all three of these men work in the Marine Physical Laboratory, one of the divisions of the Scripps Institution, on the grounds of the U. S. Navy Electronics Laboratory at Point Loma. Temperature gradients of the bottom mud were primarily in charge of James M. Snodgrass, Associate Marine Biologist on the staff of the Scripps Institution, assisted by Arthur E. Maxwell, William J. Thompson and Frank Hetzel. Collection of bottom cores was under the supervision of Jeffrey D. Frautschy, Associate in Submarine Geology at the Scripps Institution. Assisting Mr. Frautschy in taking cores of the sediments were Louis E. Garrison and George E. Brayton, Research Assistants at the Scripps Institution. Dredging and underwater photography were in charge of Dr. Robert S. Dietz of the U. S. Navy Electronics Laboratory, assisted by Dr. H. W. Menard and Carl J. Shipek of the U. S. Navy Electronics Laboratory, and Edward Hamilton of Stanford University. Professor Kenneth O. Emery of the University of Southern California was in charge of the geological work in the Marshall Islands area. He was assisted by Robert F. Dill of the University of Southern California. Dr. Sidney C. Rittenberg, Associate Professor of Bacteriology in the University of Southern California was in charge of the chemical work on the bottom sediments. Mr. Richard Y. Morita, Research Assistant at the Scripps Institution, was in charge of the bacterial work on the cores. The biological collections and hydrographic measurements on the HORIZON were made by Robert P. Huffer, and Deane F. Carlson, Marine Technicians on the staff of Scripps Institution. Studies of water temperature were made by Jeremiah S. Black and Joseph C. Roque of the U. S. Navy Electronics Laboratory. Meteorological work was

carried out by David S. Johnson, Leon Sherman and James G. Edinger of the Department of Meteorology at UCLA. Maintenance of scientific equipment on the 857 and general assistance during the entire program was given by Scott D. Cosby of the U. S. Navy Electronics Laboratory. Youngest person on the expedition was a seventeen year old high school senior, Edward S. Barr. His cheerful personality, energy and skill at seamanship added a good deal to the happiness of the expedition. Senior scientists on EPCE(R)-857 were Mr. William E. Batzler and Dr. Robert S. Dietz of the U. S. Navy Electronics Laboratory. Captain of the EPCE(R)-857 and naval commander of the expedition was Lieutenant-Commander D. J. McMillan, USN. Mr. James L. Faughn, Marine Superintendent of the Scripps Institution acted as Master of the HORIZON. Chief Engineer of the HORIZON was John Massey.

RR:mcd