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Dec. 1, 197

INTERNATIONAL DECADE OF OCEAN EXPLORATION

CONTENTS

In late 1969, the Vice President of the United States, in his capacity as Chairman of the Marine Council, formally announced the United States' intention to contribute to the International Decade of Ocean Exploration and assigned responsibility to the National Science Foundation, an independent agency of the U.S. Government established in 1950 "to promote the progress of science . . .", and authorized "to foster the interchange of scientific information among scientists in the United States and foreign countries . . . [and] to initiate and support specific scientific activities in connection with matters relating to international co-operation . . .". In charging the National Science Foundation with the responsibility for the planning, management, and funding of the United States' program, the Vice President proposed goals to:

1. Preserve the ocean environment by accelerating scientific observations of the natural state of the ocean and its interactions with the coastal margin—to provide a basis for (a) assessing and predicting man-induced and natural modifications of the character of the oceans; (b) identifying damaging or irreversible effects of waste disposal at sea; and (c) comprehending the interaction of various levels of marine life to permit steps to prevent depletion or extinction of valuable species as a result of man's activities;
2. Improve environmental forecasting to help reduce hazards to life and property and permit more efficient use of marine resources—by improving physical and mathematical models of the ocean and atmosphere which will provide the basis for increased accuracy, timeliness, and geographic precision of environmental forecasts;
3. Expand seabed assessment activities to permit better management—domestically and internationally—of marine mineral exploration and exploitation by acquiring needed knowledge of seabed topography, structure, physical and dynamic properties, and resource potential, and to assist industry in planning more detailed investigations;
4. Develop an ocean monitoring system to facilitate prediction of oceanographic and atmospheric conditions—through design and deployment of oceanographic data buoys and other remote-sensing platforms;
5. Improve worldwide data exchange through modernizing and standardizing national and international marine data collection, processing, and distribution; and
6. Accelerate Decade planning to increase opportunities for international sharing of responsibilities and costs for ocean exploration, and to assure better use of limited exploration capabilities.

The Office for the International Decade of Ocean Exploration (IDOE) was officially established within the National Science Foundation shortly thereafter. In developing the program, the Foundation has drawn on: the Intergovernmental Oceanographic Commission's "Comprehensive Outline of the Scope of the Long-Term and Expanded Program of Oceanic Exploration and Research"; the report entitled "Global Ocean Research" prepared by a Joint Working Party nominated by FAO's Advisory Committee on Marine Resources Research, ICSU's Scientific Committee on Oceanic Research, and WMO's Advisory Group on Ocean Research; the First Report of the Group of Experts on Long-Term Scientific Policy and

Planning; *An Oceanic Quest;* the Vice President's statement of intent to participate; the various Resolutions of the U.N. General Assembly and of the Intergovernmental Oceanographic Commission; and other relevant documents. The National Science Foundation has since provided the management and financial support for the United States' initial contribution to the International Decade of Ocean Exploration, an important element and the acceleration phase of the Long-Term and Expanded Program of Oceanic Exploration and Research.

In the first year of its existence, the National Science Foundation Office for the IDOE has described the U.S. program and projects for the Decade as they have evolved for the purpose of encouraging greater participation in the IDOE by all interested nations. Although the U.S. program will draw attention to selected scientific areas, a stronger international effort will result from combining the views and requirements of many nations. It should also be noted that the program, described in this report, will continue to evolve as new teams of scientists and engineers form, as their proposed work is reviewed, and as special workshops and conferences indicate a need for new directions or greater effort.

The Office for the IDOE is organized as shown in Figure 1. Program managers oversee a number of major projects within the three general categories of interest: Environmental Quality, Environmental Forecasting, and Seabed Assessment.

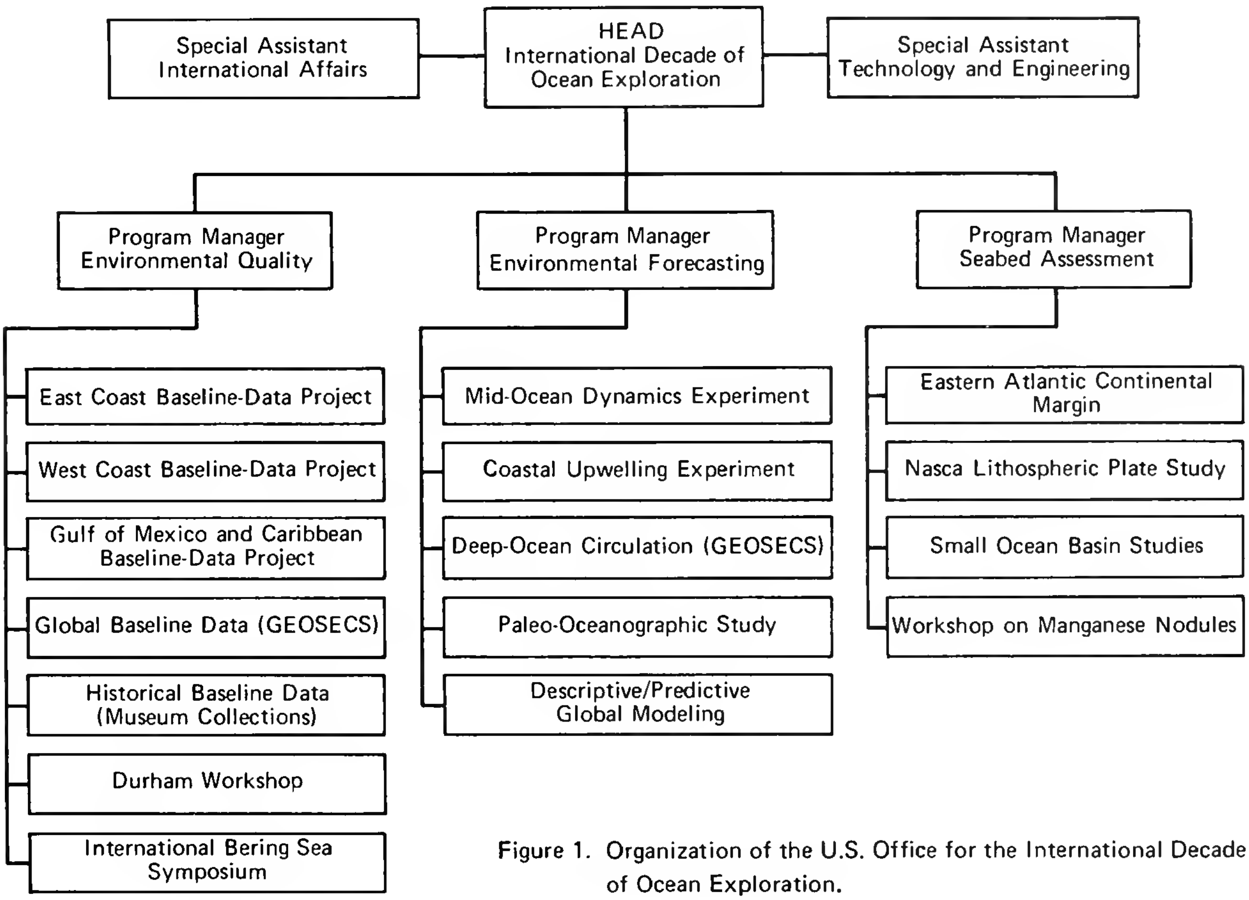

Figure 1. Organization of the U.S. Office for the International Decade of Ocean Exploration.

The Office for the IDOE communicates with scientists throughout the world through the U.S. Department of State and its counterparts in other governments, by way of the IOC and other intergovernmental organizations, through scientific bodies such as the International Council of Scientific Unions and its scientific committees, and extensively on a scientist-to-scientist basis. Often, informal communications by members of IDOE projects are undertaken on their own initiative. The spectrum of communication, bounded by the two extremes of formality and informality, is essentially continuous.

We shall use all practical means of communication to give scientists and engineers in other nations a fuller understanding of the details of the U.S. program. In so doing, it is our sincere hope that we may look forward to a greatly increased exchange of ideas and the subsequent development of new cooperative programs for the International Decade of Ocean Exploration.

The philosophy of development of the U.S. program and projects for the IDOE emphasizes scientific excellence and the potential for early realization of goals. The program is composed of large-scale projects of research focused on specific scientific areas. The projects are of such scale that they can be successfully carried out only by teams of scientists from many different disciplines (not necessarily limited to marine science), through cooperation among many types of institutions and organizations, and by participation of scientists and engineers from more than a single nation. Emphasis is placed upon the potential benefit to mankind.

Cooperation among institutions should avoid placing an impossible burden upon the facilities of any one individual or organization. This notion is carried over into the domain of sponsorship, where emphasis is placed upon cooperative funding. In this way, the National Science Foundation may partially support large projects which it might not otherwise be able to afford. Similarly, it is anticipated that other participating governments will sponsor their own scientists and IDOE programs to achieve real international scientific cooperation.

The process of selection of specific projects from the many proposed to the Office for the IDOE by the academic community, non-profit foundations and corporations, profit-making private industry, and by other Government agencies, has taken place following several guidelines:

1. The National Science Foundation Office for the IDOE does not support research which is duplicative of other efforts or the responsibility of other organizations.

2. Projects are concerned with the deep sea or the seaward portions of the continental shelf. A notable exception is in the area of Environmental Quality, where it is necessary to identify terrestrial sources of pollutants.

3. The Office for the IDOE does not sponsor isolated research. Every research component of a project must contribute to the primary goals of the entire project; thus the total project results should be greater than would be the sum of the individual parts if separately done.

4. Proposed investigations must fall within the scope of the overall program; the quality of research must be excellent; and the program must be of demonstrable benefit.

Partly because teamwork is so essential to the success of the Decade, a strong policy has been adopted concerning the management of scientific data obtained during the program (See Appendix). Prior to the final commitment of support to any project by the National Science Foundation Office for the IDOE, representatives from the appropriate U.S. national data repositories must agree with the principal investigators of the project on the documentation required for each type of data expected to be generated, in order to ensure meaningful interpretation by others. The methods, formats, and time limits whereby the data and ancillary information will be transferred to the appropriate repositories are also agreed upon. The validity and strength of the agreements are then reviewed and approved by the Office as a final requisite to funding a project. The Environmental Data Service of the U.S. National Oceanic and Atmospheric Administration has been designated to handle IDOE data and is funded by the National Science Foundation Office for the IDOE to carry out this work. The specific repositories are: 1) the National Oceanographic Data Center (NODC); 2) the National Geophysical Data Center (NGDC); and 3) the National Climatic Center (NCC). The Smithsonian Oceanographic Sorting Center (SOSC), a part of the Smithsonian Institution, has also been designated an IDOE repository. NODC, the leading center for IDOE data inventory and information, is the repository for chemical, geological, physical, and biological data. NGDC is the repository for geophysical data, and NCC for climatic data. SOSC is the repository for biological specimens.

All IDOE program data become a part of the U.S. Declared National Program and are reported internationally. All data submitted to NODC automatically become part of the notifications to the International Data Exchange System, are published in the *International Journal of Marine Science*, and are listed in the Index-Referral Service of the World Data Center/Oceanography. In addition, the National Science Foundation Office for the IDOE will publish annual summaries of all data collected by IDOE projects.

ENVIRONMENTAL QUALITY PROGRAM 2.

In the first few months after the estalishment of the U.S. IDOE program, it was realized that insufficient data were at hand to formulate a rational program of research to study marine pollution, previously recognized as a proper concern of the Decade. International workshops on environmental quality such as the one held in Williamstown, Massachusetts to consider Man's Impact on the Global Environment, had reached a consensus on only one of the aspects of marine pollution: accurate baseline data from a variety of marine areas were urgently needed. The data should establish quantitatively the present levels of suspected pollutants in typical marine situations, and identify areas of the oceans where especially high concentrations of pollutants would be expected to occur.

The panel which met in Williamstown, Massachusetts, in the summer of 1970 was of the opinion that no large-scale oceanic monitoring or related research program should be started until baseline data-acquisition projects supplying the lacking information had been completed.

REGIONAL BASELINE DATA PROJECTS

In accordance with the earlier recommendations of the environmental quality workshops, regional baseline data acquisition projects have been initiated in the oceans contiguous to the United States. Quantitative results are being obtained on the occurrence and distributions of such critical metals as mercury, lead, cadmium, arsenic, copper, and zinc, the chlorinated hydrocarbons such as DDT, DDE, TDE, the polychlorinated biphenyls (PCB), and petroleum and its byproducts.

Analyses of collected specimens are being carried out at a number of laboratories both in the United States and abroad, as shown in Figure 2. Standard material and collected specimens are constantly being exchanged to assure maximum comparability of results from each area.

Reference Samples and Calibration—In the Regional Baseline Projects a strenuous effort is being made to use all available reference samples to provide an absolute calibration of analytical data. Specifically, 1) the mercury analyses will be tied to the International Atomic Energy Agency reference sample of "fish solubles" which has been analyzed by most Scandinavian and European laboratories concerned with mercury pollution; 2) the inorganic analyses will be tied to the National Bureau of Standard's orchard leaves (Standard 1571), the series of "reference carbonate" samples recently described by Thompson et al. (1970)[1], to the "kale standard" of H. J. M. Bowen (1967)[2], and to such other reference (and widely analyzed) biological materials as can be obtained.

[1] Thompson, G., D. C. Bankston and S. M. Pasley, 1970. Trace element data for reference carbonate rocks. *Chem. Geol.*, 6: 165-170.

[2] Bowen, H. J. M., 1967. Comparative element analyses of a standard plant material. Analyst, 92: 124-131.

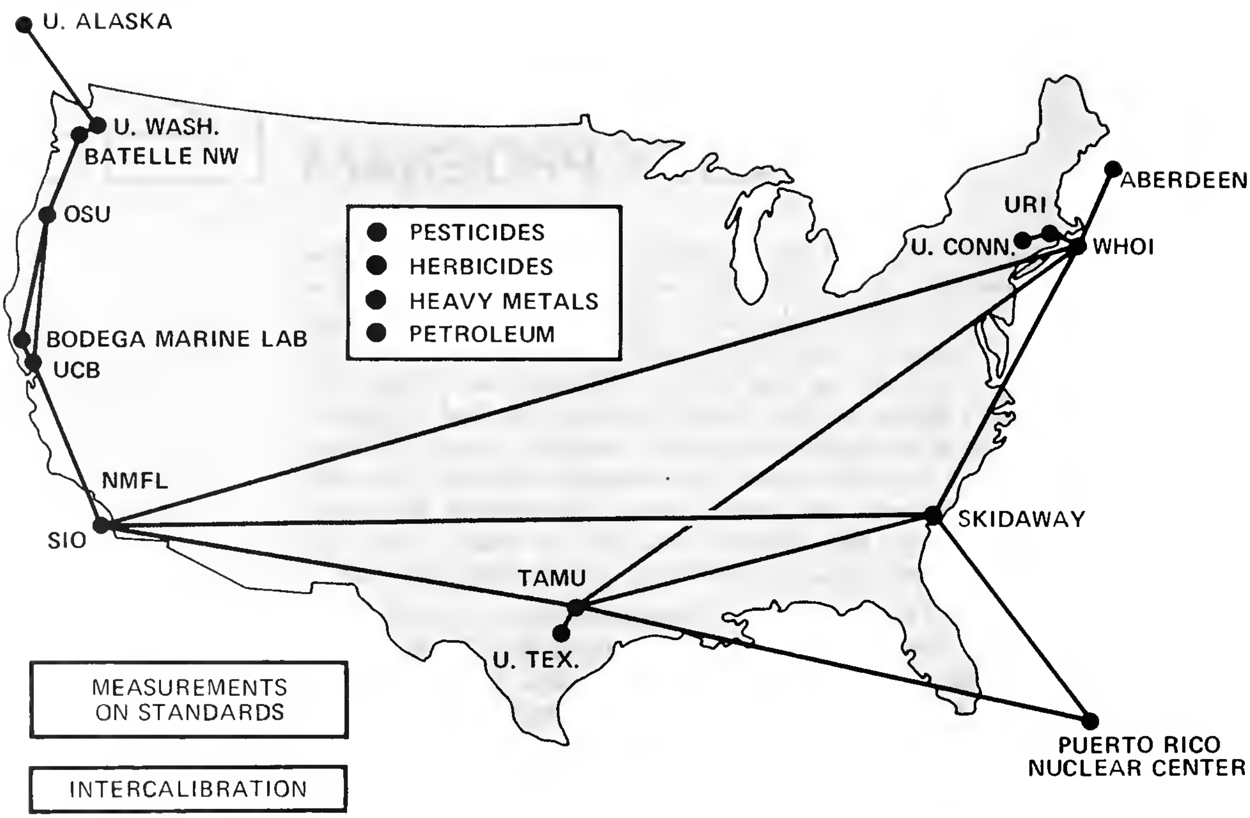

Figure 2. Environmental quality baseline data-acquisition projects.

Frequent interchange of replicate samples is being made among the various participating laboratories in the U.S.A. and United Kingdom. These will provide for intercalibration of the analytical methods and procedures for determination of the chlorinated organic toxins, of organic mercury compounds, and of the various inorganic pollutants. From some of these analyzed samples, subsamples will be reserved to be distributed for intercalibration to other laboratories that may join the programs at a later date. This procedure will also be followed with some samples analyzed for petroleum fractions.

An important part of this program is the constant interchange of data, both from samples and from intercalibration and reference analyses, among the analytical laboratories and the members of the planning and study committees. Such interchanges of information are useful in evaluating of methods and practices and in keeping the analytical results at as high a quality as can be achieved.

ATLANTIC

Figure 3 shows the cruises so far undertaken in the Atlantic to collect samples and the kinds of sampling carried out on each cruise.

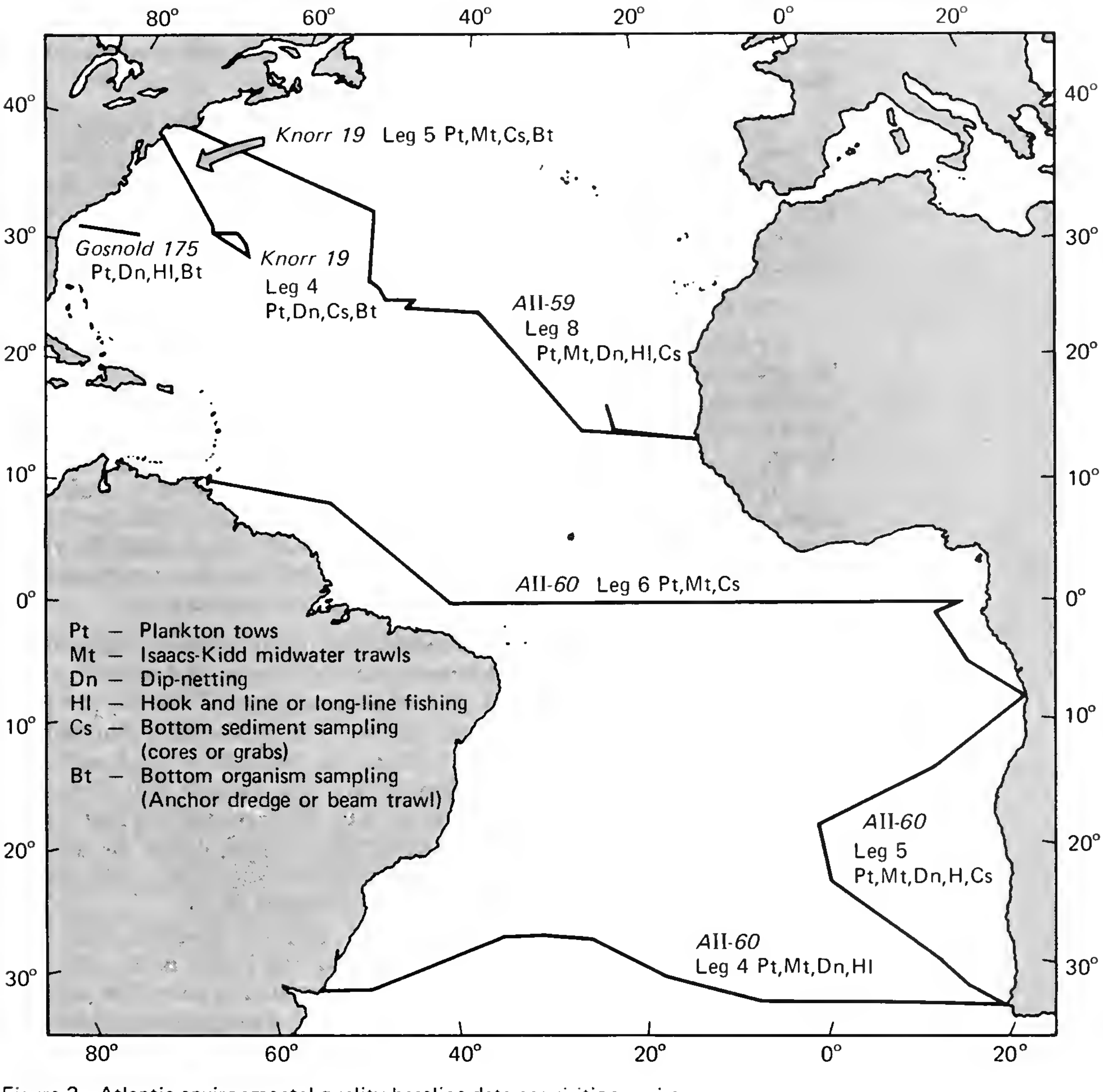

Figure 3. Atlantic environmental quality baseline data-acquisition cruises.

Organisms were collected on these cruises by dip-netting (Sargassum, flying fish, triggerfish, squid), by hook and line (dolphin-fish, sharks) by standard plankton nets, by Isaacs-Kid midwater trawls and dredges. Precautions taken against contamination included the use of residue-free ethanol (from ethylene hydration) to wash implements and containers, avoiding plastics, and preservation by freezing in glass or in washed aluminum.

As a result of these collections there now exists a fair assortment of benthic organisms caught at moderate depths and an assortment of mesopelagic fish and invertebrates from several depths between the surface and 1000 m. In making these latter collections a great effort was made to secure the same (or very closely similar) species from a wide range of latitudes and, when possible, a wide range of depths. Plankton collections and collections of surface organisms were made over as wide a geographical range as possible.

This project serves three functions: 1) to determine the absence of or, if present, the concentrations of the pollutants in organisms collected at selected localities in the ocean and in selected components of the marine food chain in the ocean; 2) to establish species and sediment variability, relating this when possible to proximity of sources; and 3) to allow intercalibration of methods among all participants.

The following are highlights of the Atlantic Project:

a) **Heavy Metals**—Specimens are being analyzed by at least two of the following methods: neutron-activation analysis, atomic absorption spectroscopy, and colorimetry. In the case of mercury, and possibly some others, attempts are being made to distinguish various organically-bound forms.

b) **Chlorinated Hydrocarbons**—Oceanic fishes, plankton, and sediments are being analyzed for DDT and PCB. These compounds have been in agricultural and domestic use on a global scale for at least 25 years. DDT has a half life in excess of four years, and has been implicated in the decline of populations of sea birds and other marine life.

c) **Petroleum-Derived Hyrocarbons**—The ratio between hydrocarbon background and the oil-derived hydrocarbons in upper and midwater marine organisms is being studied. A judicious selection of fish and invertebrates from areas of very different pollutant supply should permit assessment of the extent to which petroleum enters the marine food web. The natural hydrocarbons in the less heavily polluted samples will show how relevant existing hydrocarbon baseline data from coastal regions are to open oceanic regions. This exploratory study will both define the severity of the oil pollution problem in the open ocean and give guidelines on which to base a longer and more intense research effort.

d) **Foreign Participation**—Samples of benthos, plankton, and sediments are being collected from the North Sea, the Faroe Bank, and positions in deep water to the west and north of Scotland to cover the probable range in concentration of pollutants in the North East Atlantic. Pesticides and heavy metals are being analyzed by the Marine Laboratory, Aberdeen, Scotland, in conjunction with other interested laboratories.

e) **Results**—Data accumulated thus far support three tentative conclusions: 1) While both DDT and PCB increase in concentration along oceanic food chains, there are significant differences in their pathways; 2) There is a significant downward pathway out of the euphotic zone in the bodies of mesopelagic organisms undertaking daily vertical migrations; and 3) Fishes and crustacea which feed near the sea surface at night but migrate to considerable depths during the day show DDT and PCB concentrations not greatly different from those of predaceous organisms whose lives are spent mostly in the upper layers.

Concentrations of DDT, DDE, and their derivatives were found in most specimens. Concentrations of polychlorinated biphenyls (PCB) were found in all specimens collected.

GULF OF MEXICO AND CARIBBEAN SEA

The group obtaining baseline data in the Gulf-Caribbean areas maintains coordination with the other two ongoing environmental quality studies in the Atlantic and Pacific Oceans. Coordination involves not only external exchange of sample material and standards with each parallel investigator, but also, the exchange of recommendations on procedures for sample collection, handling, preservation and processing. The groups that make up the Gulf-Caribbean study also practice internal liaison. This internal and external exchange of samples, standards and methodology will make the regional data more meaningful in determining pollution levels in the world oceans.

Unlike the open oceans of the Atlantic and Pacific, which have a greater dilution potential, the enclosed basins of the Gulf-Caribbean, especially the Gulf, may have experienced serious industrial and agricultural pollution. The Gulf is also unique in that it receives runoff from the Mississippi, one of the world's largest contaminated rivers, draining approximately half the area of the United States. The Gulf-Caribbean project therefore has a unique opportunity to evaluate: 1) the extent of pollution and the prediction of expected "hot spots"; 2) the sources and the rates of inputs of pollutants; 3) the biochemical and geochemical interactions of each pollutant to predict possible sites of accumulation; and 4) the contamination of local marine food products.

Pollution by organic matter, including petroleum, herbicides, and pesticides, is probably the most serious type in the Gulf of Mexico. Organic pollution is difficult to study because of the variety and complexity of organic molecules.

The deep water sampling of the Gulf and the Caribbean is being carried out by RV *Alaminos* and RV *Palumbo*, as shown in Figure 4. The present plan is to repeat transects across the northern shelf of the Gulf of Mexico and off Puerto Rico in order to determine seasonal variations of pollutant concentrations.

PACIFIC

The baseline data-acquisition project in the Pacific Ocean is comparable to those in the Atlantic and in the Gulf and Caribbean. The collection and handling of organisms are being accomplished in ways compatible with those projects, and the same standards are being used for calibrating instruments.

Cruise and Sampling Plan—Trans-Pacific Section

Collections have been or will be made from RV *Thomas Washington*, as shown in Figure 5. The standard suite of samples at each station includes zooplankton, myctophids, flying fish, and squid. The methods include standard plankton tows at the surface and at mid-depths, and dipnetting under night lights.

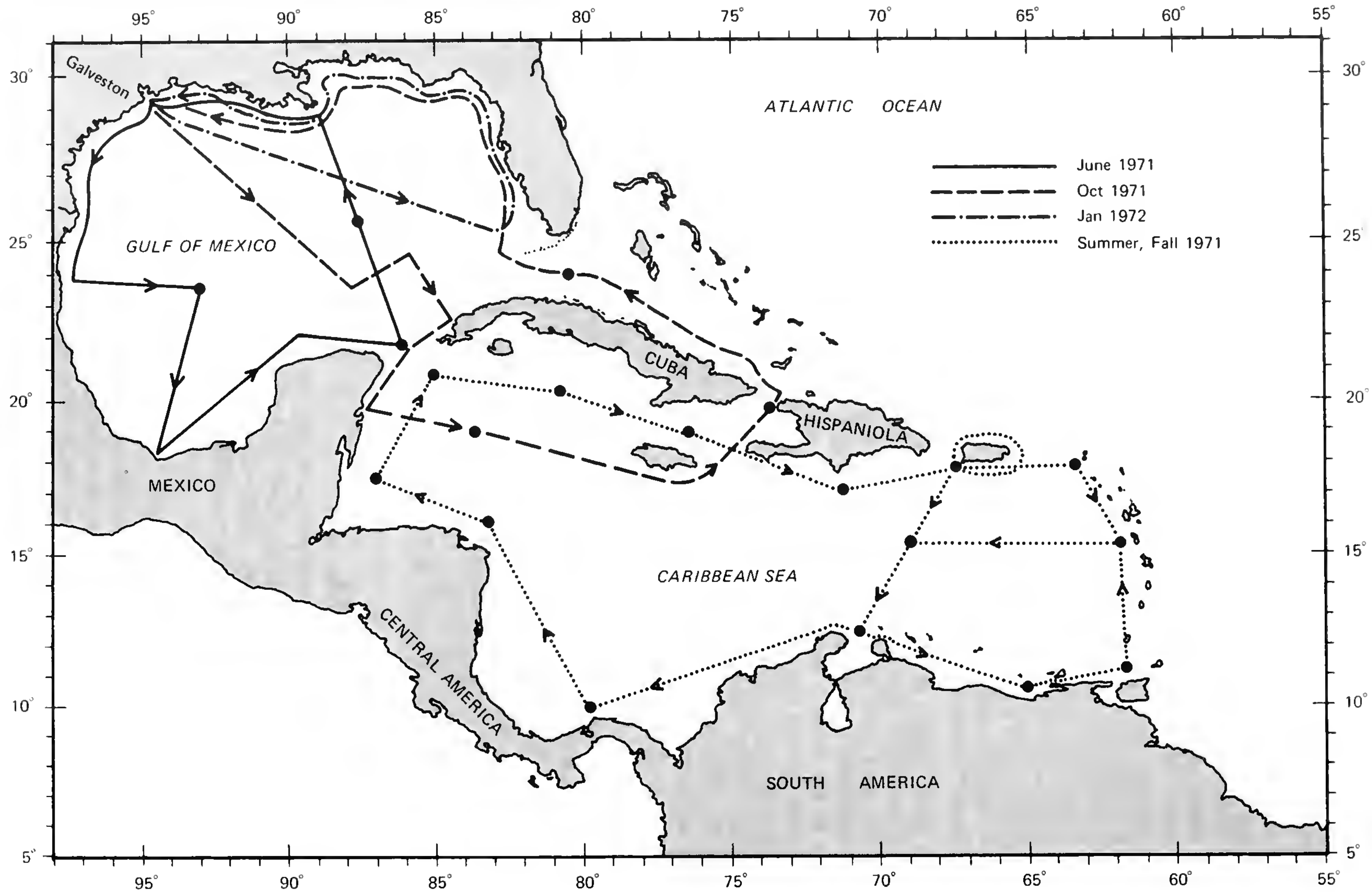

Figure 4. Gulf of Mexico and Caribbean Sea environmental quality baseline data-acquisition cruises.

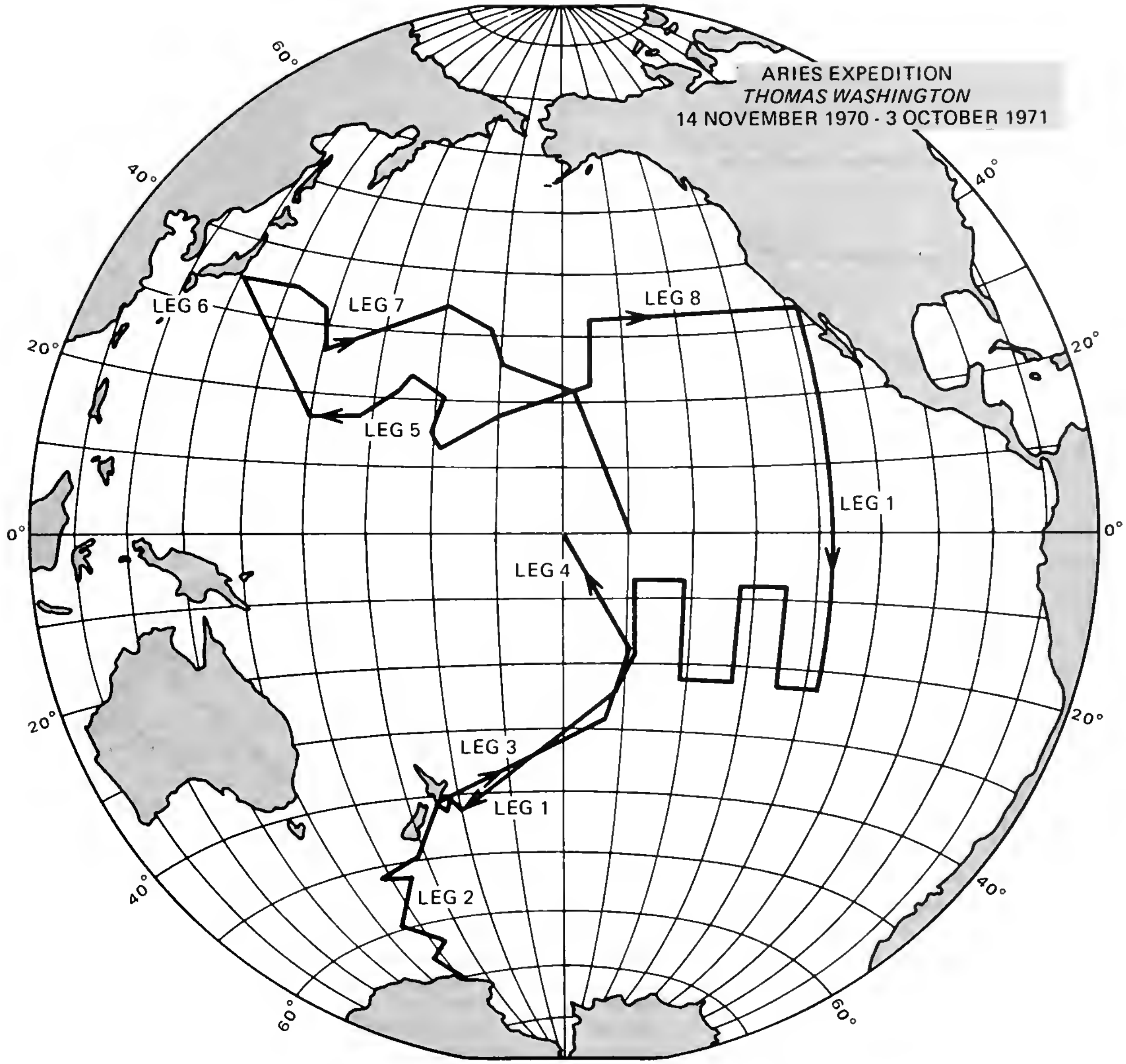

Figure 5. Pacific environmental quality open ocean data-acquisition cruises.

Cruise and Sampling Plan—Offshore Waters of California

Samples will be collected at various latitudes in the North Pacific during Marine Life Research cruises in this area. As shown on the track chart, Figure 6, these cruises run about 1200 miles offshore from San Francisco and 2000 miles offshore from Cabo San Lucas, or more than halfway to the Hawaiian Islands. Samples are being collected near shore and close to known sources of pollution—San Francisco and Los Angeles metropolitan areas and oil-producing areas—and from remote locations in the North Pacific Gyre. Attempts are being made to collect sediments and benthic organisms in the same areas. Additional samples are being obtained in the Bering Sea and Arctic Ocean.

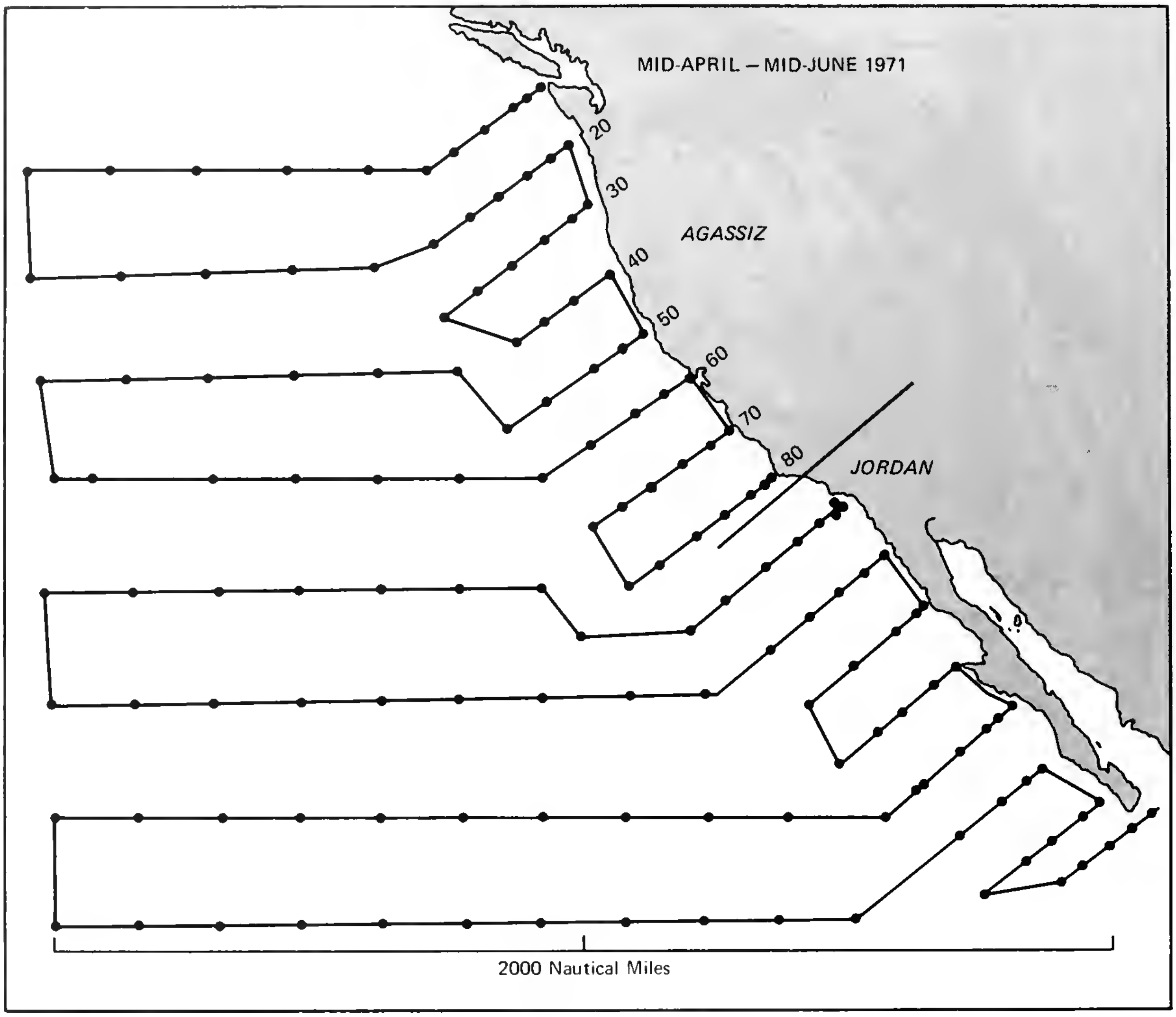

Figure 6. Pacific environmental quality coastal data-acquisition cruises.

The project is designed to take advantage of and complement the following studies:

1. The existing National Oceanic and Atmospheric Administration's National Marine Fisheries Service (NMFS) survey of mercury in tunas collected throughout the Pacific;

2. The California Cooperative Oceanic Fisheries Investigations (CalCOFI), which for 20 years have been recording conditions in the waters and populations offshore from Cabo San Lucas to the mouth of the Columbia River. In 1972 CalCOFI will be making one of its triennial intensive surveys;

3. The Southern California Coastal Water Research Project (SCCWRP), a three year study of problems of waste water disposal in the sea; and

4. The NMFS Fishery Oceanography Center measurements of DDT and its residues in fish and plankton on a section from Honolulu to San Diego.

Existing Samples in Storage

Samples of marine animals collected for measurement of traces of radionuclides over the past 20 years are available in cold storage. Other samples of organisms, sediments, and water collected and stored under conditions favorable for this work are being sought in the established collections on this coast.

GLOBAL BASELINE-DATA PROJECT (GEOSECS)

A global baseline data-acquisition project, significant to both the Environmental Quality and the Environmental Prediction programs of the U.S. IDOE, is the Geochemical Ocean Sections Study. GEOSECS is a multiyear project involving geochemists from 10 U.S. universities and participation from Canada, France, Germany, India, Italy, and Japan. The U.S. portion of the program will operate from the Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, in the Atlantic Ocean, and from the Scripps Institution of Oceanography, La Jolla, California, in the Pacific.

Eventually man's use of the planet will depend on detailed understanding of oceanic processes. These processes now are understood in only the vaguest and most qualitative way. These processes include the stirring and mixing in the deep sea, the interchange of energy and material between deep and surface water and gases with the atmosphere.

The rapid expansion of science and technology in recent years has made available many sophisticated and powerful tools for the study of the sea. At laboratories on shore, mass spectrometers, low-level radioactivity counters, atomic reactors for neutron-activation, gas and liquid chromatographs and autoanalyzers have been used for the analysis of individual constituents of ocean water, and some of these instruments have been successfully used at sea. However, well-trained geochemical oceanographers are few, and development of shipboard laboratories has lagged far behind the analytical techniques. Consequently, the potential of these new methods for studying the sea has only begun to be realized.

The basic task of the Geochemical Ocean Sections Study is the detailed measurement of the oceanic constituents along Arctic to Antarctic sections, as shown in Figure 7, at all depths, to provide, for the first time, a set of physical and chemical data measured on the same water samples. In addition to establishing geochemical baselines these data will provide input for quantitative studies of oceanic mixing, and for descriptive models of ocean circulation.

Exploration of the temperature and salinity patterns in the oceans, together with theoretical work in fluid dynamics, has provided a qualitative understanding of the large-scale processes in the sea. The ocean resembles a great convective cell in which the upper layers are heated by the sun and stirred by wind-driven waves and currents. The mechanism which drives this circulation is thought to be provided by cold water sinking in the polar regions, where surface waters lose their heat and increase in salinity by the formation of sea ice. New bottom water, thus formed, flows as abyssal currents to the deep basins of the oceans. Oceanographic and geochemical studies have identified two areas where

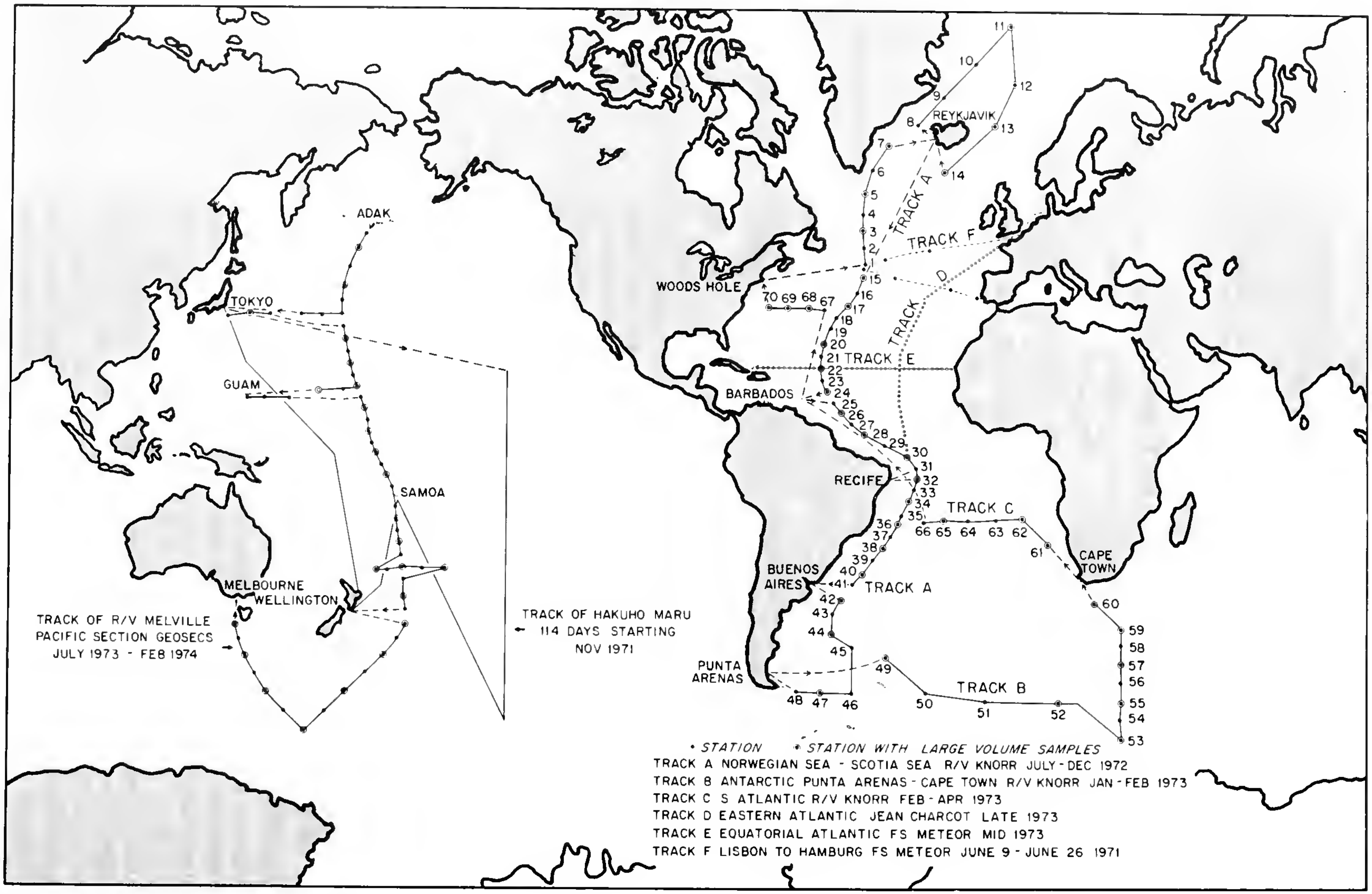

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Figure 7. GEOSECS Track chart

abyssal currents originate: the North Atlantic Ocean, and the Weddell Sea in the Antarctic region of the South Atlantic. The rates at which such water masses form, the nature of their subsequent sub-surface flow within the different oceans, and whether other sources exist, are questions which remain to be studied.

The vertical and horizontal boundaries of chemical constituents in the sea are eroded by diffusion. Although we have a crude idea of the average effective speed of diffusion processs, in a turbulent environment such as the ocean, we know little of its vertical, horizontal, or time-dependent variations, or of the source of energy that drives the turbulence. The recent introduction of fission and nuclear products such as radio-strontium and cesium, tritium, and man-produced carbon-14, as fallout to the surface waters of the ocean, provides a unique means of tagging which can be used to measure the rates of downward mixing from the surface to intermediate depths, and so of determining quantitatively the rates of turbulent diffusion and downwelling in various oceanic situations.

A complication with the use of radioisotopic tracers is that all are involved, to varying extents, with the downward flux and regeneration of biological particles within the water column. In order to obtain estimates of these fluxes, it is necessary that complete information be obtained on the corresponding stable isotopes. For example, the *in-situ* production of C^{14} by the decay of biological particles is correlated with the *in-situ* production of CO_2 which can be estimated from measurement of dissolved total CO_2, alkalinity and pH, or any two species within the oceanic carbonate system. By measuring the concentrations of the natural radioactive isotopes radium-226, silicon-32, and cosmic-ray produced carbon-14 in the deep and bottom waters of the ocean, it should be possible to improve our knowledge of advection and turbulent diffusion. These convenient nuclear clocks can be used to determine the "age" of water masses in typical situations, in much the same way that carbon-14 is used to measure the age of solid objects.

Sampling Plan

The GEOSECS project is designed to give the first detailed information of distribution patterns, by measuring simultaneously and mapping the distribution of the important oceanic tracers and properties along continuous north-south sections of the three major oceans in the world. The survey tracks follow, as far as is now known, the approximate trajectories of the bottom water currents. The United States project will carry out the major survey work along these tracks in the Atlantic, Indian, and Pacific Oceans, and in subantarctic waters. Additional projects now being planned by West Germany, Japan, and other nations will add supplementary sections.

The U.S. project calls for the occupation of 120 oceanographic stations along the main survey tracks. At each station, vertical profiles of 50 samples will be taken. At alternate stations, very large samples will be taken at 18 to 20 depths for measurements of trace constituents and low concentration radioisotopes. The vertical spacing of all these samples will be guided by continuous recording, on station, of temperature, salinity, and dissolved oxygen. Particulate matter will be collected at all depths, and dissolved gases will be extracted from the sea water for on-board analysis by gas chromatography. Much of the analytical work will be done directly on the ships during the expedition. The remaining work on the water samples will be done in the laboratories of participating geochemists throughout the United States. A library of water samples will be maintained for future work. A complete list of the properties to be measured is given in the Table.

Shipboard Laboratory Analyses

The success of the project will depend upon the precise and rapid measurement of several ocean variables aboard ship. For this reason automated analysis systems are being developed for many of the routine chemical measurements. All physical and chemical measurements made at sea will be fed into the shipboard computer. Data will be logged from principal and auxiliary sources and brought together in a real-time system to compute final values of all parameters. A large proportion of these data will be available for evaluation by the Chief Scientist before moving off station. A view of the computer console (under development) is shown in Figure 8.

Figure 8. GEOSECS shipboard data-acquisition system.

The analytical systems being automated or partially automated and interfaced with the computer are the salinometer; alkalinity-total CO_2 titration; gas chromatograph (total CO_2, N_2, A); autoanalyzer (NO_3, NO_2, PO_4, SiO_2); Rn^{222}.

Data from the thermosalinagraph, atmospheric sensors, ship speed and heading, satellite navigation, etc., will automatically and constantly be added to the computer data bank, available for instant recall.

a) *Salinometry*

In order to reduce this task to a manageable time span, a new temperature and salinity probe developed at the Woods Hole Oceanographic Institution has been interfaced with a computer to provide nearly instantaneous salinity measurements to a resolution of $\pm$ 0.002 parts per mille.

b) *Alkalinity—Total CO_2*

Analysis of Alkalinity-Total CO_2 is by one of three methods. Performance of each method is being studied to determine which gives the most precision and the most information. The three methods are: 1) the Gran plot method described by Edmond; 2) determination of end point by searching for the infection points on the titration curve; and 3) fitting the observed data to the best available titration curve by means of a non-linear least squares computer procedure.

c) *Argon and Nitrogen*

Two chromatographs will be used aboard ship, one for the analysis of total CO_2 and another for the analysis of dissolved argon and nitrogen. The two chromatographs operate concurrently and are contained in the same enclosure. The total CO_2 gas chromatograph uses a thermal detector; the argon-nitrogen an ultrasonic detector.

d) *Nutrients*

The nutrients phosphate, silicate, nitrate, and nitrite are measured using a Technicon Auto Analyzer system. However, manual spectrophotometry is used frequently to check the calibrations of the auto analyzer. Data from a four-channel auto analyzer are converted to digital form by panel meters and transmitted to the shipboard computer through a data multiplexer. The manual spectrophotometer has its own digital output and this transmits via the multiplexer to the computer. Sampling sequences are transmitted by typewriter.

e) *Radon*

Excess radon gas will be measured in both surface and near-bottom profiles at each station. The radon will be extracted from samples by flushing with helium and freezing at liquid nitrogen temperatures. Four extraction systems will be in use at all times. The extraction time is approximately 2 hours. Following purification to remove water and carbon dioxide the radon gas is transferred to a counting system consisting of eight scintillation tubes.

All of the automated systems described in the previous paragraphs will be provided with backup manual methods. A Washington bridge salinometer will be carried aboard ship, and manual alkalinity determinations could be performed using a pH meter. Both the gas chromatographs and the radon counters can be operated in the manual mode. Backup nutrient analysis facilities will be provided by manual spectrophotometry.

***In-Situ* Underwater Measurement**

In addition to measurements on board ship from bottle samples, an underwater sensor package has been developed which includes: a) Conductivity, temperature, and depth sensor; b) Bottom proximity detector; c) dissolved oxygen; and d) nephelometer. The package consists of eleven 30-liter sampling bottles in a rosette. The bottles are tripped individually by an electronic signal from the surface. Confirmation of each trip is provided.

a) *Conductivity-Temperature-Depth*

The CTD sensor is an adaptation of one constructed at the Woods Hole Oceanographic Institution. The instrument was originally intended for microstructure work and has a high rate of data accumulation. The CTD profile is fed to the shipboard computer.

b) *Bottom Proximity*

The bottom proximity detector is a special acoustic device used to measure vertical distance between the sensor package and the sea floor in the bottom 500 meters of the water column. It has a resolution of 0.5 meters. This instrument is required because of noise pollution generated by RV's *Melville* and *Knorr*. The unit transmits and receives the ping, converts the delay into a digital signal, and transmits this information up the wire along with the CTD and other data.

c) *Dissolved Oxygen*

An oxygen sensor that works below 2,000 meters is not available commercially. Investigations have been conducted of the various sensors available. Results show that the membrane-limited polarographic type is the best available, barring a completely new development program, and will serve as the basis for the GEOSECS probe. Preliminary investigations indicate that the precision is better than one percent, with a lower detection limit of 0.05 ml/l of oxygen. To obtain this accuracy, calibration facilities will be maintained on board ship.

d) *Nephelometry*

To detect suspended particulate matter a nephelometer is included in the underwater sensor package. The nephelometer uses a ruby laser beam light source. A resistive photocell placed just outside the beam detects forward-scattered radiation, and the response is a measure of the particulate matter in the water column. A similar photocell placed in the back-radiating beam of the laser monitors the emission.

Data are transmitted from the underwater sensor package up the coaxial lowering cable by frequency shift keying. On ship, a preprocessing computer converts the data to appropriate engineering units, screens the raw data for bad points, and averages over depth intervals of one meter. These data are then transferred to the shipboard computer for storage and display. Various displays are required. Temperature, salinity, oxygen, and light scattering are displayed as a function of depth; temperature is displayed as a function of salinity; and density is displayed as a function of depth. A diagram of the underwater sensor package is shown in Figure 9.

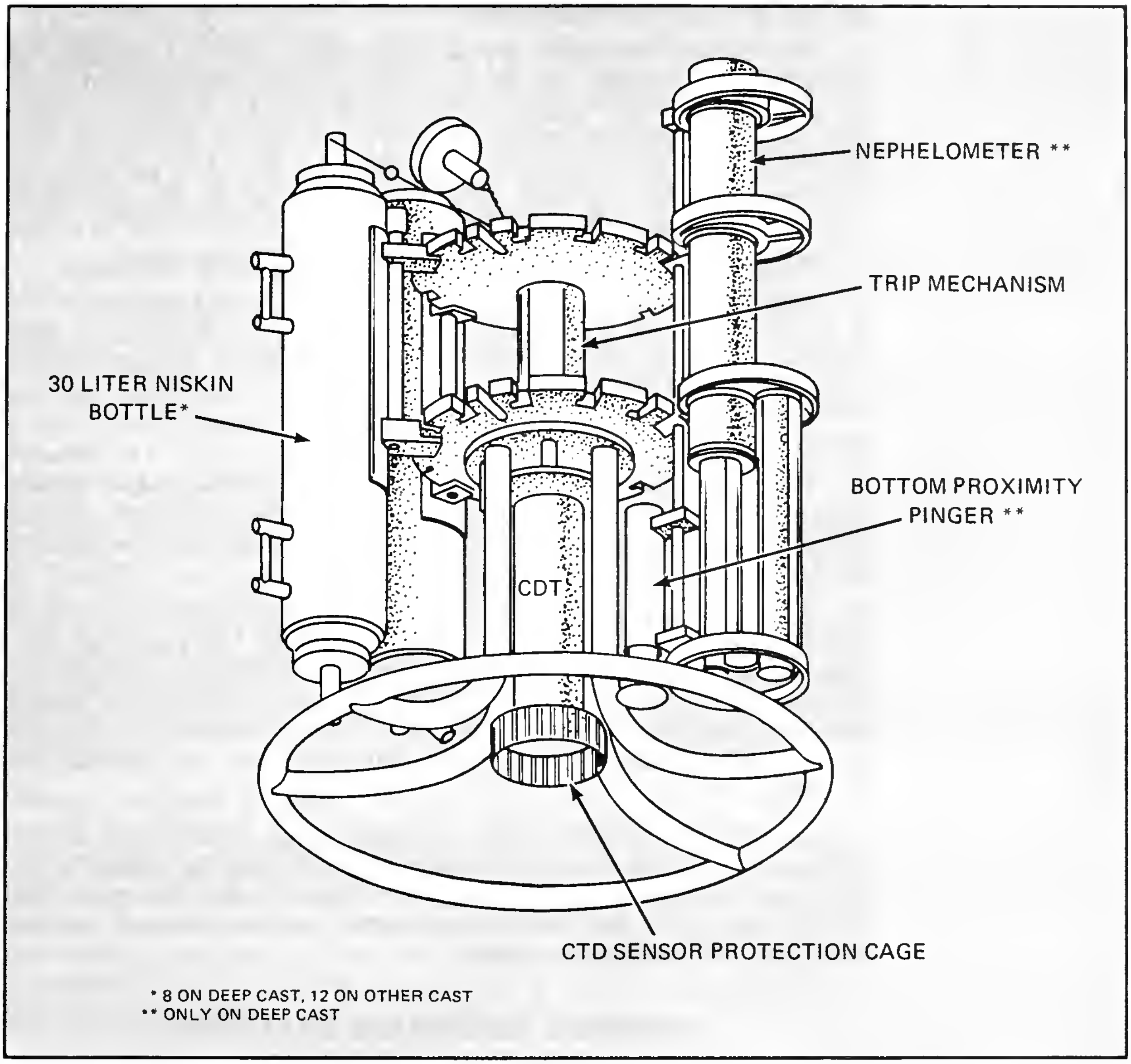


Figure 9 GEOSECS underwater sensor package.

Large-Volume Water Sampling

Large-volume water samples are required for many of the radioactive elements that will be measured during the project. Analysis of C^{14} requires 200 liters; Sr^{90} and Cs^{137}, 100 liters; Ra^{226}, 100 liters; Ra^{228}, 800 liters; and particulate matter, 250-400 liters of sea water. In some cases the same sample may be used for two or more measurements.

The requirement of 18 large-volume samples per station necessitates the use of multiple sampling devices on a single wire. Initially, it was hoped to use 1500-liter canvas bag samplers. Extensive testing during three recent cruises proved the samples extremely difficult to bring aboard ship, and in a number of cases samples from supposedly deep water clearly contained mixtures of water from shallow depths.

C^{14} and H^3 Shoreside Measurements

The GEOSECS project will generate about 1,200 C^{14} samples and about 2,500 H^3 samples. Of the C^{14} samples, about 900 will most likely be collected below 200 meters; for these, the greatest possible precision and accuracy is desired. In the C^{14} scale a precision of better than four parts per mille and an accuracy of better than five parts per mille, all experimental errors included, have been stipulated by the GEOSECS Advisory Committee. No existing radiocarbon laboratory can presently process a significant number of samples meeting these criteria.

Analytical facilities capable of such accuracy have been constructed at the University of Miami and at the University of Washington. It is expected that these facilities will be functional before the start of the major cruise in July 1972.

Preparatory Cruises

Until the present time there have been three intercalibration cruises, designed to allow the various investigators to intercalibrate their methods and to obtain detailed vertical profiles in the areas where the main cruise tracks will run.

During the period September 23-30, 1969, a test station was established in the Pacific Ocean at 28°29′ N., 121°38′ W. The results of intercalibrations from this cruise have been reported in the *Journal of Geophysical Research,* 75: 7639-7696 (1970). A second cruise aboard RV *Knorr* from August 24 to September 2, 1970, established a test station at 35°46′ N., 67°59′ W. Results from this cruise will be published late in 1971.

A third intercalibration and test cruise was completed in August 1971 as part of the Scripps Institution of Oceanography Antipode Expedition to the South Pacific aboard RV *Melville.* For November 1971 and January 1972, short cruises are planned for the testing of the complete shipboard analytical systems.

HISTORICAL BENCHMARK DATA FROM MUSEUM COLLECTIONS

In natural history museums throughout the world there are large collections of biological specimens of different types, both terrestrial and marine. There are 53 million specimens in the U.S. National Museum alone. Many of the specimens were collected during the last 200 years, before levels of industrial pollutants in lakes, rivers, and oceans had reached their present values. It seems possible that chemical analysis of some of the specimens in the older collections, depending on the way in which the specimens were preserved, might permit extension of pollutant baseline data backward in time. The statistical value of this possibility alone justifies the attempt.

A task force of ten scientists of the Smithsonian Institution's National Museum of Natural History has organized to examine for the U.S. IDOE program in Environmental Quality the feasibility of studying museum materials for pollutants. They are presently studying the various methods used to preserve specimens of plants and animals in the past and at the present time. The first goal is to determine the feasibility of analyzing specimens preserved in museum collections for heavy and transition metals, hydrocarbons, and other appropriate elements and compounds. If such analyses are deemed feasible, the second goal will be to extend the baseline data on marine environmental pollutants from the present as far back in time as possible, analyzing specimens from as many museums as are willing to participate in the project.

DURHAM WORKSHOP ON ENVIRONMENTAL QUALITY

In August 1971 a group of about 50 U.S. and foreign scientists who have been actively engaged in environmental research met in Durham, New Hampshire, in a meeting convened by the National Academy of Sciences under the auspices of the U.S. Office for the IDOE. The purpose of the meeting was to consider five major areas that are likely to be of importance in environmental quality research and to recommend research priorities in each. The five areas are: 1) the identification of major recognized and unrecognized pollutants, their sources and rates of input; 2) delineation of processes affecting the dispersal of these pollutants; 3) understanding the geochemical and biological transfer of each element or compound in the ocean; 4) establishing the effects of pollutants on organisms and their life processes; and 5) determining the sites of final deposition of specific elements and compounds in the ocean environment. Some of the recommendations relative to the above five research areas and how they relate to ongoing and future IDOE-supported programs are indicated below.

Sources and Rates of Input

Studies should be undertaken to measure the rates at which the major pollutants are being delivered to the oceans both in nearshore waters as river runoff from the continents and in the open ocean as airborne fallout compounds. The Durham Workshop singled out polychlorinated biphenyl compounds (PCB) for highest priority, and petroleum films at the ocean surface and several of the heavy metals as being the next most crucial areas for scientific investigation.

Dispersal Mechanisms

Studies should be undertaken in dispersal of airborne pollutants through the water surface films, adsorption of particles, and dilution by physical and chemical processes.

Chemical and Biological Transfers

Adequate studies in this category require an intense measurement program in a well-defined ecological environment. The high cost of data collection will limit the number of such studies to one or two locations. The field studies should be augmented by laboratory experiments on specific animals.

Effects on Organisms

The Durham Workshop concluded that most of the efforts to date in this category have been devoted to laboratory determinations of the concentrations required to kill half the animals exposed to a given pollutant. Rather than support more of those kinds of studies, the IDOE program will focus on the effects of pollutants on the life processes of organisms—breeding, feeding, respiration, reproduction, etc.—so that the effects may be detected and predicted long before concentrations sufficient to cause death are reached.

Fate of Pollutants

Knowledge of the half life of most manmade pollutants in the oceans is almost nonexistent. The processes, if any, responsible for their ultimate removal or transformation to a harmless form are equally unknown. Studies to identify these processes will be undertaken.

3. ENVIRONMENTAL FORECASTING PROGRAM

An important part of the International Decade of Ocean Exploration, and one upon which environmental quality bears, is the Environmental Forecasting program. Oceanographers are well aware that the ocean surface layers are the part of the ocean of immediate human concern. But the remarkable role of the oceans in controlling global weather and climate is not generally understood.

Uniformly mild surface temperatures do not occur everywhere on earth because of the interference of land masses and of bottom topography upon the circulation of the oceans and the interference of mountain ranges and of continental local heating and cooling upon the circulation of the atmosphere. Extreme effects tend to be smoothed over by the heat-storage capacity of the deep seas. But during much of the last 500,000 years the oceans had lost their warm surface layers and the continents had trapped that water on land in enormous ice sheets. Short-term continental interferences upon oceanic regulation of atmospheric circulation are known as weather; long-term changes of oceanic regulation of the surface temperature of the planet are known as climate.

Until recently, the oceanographer has not been faced with the same demands for forecasting that the meteorologist encounters. Formulation of predictive models has to be based on a sound theoretical understanding of the processes at work in the ocean. Because a sound understanding is lacking, it is appropriate to place major emphasis on studies of the surface layers of the ocean and their interaction with the lower atmosphere, and to determine what dynamic processes are at work in the deep ocean that influence that interaction.

In the ten years or more since its appearance in oceanography, the digital computer has made it possible to operate detailed descriptive models of oceanic phenomena. On the basis of synthetic data and assumptions—some to augment the data and others to simplify natural phenomena to make them more tractable or economical in the computer—hypothetical pictures of the oceans now being drawn by the machines closely resemble our present concepts of the oceans. For example, in one analytical model the western boundary currents are properly placed in an idealized ocean basin; in another hypothesis, cold water sinks at the poles and warmed water moves away from the equator. Based on these models, remarkable three-dimensional animated representations of the simulations have been produced by frame-by-frame exposure of motion picture film. Still, many essential details are necessarily lacking; and it must be kept constantly in mind that, although the results agree with our present concepts, it is not certain that the models describe the actual behavior of the oceans.

Eventually these hypothetical models must be tested. Great care must be exercised to select the proper kinds of experiments and experimental data. One must set phenomenon traps capable of catching the unexpected as well as the expected. To take into account important phenomena of small size and short duration, as well as those of large scale and long duration, the simulation models must repeatedly examine adequately fine-mesh grids in the ocean. There must be such horizontal grids stacked one above the other closely enough to resolve important phenomena in all three dimensions. Finally, the computer must have a large enough capability to accept and process a mountain of data every day if such requirements are to be met on a scale even approaching that of an entire ocean basin.

Experiments of this magnitude are not very easily undertaken by one academic institution or by a single country. The two largest oceanographic institutions in the United States, the Scripps Institution of Oceanography and the Woods Hole Oceanographic Institution, presently lack the facilities and organization necessary to sustain an ambitious multi-element field experiment, as a continuous commitment, without jeopardizing the rest of the institutions' research program. So it is necessary, as well as desirable, to encourage cooperation among many institutions and countries.

Five major cooperative projects are presently under way in the Environmental Forecasting program of the U.S. IDOE.

MID-OCEAN DYNAMICS EXPERIMENT (MODE)

An important element of the Environmental Forecasting Program of the U.S. IDOE is the Mid-Ocean Dynamics Experiment project, Phase I of which is already under way. It is a cooperative effort, an important portion of which is supported by the National Institute of Oceanography in England. The long-range goal of MODE is to investigate the role of medium-scale, geostrophic eddies in the general circulation of the oceans. The immediate purpose of MODE-I is to provide a kinematic description of these eddies. It is estimated that geostrophic eddies, if indeed they are ubiquitous, would contain at least as much kinetic energy as the mean oceanic circulation, and possibly ten times more. Where the energy comes from, how much there is, what it does, and where it goes are serious questions presently being asked by those who are devising descriptive numerical models. It is known that such eddies actually do exist in the atmosphere, that their kinetic energy content is comparable to that of the mean flow, and that this is enough to prevent successful descriptive or predictive numerical simulation unless it is properly taken into account. Such knowledge may be even more important in modeling oceans: In any case, it is certain that this energy must be accounted for accurately in the dynamics of the oceanic models.

MODE-I will be conducted in a small area 200 kilometers on a side and 5 kilometers deep, near the Tropic of Cancer south of Bermuda, as shown in Figures 10 & 11. Scientists participating in MODE-I are from eight different U.S. universities, two U.S. Federal laboratories, the National Institute of Oceanography and Cambridge University in England, and the Woods Hole Oceanographic Institution.

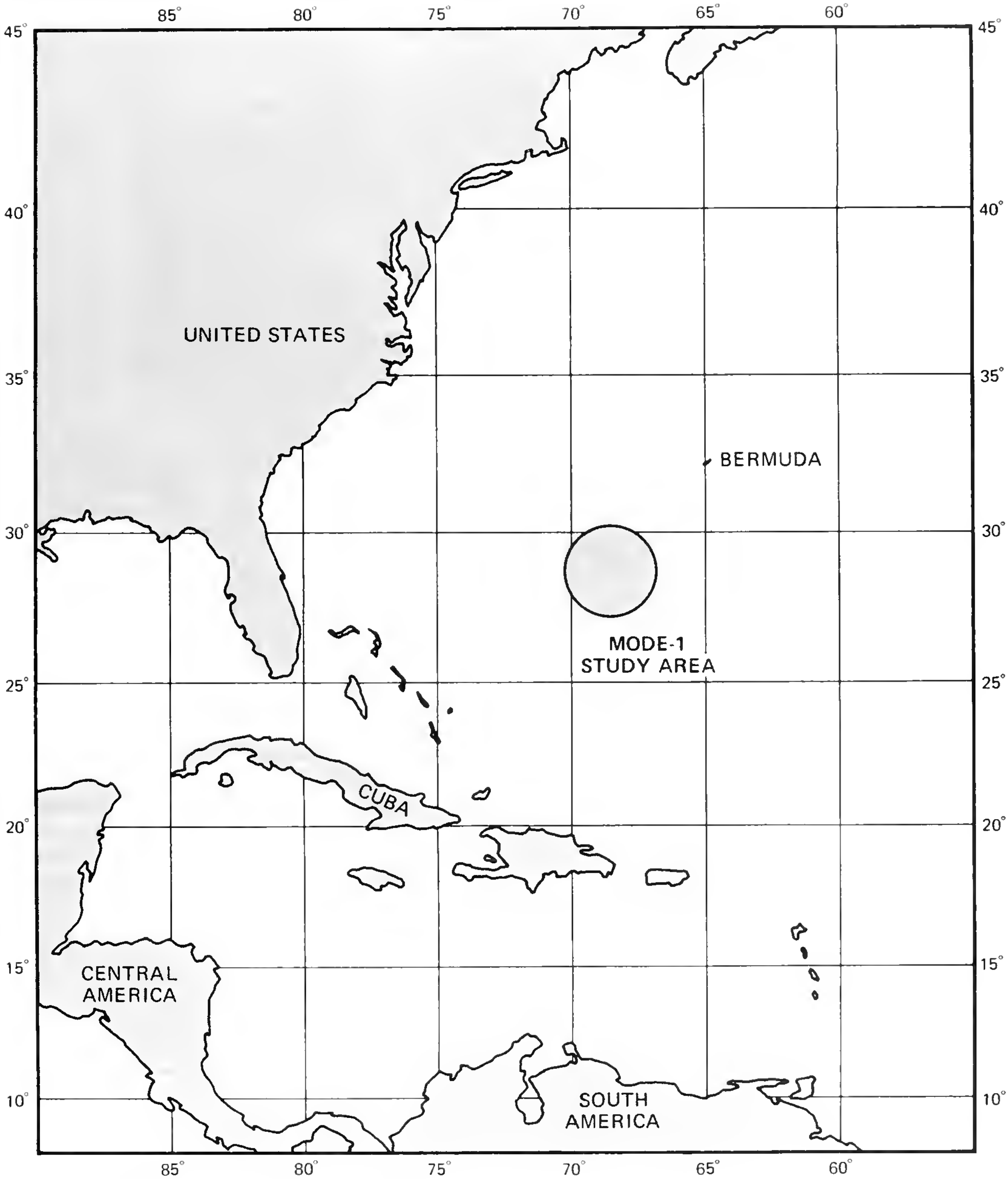


Figure 10. Location of MODE-1 Field Experiment.

MODE-I is a joint experimental-theoretical project. The major field experiment will last for four months in early 1973. Measurements will be made from an array of moored buoys, bottom-mounted and free-floating devices, and shipboard and air-borne instruments, with the central effort

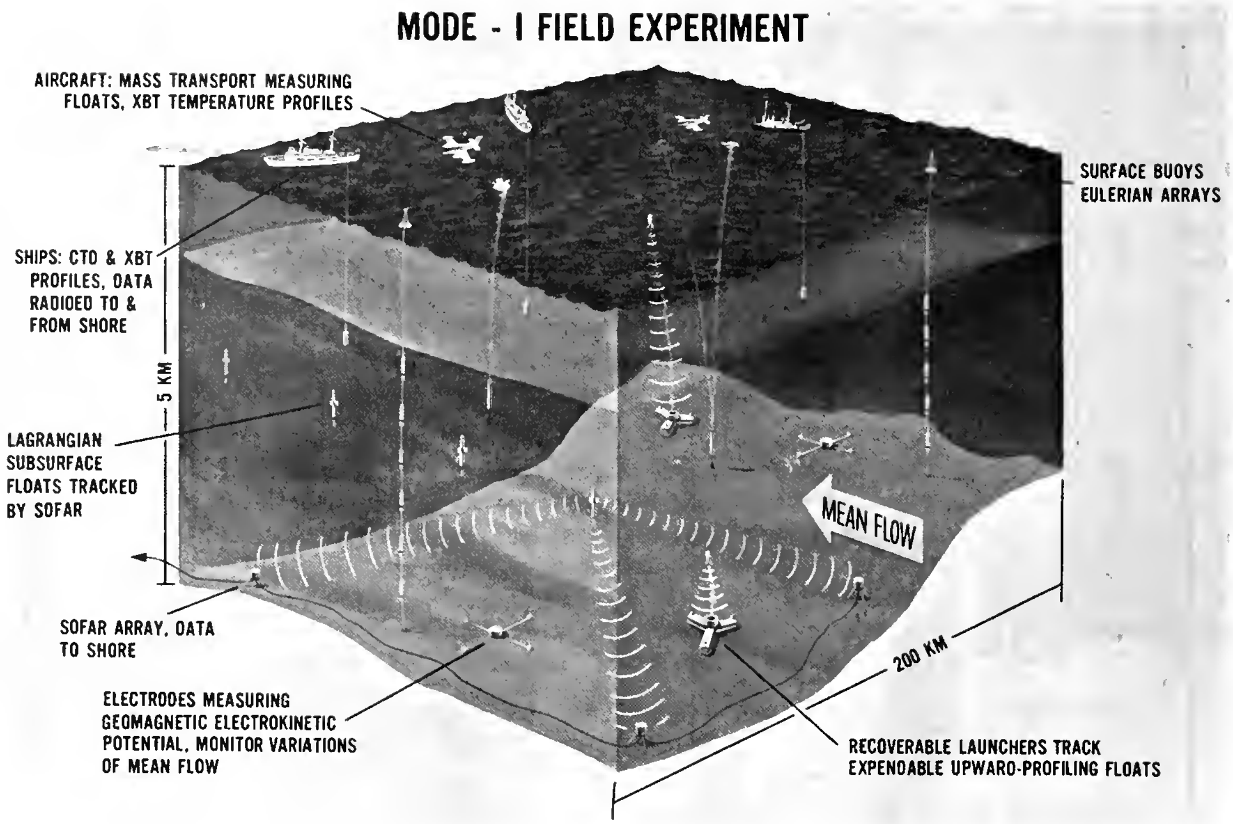


Figure 11. MODE-1 Field Experiment.

directed toward resolving the velocity fields and density fields on the time scale of days to months and a space scale of 10 to 200 kilometers. The theoretical program will involve evaluation of a variety of mathematical models designed to test kinematical hypotheses about the mesoscale motions and to explore their dynamics and their interactions with other scales. Numerical modeling and experimentation will be of primary importance in relating theoretical ideas to experimental design, in the testing of hypotheses, and in data interpretation.

Eddy Processes and the General Circulation

The concept of MODE is founded on the need for understanding the general circulation of the oceans, implying the identification of the most important quantities which are conserved physically (e.g., vorticity, mass, heat, and energy) and the discovery of the processes of their conservation in the mean, (e.g., the identification of external and internal sources and sinks, and the scales and mechanisms of transport and transfer). It is highly probable that mesoscale eddy processes (quasi-geostrophic, low frequency motions of intermediate scales) are of vital importance. Yet observations of these processes are almost nonexistent.

Considerable progress in understanding the ocean circulation in terms of steady-state models, analytical and numerical, has been made during the past 25 years. Successes in accounting in these terms for the spatial distribution and general structure of the major gyres, the existence and general level of transport of major currents, geographical and vertical variation of the main thermocline, the general distribution of properties, and features of the abyssal circulation have been remarkable. But explanation of these gross features of the circulation does not involve a crucial testing of the internal dynamics of the models. The successes may be attributable simply to the identification of primary driving mechanisms and the inclusion in the models of dominant constraints of geometry, rotation, and stratification.

However, despite the efforts of an increasing number of skilled and dedicated scientists, development of understanding in the last few years has been disappointing. Even relatively simple physical refinements of the models led to difficult nonlinear fluid dynamical problems; the deduction of general consequences from simple hypotheses has been precluded. Although studies of transient processes have been initiated, circulation models including the eddy processes in a general way have not yet been formulated. The problems involved are not overcome by the direct exploitation of numerical models in their present state of development. Present limitations of machine capability and computational techniques require the specification of model dynamics in such a way as to prohibit the occurrence of important nonlinear and time-dependent processes. For example, large positive values for horizontal eddy viscosities are often employed, and grid spacings in general circulation models are too large to allow the mesoscale eddy processes to occur spontaneously.

With regard to the dynamics of the general circulation of the atmosphere, the importance of mesoscale eddy transport mechanisms has been established on a firm theoretical and observational basis. The eddy dynamics replaced the long-prevalent concept of circulation based upon Hadley cell dynamics, which was first abandoned on empirical grounds. The late 1940's saw both the first direct calculation of the eddy transport of angular momentum from adequate data and the discovery of the fundamental process of baroclinic instability. Since that time, great strides forward have been made in the understanding of the general circulation and the ability to predict and to monitor the appropriate variables.

The evolution of the understanding of atmospheric circulation provides valuable guidance in present studies of ocean circulation. It is unlikely that there exists a strong direct analogy between atmospheric and oceanic circulation, but, as has already been indicated, the fundamental importance of eddy processes is strongly suggested. The space and time scales of the oceanic mesoscale are expected to be respectively shorter and longer than the corresponding atmospheric scales (based upon the radius of deformation, observed speeds, and the advective time scale). The strength of the physical analogy between atmospheric and oceanic circulation will depend upon the as yet unknown energy source(s) of oceanic eddies. This energy may come from baroclinic instability of the open ocean, from major ocean currents which shed long-lived eddies, from transient surface forcing with scale transfer due to interference with bottom topography, from nonlinear transfer of energy from inertial motions, or from internal waves and tides.

Direct observational evidence for the importance of the mesoscale oceanic eddy motions, although scanty and nondefinitive, provides some indication of the important scales, but more important, provides strong motivation for further study. The tracking of neutrally buoyant floats off Bermuda in 1959-60 from RV *Aries* first indicated the existence of irregular mesoscale motions in the deep water an order of magnitude more energetic (5-10 cm/sec, 200km, 40 days) than the anticipated value for the mean flow. These motions appear to be quasi-geostrophic, with significant energy in both the barotropic and baroclinic modes. If these horizontal motions are correlated with a coefficient of 0.1 they constitute a mid-ocean source of mean vorticity comparable to that due to the mean wind stress curl.

In the past decade significant technological advances have been made in oceanographic instrumentation. The considerable data obtained from moored current meters, together with some Lagrangian float tracks, time series temperature records obtained off Bermuda, and towed thermistor records, provide consistent empirical evidence for the existence of the low frequency mesoscale eddies.

Field Project

The field project is scheduled to begin with several small arrays of moored instruments in November 1971, to be followed by various tests and trials of new instrumentation during 1972, and culminating in the intensive MODE-I experiment during March through June of 1973.

At that time measurements will be concentrated in a 200-km square near 28° N., 68° W. Three U.S. and one British research vessel, shown in Figure 12 will participate in launching various free-floating devices and moored instrumentation. The ships will also conduct a program of standard measurements of the temperature and salinity fields.

The fixed array of moored instruments consists of recording current meters (about 50, on 16 buoy moorings) and some temperature recording instruments of new design. Free-floating instruments will include about 20 widely dispersed, large, neutrally buoyant floats, situated at about 1200 meters depth in the sound channel, tracked acoustically by remote observation stations. A small cluster of about 50 floats will be tracked by a movable hydrophone array. Free dropping vertical profiling instruments will be launched from ships and aircraft, measuring salinity, temperature, and horizontal currents. In addition, there will be two varieties of bottom pressure gauges, inverted echo sounders, and geomagnetic electric field recorders. These diverse measurement systems will be deployed in such a way that the results will supplement each other, permitting optimum synoptic mapping of the mesoscale velocity and density fields.

Project Management

The various components of MODE-I are substantial experiments in their own right. From one point of view, MODE-I is an assembly of associated experiments with fairly loose coordination and a decentralized technological base. But experiments performed simultaneously and in the same place strengthen each other by providing intercomparison and a richer field of data. More important is the demand that MODE-I makes for explicit decisions and the careful weighing of differing needs.

CHAIN

DISCOVERER

DISCOVERY

TRIDENT

Figure 12. Research vessels participating in MODE-1.

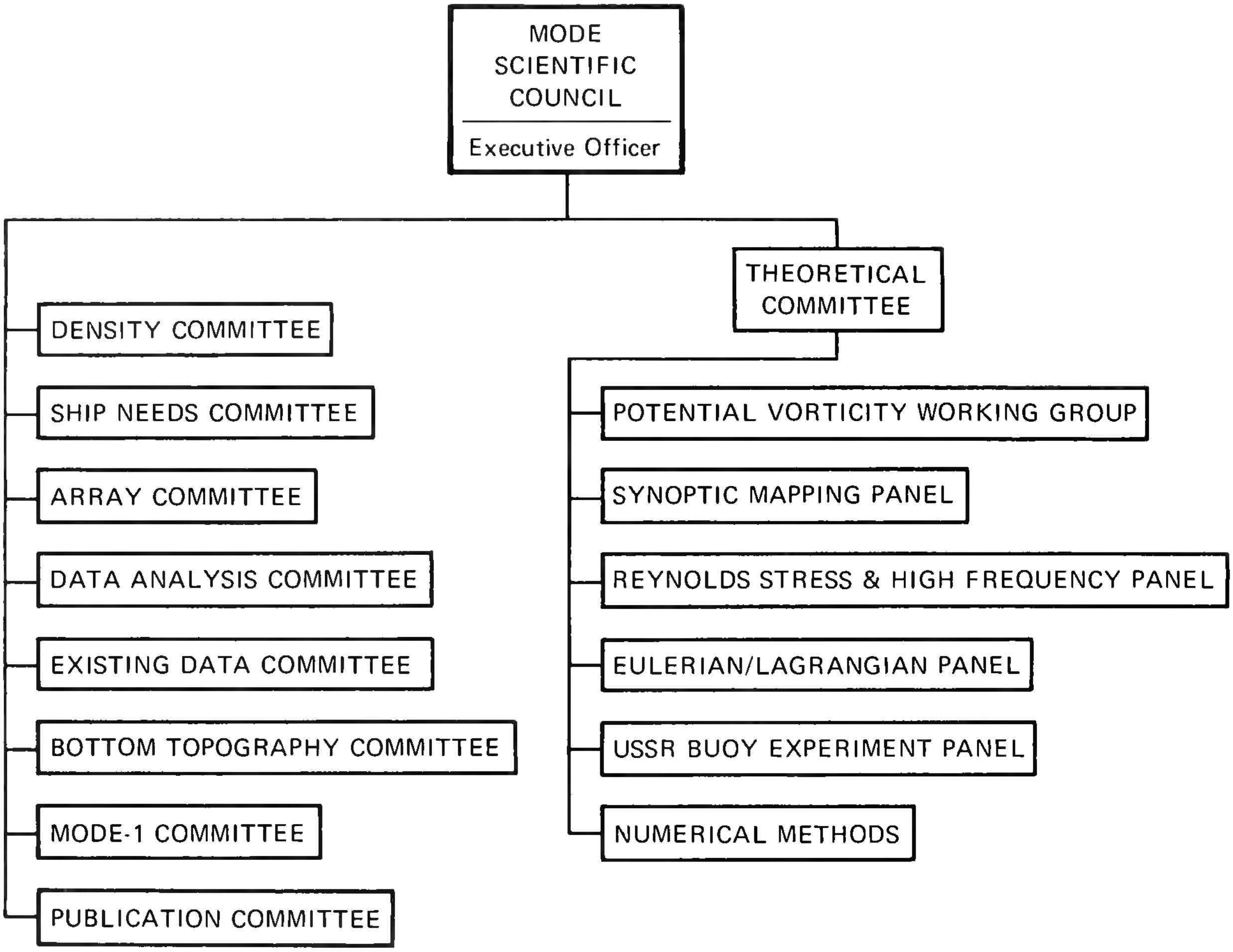


Figure 13. Organization, Mid-Ocean Dynamics Experiment.

As shown in Figure 13, working groups of investigators representing diverse techniques are determining the optimum form of arrays of fixed instruments, the patterns of shipboard and airborne measurements, and the appropriate bottom topographic survey.

These and other considerations are being addressed by the Array Committee, the Bottom Experiment Committee, the Density Committee, and others reporting to the Scientific Council. This kind of activity would not so seriously engage attention were it not for the joint nature of MODE.

Work has begun on planning for the preparation and analysis of data. Data work-up will begin with preparation, listing, and publishing results, and submitting data to the National Oceanographic Data Center. The Publications Committee will supervise publication of a complete data report. A general article describing the main highlights of the whole project will be prepared by late 1973 under the joint authorship of the principal investigators.

The Theoretical Program: Elements and Studies

Close scientific cooperation between theoreticians and experimentalists is essential to a successful investigation of the nature of the mesoscale motions and to progress towards an understanding of their dynamic interrelationships. The development and application of numerical models is of utmost importance to several aspects of the project: the design of specifics of the experiment, the evaluation of the meaningfulness of types of data and sampling rates, the development of mapping techniques, numerical experimentation, and investigation of dynamical hypotheses. Numerical models are the essential tool to be used in providing the feedback between theoretical ideas and the design and interpretation of the field experiment. The theoretical program must necessarily be fluid and evolve with the insights gained as the entire MODE-I project develops.

A computer mapping program which is under development will result initially in five-day mean maps of current and integral density anomaly at several levels. This program provides an important basis for initial input of theoretical concepts into the design of the field program and will be used in the final interpretation of the data in terms of kinematical hypotheses. Also under development are a 64x64 barotropic numerical model for the evaluation of topographic sites, and a quasi-geostrophic 32x16 eight-level baroclinic model for kinematical and dynamical studies.

Any kinematical study necessarily parameterizes the details of the dynamics of the motions. To exploit the MODE-I data fully and to begin to understand the energy source(s) of the eddies, their interactions, and their role in the general circulation, dynamical studies of mesoscale waves, eddies, and turbulence are needed.

COASTAL UPWELLING EXPERIMENT (CUE)

A second area of emphasis within the Environmental Forecasting Program is the study of upwelling. The International Decade of Ocean Exploration is sponsoring a major field project to study coastal upwelling off the coast of Orgeon in mid-1972. CUE-I (Coastal Upwelling Experiment, Phase-I), designed in close coordination with numerical models and theoretical hypotheses, is an intensive, detailed field study of the physical dynamics of the natural process by which subsurface cold, nutrient-rich water is raised to the ocean surface near the coast in response to favorable winds.

The objective is to gain an understanding of the time and space scales of coastal upwelling and to develop ability to estimate the speeds and directions of water flow in the upwelling zone and the distribution of chemical substances and biological organisms that move with the waters.

Progress in both the theory and the measurement of upwelling processes over the past few years has reached the point where a concerted scientific research effort may make it possible to predict upwelling and to understand the processes taking place within the food chain. It will surely result in an improvement of man's use of the oceans as a source of food. CUE-I is seen as the first step toward achieving that predictive capability.

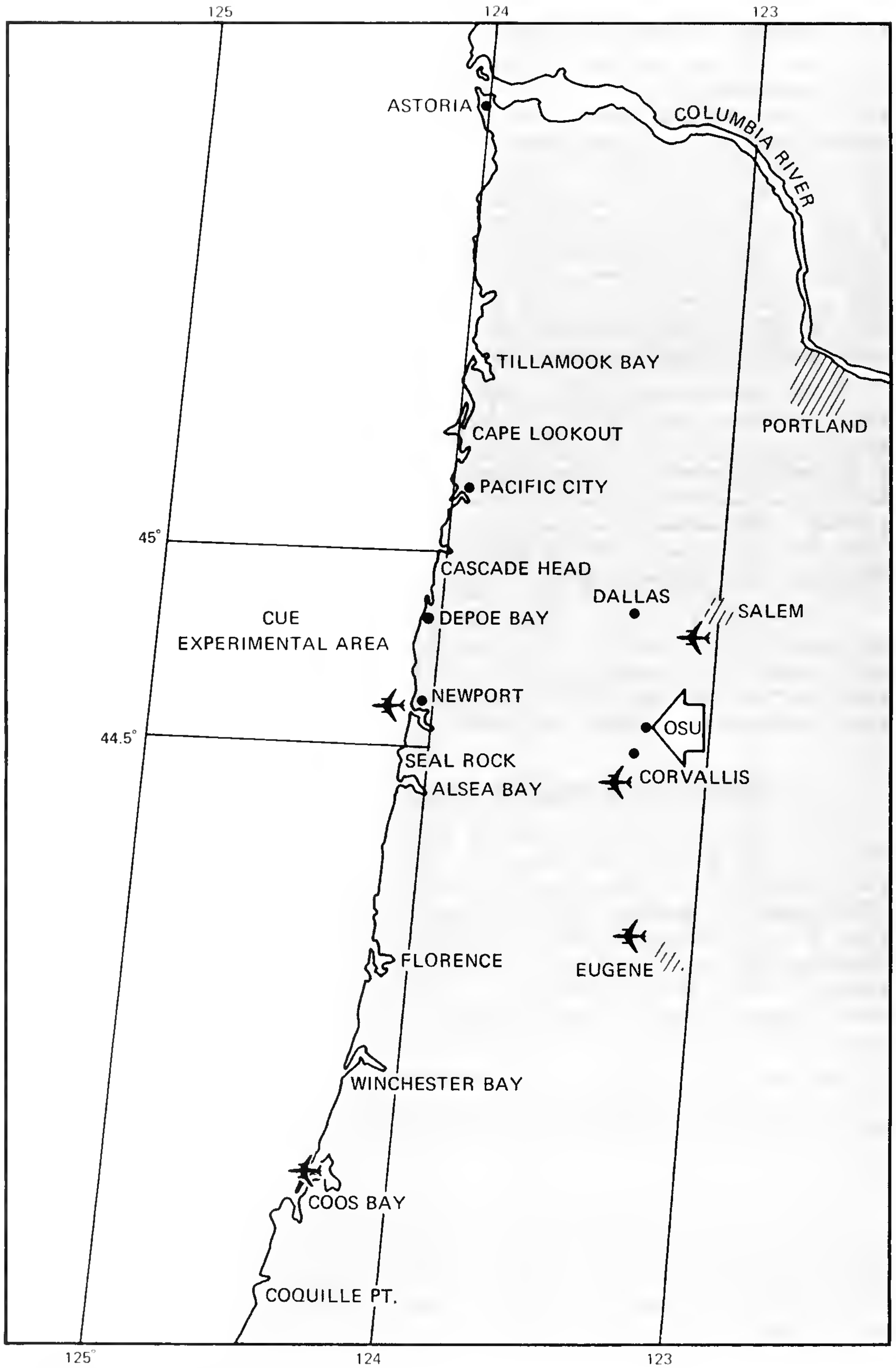


Figure 14. Coastal Upwelling Experiment (Oregon).

The instrument array of CUE-I includes recording current meters, temperature and salinity sensors, and anemometers. Additional wind measurements on shore will be made by the Marine Meteorological Station at Newport, Oregon. Data from a tide gauge at Newport will be used to measure the variation in sea level associated with upwelling. Variations in slope of the sea surface will be monitored by comparison of tide gauge data with pressures recorded by the instruments moored at sea. The arrays will be deployed off the Oregon coast, as shown in Figures 14 & 15, to obtain an intensive two-month time series of currents, density fields, and surface wind fields. The instrument arrays will be kept small so that details of the upwelling process and the ocean's response to the wind will not be missed. Synoptic observations over a larger region will be made by ship and by aircraft.

CUE-I is the first study of sufficient size and intensity to be able to define the time and space scales of coastal upwelling, and performed with sufficient oceanographic and meteorological measurements so that numerical models of coastal upwelling may be tested to determine how realistic they are.

The research vessels *Cayuse*, *Yaquina* and *Oceanographer* shown in Figure 16, will make the repeated detailed hydrographic sections through the area to define the density and nutrient fields and their variations. An instrumental research aircraft from the National Center for Atmospheric Research will be used to obtain synoptic maps of ocean surface temperature, and flight-level air temperature, relative humidity, and winds.

Upwelling patches, plumes, or other features of interest revealed by the aircraft or ship surveys, will be investigated in detail. Profiling current meters, expendable BT's, and other instruments will be kept aboard the ships for this purpose. Two or three spare instrumented moorings will be kept aboard *Yaquina* for short-term deployment to study such transient features.

Oregon is a region of climatologically expected upwelling. Because of the earth's rotation, southerly winds blowing along the coast toward the equator produce an offshore component in the flow of the surface layers of the sea, necessitating an upwelling of sub-surface water near the coast.

From a synthesis of past studies off Oregon a conceptual model of the flow field in a coastal upwelling region has been developed as diagrammed in Figure 17:

a. Because of the near-surface, offshore Ekman drift induced by the favorable winds, cold salty water is upwelled from a depth of 100 to 200 meters and reaches the surface in a band from the coastline to 10 kilometers offshore.

b. The water in this nearshore band is separated from warmer, fresher water at the surface offshore by an inclined frontal layer (pycnocline). After upwelling has established itself (in about a week) the inclined frontal layer is virtually stationary for about 150 days. Though winds favorable to upwelling persist, the inclined frontal layer does not propagate further offshore, suggesting the formation of a one-sided surface convergence and a change in dynamics from essentially advective to diffusive and advective.

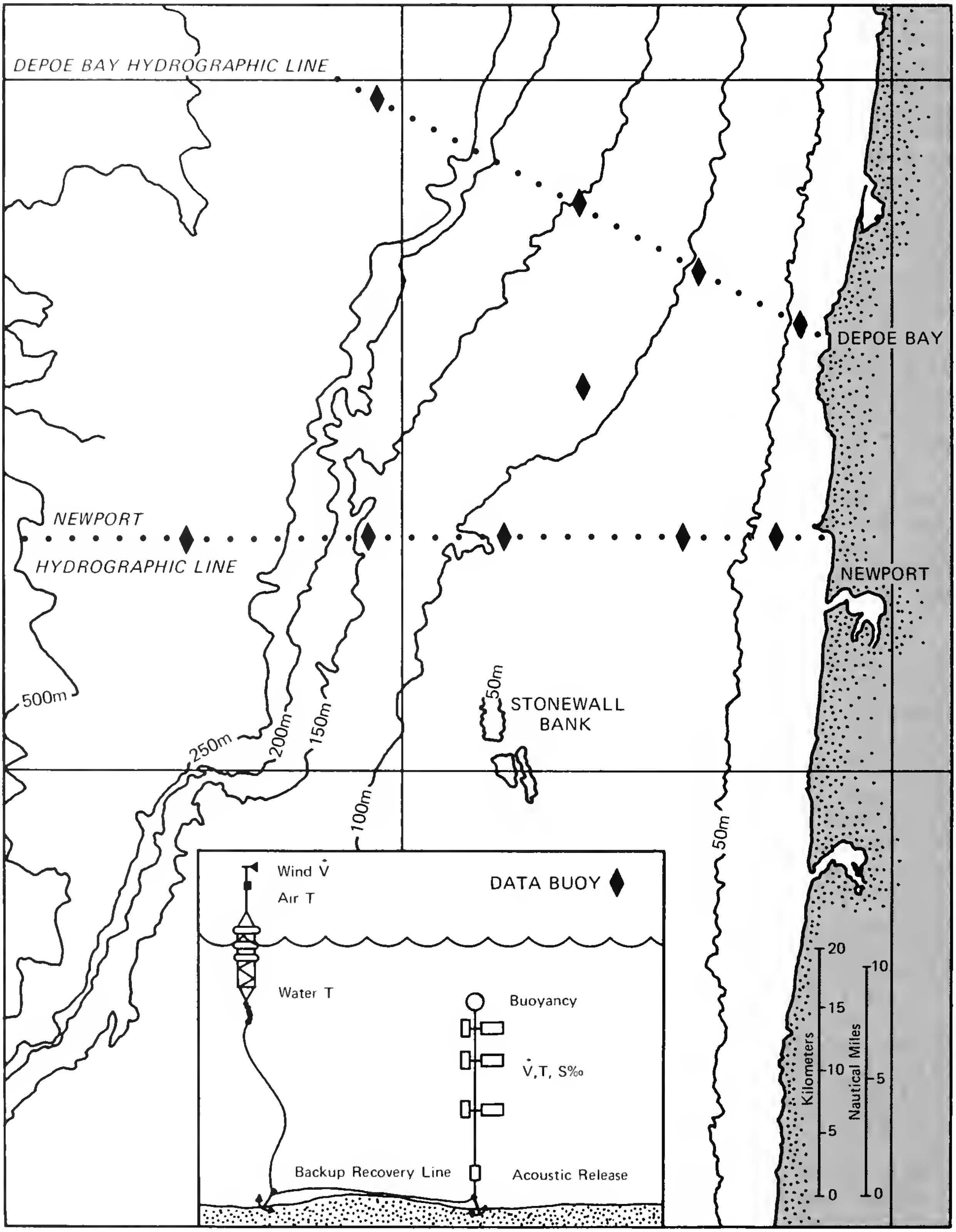
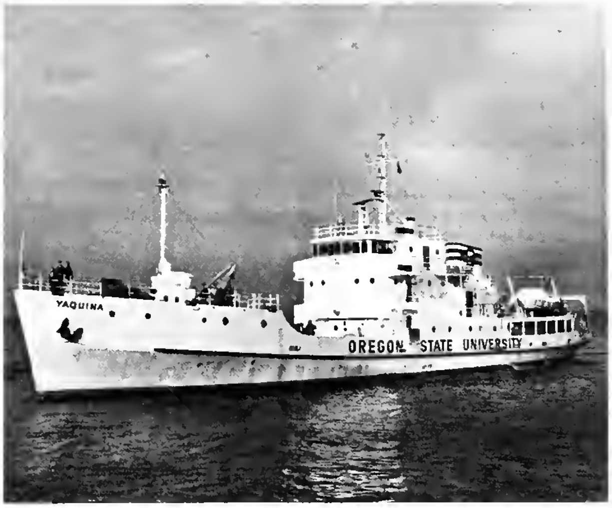


Figure 15. CUE-1 Data buoy array and hydrographic station plan.

OCEANOGRAPHER



YAQUINA

CAYUSE

Figure 16. Research vessels participating in CUE-1.

c. The water in the coastal band is modified by heating, evaporation, etc. and is mixed at the surface front (the one-sided surface convergence) with the offshore surface water to form an intermediate water mass which sinks and flows offshore along the base of the inclined frontal layer. This water mass is conveniently identified by a temperature inversion and by high suspended-particle content.

d. During the upwelling season, semidiurnal internal tides progress onshore. They are somehow dissipated in the coastal region.

e. There are at least three major sources of vertical current shear near the inclined frontal layer: the mean shear, the several-day shear, and the semidiurnal shear.

f. Frontal mixing and the subsequent offshore flow along the base of the inclined frontal layer may play a significant role in the development of undercurrents flowing toward the poles observed beneath the inclined frontal layer.

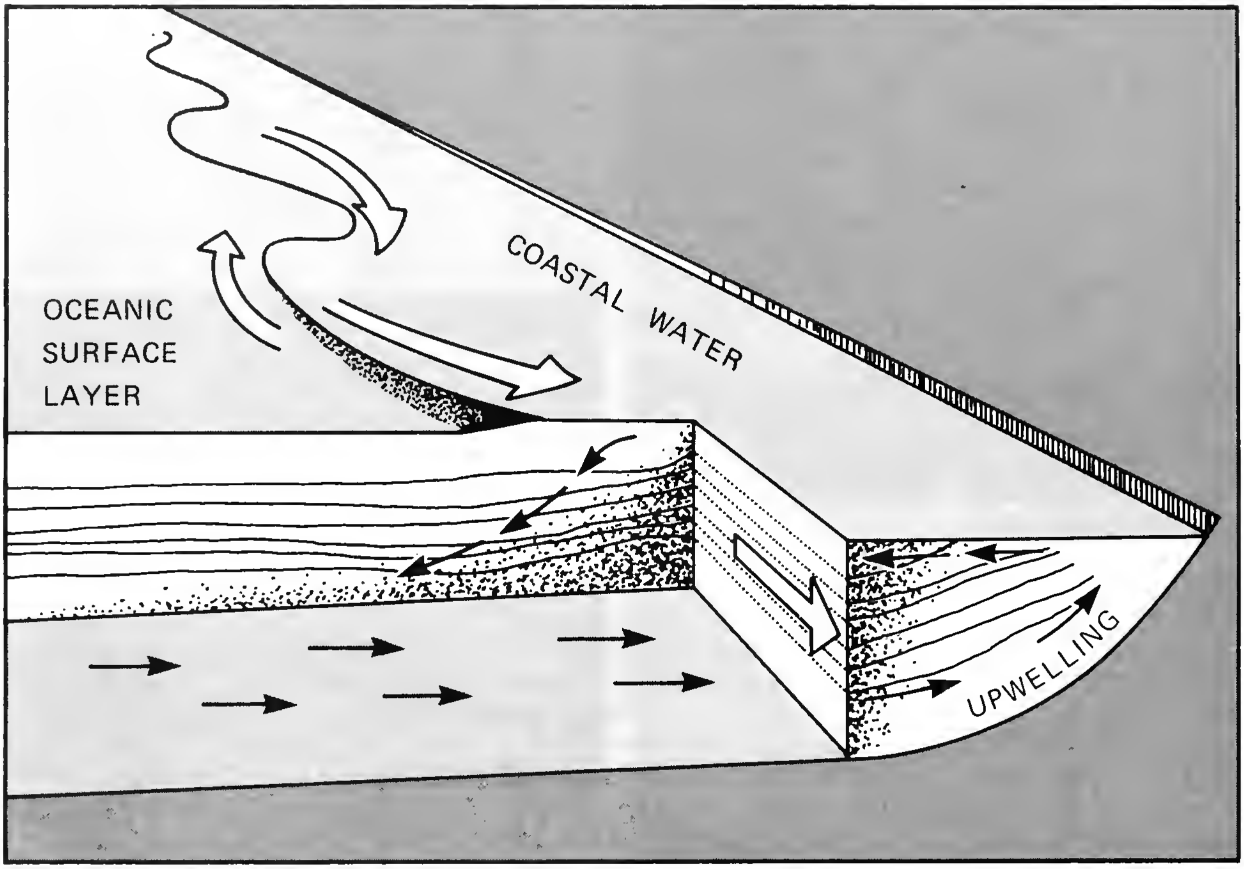


Figure 17. Diagram of conceptual model of coastal upwelling.

PALEO-OCEANOGRAPHY STUDY

Oceanic and atmospheric events have been carefully recorded in history over several centuries at a few locations about the earth. But at other locations records are not kept even today. Many important continental and oceanic island locations have no weather or ocean observation stations that could give accurate quantitative data. Data records from the open sea are substantially nonexistent, except for those of the last 30 years from a very small number of weather ships.

Long before written history, records of natural events began; consider the climatic records accumulated in tree rings. Recent advances in dating have correlated many of these chronologies. Indications of ocean and climatic events are preserved in the strata of the sediments of the oceans. Pieces of this stratigraphic record are retained in ocean botom sediment cores obtained over the years from a great many locations thorughout the world oceans and are preserved in marine geological archives.

Advances in dating techniques, automated analyses of individual ocean bottom sediment cores, and computer correlation of many features in the sediment strata may make it possible to generate truly global-scale synoptic field plots of ocean currents, seasonal weather, and climate, at least for the 70 percent of the earth that is ocean, as far back as 700 thousand years.

To be able to study these global changes on a continuous time scale of hundreds of thousands of years is exciting for two reasons. First, it provides excellent material for descriptive modeling. Second, it may reveal for the first time the actual time series of events during the transition between what are thought to be the two stable states of global climate: the ice age and the temperate age. Knowledge of the time constants of such transitions is vital to descriptive modeling of global oceans and climate. It would also help to assess in natural perspective the observed deterioration of the earth environment presently attributed to the influence of human technology.

Of the natural fluctuations in the global environment none is more profound or more significant to human ecology than climatic change, yet its mechanism is unknown. To gain an understanding of this mechanism the pattern of climatic change through time must be examined in detail.

The impact of climatic fluctuations is supported by historical records from Medieval Europe and Iceland, where during the 13th and 14th centuries, for example, deteriorating climate conditions were marked by great extensions of North Atlantic sea ice, a completely frozen Baltic, and crop failures in southern Europe.

An important factor governing climate and one that can be more accurately understood through the study of deep-sea sediments is the effect of oceanic current systems on local climate. The effect of the Gulf Stream on the present climate of Western Europe is now well known. It is known that the position of the Gulf Stream changes through time, sometimes being displaced north of its present position, sometimes to the south. It is not known if these fluctuations are in harmony with the major global cycles or if the Gulf Stream's fluctuations have a different frequency. Shifting current patterns also affect regions of ocean surface productivity. Knowledge of the historical changes in productivity will allow a clearer understanding of presently changing patterns.

Climatic fluctuations constitute the background against which the present behavior of the ocean and oceanic climate must be judged and against which all long-range forecasting must be seen. As man's concern for the deteriorating environment increases, he is inclined to blame technology for most changes. In order to assess the truth of these accusations, long-period as well as short-period fluctuations of natural origin must be accurately known. It is true that man already has modified local climate around urban areas. There has been much discussion about the possible detrimental effects on climate of the supersonic jet aircraft. If the mechanisms by which natural climatic changes occur are not understood, how can one forecast the effects of technology on climate?

Program Objectives

The objective is to examine changes in current patterns and water mass properties in the Atlantic and Pacific Oceans during the Quaternary. The areas of investigation have been selected because of an existing superior knowledge base and because of the adequacy of available core material. The time interval chosen includes at least one major glaciation bracketed by two interglacials, including the present one.

Fluctuations in oceanic conditions, which take place on time scales ranging from the almost instantaneous to tens of thousands of years, have periodic as well as random components. It is the purpose of this investigation to examine fluctuations in oceanic conditions on time scales ranging from several hundred or a thousand years to hundreds of thousands of years. They cannot be studied by the usual oceanographic means, nor can they be extrapolated from models based on the dynamics of the present ocean. The project goals are to:

a. Determine in detail oceanic and climatic fiuctuations associated with glacial-interglacial transitions and examine the mechanisms involved and the climatic consequences, separating random from directional changes;

b. Determine the effects of shifts of major oceanic circulation features on local water and climate conditions; and

c. Determine the consequences of the introduction of solutes and suspensoids in the ocean by tracking the fate of natural inputs with time and assessing the impact of changing boundary conditions.

Research Plan

Paleo-oceanographic maps will be constructed for four selected times: 6,000 years ago (the post-glacial thermal maximum), 17,000 years ago (last glacial stage), these clearly shown in Figure 18, 120,000 years ago

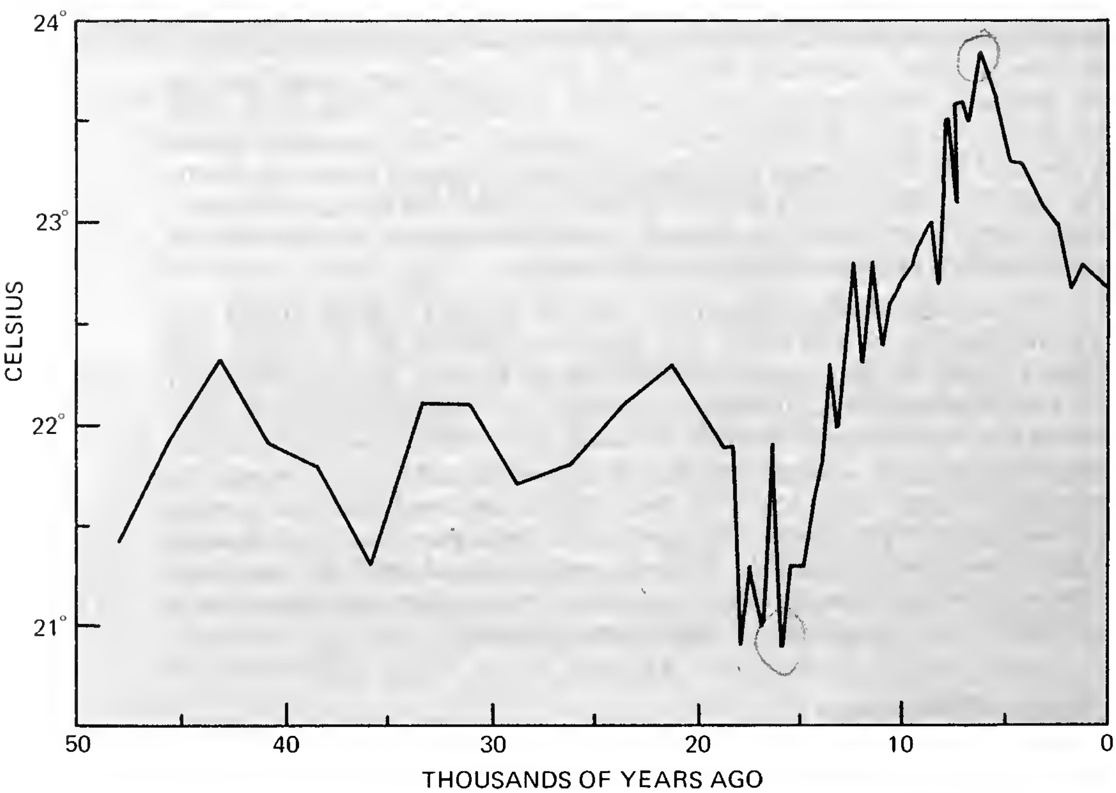


Figure 18. Equatorial ocean surface temperature during last 50 thousand years, as determined by stratigraphic analysis of deep sea cores.

(last interglacial), and 700,000 years ago (mid-Pleistocene base). Comparable maps for present time form the basis for interpretation.

Presently available core archives are adequate to provide sample material for the study. The general plan of research work, as shown in Figure 19, includes:

a. Survey of existing core collections to determine those most suitable for the base grid for the paleo-oceanographic study. This consists primarily of routine paleontological examinations, to be done within the first year;

b. Acquisition and initial interpretation of paleontological, sedimentological, and geochemical data on suitable grids for all levels;

c. Multivariate analysis and computer model application to provide interpretative paleo-oceanographic maps for each level. This is preceded by further extension and consolidation of present work on quantitative relationships between the oceanic environment and sediment properties;

d. The results of this study will be interpreted in close coordination with the ongoing examination of Greenland and antarctic ice cores, which yield critical information regarding high latitude glacial and interglacial climates and their effect on the temperature and salinity of bottom and surface ocean waters.

Project Management

This is an integrated project in which the data are produced by many individual specialists and experts. Data interpretation is a joint effort of all participants. Coordination is achieved by a managing structure, shown in Figure 20, consisting of a project manager and a number of task leaders. The Executive Committee consists of five members who: 1) assume overall responsibility for the project; 2) coordinate and assure the free flow of information among institutions; 3) assure coordination among task groups, and; 4) set and implement policy.

DESCRIPTIVE/PREDICTIVE GLOBAL MODELS

One of the goals of the U.S. contribution to the International Decade of Ocean Exploration is to advance the development of a numerical model of the world ocean. The motivation for developing such a model is to provide: 1) a tool for analyzing data collected by other IDOE programs; 2) a means for designing future large-scale observational experiments; and 3) an aid to eventual long-range prediction of weather and climate through development of large-scale air-sea interaction models by combining the global ocean model with global numerical models of the atmosphere.

Presently supported as a part of this area of emphasis are investigations carried out at the Geophysical Fluid Dynamics Laboratory (GFDL) of the National Oceanic and Atmospheric Administration, at Princeton University. The GFDL world ocean model is based on the concept of boxes or cells. The entire ocean is subdivided into as many of these small units as computer capacity will permit. The boxes make up an irregular three-dimensional array. They are stacked downward from the surface with the number in each stack dependent on the local depth.

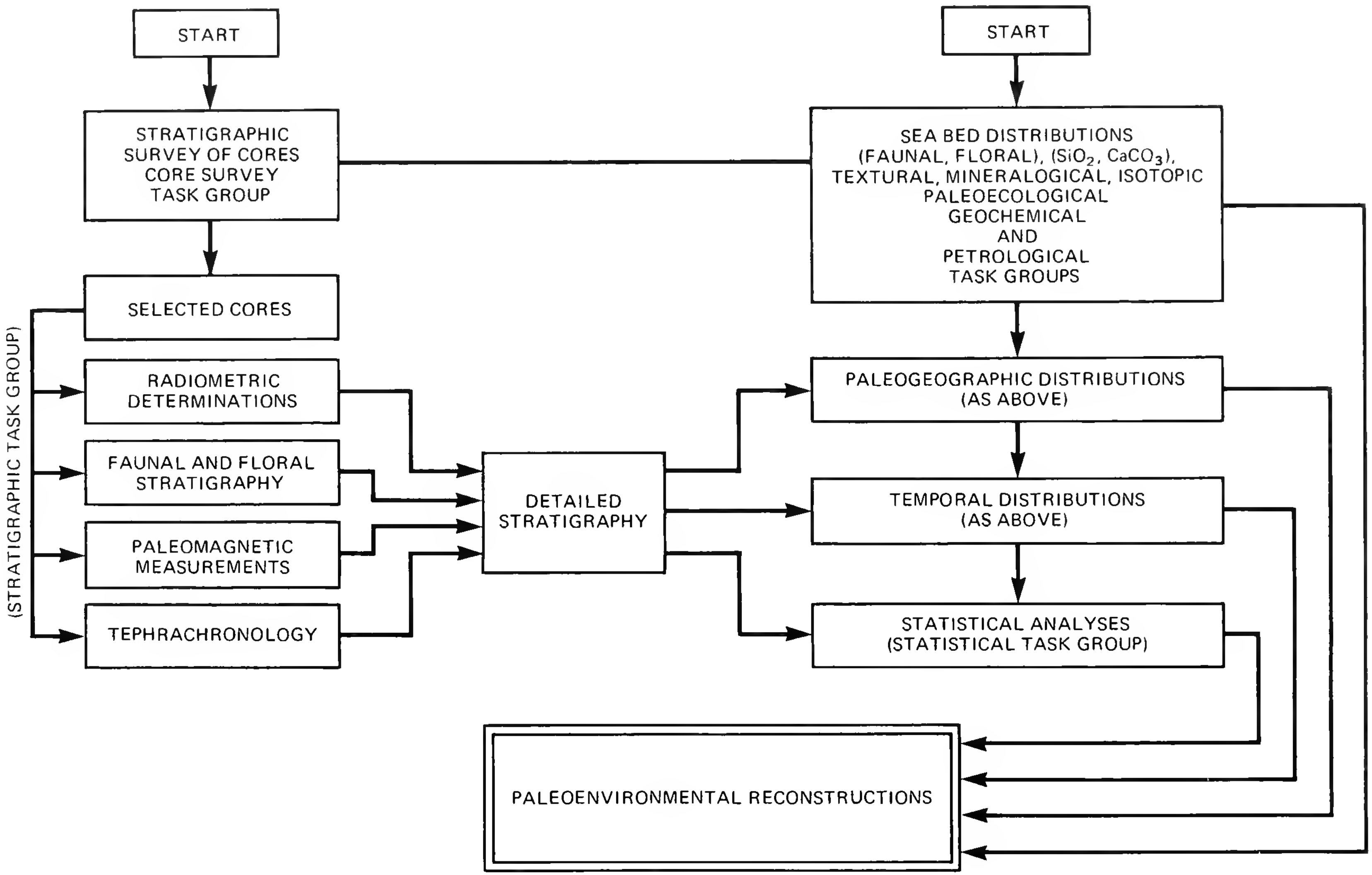


Figure 19. Research plan, Paleo-Oceanography.

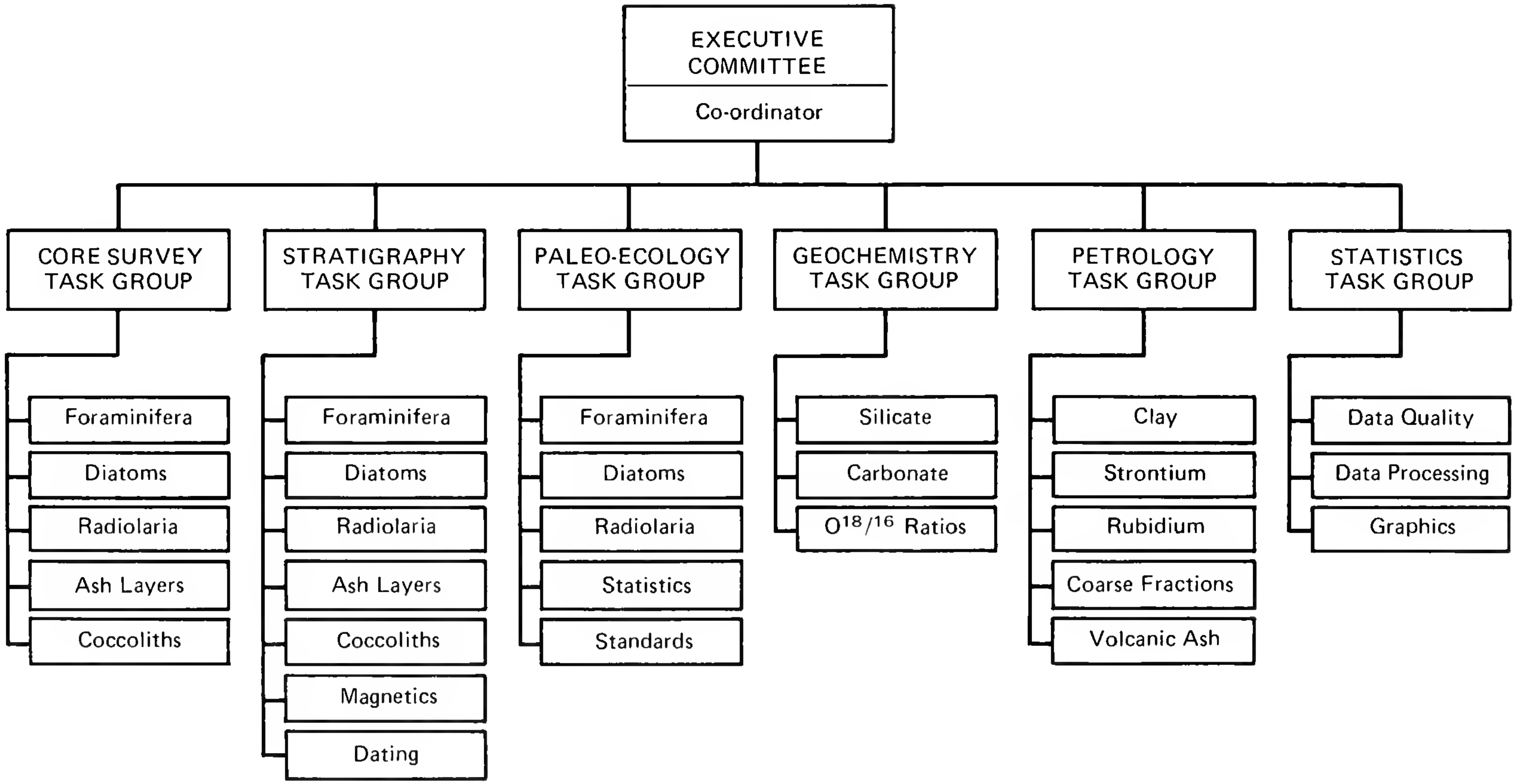


Figure 20. Organization, Paleo-Oceanographic Study.

Typically, each box represents a rectangular volume several hundred kilometers in each horizontal dimension and a few hundred meters in the vertical. An average velocity vector is calculated for each box from the equations of motion. No calculations are made for scales of motion less than the basic cell size. The interaction of smaller scale motion with larger scales is represented by Reynolds' stresses in terms of the larger scale flow pattern.

At present there is not enough empirical information on the mesoscale velocity structure of the ocean to specify an optimal closure scheme. MODE-I, described elsewhere in this report, should contribute to just this sort of information for a typical open ocean location. As an interim solution to this problem, closure for the world ocean model is made by an eddy viscosity formulation, and numerical tests are being carried out to determine the sensitivity of the results to the exact level of eddy viscosity used.

The change of temperature and salinity for each cell is computed for conservation equations which have a parallel form to the Reynolds averaged equations of motion. A detailed equation of state is used to relate density to the local value of temperature and salinity. The effect of small-scale motions is taken into account by an eddy diffusion of temperature and salinity. If the velocity, temperature, and salinity fields are known, the momentum, temperature, and salinity equations determine the time change of all the major variables in each cell. This allows a numerical integration to be carried out to calculate the time-dependent response over the entire ocean basin to a given set of surface boundary conditions.

Because of the complexity of the model, its development has proceeded in a step-by-step fashion. The first calculation carried out assumed that the world ocean has a uniform density and the only driving force is the surface wind stress. The homogeneous case provides a good test for the behavior of the model, since it allows a comparison with familiar analytic results from the theory of wind-driven currents. If the model is further simplified by making the depth uniform, there are also several published numerical calculations available for comparison, based on quite different numerical methods than the present study, thus allowing an independent check.

The wind-stress field used as an upper boundary condition is shown in Figure 21. The pattern of mass transport for the homogeneous case with uniform depth is shown in Figure 22. The direction of flow is indicated by small arrows. The pattern shown does not represent a complete equilibrium. While the flow was steady elsewhere, the transport through the Drake Passage was still increasing above the very high value of 600×10^6 m^3/sec shown. Observations indicate that the strength of the subtropical gyres is too low and the Circumpolar Current is too high.

In Figure 23 one sees the effect of bottom topography on the homogeneous, wind-driven world ocean. The Northern Hemisphere subtropical gyres are only slightly changed. The most drastic effects are in the Southern Hemisphere, notably in the East Australian and Circumpolar Currents. In contrast to the previous case, the Circumpolar Current is very weak, only about 30×10^6 m^3/sec. The Circumpolar Current is much narrower and highly controlled by bottom topography. The northward excursion of the

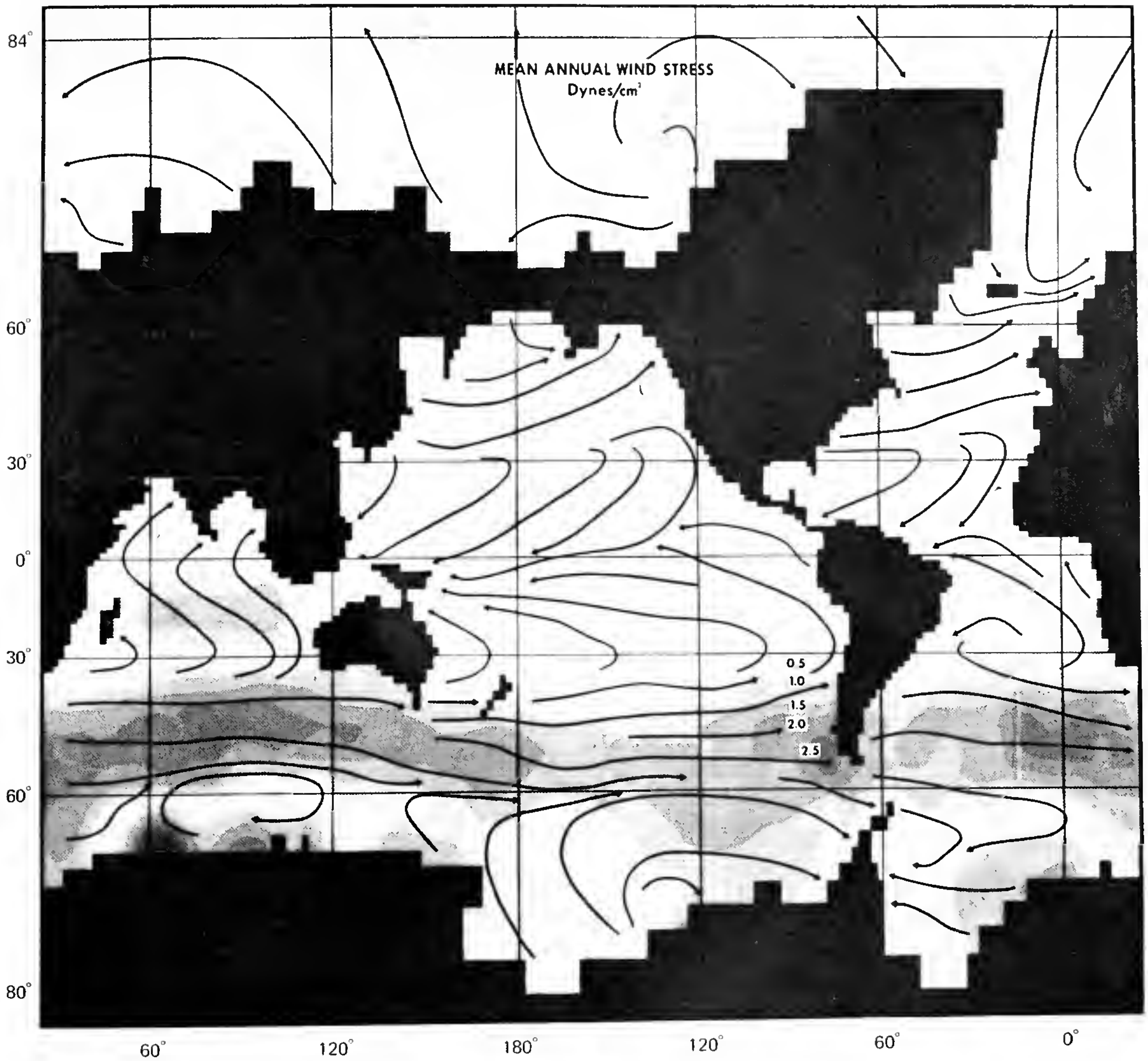


Figure 21. Wind-stress field used as an upper boundary condition for testing global ocean model.

current in the South Pacific is associated with the Mid-Pacific Rise. There is also a pronounced southward displacement where the Circumpolar Current is forced through a narrow gap south of New Zealand.

During the last 2 years, the oceanography group at the Geophysical Fluid Dynamics Laboratory has systematically compiled three-dimensional fields of temperature and salinity for the world ocean based on the National Oceanographic Data Center's files on 500,000 hydrographic stations. Although these data are unevenly distributed in both space and time, the NODC file is a valuable source for both input and verification of the world ocean model. A method of objective interpolation has been worked out to compile temperature and salinity fields on a regular three-dimensional grid. Using these synthetic synoptic data as input to the world ocean model, it is possible to carry out diagnostic calculations to find a velocity field corresponding to the observed density distribution. This approach resembles closely the pioneering ocean circulation calculations carried out by Soviet scientists at the Institute of Oceanology in Moscow.

Recently, preliminary diagnostic calculations using the synthetic synoptic data have been carried out and the results are very promising. When the results are compared with the solutions for a homogeneous ocean, the transport patterns are consistently closer to measured values. For example, the transport of the subtropical gyres in the Northern Hemisphere increases to 80 and 70×10^{6} m^{3}/sec for the Atlantic and Pacific, respectively. The transport of the Circumpolar Current is also increased about an order of magnitude compared to the value shown in Figure 23. The value is very close to that indicated by recent measurements in the Drake Passage.

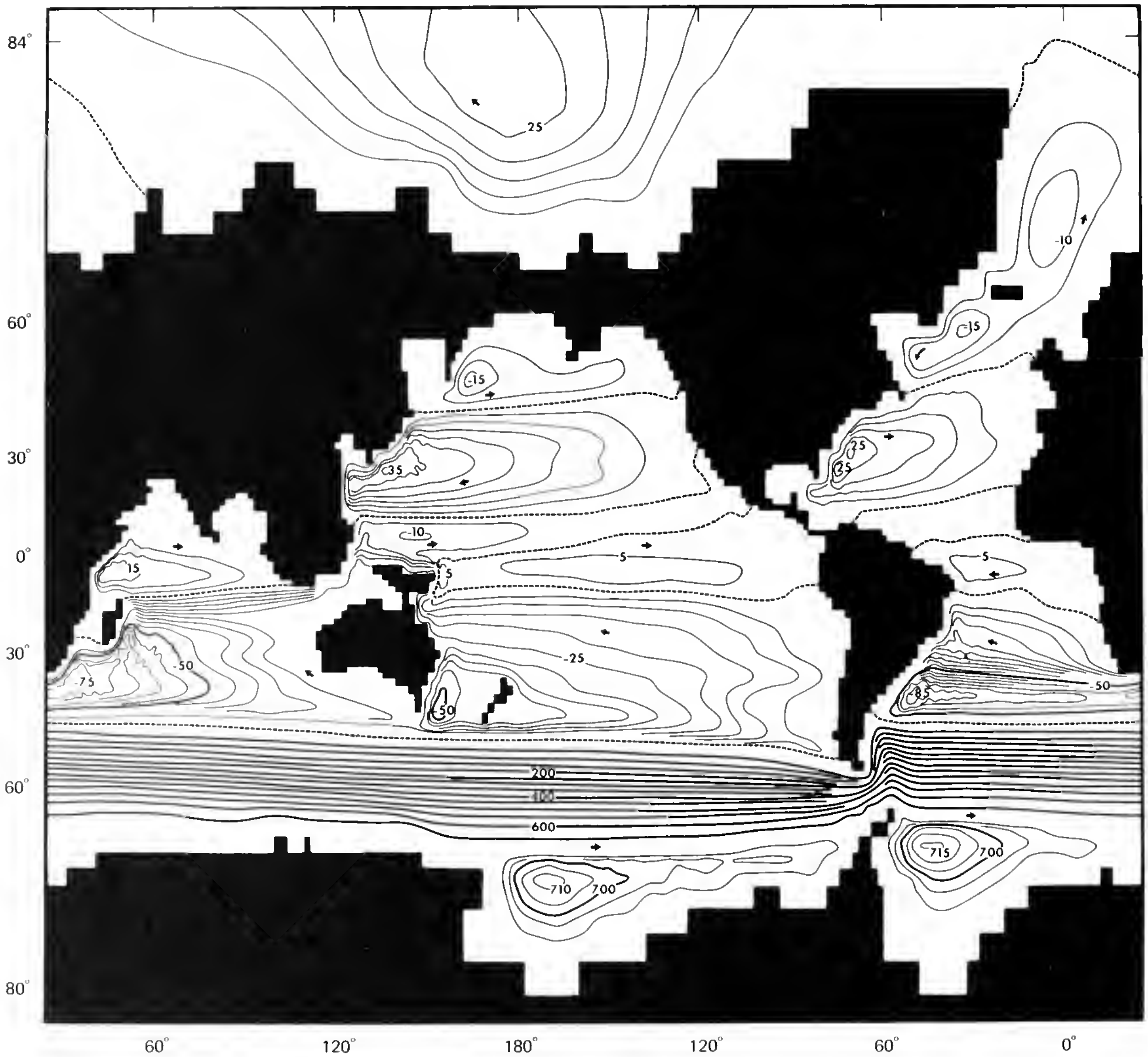


Figure 22. Ocean currents predicted by global model, assuming homogeneous ocean of uniform depth.

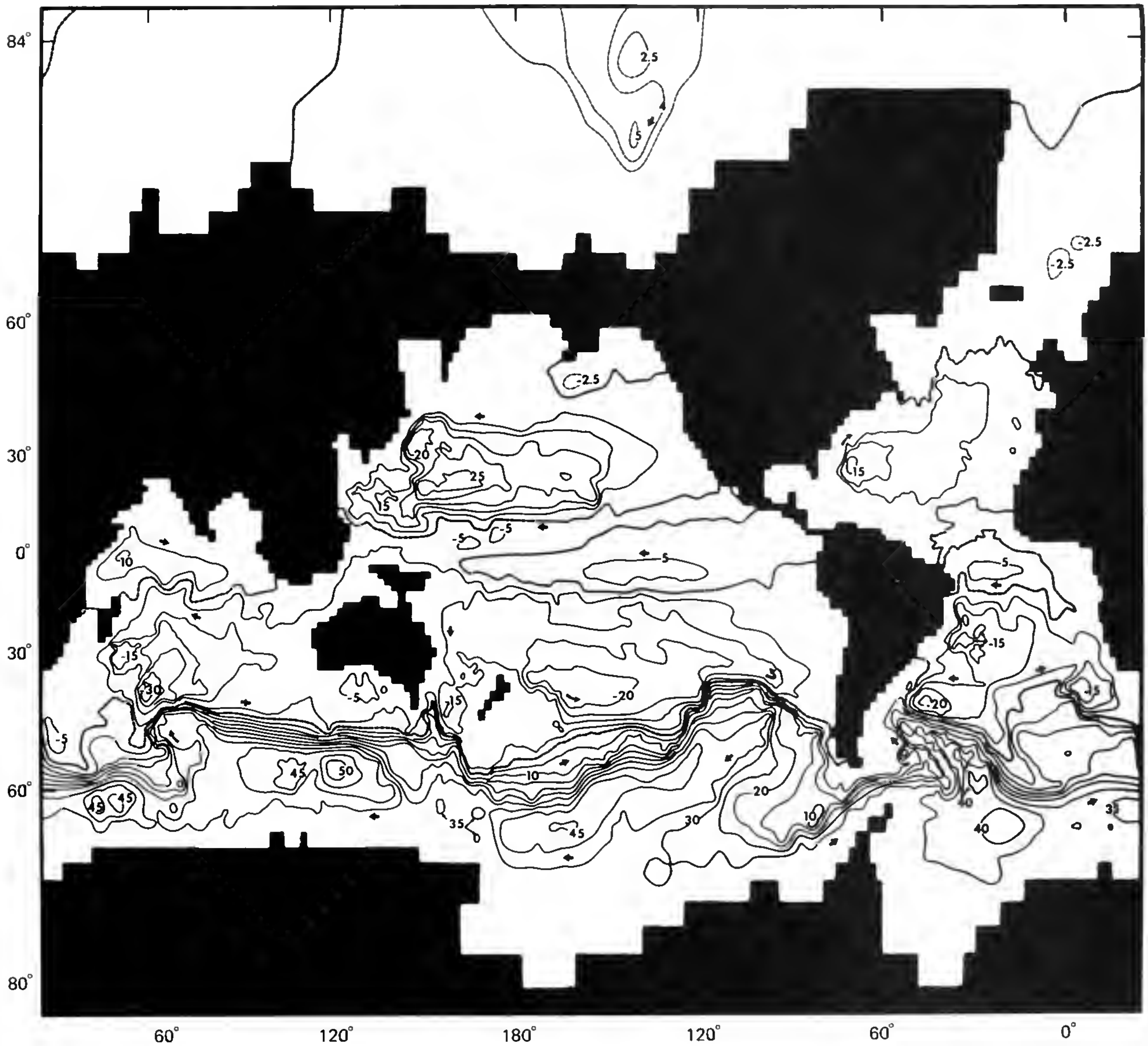


Figure 23. Ocean currents predicted by global model, assuming homogeneous ocean and actual bottom topography.

The results mentioned above will be analyzed and checked in detail. It is also planned to use the calculated velocity fields of the model to determine the poleward transport of heat and water in the ocean. The transport of heat and water by the ocean is extremely important in the global heat budget and water balance, about which almost no quantitative information exists. Present heat transport estimates for the oceans are based entirely on surface heat balance calculations using somewhat doubtful empirical formulas. Similarly, it is very difficult to explain the existing salinity field of the world ocean based on the scant data available on precipitation and evaporation at sea. If it is assumed that the salinity field is stationary, the transport of water toward the poles can be calculated from the covariance of salinity and poleward velocity along latitudinal planes. The total transport of water poleward by the world ocean should exactly compensate the water vapor transport in the atmosphere plus the equatorward flow in rivers. It is hoped that these calculations will give new insight into the global heat balance by providing an independent check on the extremely divergent estimates previously derived from atmospheric data.

Once diagnostic calculations of the circulation pattern have been completed, the next phase will be to use the model in a fully predictive mode. The fields of temperature and salinity, as well as the velocity field, will be predicted for the world ocean. Calculations will be made to determine the equilibrium adjustment of both the density and velocity fields to a given input of momentum, heat, and water transport at the surface. These calculations will develop the full potential of the numerical model. Observed subsurface temperature and salinity fields will be used for verification. The degree to which the model predicts existing details of the temperature and salinity structure will give an evaluation of its usefulness in forecasting climatic changes caused by natural and artificial alterations of the earth's environment.

4. SEA-BED ASSESSMENT PROGRAM

The Seabed Assessment Program focuses on three major areas: The continental margins, the deep ocean floor, and the oceanic rifts and trenches. Broad justification for these choices is based on the significant resources of petroleum, sulfur, and hard minerals already found in some areas of the continental margins. The deep ocean floor appears to be a favorable environment for accumulation of manganese nodules in economic quantities. The mid-oceanic rifts and trenches, judging from recent findings, are potential sources of heavy metals. Indeed, understanding the mechanism which forms the rifts could provide a valuable exploration tool in the search for new mineral deposits on land.

EASTERN ATLANTIC CONTINENTAL MARGIN

At present, the greatest economic benefits from the sea are from commercial catches of fish, but the production of oil and gas—a close second—will probably dominate by 1980. All of the present marine production of geological resources (oil, sulfur, sand and gravel, and heavy minerals), all of the chemical resources (salt, magnesium, and bromine), and perhaps 90 percent of the living resources (fish, crustaceans, mollusks, and algae) come from the continental shelves. The 1970 annual market value of all of these resources was about $12 billion.

Few continental margins are considered well known from the geological point of view. They are shown in Figure 24. The uneven distribution of existing sediment samples and geophysical data prevented, until

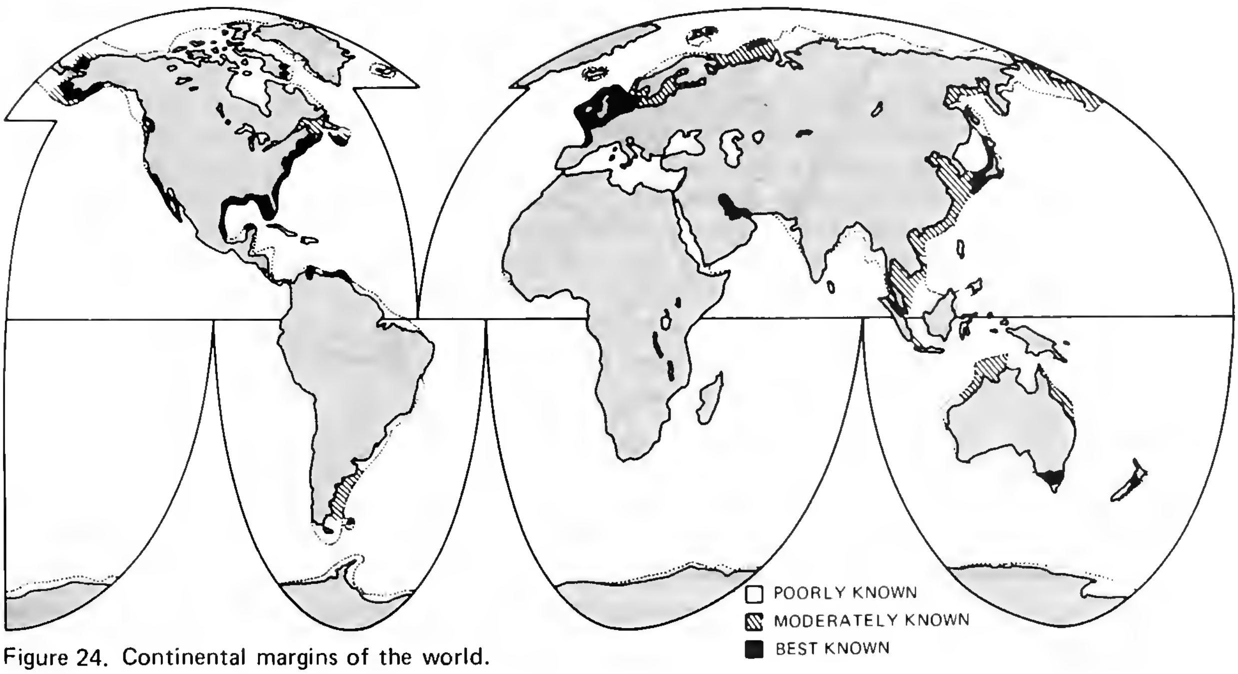


Figure 24. Continental margins of the world.

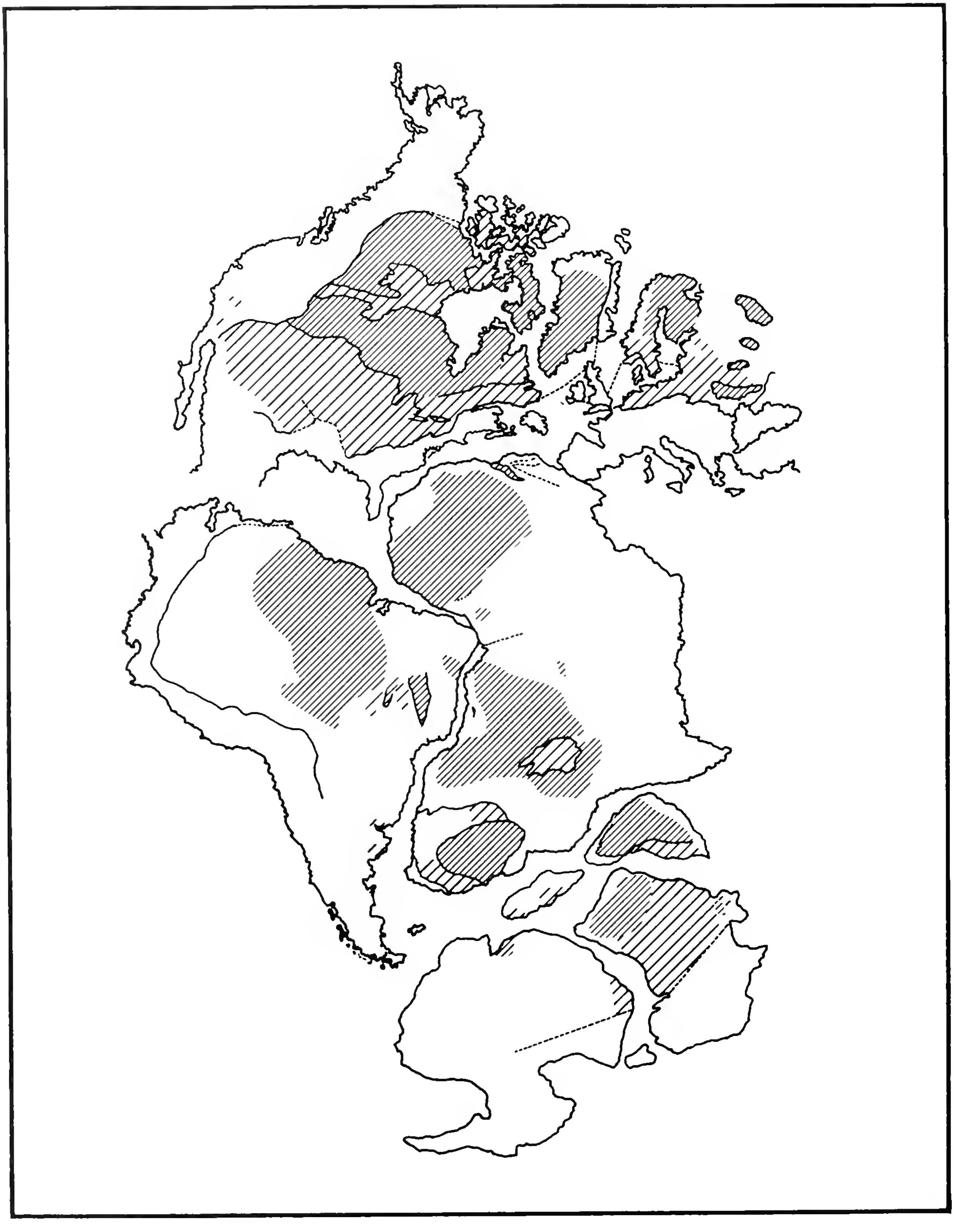


Figure 25. Ancestral land mass.

recently, the recognition that most of the area of every continental shelf is covered by relict sediments deposited at times of lowered sea level during ice ages. Less well known is the internal structure of continental margins. Only about 150 continuous seismic reflection profiles have been published that cross major parts of the continental margins of the world. These few profiles, augmented by gravity and magnetic profiles, and supplemented by analysis of rock dredgings and of projections of features on adjacent land, permit only a general classification of the structure underlying the continental shelves. They do show the presence of buried folds, faults, unconformities, salt domes, and calcareous reefs—all important potential traps for oil and gas.

Regional studies by oceanographic institutions have discovered much valuable scientific information about the origin and age of continental margins. Most striking, perhaps, is the discovery that the North American continental margin dates from the Early Mesozoic. An ancestral land mass, suggested in Figure 25, split apart at that time. Sea-floor spreading carried North and South America westward, away from Europe and Africa. The record of this event may be preserved in the sediments and structures of the continental margin of Africa.

The continental margin off western Africa, shown in Figure 26, is one of the world's most important. Its length is about 12,000 kilometers, from 35° north to 35° south latitude. A general reconnaissance of the entire region should solve many questions about sediment patterns on opposite sides of the ocean and of the ancient breakaway of North and South America from Africa. More important, it might well locate general areas of promise for mineral and non-living resources that are as yet unsuspected. Outstanding examples of this possibility are the discovery and initial exploitation of the hugh oil and gas fields in the North Sea that were completely unknown less than 10 years ago, the presence of petroleum predicted for the Atlantic shelf of the United States and Canada, and those predicted for the East China Sea. In only one of these cases had oil or gas been found in quantity on the adjacent land.

As part of its participation in the International Decade of Ocean Exploration, the Woods Hole Oceanographic Institution is beginning a study of the African part of the eastern Atlantic continental margin, using advanced equipment for seismic reflection, seismic refraction, geomagnetics, gravity, precision bathymetry, and satellite navigation, aboard the research vessel *Atlantis* II, shown in Figure 27. The geophysical traverses will be rather broadly spaced, about 200 kilometers apart, extending across the continental shelf, slope, and rise, with some of them extending to the Mid-Atlantic Ridge. Total length of all traverses is about 72,000 kilometers.

According to present plans the first cruise (except for steaming to the working area) will start in Capetown, South Africa, in early February 1972 and will end at Lagos, Nigeria, in late June, with intervening port stops at Walvis Bay, Southwest Africa; Lauanda, Angola; and Libreville, Gabon. The second cruise will begin at Lagos in late January 1973 and end at Oporto, Portugal, in early June, with intervening port stops at Monrovia, Liberia; Dakar, Senegal; and Las Palmas, Canary Islands.

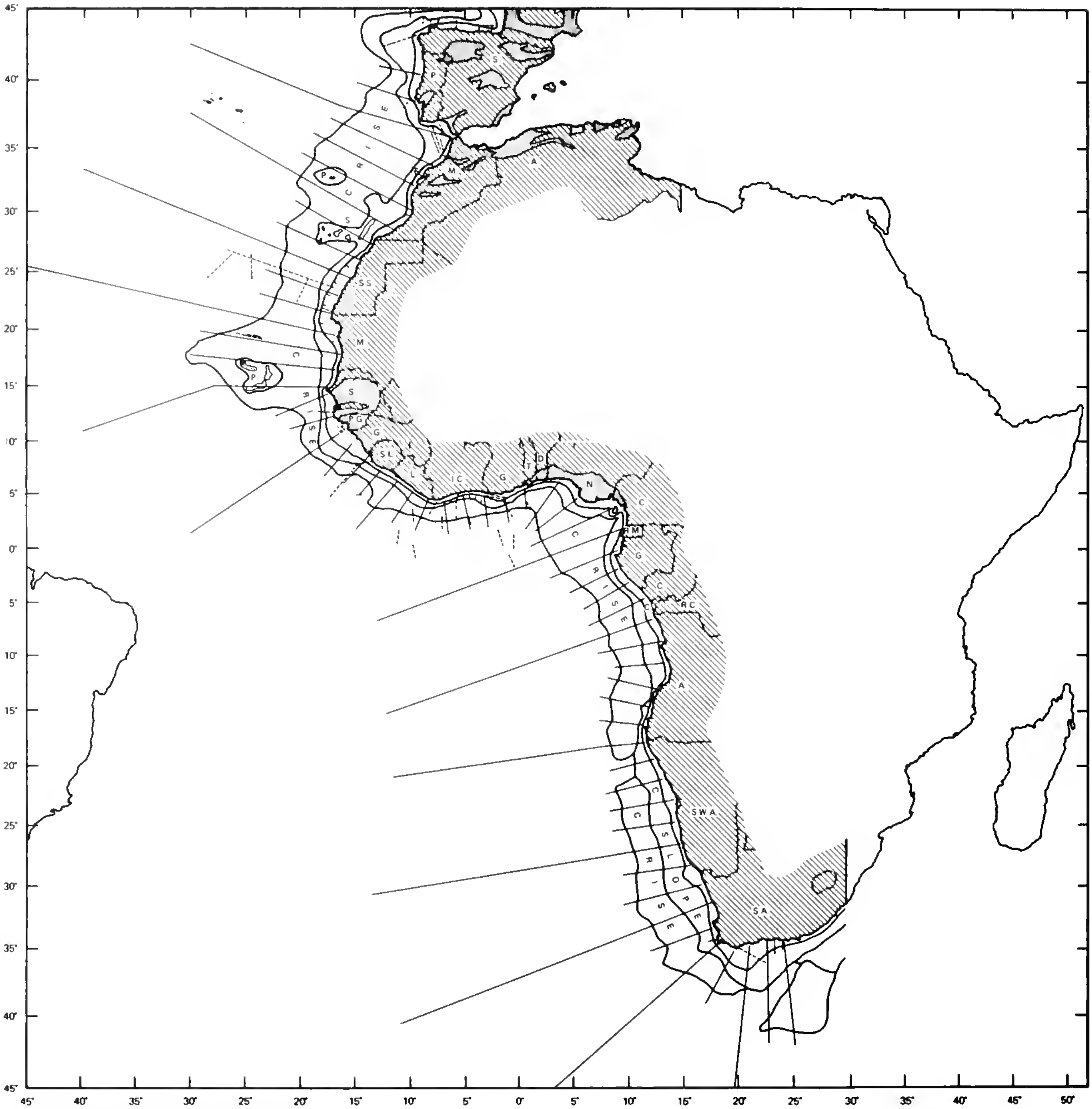


Figure 26. Continental margin off West Africa.

Interpretation of the geophysical data will be enhanced by better bathymetry and by more complete knowledge of coastal stratigraphy than is now available. New bathymetric charts of the sea floor off western Africa are being prepared in South Africa and in the U.S.S.R., and these will be improved by new soundings obtained during the *Atlantis II* cruises. Similarly, maps of the sediments on the continental shelf are being prepared on the basis of several thousand samples between Gibraltar and Nigeria, assembled from many organizations.

The geophysical results, which will be published and made available to all, should provide enough information to permit the drawing of maps for

Figure 27. Research vessel Atlantis II.

the West African continental margin similar to those that have been published for eastern North America: free-air and Bouguer gravity anomalies, trends of geomagnetic anomalies, and depths to mantle, basement, and Horizon A (where present). The construction of numerous structural cross sections and isopach maps also will be possible. All of these materials taken together should provide answers to the following questions:

(1) How and when did the South Atlantic Ocean open, and how did the process differ from that of the North Atlantic?

(2) How nearly is the oceanic basement off northwestern Africa a mirror image of that off eastern North America?

(3) How favorable is the sedimentary pattern to the discovery of large, economically important deposits of oil and gas?

(4) How do the sediment thicknesses and characteristics reflect the very different water masses on opposite sides of the ocean?

(5) What remnants of structures that lie at an angle to the coastal trends can be found in the continental margins of once-joined continents?

(6) Is the general absence of known tectonic dams at the edge of the continental shelf off Africa merely a consequence of the absence of adequate data? If the dams are present, what is their nature?

(7) Can any inferences be drawn about the separation of North America and South America (to provide space for the Caribbean Sea) using the data to be obtained from the ocean floor between Africa and the southern Mid-Atlantic Ridge?

(8) Can we improve our mapping of the Atlantic Ocean in its stages of formation in order to improve our concepts of changing ocean currents and populations of marine organisms?

(9) What is the origin of the prominent transverse ridges on the ocean floor?

The basic scientific results can be used (as they typically are used) to denote areas where detailed surveys must be made in order to outline new sedimentary basins. It would be surprising if the proposed cruise fails to cross structures such as faults, folds, and diapiric intrusions, but the traverses will be too far apart to outline these structures.

The following are target dates:

1. 1 January 1971—start of program.
2. 31 December 1971—
   a. completion of new shipboard systems: seismic profiling and enhancement of records (new); seismic refraction, magnetics, gravity, and data storage (old).
   b. publication of blue-cover report no. 1 on existing available geophysical data in the region of interest.
3. 20 January 1972—begin first cruise.
4. 30 June 1972—begin data compilation beyond the shipboard processing.
5. 30 December 1972—publication of blue-cover report no. 2: bathymetry, seismics, magnetics, and gravity of first cruise.
6. 10 January 1973—begin second cruise.
7. 30 June 1973—begin data compilation beyond the shipboard processing.
8. 30 December 1973—publication of blue-cover report no. 3: bathymetry, seismics, magnetics, and gravity of second cruise.
9. 1 January 1974—begin a full year of data analysis, model studies, and publication of results.
10. 30 December 1974—end of project.

NASCA LITHOSPHERIC PLATE STUDY

Despite the widespread acceptance of the new global tectonics in the earth sciences, there is only limited knowledge regarding the mechanisms of sea-floor spreading and of continental drift in the complete tectonic cycle of oceanic rift-plate-trench systems. In recent years our understanding of the processes taking place at the diverging edges (the oceanic rift zones of sea-floor spreading) has increased. But we have little understanding of subsequent geophysical and geological events during transport of the lithospheric plate and of the processes and events occurring in zones of convergence where an oceanic plate is subducted under a continental boundary and the crustal material, originally created at the midocean rift, is finally lost.

The zone of convergence is not only of scientific interest but of social and economic importance since it is the site and cause of one of the earth's two major zones of seismicity. It is an area marked by extensive recurring volcanism, intrusion, crustal unlift, and mountain building. Very nearly all the world's major resources of hard minerals are presently found in modern or ancient zones of plate convergence.

The purpose of the Nasca Lithospheric Plate Study is to examine in detail the processes of crustal formation and destruction that take place at the diverging and converging edges of a well-defined lithospheric plate, shown in Figure 28, in the southeastern Pacific. The diverging edge of this plate has recently been identified as a potentially important locality of mineralization of the crust and sediments. The converging edge, at the South American block, is an old and important area containing striking and outstanding examples of all the major effects of such convergence. The Nasca Plate project emphasizes geophysical, geochemical, and marine geological studies at the two plate edges and will attempt to link events and processes by geophysical studies of the structure of the plate itself.

The regional investigation at sea will be carried out on a series of approximately 14 marine geological and geophysical traverses oriented approximately east-west across the area bounded by the East Pacific Rise and the coast of South America, and latitudes 1° N. and 47° S. The ocean traverses will be conducted as a joint operation involving research vessels from the Hawaii Institute of Geophysics, Oregon State University, and the Pacific Oceanographic Laboratory (POL) of NOAA.

On the basis of existing data, and as the structure of the plate is analyzed, detailed surveys of selected portions of the East Pacific Rise crest and the Peru-Chile Trench will be carried out. The University of Hawaii and the Pacific Oceanographic Laboratory will emphasize the geophysical study of the Nasca Plate edges; Oregon State University will concentrate on local marine geological and geophysical studies of the convergent edge (the trench and the continental margin) and on problems regarding mineralization processes and igneous activity on the crest of the East Pacific Rise.

The total effort, including field operations, laboratory investigations, and data processing and analysis is divided into three subprograms of about equal size: 1) regional studies of the Nasca Plate to the extent required to interpret the findings at its boundaries and its interaction with the South American Plate; 2) detailed studies of significant areas of structure, stratigraphy, and recent sediments of the Trench margin; and 3) detailed studies of significant areas of the Rise crest, its new crust, and its mineralization.

The first work, in 1971, was to compile all existing data on the Plate and to evaluate them in view of the overall objectives of the study. Cruise track lines presently planned are shown in Figure 29.

Beginning in May 1971, both the Hawaii Institute of Geophysics and Oregon State University began equipping their respective research vessels for the IDOE cruise in the first part of 1972. Oregon State's *Yaquina*, outfitted for the geological, geophysical, and geochemical work to be carried out on the Nasca Plate, sailed 18 August 1971 for a 9-month

Figure 28. Nasca Plate and adjoining areas.

cruise to the eastern Pacific Ocean off Central and South America. Hawaii's *Kana Keoki* will be outfitted in Fiji at a later date and will join the *Yaquina* in January 1972 for the joint Nasca Plate study. Beginning in 1973 the Oceanographer from POL will join in the field studies.

All three organizations are in the process of acquiring all bathymetric, magnetic, and gravity data that are available for the Nasca Plate. Some of these data have already been reduced and will be utilized in the planning of the detailed field work to follow in 1972.

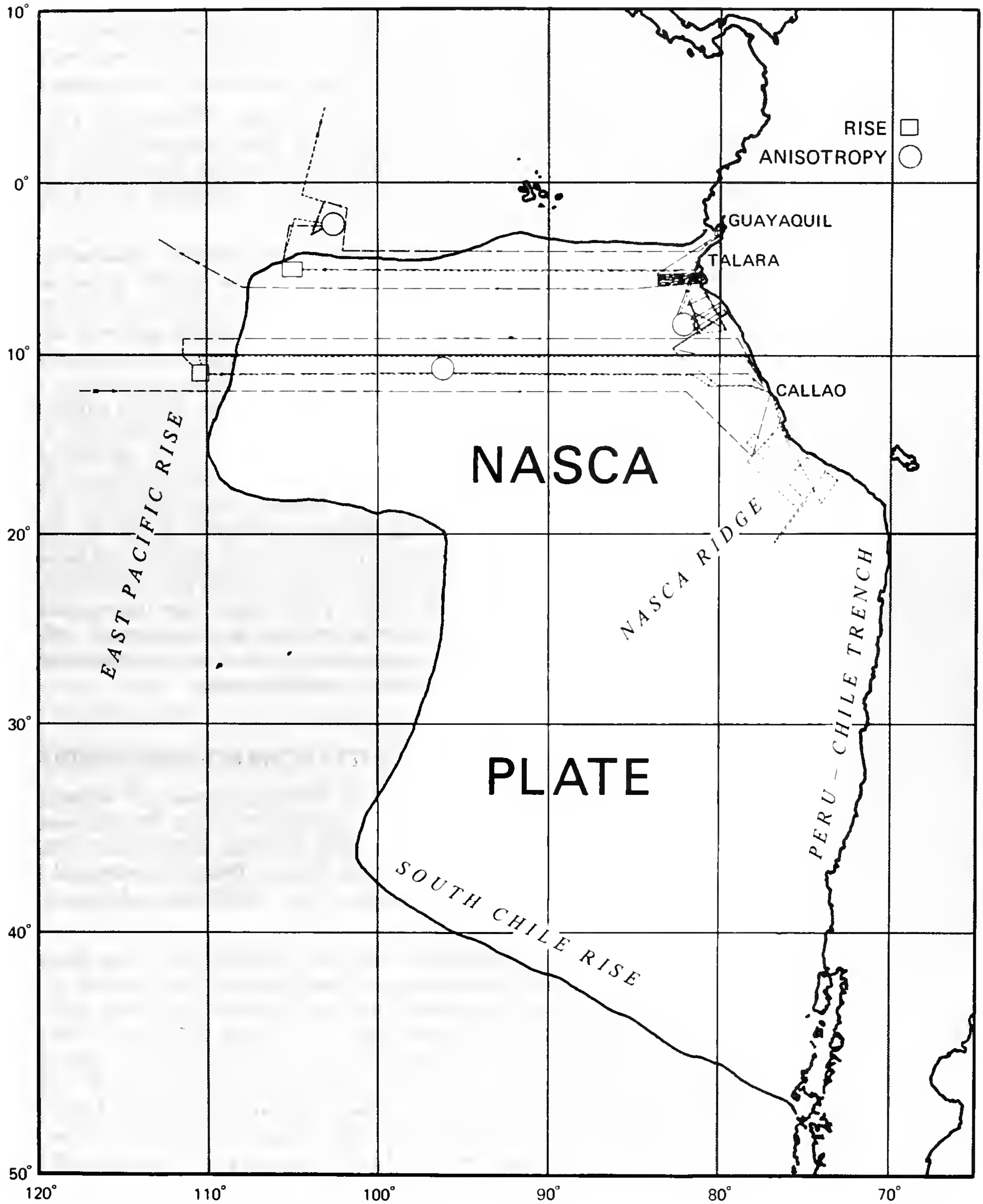


Figure 29. Nasca Plate

The geochemistry group acquired one iron-rich sediment sample from the East Pacific Rise from Woods Hole for geochemical analysis. Additional metal-rich samples have been obtained from the Deep Sea Drilling Project of the National Science Foundation, and analyses are in progress.

The program director of the Nasca Plate study is continuing his discussions with the Latin American scientists who expressed an interest in participating in the Nasca Plate study at the meeting of the Geophysical Commission of the Pan-American Institute of Geography and History held in Mexico City in July 1970.

The field work at sea in early 1972 will include the following components aimed at the specific subprograms: 1) Four parallel traverses of the Nasca Plate between 10° and 13° S., one of which would be a two-ship operation, as a reconnaissance of magnetic lineation patterns across a wide part of the Plate, as well as of regional crustal structure interpreted from the seismic, gravity, and other measurements obtained. The three traverses between 4° and 6° S., with an extended search pattern at the northwest corner of the Plate, should help relate the magnetic bight there (suggested by existing data) to the overall history of spreading of the northern end of the Plate; 2) Detailed multidisciplinary studies ranging from bathymetry through two-ship seismic refraction work in the region of the trench and continental margin between 4° and 6° S., where the shelf is narrow and the onshore structure is well known, and between 10° and 17° S., where the Nasca Ridge strikes toward the continent; and 3) Detailed studies on the crest of the East Pacific Rise over areas of ½°x½° size at about 5° S., where a fracture zone apparently offsets the Rise and the spreading rate is high, and at about 11° S., where metalliferous sediments have been found in existing cores.

WORKSHOP ON SEA-BED DEPOSITS OF MANGANESE NODULES

In December 1971, a Workshop on Seabed Deposits of Manganese Nodules will be convened at Columbia University under the auspices of the U.S. Office for the International Decade of Ocean Exploration. There, the Director and other scientists of the Lamont-Doherty Geological Observatory will present new world maps of the distribution of known deposits of manganese nodules.

The maps are being prepared now from information in the Lamont-Doherty data bank and other sources. Data obtained from bottom photographs, and from core, dredge-haul, and grab samples are being archived on punched cards at the Observatory. It is now possible to retrieve quantitative information from the data bank automatically, making it possible for the first time to prepare maps of the distribution of nodules and to complement existing maps of the chemical composition of the substrate sediments and information on the abyssal environment. The Lamont-Doherty data bank contains 15,000 bulk-property analyses of bottom sediments, from which these maps have been produced.

These data have not been collected as a study of mineral deposits specifically, but rather as part of a worldwide geophysical reconnaisance of the oceans carried out over a period of 20 years by the research vessels *Vema* and *Robert D. Conrad.*

The maps of manganese distribution are being prepared so that they may be used as overlays on maps showing distribution of other properties, such as detailed topography, heat flow, presence or absence of a nepheloid layer, depth of horizons revealed by 3.5 kHz profiler, rate of sedimentation, bottom current velocity, and local characteristics of the earth's magnetic field. For example, if the map of distribution of manganese deposits overlaid on sedimentary province charts shows that high nodule concentration is associated with particular sediments, then the lithologic properties of abyssal sediments and the development of manganese nodules may be related. Similarly, if the map of manganese deposits overlaid on maps of bottom currents and local characteristics of the magnetic field shows that high nodule concentration is associated with certain relationships of current vector and magnetic vector, then geomagnetic electrokinetic potential and the occurrence of manganese nodules may be related.

Data obtained during the August 1971 preliminary cruise of GEOSECS in the South Pacific have been made available to this study. The vertical distribution of manganese and other metals in the water column is being studied to determine the typical distribution and the range of variation. An attempt is being made to determine whether or not manganese concentration in sea water is an indicator of the presence of nodules on the bottom. GEOSECS data on near-bottom particulate matter are also being used in the study.

Study of these nodules is of great scientific interest. Studies of the control of precipitation and solution of the manganese and associated elements, the puzzles offered by the great age of the nodules, their shapes, and their escape from accumulating finer sediments will yield information of great value about other processes at the deep ocean floor.

Presentation of the maps and overlays, results of these recent studies, and other data in a workshop attended by leading U.S. and foreign experts on ocean bottom deposits will be a remarkable opportunity to gain new understanding of the mechanisms of deposition of manganese nodules. It seems possible that the Workshop will be a major turning point in man's continuing relationship with these deposits so rich in nickel, copper, and other important metals.

5. CONCLUSION

Not only is the ocean an important factor in determining the planet's climate and environment, but its resources are, in the words of President Nixon, "a common heritage of mankind, and their benefits should be shared by all." That resources exist in some areas is certain, but is doubtful in others. However, scientific study is required for such determinations. Examples of the benefits to be reaped from exploration and scientific investigation are the discovery of oil and gas in the floor of the North Sea, and the development of numerical models for predicting the location of ocean surface temperatures favorable to the occurence of the albacore tuna.

These and many other discoveries and achievements during the past few decades were in large part made possible by the great advancements in science and technology that took place during that time. These advancements are opening new avenues for the study of the world ocean, and hold promise for producing truly significant advances in our understanding of the ocean and its dominant role in controlling man's environment.

Unfortunately, technological progress has also brought mankind to the point where the products and refuse from his activities are becoming a danger to the ocean and to the rest of the environment. The recent discovery, by an International Decade of Ocean Exploration research team, that marine organisms collected throughout the North Atlantic Ocean contain significant amounts of the pollutants DDT and polychlorinated biphenyl (PCB)—whose only source is man's technology—gives evidence of this problem.

Taking advantage of the beneficial aspects of improved technology, the United States' contribution to the International Decade of Ocean Exploration program focuses considerable scientific talent and effort upon the world ocean to describe its present state and to predict its future, in terms of problems and potential. It is an exciting program because it addresses, in a comprehensive way, major scientific questions confronting man in his relationship with the ocean, and because marine scientists are organizing on a large scale to study these questions without hindrance from disciplinary, institutional, and national barriers. Although the program is still very much in the formative stage, important projects are already under way, and the progress clearly reflects a new enthusiasm that this revolutionary approach is engendering. It is earnestly hoped that this enthusiasm is communicable, and that scientists and engineers in many nations will become involved. All the nations of the world will be the beneficiaries of this great cooperative concept since the results will be available to all.

The International Decade of Ocean Exploration is dedicated to gaining sufficient knowledge about the ocean to provide: scientific capability leading to accurate long-term environmental forecasting; scientific background necessary for the rational management of the living and non-living resources of the sea; warning when man's activities endanger the environment and himself; and the scientific basis necessary for the formulation of sound international decisions on marine affairs.

The United States offers this program as its contribution to the initial phase of the International Decade of Ocean Exploration, and it is our hope that many more nations will join in this important undertaking. Major decisions must be made affecting the future of man on this planet, and these decisions should be made in the light of sound scientific knowledge.

APPENDIX

GUIDELINES FOR SUBMISSION AND DISSEMINATION OF ENVIRONMENTAL DATA COLLECTED ON INTERNATIONAL DECADE OF OCEAN EXPLORATION PROGRAMS

The potential value of the data which will be collected on programs funded by the National Science Foundation through the Office for the International Decade of Ocean Exploration (IDOE) warrants the implementation of a systematic procedure to assure that these data will be adequately documented, catalogued, disseminated, and placed in the archives. Rapid and widespread national and international dissemination of IDOE data by participants is required.

Prior to the final commitment of support to any project, the Office for the IDOE expects that representatives from the appropriate national data repositories will contact the principal investigators of potential IDOE programs expected to generate oceanographic or meteorologic data. Based on the preliminary discussions, the parties will agree on the documentation required for each type of data to ensure meaningful interpretation by others, and the methods and formats whereby the data and ancillary information will be transmitted to the appropriate data repositories. The data center representatives will submit to the Office for the IDOE, with copies to the potential investigators, a written report of these discussions and the agreements reached. The Office for the IDOE will provide the necessary funding to the appropriate environmental data centers and will ensure that center representatives contact the potential investigators and maintain this liaison.

Environmental data centers which the Office for the IDOE has designated to handle IDOE data are the National Oceanographic Data Center (NODC), the National Geophysical Data Center (NGDC), and the National Climatic Center (NCC); they are parts of the Environmental Data Service (EDS), a component of National Oceanic and Atmospheric Administration. The Smithsonian Oceanographic Sorting Center (SOSC), a part of the Smithsonian Institution, has also been designated an IDOE data center. NODC will be the lead center for IDOE data inventories, data information, and for chemical, geological, physical, and biological data; NGDC will be the lead center for geophysical data; NCC will be the lead center for meteorlogical data; and SOSC will be the lead center for collections of biological specimens.

A first level inventory of data collected is to be submitted as soon as possible (within thirty days) after completion of each cruise or data collection phase. A National Marine Data Inventory (NAMDI) form or equivalent, e.g., CICAR Data Inventory form for CICAR participants, accompanied by an annotated sketch of the trackline or survey area, should be completed and submitted as directed at this stage.

All IDOE program data will be declared a part of the U.S. Declared National Program and will be reported internationally. The completion of NAMDI or equivalent forms and submissions to EDS will eliminate the necessity of compiling Report of Observations/Samples Collected by Oceanographic Programs (ROSCOP) forms or notifications to the International Data Exchange System, a requirement for all IDOE programs.

The NAMDI information will be compiled by EDS for inclusion in *The International Journal of Marine Sciences* and for the World Data Center/ Oceanography Index-Referral Service. The Environmental Data Service has agreed to publish annual summaries of NAMDI forms for all data collected on IDOE programs.

Data submission. After reviewing the NAMDI forms, EDS or SOSC will contact the data originator to work out the final details on types of data to be transferred and shipment schedules. The Office for the IDOE will approve these agreements. Submission of the data and specimens by the originator to the appropriate repository is expected within a reasonable length of time after collection. Generally, this will be within six months in the case of raw and original records which the data centers will copy and return, or within one year in the case of processed and analyzed data. Data should be submitted with adequate ancillary information and notes on instrumentation and calibrations to permit subsequent users to attain the greatest potential use of the information. In some cases, e.g., seismic reflection profiles, the original records may be sent to EDS for duplication. In such cases, the original records will be returned within approximately three weeks. At the request of the originator, EDS will permanently retain original records of the following types: navigational abstracts and trackline sheets; geophysical, XBT and STD strip charts; fathograms; and supplemental records which will permit subsequent users to evaluate and process original records.

A second level inventory will be required for data which cannot be shipped according to the specified schedule and for special classes of observations such as bottom photos, biological samples and geological samples. The details of this second level inventory, worked out between the appropriate data center and the data originator, will be approved by the Office for the IDOE.

At the request of the originator, distribution of data by the data center may be delayed for a period of up to one year. All requests for deferment will be reviewed by the Office for the IDOE. During the period of deferment, the data will not be made available to requesters without th written permission of the originator.

Publications, resulting in whole or in part through support provided by the Office for the IDOE, should acknowledge that support. Four copies of all reports and publication reprints should be sent to the Office for the IDOE. One copy of each document based on IDOE data will be forwarded to NODC and each data center involved in the archiving of data or samples described in the document.

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