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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical Oceanography</td>
<td>1</td>
</tr>
<tr>
<td>Geological Oceanography</td>
<td>23</td>
</tr>
<tr>
<td>Geophysical Oceanography</td>
<td>33</td>
</tr>
<tr>
<td>Chemical Oceanography</td>
<td>39</td>
</tr>
<tr>
<td>Radiochemistry and Radioecology</td>
<td>47</td>
</tr>
<tr>
<td>Biological Oceanography</td>
<td>53</td>
</tr>
<tr>
<td>Degree Requirements Completed</td>
<td>65</td>
</tr>
<tr>
<td>Facilities</td>
<td>67</td>
</tr>
<tr>
<td>Staff Activities and Awards</td>
<td>73</td>
</tr>
<tr>
<td>Visiting Scientists</td>
<td>75</td>
</tr>
<tr>
<td>Publications</td>
<td>79</td>
</tr>
<tr>
<td>Data Reports</td>
<td>90</td>
</tr>
<tr>
<td>Papers in Press</td>
<td>91</td>
</tr>
<tr>
<td>Distribution List</td>
<td>97</td>
</tr>
</tbody>
</table>
PHYSICAL OCEANOGRAPHY

Atmospheric Effects on Incoming Solar Radiation over Tropical Oceans - Quinn, Burt

The following is a brief of findings reached in a paper now in press: "A Study of Several Approaches to Computing Surface Insolation over Tropical Oceans."

Out of seven meteorological factors, which were studied in relation to insolation at the earth's surface, the average total opaque sky cover during daylight hours appeared to be the best for estimating monthly surface insolation over the equatorial Pacific. Average daily rainfall duration during daylight hours appeared to be the next most suitable independent variable for determining average daily insolation on a monthly basis over this region. For annual surface insolation figures, the average daily amount of precipitation on an annual basis appeared to provide estimates reasonably close to observed values.

The investigation indicates a great need for studying additional data in regard to relationships between meteorological factors and surface insolation. Our current program sponsored by NSF Grant GA-1571 will provide additional data for this purpose.

Mean Sea Level Studies - Pattullo, Burdwell, Gilbert

Variations in sea level of time changes larger than tides are being measured at the Marine Science Center by G. Burdwell of ESSA. The deviations are determined from sea level predicted by ESSA. High levels (>1.0 feet above predicted) occurred 27 times between September and February this winter, they lasted from one to 18 days each time. The highest deviation was 3.7 feet on December 22nd. These high tides are usually related to low pressure in the Gulf of Alaska and associated southerly winds along the Oregon coast.

Antarctic Intermediate Water in the South Pacific - Johnson, Pattullo

Mr. Johnson has completed the computer work for this study and is summarizing the results. He has accepted a faculty appointment to Old Dominion College.
**Currents in Long Island Sound - Swanson, Pattullo**

Comdr. Swanson has completed the computer work for this study and is writing the paper on his results and conclusions. He has returned to East Coast duty with ESSA.

**Eastern North Pacific Ocean - Saur, Pattullo**

Mr. J. F. T. Saur, on leave from the Bureau of Commercial Fisheries, has begun probable dissertation research on the variations in upper-layer pycnocline structure and currents as determinable from Ships of Opportunity expendable bathythermograph data.

**Theoretical Studies of Time-Fluctuations in Ocean Currents - Longuet-Higgins**

The theoretical research on double Kelvin waves has been completed and is published in the form of a paper: "Double Kelvin waves with continuous depth profiles," in the Journal of Fluid Mechanics. This paper describes essentially a certain type of barotropic motion which may be excited in regions of variable depth. It is shown that the motion always progresses with shallower water to the right of the direction of propagation, in the northern hemisphere, and the period always exceeds one pendulum-day.

**Generation of Ocean Surface Waves - Longuet-Higgins**

A new departure occurred when I was asked to review the subject of "Ocean waves and turbulence" for the Symposium on Turbulence in the Ocean. As a result of this symposium, I was encouraged to make three further contributions to the problem of wave generation by wind. These have been written up as three separate papers.

A theoretical estimate is made, in the first paper, of the constant $\alpha$ in the equilibrium spectrum

$$F(\sigma) = \alpha g^{2} \sigma^{-5}$$

of a sea state limited by wave breaking. The theoretical value of $\alpha$, which is about $1.3 \times 10^{-2}$, is within the range of observation. In the second paper a nonlinear mechanism is suggested to account for the discrepancy between the observed rates of growth of waves under the wind and the wave generation theories of Miles and Phillips. The latter
predict rates of growth which may be sufficient for the shorter waves but are far too small for the longer, most energetic waves. The new suggestion is that energy may be transferred from short waves to longer waves by breaking of the short waves at the crests of the longer waves. A detailed calculation shows that this can give a growth rate for the larger waves of the same order of magnitude as that observed.

The third paper on wave generation clarifies a point whose chief importance may be in connection with the theory of wave generation. It shows the way in which a non-uniform tangential stress exerted at the free surface, either by the direct action of the wind or by the transfer of momentum from shorter waves, is converted to a normal stress such as to increase the energy of the long waves. Essentially this conversion is due to a convergence of flow in the boundary-layer at the surface, which piles up fluid on the rear slope of the longer waves. The argument used is very simple and surprisingly general in its application.

Mass Transport in Ocean Currents - Longuet-Higgins

In a study begun at Woods Hole in August and completed in Corvallis, I estimated the Stokes velocity in certain types of motion that could occur in the ocean. In most parts of the ocean, away from swift currents like the Gulf Stream, it appears that the Stokes velocity may be quite comparable to the Eulerian mean velocity, so that the Lagrangian and Eulerian means may even be in opposite directions. In particular, it appears that in double Kelvin waves the Stokes velocity takes the form of a slight forwards velocity (in the direction of wave propagation) in the regions of uniform depth at top and bottom of the slope, counter-balanced by a concentrated negative jet along the bottom contours in the region of maximum bottom gradient. Numerical calculations of the Stokes velocity carried out in Corvallis in the fall of 1968 confirmed this form of the velocity profile, and showed that as the width of the sloping region decreased the negative jet became more and more concentrated.

This type of motion may have interesting consequences for the transport of sediments parallel to bottom contours. It is possible that some local observations of sediment transport along the continental shelf off the Oregon coast may be partly explained in this way.

The Trapping of Long-Period Waves by Islands and Seamounts - Longuet-Higgins

The long-range program is to investigate the effect of bottom topography in influencing time-dependent motions in the sea.
Dr. Gordon W. Groves brought to my attention his recent studies of the spectrum of sea level at two localities on the island of Oahu. The spectrum of coherence as a function of frequency suggests organized motions at frequencies of about 0.73 c.p.d. (the local inertial frequency), 0.50, 0.33 and 0.23 c.p.d. respectively. This led me to consider the possibility that long-period waves (with periods of a pendulum-day or more) might become trapped round circular islands or seamounts. It turns out that, according to the theory of long waves in shallow water, long waves may be trapped round an island with vertical sides, provided that the radius of the island exceeds a certain critical value dependent on the local depth and the coriolis parameter. If the radius is less than a certain critical value the waves (which are essentially Kelvin waves) cannot "round the corner".

In practice, the parameters of the problem are such that effective trapping only takes place for baroclinic, not barotropic motions, if the sides of the island are vertical. But if the sides are sloping some recent work by P. B. Rhines (Ph. D. dissertation, Cambridge University, 1967) shows that a much larger selection of trapped modes is possible. I have computed the frequencies of these modes for values of the parameters appropriate to Oahu. The present indications are that some such mechanism may account for the peaks in the coherency at 0.50, 0.33 and 0.23 c.p.d.

Model Studies - Longuet-Higgins

In order to test the theoretical conclusions relating to the trapping of long waves, Mr. S. Wilcox and I set up the rotating turntable and rotoscope which I had brought with me from England. We made a small circular basin, of which the bottom was shaped in the form of a paraboloid, so designed that the depth of fluid when rotating would be uniform. Small islands, with and without sloping sides, were inserted in the basin. Forced motions were generated in the basin by a slight departure of the axis of rotations from the vertical. Strikingly, strong oscillations and even stronger mass transport currents were observed circulating the island in the counter-rotating sense. The currents were stronger for islands with sloping sides than for islands with vertical sides, as expected.

A similar experiment was carried out for a circular sill, and for a straight escarpment along one diameter of the rotating basin. In each case, strong, jet-like motions were observed, in the expected directions, along the zones of maximum bottom gradient.
Mr. Wilcox and I made a film of these experiments, and it was shown at the AGU Fall Meeting in San Francisco in December 1968.

To perform the experiments more accurately we required a better turntable with more reliable speed control. At the end of November, I was joined by Dr. Douglas Caldwell, previously a Research Associate at the Institute of Geophysics and Planetary Physics, La Jolla, and together we have constructed a one meter rotating turntable similar to the one designed by Ibbetson and Frazel at Woods Hole. This is almost ready for operation. With it we hope to test accurately the non-viscous theories of wave trapping and mass transport, round islands and along escarpments which have already been outlined, and to look for certain expected effects of viscosity. I also hope to complete the experiments on the spherical annulus.

Hydrography of Oregon Waters - Wyatt, Pattullo, Barstow, Gilbert, Washburn

Monthly hydrographic cruises were continued off Oregon with particular emphasis on the Newport line. Stations from 5 to 165 miles west of Newport were monitored to determine the salinity, temperature, oxygen, and inorganic phosphate content of the sea water. Cruise dates and samples taken are summarized in the table below.

Samples taken at 3, 5, 15, 25, 35, 45, 65, 85, 105, 125, 145, and 165 miles off Newport

<table>
<thead>
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<th>Samples taken at 3, 5, 15, 25, 35, 45, 65, 85, 105, 125, 145, and 165 miles off Newport</th>
<th>Nansen casts</th>
<th>T</th>
<th>O₂</th>
<th>PO₄</th>
<th>S</th>
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</thead>
<tbody>
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</table>
A field test of the equipment was made from the dock in Yaquina Bay in November 1968. All the equipment performed well. The preliminary results include measurements of temperature and humidity fluctuations, waves, and wind and temperature (wet and dry bulb) profiles. These results are being used as input to develop our analysis procedures. Emphasis has been placed on the fluctuations measurements.

In February a trial cruise was made on board FLIP in preparation for BOMEX. About 8 hours of useable data were obtained including humidity fluctuations (OSU), velocity fluctuations (University of British Columbia) and wet and dry temperature fluctuations (University of Washington). These data will be analyzed soon with emphasis on comparison of the spectra of the humidity and temperature fluxes.

Later in February, the air-sea interaction tower was taken to sea to test its performance as a free-floating tower. We found that we shall be able to tow the tower with most measuring equipment installed at speeds of about 5 knots. Performance was satisfactory, although the motion was larger than with the August mooring. Measurements were made of the wave height and three components of acceleration and these are being analyzed.

A continuous wave acoustic anemometer is now under construction. It should be ready for use in our data collection later this year.

The most exciting result to come out of the program is that we have found a means of measuring absolute humidity fluctuations to sufficiently high frequencies (small scale sizes) to make measurements of the moisture flux (evaporation) directly. The instrument uses the strong absorption of $\chi$ -Lyman ultraviolet by water vapor as its operating principle. The transmission path is only about 1 cm. The response is somewhat more limited, however, because the windows of the tubes are water soluble (LiF) so a flow through must be used to prevent water reaching the windows. The configuration we have designed appears to have a distance constant (for 3db response) of something less than 50 cm which should be adequate to measure the whole spectrum of the moisture flux. The instrument is commercially available and has been used on aircraft but has not been used for measurements in a marine boundary layer before. Because it is sensitive to absolute humidity, it has tremendous advantages over wet and dry bulb sensors or other sensors whose response is a function of more than one parameter.
The correlations between the humidity and temperature fluctuations are very high. The sign of the correlation depends on the air-sea temperature difference. For water warmer than air, wet and warm are correlated; for water colder than air, wet and cold are correlated. This result is not too surprising since the surface is the source of water and the source or sink of heat. However, it is important to establish just how strong the correlation is. If the correlation is always high, it may be possible to obtain the moisture flux from the sensible heat flux and the amplitudes of the humidity fluctuations at low frequencies, that is, a sort of local Bowen ratio approach. Such measurements are much easier than direct humidity measurements.

The November data have been analyzed and a short note which we hope to publish in Science is in preparation. The data obtained on the pre-BOMEX trial cruise visually show the same strong correlation and will be analyzed soon.

Physical Factors Affecting Oregon Coastal Pollution - Neal

Work is continuing in and near the surf zone at Newport, Oregon. Dye markers are released from aircraft and movement of the dye markers is measured from aerial photographs. In conjunction with the dye marker studies, water samples (salinity, temperature and D.O.) are taken in the sewer outfall area at Newport. Wind measurements are obtained from the meteorological station at the Marine Science Center. Preliminary data analysis is now being carried out to determine the interaction of the various physical factors that may influence the water movements in the Newport nearshore area.

The Dynamic Response of Moored Buoy Systems in Deep Water - Nath

A numerical model that predicts the response of a buoy and mooring line to sinusoidal waves was developed by Dr. Nath who is writing a paper on the subject for the A. S. C. E. conference on ocean engineering, Miami, December, 1969. The title and Abstract are:

Dynamics of a Single Point Mooring in Deep Water

Abstract

A numerical model was developed of the dynamic response of a single point mooring of a buoy of 40 feet diameter to sinusoidal waves in water depths of 10,000 to 20,000 feet. All forces, such as those from gravity, steady current, wind and waves and the reaction of the buoy and mooring line, were considered to act in one plane.
The numerical model was divided into two major subrouting - one dealing with the buoy motion and the other dealing with the line tension and motion. The buoy motion and position were determined at each time increment from integrating the differential equations that arise from considering the buoy as a rigid body and applying Newton's second law of motion.

The solution for the mooring line was based on considering a small element of the line. For steady forces the differential equations of statics were developed and integrated along the line and the resulting tension and coordinates were calculated for any position on the line. The solution for the dynamic case was developed by integrating the differential equations of motion that result from applying Newton's second law of motion to the line element, utilizing the method of characteristics. The boundary condition at the anchor was that the anchor coordinates remained fixed and the line velocity and acceleration remained zero. The kinematic boundary condition at the top of the line was that the motion of the line must be the same as the motion of the buoy attachment point. The stress-strain diagram of the line was considered to be non-linear.

Some preliminary results were obtained for a few mooring configurations both with and without considering the internal damping within the line. The results show that the dynamic line tension may be larger than the static line tension by a factor as large as 2.4.

The Design of a Two-Point Mooring of the TOTEM Spar Buoy - Nath, Neshyba, Young, McDuff

A two-point mooring for the TOTEM spar buoy was designed. A hydraulic model study was performed to determine the modes of motion and resonant frequencies of the buoy. The scale ratio between model and prototype was 1:100. The two-point mooring allows a yielding of the system when subjected to storm forces without excessive mooring line loads or excessive vertical loads on the buoy. Mr. McDuff will write a Master's thesis from this basic topic.

Modification of Precipitation on the Oregon Coast - Elliott, Burt

This period we spent gathering data on the precipitation patterns found on lines between the coast and Corvallis. These data will be subject to statistical treatment to describe the frequency spectrum of rainfall with the ultimate purpose of describing the time history of rainfall in storms and their modification by the Coast Range.
Theoretical studies of the events taking place inside a thermal-diffusion cloud-nuclei-counter were carried out to determine the optimum design of such instruments. Such modifications will be incorporated in the next counter. We also used our existing instruments to measure the nuclei content of the air at the Yaquina Head Light House. Although the data have not been fully reduced the indications are that essentially continental air takes a considerable time to acquire marine characteristics when it passes out to sea and returns via the afternoon sea-breeze.

Physical Oceanography of Shelf and Slope Waters - Pattullo, Smith, Pillsbury, Muller, Keith, Mooers, Cutchin, Fisher

During the past six months the major effort has been on processing of the current meter data from the observational program of 1967 and 1968. Work has proceeded on improving the computer programs for the time series analysis. The observational program for the coming summer is being planned. A four point array of moored current meters and thermographs will be placed to define both the alongshore and offshore variation in currents and temperature on the continental shelf between Newport and Depoe Bay. An intensive survey will be made of the region in cooperation with the chemists and biologists.

C. Fisher is completing his M. S. Thesis, in which the relation of temperatures at 25 meters depth were measured with the recording thermograph during the early stage of upwelling in 1967 and 1968, are compared with the geostrophic winds. A comparison is also made between the geostrophic winds and observed winds at Newport measured by the USCG.

Remote Sensing of the Pelagic Fisheries Environment off Oregon - Pearcy, Smith, Mueller

Plans are being made for a remote sensing study of coastal upwelling and the Columbia River plume. Remote sensing from NIMBUS Satellite and a NASA furnished aircraft will be made in conjunction with the OSU Research Vessels. A PRT-5 infra-red radiation thermometer has been purchased to provide "ground truth" measurements from the ships.

Sea-level Studies and Continental Shelf Waters - Ma, Mooers, Smith

A power spectral analysis of the sea level data and atmospheric pressure system on the West Coast is being made for three tide-gage/weather station pairs: San Francisco, Calif; Coos Bay, Ore; and Tofino, B. C., Canada. Small but significant peaks are found in the autospectra of sea level in the frequency band 0.25 to 0.4 cpd. Cross-spectral analysis, giving coherency and phase indicate a continental shelf wave propagating
from N to S at a phase speed close to that predicted by Robinson's model for continental shelf waves.

The Interaction of an Internal Tide with the Frontal Zone in a Coastal Upwelling Region - Mooers, Smith

C. N. K. Mooers is presently completing his Ph. D. dissertation. The central question of how an internal tide interacts with the frontal zone in a coastal upwelling region is discussed from a theoretical viewpoint and is studied with field observations taken in late summer of 1966. A self adjoint linear governing equation is derived for inertial-internal waves propagating transverse to a frontal region. In the theoretical study the effects of horizontal density gradients and the shear in the mean long-shore flow are included in addition to vertical density gradients and the Earth's rotation. The interaction causes modification of the incident internal tide and the reduction of the dynamic stability in the frontal zone. The observational study indicates that the dynamic stability is the lowest near the base of the permanent frontal layer. The Richardson number attains critically low values, which are associated with the semi-diurnal internal tide.

Upwelling Study - Peru Coast - Smith, Pillsbury, Enfield

In March and April (1969) an intensive 3 week study was made of the physical oceanography in a region of persistent upwelling, near 15°S along the Peruvian coast. The study was done in cooperation with the University of Washington, aboard the R/V THOMPSON, Dr. R. C. Dugdale, chief scientist. Current meters and thermographs set at 25 m depth and 50 m depth at three stations on the continental shelf, plus one recording anemometer as set on a surface buoy. STD and hydrographic data were taken. Processing of the time-series current, and temperature data has begun.

Arctic Oceanography - Neal, Neshyba, Beardsley, Mesecar, Denner, Robinson

Using funds originally allocated by ONR for a detailed hydro section survey in the Gulf of Alaska, two OSU personnel and two from the Post-graduate School, Monterey, made a cruise to Ice Island T-3 during March 1969. The cruise purpose was to determine if fine temperature structure exists under the ice. Using instrumentation furnished by the PG School and modified at OSU, we were able to record temperature with a resolution less than a millidegree centigrade. Fig. 1 is a typical temperature profile, with a section amplified and shown as a separate record. We believe these records are the most precise temperature profiles ever obtained in the upper 500 meter water layer; in part, this is due to the stability of the platform itself.
Figure 1. Vertical profile of temperature under T-3 (84°38' N, 128°21.6' W, 19 March 1969). Shaded section of profile (a) shown as observed in profile (b) to left.
These data and their interpretation are the subject of two papers being prepared. Over a 20 hour period all of the individual layers retained full identity, indicating that the system is comparatively in steady state.

Plans are under way to return to the island for the purpose of obtaining density data with a precision concomitant to these temperature data.

**Hydrographic Capability - Curtin, Jeter, Pawley, Still, Neshyba, Mesecar**

CCTD and Digital Data Logging. The CCTD was delivered in November 1968 and taken to sea that month. The immediate result was our discovery of the fascinating world of small scale structure in temperature and salinity in deeper ocean water. Oregon waters are now known to consist of many superposed water layers. A second cruise in February was designed specifically to investigate the horizontal nature and extent of some of these layers. The cruise gathered significant data but uncovered a basic manufacturing defect in the CTD, namely, that vibration in the cable-fish system destroys conductivity data. Extensive correspondence together with two weeks of experimental vibration testing, showed that the conductivity head must be rigidly potted. A fix has been made and tests at sea are thus far satisfactory. A third cruise was made to track the lateral extent of the temperature inversion commonly found in scattered areas off the Oregon coast. Spirally sequenced stations were occupied until weather forced an abort. These data await computer processing and are to be studied by Dr. T. Sakou. A final cruise this fiscal year will use five days to attempt a full current profile of the continental slope waters off Depoe Bay.

Deep Ocean Current Measurements. Two devices have been fabricated and tested at sea. They will be used in May for the Continental Slope Current cruise. These incorporate Corning Glass floats, dual-redundant timed release mechanisms firing separate squibs, radio direction beacons and Xenon flashing lights. The system is now complete and rather exhaustively tested.

Oxygen Probe. During the past year, the construction of the in-situ digitizing and sensor scanning system was completed in designed final form and mated to the shipboard telemetry system of the CCTD. A preliminary test at sea was conducted, and uncalibrated data was received
from the probe. The towing system, including fish and haired cable, was completed and tested successfully at sea. At present the probe is being fitted for electronic noise suppression, and is being calibrated. Noise has been a consistent problem in the 14 bit digitizer around which the unit is designed.

Geo-Electrokinetograph. Present GEK equipment includes a dual pen Moseley strip chart recorder, two hundred meters of four conductor cable on its own winch reel, several sets of electrodes, electrode cases, and supporting equipment. All of the above was procured and deployed during the past year. It was used to gather data on a one month cruise to southeast Alaska, a two month cruise to the eastern tropical Pacific and several shorter cruises off the Oregon coast. Thus over three and a half months were spent at sea taking GEK measurements with all newly acquired instrumentation. In addition, a data report was published in September from GEK measurements gathered the previous year.

During YALOC 69, a high speed surface current was discovered in the Eastern Tropical Pacific Ocean between 5°S and 15°N latitude. Speeds were measured with a GEK instrument at between 1 and 4 knots, with larger values below the equator and southeast of the Galapagos. These are shown in Fig. 2, along with a monthly chart of the surface circulation (BCF) which shows surface currents for this region as compiled from previous work in this area. Surface currents of this magnitude have not been reported previously in this region. It is highly unusual to find southwestward flow of this magnitude south of the equator. Flow in this area is usually dominated by the northwesterly trend of the Peruvian Current as it turns and joins the South Equatorial Current.

The interpretation of these data, along with Summer '68 Gulf of Alaska data, is the basis of an MS thesis being prepared by T. Curtin.

Specific analyses are:

1) Correlation between velocity fields and electromagnetic fields, employing hydro data and theoretical considerations.

2) Eastern Tropical Pacific current anomalies described and interpreted from GEK measurements and other data.
Figure 2. Current pattern for the East Tropical Pacific Ocean.
(a) Pattern as previously compiled by BCF;
(b) Contrasting strong surface currents recorded by GEK.
Note direction from N and NE
Model Study of Free Oscillation - Caldwell

A one-meter rotating table has been constructed for model studies. The results of Dr. Longuet-Higgins calculations on the effect of bottom topography on long period oscillation in the oceans are being investigated. We have seen the modes of oscillation trapped by a submarine escarpment.

Wind Wave Properties - Beardsley, Earle

A three-axis drag probe was constructed and calibrated, and three more similar probes are under construction and these devices will be used to measure orbital velocities at sea during two summer cruises. The remainder of the data system is completed and has been successfully used at sea.

As a test of the data system and supporting equipment several simultaneous measurements of height and pressure have been carried out at different locations. Spectra, coherence, and transfer functions were computed using standard time series analysis techniques. A typical pan of spectra are shown in Fig. 3.

Optical Oceanography - Pak, Beardsley

Columbia River Plume Study. An extensive survey of the Columbia River plume was made during the summer of 1968 with light scattering measurements surveyed in addition to the standard hydrographic data and chemical data. The salinity distribution, one of the most common parameters used in delineating river plumes, was used as reference of the other parameters. One such comparison is shown in Fig. 4, and a typical picture of the summer Columbia River plume is given in Fig. 5.

The Columbia plume measure by light scattering measurements showed good agreement south to 150 nmi from the source. This implies that the suspended particles carried by the plume have been contained in the plume water about 20 to 30 days. Thus the light particles introduced by the Columbia River may be approximated as a conservative property of the river plume, and the flow and mixing of the plume water can be studied in terms of light scattering.

An application of optical data to the dynamic conditions of the ocean was made by Pak et al (1968) under the upwelling condition. Similar application to the Columbia plume data has shown some important features of the general circulation system in the plume region.
Figure 3. Shallow Water, Run No. 1

PERIOD (sec)

ENERGY (m² - sec)

COHERENCE²

PRESSURE (1.5 m below MWL)

HEIGHT

FREQUENCY (cps)
Figure 4. Columbia River Plume. Comparison of parameters.
Figure 5. Columbia River Plume. Typical summer picture.
Figure 6. Relative light scattering at 45° along the 91°40' W section.
Based on the results obtained from the Columbia plume survey, an optical model plume was developed to generalize the fundamental processes by which the river introduces particles to the plume region.

The model shows that dense particles are immediately lost by sinking to deep water within a few miles from the source, and less dense particles are retained in the plume water. Under an upwelling condition the plume is carried by the wind and becomes oriented almost parallel to the shoreline since the wind blows approximately parallel to shore. The vertical extent of the plume is limited by the stratification of the plume, and the plume tends to float over the dense sea water for a long time with mixing across the boundary. The less dense particles are stratified in the plume water and approximately conserved, with only few particles lost by sinking. Within the plume, there is a tendency for particles to be trapped into one or two layers corresponding to a maximum stability layer associated with therocline and halocline. The particles are eventually released from the plume when the stability layers are removed by mixing. Thus the Columbia River effectively introduces a low density of particles over a large surface area off Newport rather than a high density of particles at Astoria.

Yaloc '69 - Beardsley, Pak, Hodgson, Zaneveld, Plank. During Yaloc '69 (January 2- April 24) over 100 hydro-optics cases were completed. Measurements included light scattering, beam attenuation, diffuse extinction, polarization of daylight, and the standard hydrographic variables.

The data show considerable structure in the horizontal and vertical field of optical properties. This data will be analyzed in detail during the coming year.

During Yaloc '69 two cross-sections of the Cromwell current were taken. On each of these cross-sections, besides the usual hydrographic observations, measurements were made of optical properties. These properties were the light scattering, light transmission, and particle counts. These measurements such as the one shown in Fig. 6, made clear that at present a very incomplete understanding exists of the dependence of optical properties on other seawater properties such as density, oxygen content, currents, etc.

Some preliminary results of Yaloc '69, indicate a dependence of scattering on density gradients. Strong density gradients tend to form "traps" for sinking biological decay materials, greatly increasing
scattering at the strong gradient. This trapping effect was also observed in a strong horizontal density gradient at a convergence zone near the Galapagos Islands. It was observed that the main thermocline can readily be identified from transmission and scattering data. If the thermocline becomes less well defined, such as over Cromwell current the scattering maximum also becomes less well defined.

In a stably stratified ocean without circulation we may expect lines of constant scattering to run parallel to the surface. The introduction of currents disturbs this initial distribution in a complex manner. The circulation not only directly modified the distribution of suspensoids, but also changes the distribution of materials essential to the growth or decay of biological materials.

This process becomes apparent when trying to explain the distribution of scattering over the equator. Upwelling of oxygen-rich water occurs near the equator over the Cromwell current. The influence of this process on scattering is two fold. The increased oxygen content tends to increase biological activity and hence increase scattering. The upwelled water contains fewer suspensoids and so decreases scattering. A more complete understanding of these processes is essential to the growth of optics as an oceanographic tool. It should be possible to use light scattering cross-sections of the equator to determine the, as yet, poorly understood meridional circulation. Especially near the surface light scattering is a sensitive variable. The observations of Yaloc 69 do not contradict either Charney's (1960) theoretical model of the meridional circulation or Knauss' (1966) observations. With further expansion of our knowledge of the behavior of light and light scatterers in seawater such problems as the meridional circulation could be better understood through the use of optical oceanography.
Foraminiferal Ecology, Oregon Sublittoral - Fowler, Gunther

Sea Grant research into foraminiferal ecology is concerned with the seasonal variation in abundance of foraminiferal species at selected stations on the Oregon shelf. Ecologic data from the sediment and from the water directly above the bottom will be used to evaluate the expected seasonal variation in species composition of the living fauna. Water samples are being analyzed by the Chemical Oceanography Lab at Newport for concentrations of oxygen, silicate and phosphate, and for salinity. Frozen sediment samples are being analyzed in the Benthic Ecology Lab at Corvallis for organic carbon, total carbonate, and organic nitrogen. The surface layer of sediment from cores is being analyzed in the Geological Oceanography Sediment Lab for texture and percent glauconite. In the Foram Lab of Geological Oceanography, the 239 samples collected on the four Sea Grant cruises (Cruise 6808E, 131 foram samples; 6810C, 45; 6901C, 23; 6904E, 40) have been wet-sieved to remove silt and clay and stained with rose bengal to mark the specimens alive at the time of collection. The foraminifers from most of the samples have been concentrated by tetrachloroethylene flotation to remove the inorganic sand and are ready for species identification and counting under the microscope. The living foraminifers from a few samples have been counted but the number of samples is too small at this time to allow the formation of any conclusions. The project will continue through this summer with the collection of samples from two more cruises; sample processing and evaluation will continue through the summer and school year of 1969-1970.

Stratigraphy and Geologic History of the Oregon Continental Margin - Fowler, Muehlberg

Several thousand feet of late Tertiary marine sediments crop out across Heceta Bank on the central Oregon shelf. Rock samples from two east-west profiles (44°05' and 44°10'N) have yielded large, well-preserved foraminiferal faunas. The stratigraphic sequence of the samples has been determined using sparker subbottom profiles.

Two possible stratigraphic units are delineated on the basis of their foraminiferal content, seismic-reflection characteristics, and lithology. The older is characterized by Bolivina seminuda foraminata, B. semiperforata, B. spissa, Bulimina subacuminata, B. subcalva, Buliminella cf., B. exilis, Epistominella pontoni californica, and Uvigerina peregrina;
less than 10 percent planktonic foraminifers; and right-coiling *Globigerina pachyderma*. This fauna represents paleodepths of 500-1,000 m and is dated as Pliocene. The younger unit is characterized by *Cassidulina minuta*, *Eilohedra levicula*, *Epistominella exigua*, *Nonionella* spp., *Trifarina angulosa*, and *Uvigerina juncea*; more than 50 percent planktonic foraminifers; and left-coiling *G. pachyderma*. This unit was deposited at depths of 100-200 m. This fauna could be Pliocene or Pleistocene. Paleoenvironmental data require minimal uplifts ranging from approximately 1,000 m for the oldest sampled strata to 100 m for the youngest. There was a general shoaling throughout the deposition of the units.

Ecology of Paralic Foraminifers - Fowler, Margules

A pilot study is underway to determine the distribution of live marsh foraminifers with regard to depth below the sediment surface and relative tidal exposure in a marsh to mud flat environment. Five core samples taken at 20 cm intervals up a marsh bank face were divided into five subsamples at suitable intervals from 0-4 cm down the cores. The subsamples are being processed using the standard rose bengal staining technique to distinguish live foraminifers. However, since there is some question about the technique, an investigation into other possible techniques is being made. This is part of a longer range study to investigate the synergistic effects of variation of salinity, temperature, pH, Eh, sediment organic content, and sediment grain size on the distribution of selected paralic foraminifers.

Computer Programs for Foraminiferal Ecology - Fowler, Gunther

The computer program for foraminiferal faunal analysis, SYNECOLOGY, is now fully operational after modification to use the more efficient BUFFER statements for recording and reading information on magnetic discs.

A new subroutine for SYNECOLOGY calculates direct and inverse abundance ratios for every species pair in the sample, and for every sample in the run. This is intended to provide data for locating faunal boundaries using the stratigraphic distribution of planktonic foraminiferal indicator species in deep-sea cores. However, the data may also be useful in determining the species composition of foraminiferal biofacies in surface sediments. The calling of the program is under the direct control of the investigator through the use of the SYNECOLOGY control card.

A new program, SOS (Short Order Synecology), has been written to do some of the summation routines also done by SYNECOLOGY. This
specialized version is more efficient than SYNECOLOGY when only distribution charts or similarity matrices are wanted, since it does not produce station-by-station data.

The computer programs SYNECOLOGY and SOS are being used to calculate similarity matrices to aid in the evaluation of foraminiferal faunal boundaries on the Oregon shelf. Relative abundance data determined by Boettcher (OSU, Oceanography MS thesis, 1967) from multiple corer samples is being examined for in-station similarity and between station similarity. The programs calculate similarity matrices based on the weighted Jacard Coefficient for both living and total fauna of the following groups: 1) planktonic foraminifers; 2) total benthic foraminifers; 3) agglutinated benthic foraminifers; 4) porcellaneous benthic foraminifers; and 5) hyaline benthic foraminifers.

Deep-Sea Biostratigraphy - Fowler, Tapley

We are continuing a detailed stratigraphic analysis of an 11.8 m piston core (6709D-20) taken 42 nautical miles SSW of Cobb Seamount on the western flank of Juan de Fuca Ridge. The percent by weight of CaCO₃ determined at 10 cm intervals displays trends that reflect and accentuate the stratigraphic trends discussed earlier for the radiolarian to planktonic foraminifer ratio. The zones of increase in radiolarian percentage (0-12 cm, 200-350 cm, 745 cm, 890 cm, and 1090-1140 cm) universally occur in reddish-brown muds low in calcium carbonate.

Four other cores (4.8, 5.3, 11.6, and 12.8 m long) taken last August from the area surrounding 6709D-20 have been opened and logged. Of particular interest is a layer of ash encountered 4.3 m deep in one of the cores. The layer will hopefully provide us with a radiometric date deeper in the stratigraphic section than radiocarbon techniques are effective.

Structure of the Mid-Atlantic Ridge - North Atlantic - van Andel, Heath, Moore

Based on data acquired on cruise 1965-1 of R/V Thomas Washington, cruises 20 and 31 of R/V Atlantis II, Lusiad Expedition of R/V Argo, and several Vema cruises, a detailed bathymetric chart of the intersection of the Vema fracture with the Mid-Atlantic Ridge at 11° north has been completed. The chart shows the presence of several old fracture zones at slight angle to the trend of the present one; these fractures have not participated in recent seafloor spreading and do not cross the present ridge crest. The morphology of the Vema fracture itself can best be interpreted by the assumption that it also is a spreading center from which spreading to the north and south takes place at a slow rate. The Vema is filled with more than 1 km of sediment; originally interpreted
as evidence for a substantial age, recent drilling by the JOIDES project has indicated that most or all of this fill is of very late Cenozoic age.

A paper, based on the bathymetry, some seismic reflection data, and heat flow and magnetic observations, is in preparation. This paper, co-authored by R. P. Von Herzen and J. D. Phillips of Woods Hole Oceanographic Institution will be the last report on our series of studies of this part of the Mid-Atlantic Ridge system.

Geophysical and Geological Studies in the South Atlantic - van Andel, Heath, Moore

From October 9 to December 3, 1968, geological studies were carried out from R/V Argo in the South Atlantic on legs 8 (Mozambique to Luanda, Angola) and leg 9 (Luanda to Fortaleza, Brazil) of CIRCE Expedition. A detailed geophysical survey was made of a small portion of the Walvis Ridge, including seismic reflection, magnetic and bathymetric observations combined with coring and dredging. The first samples of the Walvis Ridge easement ever obtained were acquired; they consist of basalt of probably middle Eocene age according to the foraminiferal assemblages in baked foraminiferal ooze. The structure of the ridge appears to consist of en echelon faults along which, probably in late Miocene time, substantial uplift has taken place. The faults also affect even the youngest sediments in the Cape Basin at the foot of the Ridge.

Together with S. E. Calvert and N. B. Price of Edinburgh University, a detailed sampling and water chemistry program was carried out on the continental margin of the Walvis Bay region, where in the area of high productivity of the Benguela current, highly organic sulphidic muds of particular interest are being deposited.

Between Luanda and Brazil, five detailed geophysical studies were made of small areas on the Mid-Atlantic Ridge from the eastern margin near anomaly 20 to the crest. The surveys, during which sediment cores and rock samples were also obtained, revealed distinctive differences in structural patterns. At the crest of the ridge, on the flank of the median rift and within the central magnetic anomaly, a basalt sample was obtained that contained baked foraminifera of latest Pliocene age, a date at variance with the assumed maximum age of the central anomaly of middle Pleistocene. An additional survey was made of the western end of the Ascension fracture zone.

The data from this cruise are at present being processed, and the cores have been opened and described. Most of the material is not yet ready for even preliminary conclusions.
Sediments and Stratigraphy of the Equatorial Atlantic West of St. Paul's Rocks - Dinkelman

During various cruises in the past ten years a series of long piston cores has been obtained in this area that extends from the intermontane valleys of the Ridge to the Amazon abyssal plain in the west. The cores show decreasing carbonate content westward and increasing appearance of calcareous turbidites of local origin eastward. They include post-glacial, glacial and probably interglacial sediments. They will form the basis for an examination of the detailed late Quaternary stratigraphy of the equatorial Atlantic, and for a study of sediment sources, sedimentation processes, and depositional history in this region. A beginning has been made in establishing a stratigraphic framework based on planktic foraminifera.

Mineralogy of Deep-Sea Sediments - Heath

Variations in the mineralogy of deep-sea sediments from the equatorial Pacific have been studied by X-ray diffraction analysis of core samples ranging from early Tertiary (50 million years old) to Holocene in age. The mineralogy of fine fractions of these deposits shows that a component derived in large part from tholeiitic debris is the principal constituent of all middle Eocene (50 m. y.) to late Miocene (10 m. y.) deposits. This component is characterized by abundant montmorillonite, plagioclase of intermediate composition, and the zeolites phillipsite and clinoptilolite-heulandite. It persists as a major constituent of many late Cenozoic southern equatorial deposits, but forms a minor portion of Quaternary sediments from the North Pacific.

Southern and western equatorial sediments younger than late Miocene (10 m. y.) are rich in pyroxene (including orthopyroxene) and chlorite, and have high pyroxene: plagioclase ratios (typically 1.4:1) in 2-20 micron fractions. The abundance of pyroxene may in part reflect late Cenozoic changes in the tenor of oceanic volcanism. However, most of the pyroxene-rich debris is derived from the island arcs that form the western margin of the Pacific basin, and to a much lesser extent from Andean volcanoes. The appearance of the "island arc" material coincides with a period of heightened tectonism in many marginal areas of the Pacific, and also with an interval when it has been suggested that the rate or pattern of sea floor spreading was undergoing a marked change.

Northern equatorial deposits of Quaternary age are dominated by windborne continental debris rich in quartz and illite. Fine fractions of periglacial loess deposits associated with Pleistocene ice masses in the northern hemisphere probably constitute the main source of such debris.
Tertiary equatorial sediments (with the exception of a few northwestern equatorial occurrences of Pliocene age) consist of less than 20 percent "continental" material.

Of the minerals studied, only chlorite appears to be modified by prolonged exposure to porewater. The crystallinity of chlorite deteriorates over a period of 5-10 million years, but then changes little over additional periods of tens of millions of years. The only other observed pronounced diagenetic effect is a systematic increase in the grain size of older sediments due to dissolution of opaline tests and reprecipitation of the silica as cement.

X-ray Diffraction Analysis of Marine Sediments - Heath

An X-ray diffractometer has been installed and requires only minor adjustment to become operational. Modifications to produce digital output compatible with existing programs designed to filter and analyse diffraction data are in progress. Specifications have been developed for a fully automated system to handle the large number of samples which will be generated within the marine geology group by projects involving studies of the mineralogy of marine sediments.

Sedimentation in the Panama Basin - Heath, Beer

The first stage of a planned study of sedimentation in the Panama Basin, a deep-sea, nearshore, silled basin, was completed during February and March, 1969, on the YALOC '69 cruise.

More than 6500 miles of track with gravity, magnetics, bathymetry and continuous seismic reflection profiler (airgun) coverage, as well as 42 cores taken at 24 locations in and around the basin will provide the basic knowledge of structure and sediment distribution needed to plan future investigations of critical areas.

Most of the data is still to be processed, but it appears that active sedimentation is largely restricted to three sub-basins separated by volcanic outcrops and structural discontinuities resulting from creation of new crust at a spreading zone complementary to the East Pacific Rise, and from movement along transform faults. Processing of results, which are in digital form, awaits the completion of a library of CDC 3300 computer programs.
Radiometric dating of a sediment section from an intensively studied area southeast of Hawaii has enabled us to make quantitative estimates of the rates of accumulation of the various constituents of Quaternary sediments. This data will form the basis for a budget of the several inorganic and biogenous components, as well as of the reworked versus newly deposited sediment.

Marine Stratigraphy - Moore

Much effort has been expended on a type collection of radiolaria and nannoplankton of stratigraphic value. For this purpose, the stratigraphy of calcareous nannoplankton is being investigated in samples from the equatorial Pacific. In addition, arrangements have been made to receive samples from large core collections obtained by the Navy's Marine Geophysical Surveys, and by V. T. Bowen at Woods Hole Oceanographic Institution, mostly from the Atlantic Ocean.

Core and Dredge Collections - Moore

With the rapid growth of our geological sample collections it has become imperative to systematize the core description and data recording and to provide more extensive facilities for description, treatment and storage. Procedures and forms for core descriptions have been prepared, which are similar to and compatible with the procedures used at Scripps, at Miami and in the Deep Sea Drilling Project. Record keeping procedures will permit efficient production and distribution of abbreviated core descriptions to other institutions, and storage is designed so that samples can be made available readily on request. At the moment we are constructing improved storage facilities, but improvisation will remain necessary until funds are available for properly equipped space.

Cascadia Deep-Sea Channel - Kulm, Griggs

The study of the more than 600 km of Cascadia Channel in Cascadia Basin and Blanco Fracture Zone has been completed. A comprehensive manuscript dealing principally with the turbidites in the channel axis was prepared for publication.

Deep-Sea Sands and Silts - Kulm, Allen

Laminated sands and silts from Cascadia Channel and Cascadia Abyssal Plain, including both Holocene and Pleistocene glacial deposits, have been studied in great detail. A manuscript is being prepared from
the results of this investigation. The data strongly suggest that certain laminated sand and silt sequences in the deep sea develop under a rigid set of dynamic conditions, which are reflected in the textural and compositional characteristics of the laminae themselves. It is tentatively suggested that such conditions occur during a particular phase of a turbidity current flow period.

Oregon Continental Margin Structure - Kulm, Bales, Mackay, Fowler, Buehrig.

The study of the structure of the southern Oregon continental shelf between Coos Bay and Cape Blanco was completed in November. We now have a better understanding of the late Cenozoic development of this part of the shelf. A similar investigation is being conducted on the southern shelf from Cape Blanco to the Oregon-California border. A major change in the structural pattern, separated by a marked angular unconformity, occurs south of Cape Sebastian where a young Tertiary basin occupies the southernmost part of the shelf.

Sediments - Kulm, Buehrig, Spigai, Roush

Textural analyses have been completed on the sediments from box cores taken along three different profiles on the central Oregon shelf. These analyses show that the central shelf mud facies, present off southern Oregon, is generally lacking on the shelf off Yaquina Bay and Cascade Head. An attempt is being made to determine how the width of the shelf and the rate of supply of terrigenous sediments to the shelf have affected shelf sedimentation during the last rise of sea level.

A comprehensive analysis of heavy-mineral suites of the southern Oregon continental shelf and of the adjacent coastal source areas is in progress. The heavy-mineral assemblages will be used to determine the predominant direction of littoral drift of sand along the modern beaches and the movement of sand on the continental shelf, which includes both relict and modern sands.

Sedimentation on the southern Oregon continental slope is being studied through the analyses of sediments from 20 piston cores taken in this area. Textural analyses have been completed for more than one-half of the cores.
Sedimentary Processes - Kulm, Neudeck, Harlett

A sedimentation model is being developed for the central Oregon shelf and slope. The sedimentary processes operating on the margin are being studied by underwater photography and by bottom-current measurement.
GEOPHYSICAL OCEANOGRAPHY

Marine Gravity - Banks, Couch, Gemperle, Heinrichs

Preliminary reduction of gravity measurements made along approxi-
mately 2000 miles of trackline in the Strait of Juan de Fuca and in south-
east Alaska (including the continental shelf) between Chatham Strait and
Icy Strait has been completed. Progress on construction of detailed
sections has been delayed while Banks, Gemperle, and Heinrichs were
at sea on YALOC-69.

Gravity measurements were made along 10,775 miles of trackline
during the YALOC-69 cruise from 14 February to 20 April 1969. Geologic
areas of interest include: Panama Basin (8 tracks); Carnegie Ridge
(6 crossings); Cocos Ridge (7 crossings); Peru-Chile trench (6 crossings);
Middle Americas trench (8 crossings) and the East Pacific Rise (3 cross-
ings). The reduction and interpretation of these data will be a major task
during the next report period.

Mr. Couch has completed a study of the gravity and structures of
the crust and subcrust in the Northeast Pacific Ocean west of Washington
and British Columbia.

Work is continuing on the reduction and analysis of data from the
Pioneer fracture zone and continental margin off northern California.

Marine Magnetics - Banks, Couch, Gemperle, Heinrichs

Preliminary reduction of magnetic measurements obtained September
1969 west of Oregon and Washington, in the Strait of Juan de Fuca, and in
the Strait of Georgia has been completed. These data together with gravity,
seismic reflection, and heat flow information are being analysed by Mr.
Banks to determine the structure and tectonic activity of this region.

A detailed study of 15 long magnetic profiles from both the Atlantic
and Pacific Oceans has been completed. Ocean floor spreading rate
curves based on the usual association of magnetic anomalies with the
paleomagnetic time scale were constructed. Two different interpretations
appear possible: (1) Spreading rates have been non-uniform along the
whole mid-ocean ridge system, and have changed in the same way and at the same time during the past 3.32 million years. (2) Spreading rates have been nearly uniform and the anomaly usually associated with the Olduvai event should be associated with the Gilsa event. Another anomaly, called W, should be associated with the Olduvai event. The latter interpretation is more acceptable.

Magnetic measurements were made along 10,775 miles of trackline during the YALOC-69 cruise from 14 February to 20 April 1969. (See Marine Gravity for tracklines). Reduction of these data has started. Preliminary interpretation indicates that a proposed spreading axis in the Panama Basin is real and may extend further east than previously believed. A new fracture zone was discovered at approximately 13°N, 108°N in the East Pacific Rise. This needs to be confirmed by additional analysis and a literature search.

The OSU proton magnetometer was inoperable for the first month of the cruise. A complete overhaul, including washing with distilled water, repaired the unit. No data was lost, however, since Scripps Institution of Oceanography (Dr. John Mudie) loaned us an operating magnetometer. All of the Panama Basin data was obtained using their magnetometer.

Seismic Profiling – Banks, Couch, Gemperle, Heinrichs

Prior to the YALOC-69 cruise the continuous seismic profiling system was rebuilt based upon operating experience obtained in September 1968. The current system still needs minor modification but is a good operating unit. A third air gun is needed to complete the system.

Approximately 7000 miles of continuous seismic profiling measurements were made during YALOC-69. These data indicate that the Panama Basin is structurally complex and tectonically active. Reduction and interpretation of these measurements will be done during the next report period.

Seismic measurements obtained during September 1968 on the Straits of Juan de Fuca and Georgia, along Chatham Strait and Icy Strait and over the continental shelf west of Chichagof and Baranof Islands in Southeast Alaska are being analysed by Banks and Gemperle.
Land Gravity - Heinrichs

Structure cross-sections, simple bouguer gravity anomaly maps, and free-air gravity anomaly maps of the Silver Peak Range, Nevada have been completed. Two terrain corrected profiles are being constructed and a paper for GSA is in preparation. Dr. Paul Robinson, Geology Department, OSU, is a co-investigator.

The final analysis of a regional gravity survey of Oregon has been accepted for publication by the Geological Society of America. (See Progress Reports 19 and 20). The paper includes a regional geologic map of Oregon with superimposed gravity anomaly contours.

Paleomagnetic Studies - Heinrichs, Lu

The measurement program for paleomagnetic samples continued at a reduced rate this last quarter due to Dr. Heinrichs absence (at sea) and difficulties with the spinner magnetometer. Mr. McKnight, who was working on the project, has left OSU.

Earthquake Seismology - Couch, Gallagher, French, Johnson, Pietrafesa

The World-Wide Standard Seismic Station at Corvallis was operated continuously during this report period. The satellite seismic station at Klamath Falls, Oregon, experienced timing problems and was inoperative for the months of October, November and December. The seismograph records of the Corvallis, Klamath Falls, and Portland, (OMSI) stations have been read and catalogued.

Local earthquake activity occurred in the vicinity of Portland, and Adel, Oregon, and off the coast of southern Oregon during the first eight months of 1968. This activity has been investigated and the results published.

The epicenter for the Portland earthquake (magnitude 3.8) of May 13, 1968, lies north of Portland, close to the Columbia River and nearly coincides with the epicenters of earthquakes occurring in January 27, 1968, and November 5, 1962. Chronologically, the three earthquakes show a decreasing focal depth, and the sense of motion on all three is consistent
with a right-lateral displacement along a north-northwesterly trending strike-slip fault. Cumulative seismic energy release in the Portland area was computed for the period 1877-1968. The results indicate that the rate of energy release has increased approximately ten times since 1950. The present rate of energy release is equivalent to one magnitude 4.8 (unified magnitude scale) earthquake each year.

A series of earthquakes occurred in the Warner Valley near Adel in southeast Oregon in May and June, 1968. More than 120 shocks were registered at the nearest permanent seismic station located at Klamath Falls. The largest earthquake had an estimated magnitude of 5.1 on the Richter Magnitude Scale while 13 earthquakes had a magnitude greater than 4.1. The earthquakes caused minor building damage in the Warner Valley in addition to numerous rockslides which damaged irrigation systems. Personal inspection of the epicentral area failed to reveal evidence of fresh faulting of the surface although minor slumping was observed. Studies of the source motion indicate that movement was vertical, probably along old faults, which originally formed the Warner graben. The Warner Valley earthquake sequence represents the largest seismic energy release in Oregon since the Portland earthquake of November, 1962, and is unusual in the sense that it occurred in an area previously thought to be aseismic.

Twenty-two earthquakes with magnitudes between 3.6 and 6.3 occurred during the first eight months of 1968 off the coast of southern Oregon. The epicenters straddle the Blanco Fracture Zone which trends in a northwesterly direction from Cape Blanco. Studies of the source motion suggest possible right lateral displacement along a west-northwesterly trending strike-slip fault.

Dr. Gallagher has completed a study which develops a method of determining earthquake fault-plane solutions from a small number of station observations of short-period P-waves (see Progress Report 22).

Mr. French is completing a study of seismic arrivals which are believed due to reflection and conversion of head-waves.

Direct Interpretation of Potential Field Data - Bodvarsson, Emilia

Direct interpretation methods have been applied to marine magnetic data, mainly to magnetic anomalies associated with sea-floor spreading. The first phase of this work has been completed and the results are being
prepared for publication. Results obtained so far, which have been described in the previous Progress Report, show that this method yields new and interesting results.

Bottom Current and Temperature Studies - Bodvarsson, Korgen

A considerable number of bottom current and temperature data have been obtained in waters off the coast of Oregon with the new current-temperature probe. The data have been processed and are being evaluated. The current data are consistent with rough theoretical estimates and with experimental data from other areas. The temperature data have yielded some unexpected results which are being studied.

Physics of Geothermal Areas - Bodvarsson

A theoretical study is being carried out on the energy balance of geothermal areas. This work is being carried out in cooperation with Dr. Don E. White of the U.S. Geological Survey, Menlo Park, California.

Theoretical Geophysics - Bodvarsson, Lowell, Pietrafesa, Rands

A new series of solutions of the one-dimensional heat transport equation has been obtained. The work on (1) the theory of the internal structure of planets, (2) diffusion problems in the oceans and (3) mathematical theory of guided waves has been continued.

Geoelectrical Methods - Bodvarsson

A study of inductive effects in low-frequency geoelectrical exploration work is being completed.
CHEMICAL OCEANOGRAPHY

Chemistry of the Subarctic Boundary in the North Pacific Ocean - Park Gordon, Hager, Cissell

Aboard USC & GSS SURVEYOR and CNAV ENDEAVOUR we continued to study the chemistry of the subarctic region of the Pacific Ocean. In September-October 1968, we concentrated our chemical works, which include PCO₂, pH, oxygen, nutrients, alkalinity, in the western part of the Subarctic Boundary (Fig. 7) while in March-May 1969 we determined the surface distributions of PCO₂ and pH in the subarctic region from Canada to Japan (Fig. 7).

In January-February 1969, Messrs. Ryan and Reed of ESSA obtained the seawater samples along the 160° W for the nutrient determinations.

The ENDEAVOUR cruise, led by T. R. Parsons of Canada, March-May 1969, has yielded uninterrupted continuous PCO₂ and pH data from the North American continent to Japan.

Chemistry of Columbia River Plume - Cissell, Park

An intensive chemical investigation, that includes the determinations of salinity, oxygen, nutrients, pH, alkalinity, and total carbon dioxide of the Columbia River plume off the Oregon coast in July 1967 shows the following unique features:

1. Along the axis of the river plume both the salinity minimum and temperature maximum occur. The location of these extremes at zero, ten, twenty meters depths differ considerably, suggesting different patterns of water flow at different depths.

2. Throughout the plume region, at salinities less than 32.5‰, the plume water is supersaturated with respect to dissolved oxygen, and a subsurface oxygen maximum exists at the depths of 30-50 meters.

3. The relationship between apparent oxygen production by marine organisms and nutrient concentrations shows biological production of dissolved oxygen is a definite cause for the oxygen supersaturation in the plume region.

4. The plume area off Oregon is a source of oxygen transfer from the ocean into the atmosphere.
Figure 7. Cruise tracks of USC&GSS SURVEYOR and CNAV ENDEAVOUR for Subarctic Water Study March-May 1969.
Seasonal Distribution of Nutrients off Oregon - Ball, Park

Seawater samples collected monthly along the Newport hydrographic line were analyzed for phosphate, silicate, and nitrate using a Technicon Auto-Analyzer and manual methods. In January, phosphate is less than 0.5 µM at the surface increasing to a 3.3 µM maximum at 1000 m. (Maxima for phosphate and nitrate occur at 1000 m throughout the year.) A minimum (less than 0.4 µM) rises from 40 m offshore to 10 m onshore during March. Surface concentrations are less than 0.4 µM with a 2.5 µM maximum. In the summer (July) a minimum occurs at 20 m (less than 0.4 µM) increasing to a 3.2 µM maximum. At the end of the productive season (October), no minimum exists with a surface concentration increasing from 0.1 to 0.6 µM onshore. The maximum was 2.7 µM.

Silicates increase to 175 µM at 2600 m depth during the entire year. In January, silicates show a 0.8 µM minimum at 75 m depth offshore shallowing to 5 m depth nearshore. Surface silicates increase from 5 µM offshore to 30 µM nearshore with a 4-6 µM minimum occurring at 30-50 m. The July minimum is shallower, occurring at 10-30 m with a concentration less than 3 µM. Surface concentrations are less than 2 µM, increasing to 40 µM nearshore. October surface concentrations decrease from 5 µM at NH-165.

Nitrates reach a maximum of 40-45 µM at 1000-1200 m. The January minimum decreases from 7 µM and 30 m nearshore to less than 2 µM at 50 m. The March minimum is shallower, occurring from 10-30 m with concentrations of 1-3 µM increasing nearshore. The July minimum is at 50 m offshore surfacing at NH-25. In the late season (October) nitrates are higher (5-6 µM) near the coast dropping to less than 0.1 µM offshore. No minimum exists.

Cruise Y6806-C investigated upwelling with DB 1-40 occupied 3 times in 10 days. The Columbia River plume extends to 60 m. Phosphates at the surface were less than 0.1 µM with the plume with an increase to greater than 1 µM in both directions from the plume with no minimum. Silicates show a minimum (less than 1 µM) at the plume center. Nitrates also show a minimum at the plume center and are less than 0.1 µM in much of the plume influence.

Chemistry of Upwelling Off Oregon - Park, Gordon, Hager, Cissell, Ball

In June and July of 1968, continuous measurements of carbon dioxide tensions (PCO2) in the surface waters off Oregon were carried out. Discrete analyses performed simultaneously were temperature, salinity, oxygen, pH,
alkalinity and plant nutrients. The latter observations were also done at depths to 200 m. The region of study lay between the mouth of the Columbia River and 43°20' N; between the Oregon coast and 125° W. PCO₂ was measured as carbon dioxide partial pressure in an air stream continuously equilibrated against sea water flowing from a sea cock at two and a half meters depth. The observed values were between 175 and 530 ppm. The variations in PCO₂ correlated predictably with those of the other parameters measured and could be explained in terms of the physical and biological processes acting at the time in the region; that is, with upwelling of high-PCO₂ deeper water to the surface and its subsequent mixing with local surface water and Columbia River water, and with photosynthesis and oxidation of organic matter. Illustrated in Fig. 8 is the correlation between AOU (Apparent Oxygen Utilization) and P_CO₂. The approximate composition of the upwelling water is indicated and the two dashed straight lines indicate equilibrium with the atmosphere with respect to each of the gases. The curved solid line illustrates the approximate trajectory of water initially equilibrated with the atmosphere and in which photosynthesis and respiration take place according to the relation. AOU: Total CO₂ equals 138:106 (in molar units). Carbon dioxide tension appears to be one of the more sensitive indicators of upwelling. This results from the large difference in PCO₂ between the surface and upwelling waters.

Silicate Chemistry in the Northeastern Pacific Ocean - Hager, Park

Surface and vertical distributions of dissolved "reactive" silicate were measured by means of a Technicon Autoanalyzer® in the northeastern Pacific Ocean. Surface measurements were made on September 1968 cruise of the USC & GSS SURVEYOR. Vertical and surface distributions were studied on the April 1968 cruise of the SURVEYOR and the 6801F and 6806C cruises of the R/V YAQUINA. In addition silicate analyses were run on frozen samples from Newport (Oregon) Hydrographic Line cruises.

Near the Oregon coast, distributions were found to result from the combined effects of primary productivity and subsequent nutrient regeneration, the Columbia River Plume, and coastal upwelling. In the open ocean, vertical silicate distributions result from water mass characteristics, primary productivity, and nutrient regeneration. Precise deep ocean data from the April 1968 SURVEYOR cruise (Fig. 9) have enabled a study of the factors leading to the silicate maximum at about 2300 m in the Pacific Ocean.

Oceanic CO₂ System: An Evaluation of 10 Methods of Investigation - Park

By combining two or more of the chemical parameters pH, alkalinity, total CO₂, P_CO₂, six equations were obtained to express the concentration of CO₂, 10 equations for HCO₃⁻, and 11 equations for CO₃²⁻. Limnology and Oceanography has published its details (14, 179-186, 1969).
Figure 8. Surface $\text{PCO}_2$ and AOU on R/V YAQUINA Cruise 6806C. Dashed lines indicate saturation with respect to the atmosphere. The solid line indicates the trajectory imposed by photosynthesis and respiration on air-saturated water.
Figure 9. Observed silicate and non-oxidative silicate for stations SU-91-68 and SU-105-68.
Columbia River CO₂ System - Park, Gordon, Hager, Cissell

In December we carried out a chemical cruise from Portland, Oregon to Astoria (river mouth) aboard R/V YAQUINA. We determined PCO₂, pH, alkalinity and total CO₂. We discovered that the high PCO₂ 500-1000 ppm, of the river water can not be explained by the carbonic and dissociation constants for fresh water.

Chemistry of Columbia River Estuary - Park, Osterberg, Forster, Haertel, Catalfomo

The three-year survey of the seasonal distributions of nutrients, pH, alkalinity, total carbon dioxide, oxygen for 1966-1967-1968 has been completed. We noticed that on stream, primary production lowers the nutrient concentrations drastically, while the wind-induced coastal upwelling brings the nutrient-rich seawater into the estuary.

The nutrient budget study for the Columbia River system in 1966 shows a definite pattern in its seasonal distribution; a maximum during winter months and a minimum during summer months.

Alkalinity Budget of the Columbia River - Park

The chemical nature of the alkalinity, an index of weathering of rocks, for the Columbia River system has been studied, and we agree with other investigators that the river-water alkalinity essentially consists of carbonate alkalinity, 94%. Limnology and Oceanography will publish our findings.

Carbonate Complexes - Pytkowicz, Hawley

A procedure was developed and is being used to determine carbonate complexes in seawater as a function of temperature and pressure. The results, in conjunction with those that we obtained for sulfate complexing, will yield a chemical model for seawater.

Nearbottom Studies - Pytkowicz, Culberson, Hawley

A procedure was developed for the precise determination of the titration alkalinity (Culberson, Pytkowicz, and Hawley, in preparation) This procedure, in conjunction with the near bottom samplers developed in our laboratory, was used for measurement of the near-bottom chemistry during a cruise of the R/V YAQUINA to the eastern tropical Pacific Ocean. The data is being processed at present.
Sulfate Complexes - Pytkowicz, Kester, Gates

The measurements at atmospheric pressure and 25°C, on sodium sulfate and magnesium sulfate complexes were published (Pytkowicz and Kester, 1969; Kester and Pytkowicz, 1968). The measurements with electrodes were extended to 2°C. At this temperature and 34.8 ppt salinity, the speciation is as follows:

<table>
<thead>
<tr>
<th>Percentage of Sulfate</th>
<th>Free $SO_4^{2-}$</th>
<th>Na$SO_4$</th>
<th>Mg$SO_4$</th>
<th>Ca$SO_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>28</td>
<td>47</td>
<td>21</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

The variation of the stoichiometric association constants with temperature was

<table>
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<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_{NaSO_4}$</td>
<td>3.64</td>
<td>3.21</td>
<td>2.84</td>
<td>2.52</td>
<td>2.25</td>
<td>2.01</td>
</tr>
<tr>
<td>$K_{MgSO_4}$</td>
<td>15.50</td>
<td>14.20</td>
<td>13.00</td>
<td>12.00</td>
<td>11.00</td>
<td>10.20</td>
</tr>
</tbody>
</table>

The effect of pressure on $K_{NaSO_4}$ at 1.5°C was also determined and was found to be

<table>
<thead>
<tr>
<th>$P(\text{atm})$</th>
<th>1</th>
<th>500</th>
<th>1000</th>
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<tbody>
<tr>
<td>3.50</td>
<td>2.49</td>
<td>1.74</td>
<td></td>
</tr>
</tbody>
</table>

The results were used to calculate the enthalpy, entropy, and free energy and to study the effect of ion pairing on physico-chemical properties of seawater.

Calcium-Carbonate - Pytkowicz, Hawley

The pressure coefficient of the solubility of calcium carbonate in seawater at low temperatures was used, in conjunction with Vityaz data, to examine the degree of saturation in the Pacific Ocean (Hawley and Pytkowicz, in preparation).
Specific Activity Studies of $^{65}\text{Zn}$ in Various Soft Body Parts of *Mytilus californianus* - Larsen, Forster

An analysis of various metals present in sea mussels is underway. The specific activity of Zn-65 for various organs of these mussels is presently being determined. Detection of Zn-65 was by a NaI(Tl) detector coupled to a 512 multichannel analyzer. Stable metal analysis is by atomic absorption spectrometry and neutron activation analysis for comparison.

Preliminary results show higher specific activities of Zn-65 at locations closer to the Columbia River than those stations further away, as expected. Specific activity values for Zn-65 ($\mu$Ci Zn-65/gm Zn) ranged for a low value of 0.0151 to a high value of 0.772.

Radioanalysis - Larsen

Radioanalysis is accomplished by Gamma Ray Spectrometry. Samples conforming to a standard geometry are counted in one of three NaI(Tl) well detectors, each coupled to a 512 multichannel analyzer. Environmental samples are generally counted for 100 or 400 minutes, depending upon the level of radioactivity present. After counting, the background is subtracted and the count rate of the various radionuclides is converted into units of radioactivity (picocuries) by use of a CDC 3300 computer. Complex spectra (those spectra which have overlapping photopeaks) are reduced by means of a least squares program. This procedure measures up to nine radionuclides in one sample. Simpler spectra are reduced by comparing the counts under a photopeak to the known standard count rate. Calculations for decay and sample size are made to give units of radioactivity per unit sample size at the time of collection.

Water Mass Tracer - Hanson, Forster

The use of several stable element complexes to determine the flow characteristics of a river are evaluated by neutron activation analysis by Hanson. This project is conducted at USAEC's Battelle-Northwest operation under the guidance of Julian Nielson's lab.

The organic ligands, EDTA and DPTA are complexed with the stable elements Cs, Rb, Eu, Tb, Dy, Sb, Sc, Co, Hg, In, and Cr. These are thoroughly mixed with water, suspended sediments, and stream bed sediments before removal and analysis. The resulting plots of the amount left
in solution relative to time should give a comparison of the efficiency of the tracer to remain in solution.

Analysis of the stable element by neutron activation with ultrasensitivity is necessary in the processing of the above trace elements in the ppb range. We hope to use this technique as a sensitive tool for following the flow of fluvial, ground, estuarine and possibly marine waters.

**Estuary Plankton Study - Haertel**

Analyses of results from the Columbia Estuary sampling program extending from April 1967 to August 1968 are currently being incorporated into a dissertation. Chemical parameters such as salinity, oxygen, nitrates, silicates, and phosphates were correlated with areal and temporal distribution of the plankton.

**Radionuclide Transfer through Food Webs - Renfro, Steinfeld**

Radioecological studies in the Alder Slough section of the Columbia River Estuary have been carried out since April 1966. Measurements of both radioactive and stable nuclides of several elements are made in order to calculate specific activities in the biota of the ecosystem. Specific activity, expressed in microcuries of the radionuclide per gram of the element in the organism, provides an indication of the turnover rate of the radionuclide through various trophic levels.

In July and December 1968, inventories of gamma-emitting radionuclides in the water, sediments, and biota of Alder Slough were made. Within this 7,000 square meter area $^{65}$Zn, $^{51}$Cr, and $^{46}$Sc were the most abundant radionuclides present. Preliminary study of these data show that, regardless of the season or biomass of the biota, a very large fraction of the total radioactivity is in or on the sediments.

**Columbia River Estuary Fishes - Renfro, Steinfeld, Ellison**

Monthly collections of fishes and crustaceans from several stations in the Columbia River Estuary were continued. Concurrent measurements of water temperature, salinity, dissolved oxygen, nutrients, and radioactivity were also made. Analysis of the $^{65}$Zn specific activities in these samples over a five year period have shown large seasonal fluctuations associated with changes in river discharge rates and biological turnover rates. In addition, reductions in the number of plutonium
production reactors at Hanford, Washington appear to have caused some decrease in $^{65}$Zn specific activities of fishes and invertebrates.

Direct Determination of Total Zinc and Lead in Estuarine Waters - Wagner, Forster

In the past, atomic absorption spectrophotometric analyses of water samples required concentration by at least thirty times before either zinc or lead could be measured. Recently we have been using an accessory for the Perkin-Elmer model 303 AAS called a "Sample Boat" which improves the sensitivity for zinc about sixty-five times and for lead about thirty times. In terms of detection limits, zinc may be detected at levels as low as 0.08 $\mu$g/liter (80 parts per trillion), for lead the detection limit is about 0.5 $\mu$g/liter (0.5 parts per billion).

The significance of these detection limits permits collecting small quantities of estuarine water (about ten milliliters) and rapidly determining total zinc and lead concentration without further processing. Each sample requires about five to ten minutes per determination. Further work is being done to determine the applicability of this technique for determinations of zinc and lead concentrations in sea water.

Determination of Antimony-124 in the Columbia River - Pope, Forster, Renfro

Antimony-124 is present in the Columbia River as a product of neutron activation from the Hanford reactors. It is believed to remain primarily in the soluble phase. However, previous counting techniques could not measure its activity with adequate sensitivity. The method of coincidence counting was developed at the Department of Oceanography to permit measurement of antimony-124 without interference from other radionuclides. Samples were taken at different locations on the Columbia River between Bonneville Dam and Pt. Adams, Oregon during February, March and April of 1969. Relative to experimental error coincidence counting promises to be a better method for determining antimony-124 than regular $4\pi$ counting techniques.

Distribution of Zn-65 and Co-60 in Fractionated Sediments of the Columbia River Estuary - Delaplane, Forster, Renfro

Radioactivity measurements of Zn-65 and Co-60 in sediments of the estuary were made to determine whether Zn-65/Co-60 ratios are constant in either bulk sediments or in sand, silt, or clay fractions.
These ratios may be used to trace rate and direction of sediment movement from the estuary. Throughout the estuary Zn-65/Co-60 ratios were found to range from 2.48 to 43.4 with a mean of 11.5.

To determine which particle size fraction would best serve as a monitor for sediment radioactivity, a method was developed to disperse and fractionate sediments into sand, silt, and clay. To minimize processing effects on radionuclide distribution, several methods of dispersion were studied. Of these, dispersion by mechanical shaking in distilled water was found to have the best combination of completeness of separation and low statistical variability.

Vanadium, Its Detection and Distribution in the Water, Sediments, and Biota of the Columbia River Estuary and Plume Waters - Dyer, Forster, Renfro

Geochemical action of the Columbia River has introduced large amounts of vanadium into the sea, yet sea-water analysis via large volume precipitation has shown vanadium to be present in extremely low concentrations, 3-5µg/kg (ppb). Biological mechanisms appear to be the most effective removal agents at present. Atomic absorption analysis shows enrichment factors (V in organism, ash/V in sea water) in some marine and estuarine organisms ranging from a high of 40,000 in algae to between 8,000 and 13,000 in selected invertebrates. No vertebrates have shown detectable vanadium concentrations. It appears most biological removal of vanadium from the water is done by plants, or animals in the lower phyla.

Studies of $^{65}$Zn Uptake by Phytoplankton at Three Temperatures - Tomlinson, Renfro, Forster

Studies of the uptake and retention of radionuclides by species of motile, unicellular algae have various inherent problems due to the inadequacy of existing experimental systems. These difficulties include the inability of workers to efficiently separate radionuclide adsorption from radionuclide assimilation, without subjecting the cells to stresses that may alter the characteristics of radionuclide uptake and transfer. On this basis, a study is recently underway to use an electronic particle counter (Coulter Counter Model A) to obtain statistical parameters related to changes of particles size distribution. These parameters may in turn be correlated with the extent of radionuclide accumulation or loss.
Phosphorus-32, a neutron activation product produced in the coolant water of the Hanford reactors, is present in detectable amounts in the Columbia River and its estuary. This radionuclide was found to be of major biological importance, being highly concentrated in most aquatic organisms and waterfowl. Its presence in the river provides an ideal tracer to study various aspects of the phosphorus cycle. Phosphorus-32 is a beta emitting radionuclide; therefore, the techniques for sample preparation and counting, which are routinely used for detection of gamma emitting radionuclides, are unsatisfactory for its detection. To date, the majority of the work has gone into the adaptation and testing of a technique to extract total phosphorus from organisms with subsequent determination of the phosphorus-32 specific activity. The method entails a preliminary separation of the phosphorus by precipitation as ammonium phosphomolybdate, and a final purification of the phosphorus by two successive precipitations as magnesium ammonium phosphate. Field work has consisted of the determination of phosphorus-32 specific activities for starry flounder (Platichthys stellatus) and a number of its food organisms, a retention study using starry flounder, and the determination of phosphorus-32 specific activities for fingerling silver salmon.
Yaquina Bay Plankton Studies - Frolander, Bergeron, Flynn

The weekly zooplankton collection from Yaquina Bay has been continued. The physical, chemical, and biological data collected weekly from four stations in the bay for the last six years has been analyzed by computer. A Ph.D. thesis on the factors affecting the distribution of zooplankton in the Yaquina Estuary is in the final stages of completion.

Porcellanidae Crab Studies - S. Gonor, Frolander

The behavior, ecology, and morphology of the larval life histories of three species of Porcellanidae (Decapoda, Anomura) is presently being studied. Experiments and observations have been completed concerning feeding, cleaning, respiratory and locomotory behavior of these organisms. Plankton samples collected in Yaquina Bay have indicated approximately where and when large numbers of the larvae in the plankton or settling out as megalopa may be found.

Phytoplankton Ecology - Curl, Small, Myers, Becker

In preparation for forthcoming Coastal Oceanography cruises in the summer of 1969, CAYUSE cruise C 6904-A was made to determine the spatial distribution and daily change in phytoplankton abundance to be expected when following a drogue. A comparison also was made between production measured in a deck incubator and that measured in-situ. In summary, we found that, at low population levels, we could expect a variation among replicate samples of between twenty-five and forty percent, on the average. Correspondence between the on-deck and in-situ measurements was adequate.

Ecosystem Simulation - Curl, Iverson

The Riley-Steele models of lower trophic level, marine pelagic ecosystems has been extended by construction of a set of equations describing relations of different, major species of phytoplankton and herbi-
vores as functions of nutrient and stability conditions. Two models have been constructed: one describing conditions off the Oregon coast during upwelling and the other for an isolated estuary with sharp pycnocline and no advection. Data obtained this summer in these two environments will be used in a computer simulation to test the models.

Terrestrial Cryobiont Algae - Curl, Sutton, Becker, Weers

Numerous strains of cryobiont algae are in culture. More or less complete life cycles of some of these organisms have been observed. However, optimum culture median conditions have not been obtained for a number of species. The composition of media has a very decided effect on the vigor of the organism. We have been collecting snow at Mary's Peak, Santiam Pass and Mt. Bachelor for analyses of NO₃, PO₄ and transition metals. Obvious environmental contamination by man has shown up incidental to these analyses, the purpose of which is to look for nutrient enrichment as a function of ablation and sublimation.

Current investigations include the determination of the light-temperature-nutrient response surface of various algal strains and the determination of photosynthesis in-situ. We are monitoring a pyranometer installed at Mt. Bachelor as a part of this latter project. Heavy, recent snowfall precludes an early start, however.

Estuarine Benthos Study - King, McCauley

A quantitative biological survey was made to determine the differences between the populations a short distance inside and outside the mouth of Yaquina Bay. Collections were made with a five foot wide beam trawl that had a wheel to measure distance over the bottom. A Clarke-Bumpus zooplankton net, #6 mesh, was attached to a runner of the beam trawl to measure the associated zooplankton. Twenty-two trawls were made, but only four were in the ocean due to sampling difficulties. Twenty-five Shipek grabs were taken between Yaquina Bay bridge and buoy "9".

The data is being checked for correlations to physical and biological factors.
Deep-Sea Fish Trematodes - Smoker, McCauley

A new monogenetic trematode of the genus Choricotyle has been described and Cyclocotyloides pinguis (Linton, 1940) redescribed. The paper is accepted for publication. Several additional trematode species are under study.

Echinoid Biology Studies - Brownell, Sumich, McCauley

Brisaster latifrons and Allocentrotus fragilis are two of the major macrofaunal species in the benthos of the outer shelf and upper slope. These are being investigated with respect to morphological variations and their relationship to depth, with reproductive periodicity, and with other selected aspects of the ecology. Several species of parasitic gregarine protozoa in B. latifrons are being studied in detail.

Checklist of Benthic Invertebrates - McCauley

The checklist of benthic invertebrates is continually being revised to include new reports of species and new depth and distributional records.

Albacore and Coastal Oceanography - Pearcy, Smith, Bohannon, Small, Panshin, Gordon, Wyatt, Barstow, Curl, Forster, Mueller, Evans

Preparations for the intensive study of oceanographic features in nearshore waters during the summer of 1969 included:

1. Coordination and formulation of 11 cruise plans within the Department of Oceanography for 1969.

2. Coordination with Dr. Glenn Flittner, BCF La Jolla, and arrangements for exchange of weather and sea surface temperature data.

3. Initial planning of NASA overflights in June, August and September.

4. Publication of 500 "albacore log books," most of which are in the hands of selected fishermen from San Diego to Seattle, thanks to Frank Bohannon.
5. Distribution of eight mechanical BT's to selected boats for use next summer. BT's were loaned by BCF La Jolla.

6. Two expendable BT systems were made available by BCF, U.S. Navy, and Sippican Corp. These will also be used on albacore vessels next summer.

Growth and Reproduction of a Lanternfish - Smoker, Pearcy

Growth, life span, and reproductive season of the Myctophid, Stenobrachius leucopsarum, are being determined from collections made off Oregon. Ages are determined from size-frequency data from six years of monthly collections and from examination of otoliths from freshly taken specimens. Reproductive pattern is being described from the annual appearance of larvae in collections and examination of ovaries.

Radioecology of Benthic Fishes - Vanderploeg, Pearcy

In progress is a study of zinc-65 and its specific activity in benthic fishes giving special attention to the benthic fishes at 200 m depth, 25 miles off Newport. We are examining each species separately to determine the effect of their individual ecologies on radio-zinc dynamics. An important aspect is the effect of diet on specific activity. Data are being collected on the food habits of the fish and on the specific activities of their prey. Another aspect relates to the seasonality in specific activity that may occur with the seasonal change in direction of flow of the Columbia River plume, the source of the nuclide.

Size Structure and Growth of Euphausia pacifica off the Oregon Coast - Smiles, Pearcy

Changes in the length-frequency distributions of Euphausia pacifica collected with meter nets over a four year period, indicate that this common euphausiid lives for approximately one year. Based on recruitment of young, we conclude that spawning is prolonged, extending from June through December, but generally is most prominent in the autumn months.

Average growth was calculated to be about 2.0 mm per month with growth appearing to be faster during adolescent than older stages. It disappears from our catches at a size of about 22-24 mm.
The population density of *Euphausia pacifica* was higher at stations within 25 miles of the coast than farther offshore. Moreover, the proportion of juveniles was much higher inshore, suggesting that spawning is concentrated there.

Feeding Habits of Lanternfishes - Tyler, Pearcy

The feeding habits of the lanternfishes *Tarletonbeania crenularis*, *Diaphus theta*, and *Stenobrachius leucopsarus* were studied by analyzing 1,714 stomachs from 54 collections in the slope waters off Newport, Oregon, 1961-1967.

Forty-two food taxa consisting primarily of copepods, amphipods and euphausiids were identified from the stomach contents. *Euphausia pacifica*, *Calanus* spp. and *Metridia* spp., and *Parathemisto pacifica* dominated the euphausiids, copepods and amphipods respectively. Copepods were numerically dominant but euphausiids made up most of the biomass. *Tarletonbeania crenularis* fed more on near-surface copepods than *S. leucopsarus* which fed more on deeper-water copepods. The smallest sizes of *T. crenularis* and *S. leucopsarus* fed more on copepods than the largest sizes which fed more upon euphausiids. Empty stomachs were found in 1% of the *D. theta*, 20% of the *T. crenularis* and 24% of the *S. leucopsarus* collected at night.

Changes in stomach fullness and state of digestion during the night, morning and afternoon indicated that most of the lanternfishes fed primarily at night in the upper 200 meters.

Polychaete Systematics and Ecology - Hancock, Carey

A Masters thesis has been completed by Danil Hancock; several papers on polychaete systematics and ecology are in preparation. The following is a summary of the research and is derived from the thesis abstract.

Polychaete annelids from 48 benthic samples containing over 2000 specimens were identified. Samples were taken with either an anchor dredge or an anchor-box dredge from a 15 station transect (44°39.1'N) that ranges from 800 to 2900 meters in depth. Sediment subsamples were
collected and analyzed for organic carbon and sediment particle size using standard techniques. Temperature and oxygen of the water near the bottom were taken with a modified Smith-McIntyre grab; however, these measurements were not taken simultaneously with the dredged biological samples.

The results indicated that at least 115 species in 53 families of the class Polychaeta were represented in this transect line. This study found an absence of the families Serpulidae and Syllidae and a reduction of the number of species in the families Nereidae, Cirratulidae and Capitellidae. Only five genera had not previously been reported from the deep sea. The depth distribution of the polychaetous annelids recovered in this study, coupled with limited physical data, suggest that five faunal regions can be distinguished. Nine new forms of polychaeteous annelids are tentatively described, and others are anticipated in future collections. Suggestions for future studies are also indicated.

Diversity and Abundance of Benthic Fauna - Stander, Carey

Determination of the diversity and abundance of benthic invertebrate populations along the standard sampling line off Newport, Oregon is the major objective of this research. Correlation of the results with known data on physical and chemical factors along transect lines will be undertaken.

Samples of macro-epibenthic fauna taken with the Carey-Paul quantitative beam trawl have been analyzed for species identity, number of individuals, and wet weight. Conversion factors determined from available radioanalysis worksheets were employed to find dry weight and ash-free dry weight for each species in the various samples.

Species identities and numerical data on polychaetous infauna have been made available through the courtesy of Mr. Danil Hancock. These data were obtained by use of the anchor-box dredge, also a quantitative sampler. Since the polychaetes make up a very large proportion of the infauna it is assumed that they are representative of the infaunal population. The data for both samplers is summarized in Table 1 by depth and station.
### MACRO-EPIFAUNA:

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</tr>
<tr>
<td>NAD 4N</td>
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<tr>
<td>NAD 11</td>
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Total = 14

### POLYCHAETOUS INFAUNA:

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### TABLE 1

Summary of trawls and dredges.
The numerical data derived from the samples have been analyzed on the OS3 computer system of the Oregon State University Computer Center using the AIDONE program developed by Dr. Scott Overton of the Department of Statistics. The bio-index selected for use in this study, one calculated by AIDONE, is Simpson's index, 

$$\lambda = \sum_{i=1}^{Z} \frac{\pi_i}{Z}$$

where $\pi_i$ is the proportion of total individuals in the $i^{th}$ species, and $Z$ is number of groups or species in the population. The value $\lambda$ varies from $1/Z$ to 1; the former representing greatest diversity, where there are $Z$ species and $Z$ individuals, and the latter representing the least, that case where the population is composed of but one species. Lambda ($\lambda$) becomes the probability that two randomly selected individuals from the same population are of the same species. This index is a population constant which can be estimated by an unbiased estimator. Work is now in progress on developing a program to utilize this estimator. Simpson's index is readily understandable through the use of a simple graphical analogy, and the estimator is independent of sample size. A comparison between samples, or stations, in terms of a graphically analogous "distance" measurement is being undertaken.

In addition to providing data for analysis of diversity the two quantitative samplers provide an estimate of the abundance of large epifauna and polychaetous infauna along the transect line. The diversity and abundance parameters, when compiled, will be related to certain physical and chemical factors that vary as gradients along the seabottom. These factors of interest have been determined from other studies. Correlation of physico-chemical factors with the bio-indices may indicate fruitful lines of future study.

Benthic Ecology and Systematics - Carey, McCauley, Kyte, Bruce

Field work was undertaken on two cruises off central and northern Oregon; 18 otter trawl, 26 Smith-McIntyre bottom grab, 8 bottom water, and 1 multiple core samples were taken. A study of the ecology of Cascadia Abyssal Plain was initiated in January; immediate objectives are to determine the distribution and abundance of the large epifauna and to relate these to various features of the benthic environment. Quantitative beam trawls and multiple cores have been obtained at a series of stations up the axis of the Plain between the Newport and Tillamook Head station lines.
Laboratory analysis and identifications of the samples continue. Systematics projects on scaphopods and ophiuroides are underway.

Radioecology of the Benthos - Carey, Kyte, Bruce

During this report period 187 samples, representing 29 species from 17 stations have been analyzed for gamma-emitting radionuclides. Animals with significant amounts of radiozinc were analyzed for total zinc by atomic absorption spectrometry for calculation of specific activities.

Detailed seasonal sampling of the Newport, Tillamook Head, and 200 meter Contour station lines was completed in October. Data from these studies are being summarized and analyzed.

Progress has been made on the design of bottom sediment collectors for use during the summer of 1969. The design by R. Mesecar includes accurately timed releases and a 2M² collecting area. The collectors will be used to obtain estimates of sedimentation and input of radionuclides to the bottom environment under the Columbia River plume.

Sea Grant - Benthic Environment, Project No. 62 - Carey, Fowler, Kulm, Pearcy, Bertrand, Gunther, Margules

Two seasonal cruises were undertaken, and the standard Benthic Environment stations (Figure 10) were sampled for large epi-fauna, infauna, forams, sediment, and bottom water. Analyses of these samples are underway.

Assimilation of Organic Matter by Marine Second Trophic Level Grazers - O'Connors, Menzies, Small

Mr. O'Connor's master's thesis, titled Determination of food carbon assimilation in copepods, was completed and is now being prepared for publication. Preparations are going forward for an Auke Bay, Alaska research project for this summer. Feeding relationships of Auke Bay summer zooplankton will be investigated with the eventual aim of predicting ingestion and assimilation in this hopefully simplified environment. Some pertinent literature has been reviewed, tentative sampling plans developed, and equipment devised and assembled for this project. Particulate carbon and nitrogen analyses on particles filtered from the water are being carried out as part of primary productivity and coastal oceanography studies for the Oregon coast. The filtered particles are assumed to be
Figure 10. Standard benthic environment stations.
representative of the food available to second trophic level grazers off the coast.

Mr. Menzies' work has centered around collection and maintenance of copepod grazers and collection of relatively clean fecal pellet samples. Trouble has been encountered in separation of fecal pellets from copepod eggs in spring-collected samples. A study of the salt occlusion effect on gravimetric analysis of assimilation efficiency is in progress, as well as the groundwork for $^{14}$C and $^{32}$P radiotracer work. The ultimate aim of Mr. Menzies' project is to make detailed comparisons among radiotracer and gravimetric methods for determining grazer assimilation.

Phytoplankton-Zooplankton Relationships in Different Hydrographic Regimes off Oregon - Pequegnat, Ramberg, Vogel, Small

Mr. Ramberg is investigating the carbon (C) and nitrogen (N) budgets in water, filtered particles, and small grazing animals in upwelled water, Columbia plume water, and oceanic water.

Many of the particulate matter samples collected on past cruises have now been analyzed on an F & M CHN analyzer. The values for $\text{mg N/m}^3$ and $\text{mg C/m}^3$, and C/N ratio, have been computed for these samples. These data have been plotted in relationship to salinity, temperature, other nutrients, and chlorophyll in the water. The salinity and temperature data give us an indication of upwelling, if any is present. From these comparisons, several interesting correlations have been suggested, and will be pursued more when more data is ready.

Oxygen, alkalinity, and phosphate in water samples have been analyzed and nitrate will be completed soon. The chlorophyll samples from this cruise have been analyzed. The ammonia samples were to be analyzed by the method of Newell, but after several months of attempting to gain satisfactory precision the method was abandoned. In the future, total N in the water will be done by AutoAnalyzer.

Mr. Vogel is initiating a comparative study of phytoplankton species composition and species composition changes off the Oregon coast, in relation to upwelled water, Columbia plume water, and oceanic water. Efforts also will be directed to samples shoreward of five miles, in polluted water versus non-polluted water.

Mr. Pequegnat has been investigating trace element, lipid, and protein composition of phytoplankton and grazers off the Oregon coast. Trace element analyses of "clean" phytoplankton samples were completed for
Co, Cr, Cu, Fe, Mn, Sn, and Zn, using Atomic Absorption Spectroscopy (AAS). Additional samples have been collected for comparison of the effects of wet and dry ashing techniques on AAS. Standard addition methods will also be employed to test the "salt effect" on trace element analysis of phytoplankton with the AAS.

Methods for microanalysis of lipid and protein in small samples of phytoplankton and zooplankton are being perfected. Freeze-dry apparatus was designed and constructed. The freeze-dry unit is to be used for shipboard preservation of samples for subsequent organic analysis. Phytoplankton collecting nets are being redesigned, with Mr. Menzies.

Photoperiodism in Phytoplankton Carbon Assimilation - Donaghay, Small

In an effort to provide better field comparisons of both standing stocks and production rates of phytoplankton, a determination of correction factors arising from photoperiodic effects on phytoplankton carbon assimilation will be made. These correction factors will be estimated on the basis of controlled, uniform-condition experiments on diel rhythms of chlorophyll "a", C\textsuperscript{14} uptake, particulate carbon, and oxygen evolution.
DEGREE REQUIREMENTS COMPLETED

CISSELL, Milton
Thesis Title: M. S. Chemical Oceanography
Chemical Features of the Columbia River Plume
Off Oregon
Major Professor: P. Kilho Park

COUCH, Richard
Thesis Title: Ph. D. Geophysical Oceanography
Gravity and Structure of the Crust and Subcrust
in the Northwest Pacific West of Washington
and British Columbia
Major Professor: Peter Dehlinger

DENNER, Warren
Thesis Title: Ph. D. Physical Oceanography
The T-S Gradient Method, a New Method of
Computing Geostrophic Currents Over Large
Ocean Areas
Major Professor: Steve Neshyba

EMILIA, Dave
Thesis Title: Ph. D. Geophysical Oceanography
Numerical Methods in the Direct Interpretation of
Marine Magnetic Anomalies
Major Professor: Gunnar Bodvarsson

FOWLER, Scott
Thesis Title: Ph. D. Biological Oceanography
The Distribution and Transfer of Zinc-65 Accu-
cumulated from Food and Seawater by Three
Marine Crustaceans
Major Professor: Lawrence F. Small

GALLAGHER, John
Thesis Title: Ph. D. Geophysical Oceanography
A Method for Determining the Source Mechanism
in Small Earthquakes with Application to the
Pacific Northwest Region
Major Professor: Peter Dehlinger

GATES, Richard
Thesis Title: M. S. Chemical Oceanography
Magnesium Sulphate Ion Association in Sea-
water
Major Professor: Ricardo M. Pytkowicz
GRIGGS, Gary
Thesis Title: Ph. D. Geological Oceanography
Cascadia Channel: The Anatomy of a Deep-Sea Channel
Major Professor: Lavern D. Kulm

HAGER, Stephen
Thesis Title: M. S. Chemical Oceanography
Processes Determining Silicate Concentrations in the Northeastern Pacific Ocean
Major Professor: P. Kilho Park

HANCOCK, Danil
Thesis Title: M. S. Biological Oceanography
Bathyal and Abyssal Polychaetes (Annelids) from the Central Oregon Coast
Major Professor: Andrew G. Carey

KORGEN, Ben
Thesis Title: Ph. D. Physical Oceanography
Temperature and Velocity Fields Near the Deep Ocean Floor West of Oregon
Major Professor: Gunnar Bodvarsson

MACKAY, Angus
Thesis Title: M. S. Geophysical Oceanography
Continuous Seismic Profiling Investigation of the Southern Oregon Continental Shelf Between Coos Bay and Cape Blanco
Major Professor: D. F. Heinrichs

O’CONNORS, Harold
Thesis Title: M. S. Biological Oceanography
Determination of Food Carbon Assimilation in Copepods
Major Professor: Lawrence F. Small

SMILES, Michael
Thesis Title: M. S. Biological Oceanography
Age Structure and Growth Rate of Euphausia pacifica off Oregon
Major Professor: William G. Pearcy

WHITE, Franklin
Non-thesis:
Major Professor: William G. Pearcy
FACILITIES

Marine Science Center

During the six month reporting period from 1 October 1968 to 31 March 1969 the public aquarium wing of the Center had the most visitors in March. There were 18,503 visitors in March, 5,856 in February, 3,635 in January, 4,213 in December, 7,200 in November, and 7,532 during October. This is a total of 46,939 during the non-tourist season. School children especially are encouraged to visit the Center and many groups of young people do take the opportunity during the school year.

Research Vessels

R/V YAQUINA

During the past six months our 180-foot Research Vessel YAQUINA has traversed 15,305 miles of Pacific water. The Yaquina departed from her home port on 2 January to conduct geological and physical research in the Panama Basin. The cruise will continue until 26 April. During her 1099 total days at sea since her commissioning in September 1964, scientists have been able to carry out all types of marine research. A time-at-sea chart and track lines of individual cruises are found in Figures 11 and 12.

R/V CAYUSE

Since her commissioning in April 1968, R/V CAYUSE has traveled 8735 miles. Scientists have spent 151 days carrying out all phases of marine research. A time-at-sea chart and track lines of individual cruises are found in Figures 13 and 14.

R/V PAIUTE

The R/V PAIUTE, our 33-foot coastal day boat, has been used for estuarine and coastal research. Animal specimens have been collected for research, aquarium displays, and class work by the marine biologists. She also services oceanographic and meteorological buoys in the offshore buoy program.
Figure 11

TIME AT SEA

YALOC '69

R/V YAQUINA

DAYS OF MONTH

1968

1969
Figure 12. Cruise tracks of R/V YAUQUINA
TIME AT SEA

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R/V CAYUSE

Figure 13
Cross-hatched area indicates various near-shore, one day, test & trial cruises.

Figure 14. Cruise tracks of R/V CAYUSE
STAFF ACTIVITIES AND AWARDS

Dr. Wayne V. Burt was designated as the Alumni Distinguished Professor for 1968-69, a truly significant honor. In addition Dr. Burt also was selected to receive an OSU Centennial Award as one of fifteen people who made significant contributions to Oregon State University during its first 100 years. Dr. Burt received these awards at the Charter Day Ceremony, October 1968.

A signal honor has come to Professor Michael Longuet-Higgins. Professor Longuet-Higgins has been appointed a Royal Society Research Professor. This is a high honor which has come to only nine other individuals. Professor Longuet-Higgins, who will take up his appointment on 1 July 1969, will work at the Department of Applied Mathematics and Theoretical Physics, University of Cambridge, and also at the National Institute of Oceanography, and will be known as Royal Society Research Professor at the University of Cambridge.

Dr. Tjeerd H. van Andel served as Distinguished Lecturer in Marine Science at the University of Wisconsin, Madison, March 1969.

Dr. van Andel and Dr. Heath visited the Geology Departments of Witwatersrand University and Randse Afrikaanse Universiteit in Pretoria, and the Geology and Oceanography Departments, University of Capetown, Capetown, South Africa, Sept. 27-Oct. 5, 1968. Dr. van Andel also visited the Department of Geology, University of California, Riverside, and the Scripps Institution of Oceanography, February 1969.


Dr. G. Ross Heath was appointed assistant professor of Oceanography, February 1969, visited Scripps Institution of Oceanography, La Jolla, California, and attended the Symposium on Shipboard Computer Systems, January 1969.

Dr. June G. Pattullo is on sabbatical leave at the University of South Africa, Capetown.
Dr. Joel Hedgpeth spent two months, January and February 1969, at Palmer Peninsula, Antarctica as part of an NSF project entitled Pycnogonida of the Antarctic Regions.

Dr. Douglas Caldwell joined the staff in Physical Oceanography 1 November 1968 from the University of California at San Diego.

Dr. Jack Dymond will join the staff as a geochemist 1 April 1969 from Columbia University.

Non-Resident Cruises

Dr. Heath, Dr. Moore, and Dr. van Andel participated in the Mozambique to Luanda, Angola, to Fortaleza, Brazil, legs of CIRCE cruise on board R/V Argo of Scripps Institution, October-December 1968, and Dr. van Andel served as chief scientist.

Dr. G. S. Pond was aboard a cruise on FLIP out of San Diego in February 1969.

Dr. R. Smith was aboard the R/V T. G. Thompson off Latin America during part of March and April 1969.

Visiting Staff

Dr. Fred Spiess is on sabbatical from Scripps Institution of Oceanography and is working in the Department.

Dr. John H. Nath is on sabbatical from Colorado State University Department of Civil Engineering and is working in the Department.
VISITING SCIENTISTS

October

John A. Day, Linfield College, McMinnville, Oregon, "Precipitation nuclei".

November

M. A. Johnson, National Institute of Oceanography, England, "Long internal waves in the Great Lakes".


Dr. L. van der Plas, Geology and Mineralogy Department, Agricultural State University, Wageningen, The Netherlands. "Identification of Feldspars".

Dr. Jack Dymond, Lamont Geological Observatory, "Potassium-Argon Dating of Deep Sea Ash Layers".

Bruce W. Frost, Scripps Institution of Oceanography, La Jolla, California, "Influence of interspecific interactions on the distribution of oceanic herbivorous copepods of the genus Clausocalanus."

Dr. John S. Rinehart, Geophysicist and Senior Research Fellow, Environmental Science Services Administration, Boulder, Colorado, "How and why of geysers", "Transient stress waves in solids".

Dr. Paul E. Smith, U.S. Bureau of Commercial Fisheries, La Jolla, California, "Evaluation of sonar for fish school counting".

December

Dr. James J. O'Brien, National Center for Atmospheric Research, Boulder, Colorado, "A numerical model of the wind-driven Pacific Ocean".

Mr. John Edmond, Scripps Institution of Oceanography, La Jolla, California.

Dr. Weiler, Physical Oceanographer from the Canada Center for Inland Water.

January

Dr. George Llano, National Science Foundation, Antarctic Biology Program Director, "Facilities for Research in Antarctica".

Charles B. Miller, Scripps Institution of Oceanography, La Jolla, California, "Some Environmental Consequences of Vertical Migration by Zooplankton".

Dr. Klaus Grasshoff, Institut fur Meereskunde, Kiel, "Chemical Indicators for the Circulation of the Red Sea."

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February

Dr. Lawrence H. Larsen, University of Washington, Seattle, Washington, "Recent Work on Internal Waves".

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Mr. D. C. Skeels, Esso Production Research Laboratory, Houston, Texas.

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March

Al Pruter, U. S. Bureau of Commercial Fisheries, Seattle.

Dr. Thomas G. Thompson, Pan American Petroleum Co., Tulsa, Oklahoma.

Dr. Karl Turekian, Department of Geology, Yale University, New Haven, Connecticut.

Dr. Charles L. Drake, Lamont Geological Observatory, Columbia University, Palisades, N. Y., Condon Lecturer, "The Geological Revolution".


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Berg, Joseph W., Jr. See Trembly and Berg. 1968.

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Bodvarsson, G. See Emilia and Bodvarsson. 1968.


Burdwell, Gerald B. See Pattullo, Burt and Burdwell. 1968.

Burt, Wayne V. See Pattullo, Burt and Burdwell. 1968.


Carder, Kendall. See Neshyba, Beardsley, Neal and Carder. 1968.


Curl, H. C., Jr. See Glooschenko and Curl. 1968

Curl, H. C., Jr. See Hardy and Curl. 1968.

Dean, J. M. See Cross, Fowler, Dean, Small and Osterberg. 1968

Dean, J. M. See Cross, Dean, Osterberg. 1969

Dean, J. M. See Fowler, Small and Dean. 1969

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Fowler, G. A. See Boettcher and Fowler. 1969.


Fowler, S. W. See Cross, Fowler, Dean, Small and Osterberg. 1968.

Fowler, S. W. See Pequegnat, Fowler and Small. 1969.


Guthrie, Thomas F. See Renfro, Phelps and Guthrie. 1969.


Hager, Stephen W. See Park, Hager, Pirson and Ball. 1968.

Haight, R. D. See Langridge, Haight and Morita. 1968.


Hunger, Arthur A. See Fowler, Hunger and Manske. 1968.


Johnson, Stephen. See Couch and Johnson. 1968.


Kulm, L. D. See Mackay and Kulm. 1968.

Kulm, Sally A. See Neal and Kulm. 1968.

Kulm, Sally A. See Pattullo, Burt and Kulm. 1969.

Kulm, Sally A. See Neal and Kulm. 1968.


Morita, Richard Y. See Albright and Morita. 1968.

Morita, Richard Y. See Kenis and Morita. 1968.


Mudie, John D. See Atwater, Fowler and Mudie. 1968.

Neal, Victor. See Neshyba, Beardsley, Neal and Carder. 1968.


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Osterberg, Charles L. See Jennings and Osterberg. 1969.

Osterberg, Charles L. See Kujala, Larsen and Osterberg. 1969.

Osterberg, Charles L. See Renfro and Osterberg. 1969.

Pak, H. See Beardsley, Pak and Smith. 1968.

Panshin, Dan. See Byrne and Panshin. 1968.


Pattullo, June G. See Blanton and Pattullo. 1969.


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Pequegnat, Willis E. See Marmelstein, Morgan and Pequegnat. 1968.

Phelps, Roger B. See Renfro, Phelps and Guthrie. 1969.


Pirson, Jacques E. See Park, Hager, Pirson and Ball. 1968.


Pytkowicz, R. M. See Kester and Pytkowicz. 1968.


Small, L.F. See Fowler, Small and Dean. 1969.


Smith, R.L. See Beardsley, Pak and Smith 1968.


Smith, R.L. See Mooers and Smith. 1968.

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Thompson, G. See Melson, Thompson and van Andel. 1968.

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