WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

TABLE OF CONTENTS

Board of Trustees*

To Serve until 1966

CHARLES FRANCIS ADAMS	Raytheon Company, Spring Street, Lexington 73, Massachusetts
COLUMBUS O'D. ISELIN	Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
AUGUSTUS P. LORING	Loring, Wolcott Office, Inc., 35 Congress Street, Boston, Massachusetts
ALBERT E. PARR	American Museum of Natural History, Central Park West at 79th Street, New York, New York
ATHELSTAN SPILHAUS	Institute of Technology, University of Minnesota, Minneapolis 14, Minnesota
ALFRED M. WILSON	Honeywell Inc., 2747 4th Avenue South, Minneapolis 8, Minnesota

To Serve until 1965

HARVEY BROOKS	Division of Engineering and Applied Physics, Pierce Hall, Harvard University, Cambridge 38, Massachusetts
HUDSON HOAGLAND	Worcester Foundation for Experimental Biology, 222 Maple Avenue, Shrewsbury, Massachusetts
J. SEWARD JOHNSON	Cedar Lane Farm, Oldwick, New Jersey
ROBERT R. SHROCK	Department of Geology and Geophysics, Massachusetts Institute of Technology, Cambridge 39, Massachusetts
RAYMOND STEVENS	Arthur D. Little, Inc., 25 Acorn Park, Cambridge 40, Massachusetts
E. BRIGHT WILSON, JR.	Department of Chemistry, Harvard University, Cambridge 38, Massachusetts.

Ex Officio

EDWIN D. BROOKS, JR.	P.O. Box 1135, Boston 3, Massachusetts
PAUL M. FYE	Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
NOEL B. MCLEAN	Edo Corporation, College Point 56, Long Island, New York
MARY SEARS	Woods Hole Oceanographic Institution, Woods Hole, Massachusetts

Officers

PAUL M. FYE *President of the Corporation*	Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
NOEL B. MCLEAN *Chairman of the Board of Trustees*	Edo Corporation, College Point 56, Long Island, New York
EDWIN D. BROOKS, JR. *Treasurer*	P.O. Box 1135, Boston 3, Massachusetts
MARY SEARS *Clerk of the Corporation*	Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
GEORGE HOWLAND *Assistant Treasurer*	P.O. Box 1135, Boston 3, Massachusetts
FRANCIS C. WELCH *Deputy Clerk*	73 Tremont Street, Boston, Massachusetts

**As of 31 December 1964*

Frank A. Howard

5 January 1890

25 September 1964

Mr. Howard was long associated with scientific research not only through his business connections with the Standard Oil Company of New Jersey but also through his philanthropic interests in establishing the Sloan-Kettering Institute for Cancer Research. He organized and became president of the Standard Oil Development Company which later became the Esso Research and Engineering Company. Such varied experience peculiarly fitted him to serve as a wise counselor for other research organizations. Several of the Trustees, recognizing these qualifications, nominated him and he became a Trustee of the Woods Hole Oceanographic Institution at the annual meeting in August 1949. In August of 1961 he was made an honorary Trustee.

He received a Bachelor of Science degree in mechanical engineering from George Washington University in 1911 and later an LL.B. (1914) and a D.Sc. (1961) from the same University. In the early days of his career he served as an assistant examiner in the U.S. Patent Office and he practiced law for five years. After his election to the board of managers of the Memorial Hospital in New York in 1939 he was instrumental in developing support for a cancer research project which later (1945) became the famous Sloan-Kettering Institute. He served as Chairman of its scientific policy committee and of its Board of Trustees.

Although his many activities did not always permit him to attend the annual meetings of the Board of Trustees in Woods Hole, he contributed much to the well-being of the Institution by serving conscientiously for many years on the Audit Committee. More especially he gave freely of his wisdom. During the early 1950s, the Institution began its recovery from the tumultuous growth of the war years and started to build on a firmer foundation for the expansion that continues today. The director frequently turned to Mr. Howard for advice on a great variety of matters from buildings, to ships and potential sources of funds. During his last appearance at an annual meeting he made many recommendations concerning future building programs that are still under active consideration. The Institution had his enthusiastic support until the very end.

Thus, one of his outstanding characteristics — that of working diligently in support of each area of his wide field of interest — provided the Institution with the sort of assistance which cannot be measured but which will be well remembered.

Members of the Corporation

CHARLES FRANCIS ADAMS
Raytheon Company
Spring Street, Lexington 73, Massachusetts

OLIVER AMES, III
"Edgewater", Beverly Farms, Massachusetts

PHILIP B. ARMSTRONG
Medical Center, State University
of New York, Syracuse, New York

ARNOLD B. ARONS
Department of Physics, Amherst College
Amherst, Massachusetts

ERIC G. BALL
Harvard Medical School
Shattuck Street, Boston, Massachusetts

ALAN C. BEMIS
Westford Road
Concord, Massachusetts

HENRY B. BIGELOW
Museum of Comparative Zoology
Cambridge 38, Massachusetts

KINGMAN BREWSTER, JR.
Yale University
New Haven, Connecticut

DETLEV W. BRONK
The Rockefeller Institute
66th Street and York Avenue
New York 21, New York

EDWIN D. BROOKS, JR.
P.O. Box 1135, Boston 3, Massachusetts

HARVEY BROOKS
Division of Engineering and Applied Physics
Pierce Hall, Harvard University
Cambridge 38, Massachusetts

GEORGE F. CARRIER
Division of Engineering and Applied Physics
211 Pierce Hall, Harvard University
Cambridge 38, Massachusetts

JOHN P. CHASE
The Chase Building, 535 Boylston Street
Boston, Massachusetts

C. LLOYD CLAFF
Single Cell Research Foundation, Inc.
5 Van Beal Road, Randolph, Massachusetts

W. VAN ALAN CLARK, JR.
Ram Island
Marion, Massachusetts

L. O. COLBERT
4408 29th Street, N.W., Washington, D. C.

KENNETH S. COLE
National Institutes of Health
Bethesda 14, Maryland

JAMES S. COLES
Bowdoin College, Brunswick, Maine

PAUL C. CROSS
Mellon Institute
4400 Fifth Avenue
Pittsburgh, Pennsylvania

EDWARD M. DOUGLAS
West Chop, Massachusetts

HENRY B. DUPONT
Wilmington, Delaware

FERDINAND EBERSTADT
65 Broadway, New York 6, New York

CARL H. ECKART
Scripps Institution of Oceanography
La Jolla, California

HARRISON P. EDDY
c/o Metcalf & Eddy
1300 Statler Building, Boston, Massachusetts

GIFFORD C. EWING
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

HOMER H. EWING
Greenville, Wilmington 7, Delaware

ALEXANDER FORBES
610 Harland Street, Milton, Massachusetts

HORACE S. FORD
100 Memorial Drive
Cambridge 42, Massachusetts

PAUL M. FYE
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

JOHN A. GIFFORD
14 Wall Street, New York 5, New York

**As of 31 December 1964*

Cecil H. Green
Airlawn Station, P.O. Box 35048,
Dallas 35, Texas

Donald R. Griffin
Department of Biology
Harvard University
Cambridge 38, Massachusetts

Paul Hammond
Hammond, Kennedy Company
230 Park Avenue, New York, New York

Caryl P. Haskins
Carnegie Institution of Washington
1530 P Street N.W., Washington, D. C.

Halsey C. Herreshoff
Department of Naval Architecture
and Marine Engineering,
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Hudson Hoagland
Worcester Foundation for
Experimental Biology
222 Maple Ave., Shrewsbury, Massachusetts

George Howland
P.O. Box 1135, Boston 3, Massachusetts

Edwin V. Huggins
Suite 3120, 120 Broadway
New York 5, New York

Columbus O'D. Iselin
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Frank B. Jewett, Jr.
Vitro Corporation of America
90 Park Ave., New York, New York

Howard C. Johnson, Jr.
International Bank for Reconstruction
and Development
33 Liberty Street, New York 5, New York

J. Seward Johnson
Cedar Lane Farm, Oldwick, New Jersey

Augustus B. Kinzel
Union Carbide Corporation
30 East 42nd St., New York 17, New York

Milford R. Lawrence
Siders Pond Road, Falmouth, Massachusetts

Edwin A. Link
10 Avon Road, Binghamton, New York

Alfred L. Loomis
Room 2420, 14 Wall Street
New York, New York

Augustus P. Loring
Loring, Wolcott Office, Inc.
35 Congress Street, Boston, Massachusetts

W. H. Lycan
Johnson & Johnson
New Brunswick, New Jersey

Gordon J. F. MacDonald
Institute of Geophysics and
Planetary Physics
University of California
Los Angeles 24, California

Leroy F. Marek
Arthur D. Little Co., Inc.
30 Memorial Dr., Cambridge, Massachusetts

Arnaud C. Marts
521 Fifth Avenue, New York, New York

Ernst Mayr
Museum of Comparative Zoology
Cambridge 38, Massachusetts

Robert E. McConnell
Hobe Sound, Florida

Francis K. McCune
Engineering Services
General Electric Company
570 Lexington Avenue
New York 22, New York

William D. McElroy
Department of Biology
The John Hopkins University
Baltimore 18, Maryland

Noel B. McLean
Edo Corporation
College Point 56, Long Island, New York

Daniel Merriman
Bingham Oceanographic Laboratory
Yale University, New Haven, Connecticut

Robert Rulon Miller
Dixon Corporation
Bristol, Rhode Island

Henry S. Morgan
2 Wall Street, New York, New York

Henry A. Morss
6 Ballast Lane
Marblehead Neck, Massachusetts

Chester W. Nimitz, Jr.
The Perkin-Elmer Corporation
Norwalk, Connecticut

Frank A. Pace, Jr.
General Dynamics Corporation
1 Rockefeller Plaza, New York 20, New York

Albert E. Parr
American Museum of Natural History
Central Park West at 79th Street
New York, New York

John C. Pickard
Box 3797, Greenville, Delaware

Sumner T. Pike
Lubec, Maine

Emanuel R. Piore
International Business Machines Corporation
590 Madison Ave., New York 22, New York

Alfred C. Redfield
Maury Lane, Woods Hole, Massachusetts

Alfred G. Redfield
Watson Laboratories
International Business Machines Corporation
612 West 115th Street
New York, New York

George H. Richards
68 Williams Street, New York, New York

Lawrence B. Richardson
1150 The Terrace, Hagerstown, Maryland

Lawrason Riggs III
St. Joseph Lead Company
250 Park Avenue
New York, New York

William W. Rubey
Institute of Geophysics,
University of California
Los Angeles 24, California

Francis C. Ryder
37 Larchwood Drive
Cambridge 39, Massachusetts

Mary Sears
Woods Hole Oceanographic Institution
Woods Hole, Massachusetts

Frederick Seitz
Department of Physics, University of Illinois
Urbana, Illinois

Harlow Shapley
Sharon Cross Road
Peterborough, New Hampshire

Henry L. Shattuck
10 Milk Street, Boston, Massachusetts

Robert R. Shrock
Department of Geology and Geophysics
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Athelstan Spilhaus
Institute of Technology
University of Minnesota
Minneapolis 14, Minnesota

H. Burr Steinbach
Department of Zoology
University of Chicago
Chicago 37, Illinois

Raymond Stevens
Arthur D. Little, Inc.
25 Acorn Park, Cambridge 40, Massachusetts

Gerard Swope, Jr.
General Electric Company
570 Lexington Avenue, New York, New York

Selman A. Waksman
Institute of Microbiology
New Brunswick, New Jersey

Thomas J. Watson, Jr.
International Business Machines Corporation
590 Madison Ave., New York 22, New York

William Webster
250 Beacon Street, Boston, Massachusetts

Francis C. Welch
73 Tremont Street, Boston, Massachusetts

Jerome B. Wiesner
School of Science
Massachusetts Institute of Technology
Cambridge 39, Massachusetts

Alfred M. Wilson
Honeywell Inc.
2747 4th Avenue South
Minneapolis 8, Minnesota

Carroll L. Wilson
Jacobs Hill, Seekonk, Massachusetts

E. Bright Wilson, Jr.
Department of Chemistry
Harvard University
Cambridge 38, Massachusetts

Chen W. Yang
Institute of Advanced Study
Princeton, New Jersey

Citation on Awarding the Bigelow Medal to Bruce C. Heezen, 17 June 1964

"The geologic structure and history of the crust of our planet has been pieced together largely from evidence found in the topography, stratigraphy, structure and composition of rocks exposed to view on land. The vast remainder, some three-quarters of the earth's crust, has been obscure because of its remoteness from the normal habitat of man and even more importantly because it is overlain by miles of ocean water. Thoughtful men have often asked: What would the sea floor look like if the oceans were to be stripped away, and what geologic processes are peculiar to the oceanic crust?

"The third Henry Bryant Bigelow Medal honors the work on these questions by Bruce Charles Heezen. Although Dr. Heezen came to the ocean only in 1947, his energy and ability in both field and laboratory have brought him to a position of international respect in marine geology. At the time of his introduction to the ocean, the decade-old concept of turbidity currents had come to be widely discussed theoretically and studied in models, but field data were generally lacking. His interests in submarine canyons, continental rises, and abyssal plains soon were joined with observations of clean sands present in many cores from the deep sea; all of which are related in the turbidity current mechanism. While others contributed to knowledge of topography, sediments, and turbidity currents before and during his work, Bruce Heezen was soon acknowledged as a leader in the development of the concept and its verification by field data. Closely related to this, and perhaps resulting directly from his concern for dynamic processes, was the production with Marie Tharp of the first physiographic charts of the Atlantic and Indian Oceans. Review of these charts, in turn, led to the controversial idea of a 65,000 km rift zone which unites observations of topography, seismic activity, and heat flow, all of which may provide significant insight into the origin of the earth's crust.

"Bruce Heezen spent his youth in a region distant from all oceans. He was born 11 April 1924 in Vinton, Iowa. In that state he obtained his school and college education, receiving the Bachelor of Arts degree from Iowa State University in 1948. It was in the summer of 1947, while working at the Woods Hole Oceanographic Institution, that he discovered and entered wholeheartedly the field of marine geology.

In 1948 he joined Maurice Ewing's group at Columbia University and became a charter member of the staff of the Lamont Geological Observatory where he rose from Research Assistant in 1953 to Senior Research Scientist in 1958. In 1960 he was appointed Assistant Professor of Geology, Columbia University. Along with his research activities at Lamont, Dr. Heezen earned both his M.A. in 1952 and Ph.D. in 1957 in the Department of Geology at Columbia University.

"Well over one hundred scientific papers, articles and reviews in several languages bear Dr. Heezen's name as author or coauthor. The frequency with which he has collaborated with others in domestic and foreign scientific publication and the scope of the subject matter covered is a tribute to the breadth of his scholarly interests and his flexibility as a man. But enmeshed in all this lies a thread of scientific concern that is Dr. Heezen's own and which the Bigelow Medal seeks to recognize; his enterprise in putting before the eyes of us all a clear conception of the physiography of nearly half of the earth covered by oceans and his enlightening interpretation of some of the sedimentary and tectonic processes that can be presumed to have governed the development of these forms and structures."

Portion of the Heezen-Tharp physiographic chart of the South Atlantic Ocean.

Resident Scientific and Technical Staffs

PAUL M. FYE . . . . . *Director of the Woods Hole Oceanographic Institution*

BOSTWICK H. KETCHUM . . *Associate Director for Biology and Chemistry*
Lecturer on Biological Oceanography, Harvard University

COLUMBUS O'D. ISELIN . . *Henry Bryant Bigelow Oceanographer*
Professor of Physical Oceanography, Harvard University
Research Oceanographer, Museum of Comparative Zoology
Professor of Oceanography, Massachusetts Institute of Technology

Department of Applied Oceanography

LINCOLN BAXTER II, *Applied Physicist*
ROBERT R. BROCKHURST, *Applied Physicist*
NICHOLAS P. FOFONOFF, *Senior Scientist*
EARL E. HAYS, Department Chairman, *Senior Scientist*
Associate Professor of Physics (Affiliate), Clark University
HENRY M. HORN, *Research Associate*
WILLIAM M. MARQUET, *Research Associate*
JAMES W. MAVOR, JR., *Mechanical Engineer*
DUNCAN E. MORRILL, *Research Associate*
DAVID M. OWEN, *Research Associate*
WILLIAM O. RAINNIE, JR., *Oceanographic Engineer*
ARNOLD G. SHARP, *Research Associate*
PAUL B. STIMSON, *Research Associate*
ROBERT G. WALDEN, *Electronics Engineer*
DOUGLAS C. WEBB, *Research Associate*

Department of Biology

EDWARD R. BAYLOR, *Associate Scientist*
ROBERT J. CONOVER, *Assistant Scientist*
Visiting Associate Professor of Oceanography, University of Washington
NATHANIEL CORWIN, *Analytical Chemist*
GEORGE D. GRICE, JR., *Associate Scientist*
ROBERT R. L. GUILLARD, *Associate Scientist*
ROBERT R. HESSLER, *Assistant Scientist*
EDWARD M. HULBURT, *Associate Scientist*
KUNIGUNDE HÜLSEMANN, *Assistant Scientist*
HOLGER W. JANNASCH, *Senior Scientist*
Privat Dozent in Microbiology, University of Göttingen
JOHN W. KANWISHER, *Senior Scientist*
Associate Professor, Massachusetts Institute of Technology
ANDREW KONNERTH, *Research Associate*
EDWARD J. KUENZLER, *Associate Scientist*
FRANK J. MATHER III, *Associate Scientist*
DAVID A. MCGILL, *Assistant Scientist*
DAVID W. MENZEL, Assistant Department Chairman, *Associate Scientist*
JOHN H. RYTHER, Department Chairman *Senior Scientist*
HOWARD L. SANDERS, *Associate Scientist*
Instructor in Marine Ecology, Marine Biological Laboratory
RUDOLF S. SCHELTEMA, *Assistant Scientist*
WILLIAM C. SCHROEDER, *Senior Scientist*
Honorary Associate in Ichthyology, Museum of Comparative Zoology, Harvard University
MARY SEARS, *Senior Scientist*
JOHN M. TEAL, *Assistant Scientist*
HARRY J. TURNER, JR., *Associate Scientist*
Lecturer in Zoology, University of New Hampshire
RALPH F. VACCARO, *Associate Scientist*
MARGARET E. WATSON, *Assistant Scientist*
STANLEY W. WATSON, *Associate Scientist*
CHARLES S. YENTSCH, *Associate Scientist*

Department of Chemistry and Geology

WILLIAM D. ATHEARN, *Research Associate*

MAX BLUMER, *Senior Scientist*
Research Affiliate in Chemical Oceanography, Massachusetts Institute of Technology

VAUGHAN T. BOWEN, *Senior Scientist*
Lecturer in Biology, Yale University

FRANCIS G. CAREY, *Assistant Scientist*

DOUGLAS CORMACK, *Assistant Scientist*

EGON T. DEGENS, *Associate Scientist*

KENNETH O. EMERY, *Senior Scientist*

CHRISTOPHER GATROUSIS, *Assistant Scientist*

JOBST B. HÜLSEMANN, *Associate Scientist*

JOHN M. HUNT, Department Chairman
Senior Scientist

VICTOR E. NOSHKIN, JR., *Assistant Scientist*

RICHARD M. PRATT, *Assistant Scientist*

PETER L. SACHS, *Research Associate*

ALVIN SIEGEL, *Assistant Scientist*

ELAZAR UCHUPI, *Associate Scientist*

DAVID WALL, *Assistant Scientist*

JOHN M. ZEIGLER, *Associate Scientist*
Lecturer in Geology, University of Chicago

Cooperating Scientists U. S. Geological Survey

JOHN C. HATHAWAY · ROBERT H. MEADE · A. RICHARD TAGG · FRANK T. MANHEIM · JOHN S. SCHLEE · JAMES V. A. TRUMBULL

Department of Geophysics

RICHARD H. BACKUS, *Senior Scientist*
Associate in Ichthyology, Harvard University

JOHN C. BECKERLE, *Associate Scientist*

STANLEY W. BERGSTROM, *Research Associate*

CARL O. BOWIN, *Assistant Scientist*

ELIZABETH T. BUNCE, *Associate Scientist*

RICHARD L. CHASE, *Assistant Scientist*

WILLARD DOW, *Electronics Engineer*

WILLIAM M. DUNKLE, JR., *Research Associate*

JOHN B. HERSEY, Department Chairman
Senior Scientist
Professor of Oceanography, Massachusetts Institute of Technology

FREDERICK R. HESS, *Research Associate*

SYDNEY T. KNOTT, JR., *Hydroacoustics Engineer*

GODFREY SAVAGE, *Research Associate*
Visiting Engineer, Department of Naval Architecture and Marine Engineering, Massachusetts Institute of Technology

EDWARD R. TASKO, *Research Associate*

ALLYN C. VINE, *Senior Scientist*

WILLIAM A. WATKINS, *Research Associate*

ASA S. WING, *Research Associate*

WARREN E. WITZELL, *Research Associate*

Department of Physical Oceanography

JOSEPH R. BARRETT, JR., *Research Associate*

ALVIN L. BRADSHAW, *Applied Physicist*

JOHN G. BRUCE, JR., *Research Associate*

DEAN F. BUMPUS, *Senior Scientist*

JOSEPH CHASE, *Associate Scientist*
Visiting Lecturer, State College at Bridgewater

C. GODFREY DAY, *Research Associate*

FREDERICK C. FUGLISTER, Department Chairman, *Senior Scientist*

WILLIAM G. METCALF, *Associate Scientist*

ARTHUR R. MILLER, *Associate Scientist*

KARL E. SCHLEICHER, *Oceanographic Engineer*

ELIZABETH H. SCHROEDER, *Research Associate*

GORDON H. VOLKMANN, *Research Associate*

ARTHUR D. VOORHIS, *Associate Scientist*

BRUCE A. WARREN, *Assistant Scientist*

T. FERRIS WEBSTER, *Assistant Scientist*

GEOFFREY G. WHITNEY, JR., *Research Associate*

L. VALENTINE WORTHINGTON, *Senior Scientist*

Department of Theoretical Oceanography and Meteorology

DUNCAN C. BLANCHARD, *Associate Scientist*

ANDREW F. BUNKER, *Associate Scientist*
Adjunct Associate Professor in Oceanography, New York University

ALAN IBBETSON, *Assistant Scientist*

COLUMBUS O'D. ISELIN, Acting Department Chairman, *Henry B. Bigelow Oceanographer*

ERIC B. KRAUS, *Senior Scientist*

JOSEPH LEVINE, *Assistant Scientist*

F. CLAUDE RONNE, *Photographic Specialist*

CLAËS G. H. ROOTH, Assistant Department Chairman, *Associate Scientist*

PETER M. SAUNDERS, *Assistant Scientist*

ALLARD T. SPENCER, *Design Engineer*

RAYMOND G. STEVENS, *Assistant Scientist*

J. STEWART TURNER, *Associate Scientist*

Administrative Staff of the Woods Hole Oceanographic Institution

DAVID D. SCOTT	Assistant Director for Administration
RICHARD S. EDWARDS	Marine Superintendent
JONATHAN LEIBY	Naval Architect
ARTHUR T. HENDERSON	Procurement Supervisor
HARVEY MACKILLOP	Controller
JAMES R. MITCHELL	Facilities Manager
L. HOYT WATSON	Personnel Manager
NORMAN T. ALLEN	Archivist
H. V. R. PALMER, JR.	Public Affairs Officer
FREDERICK E. MANGELSDORF	Administrative Aide to the Director
JOHN F. PIKE	Port Captain
JESS H. STANBROUGH	Technical Assistant to the Director
RONALD A. VEEDER	Development Program Manager

Non-Resident Research Staff

DAVID L. BELDING, *Emeritus Scientist*

HENRY B. BIGELOW, *Emeritus Scientist*

CORNELIA L. CAREY, *Emeritus Scientist*

ALFRED C. REDFIELD, *Emeritus Scientist*

ARNOLD B. ARONS, *Associate in Physical Oceanography*
Professor of Physics, Amherst College

BRUCE B. BENSON, *Associate in Physics*
Professor of Physics, Amherst College

BERT BOLIN, *Associate in Meteorology*
Director, Institute of Meteorology, University of Stockholm
Director, International Institute of Meteorology, Stockholm

KIRK BRYAN, JR., *Associate in Meteorology*
U. S. Weather Bureau

GEORGE L. CLARKE, *Associate in Marine Biology*
Professor of Biology, Harvard University

GIFFORD C. EWING, *Associate in Physical Oceanography*
Chairman, Division of Oceanic Research and Research Oceanographer, Scripps Institution of Oceanography; Visiting Scientist, Department of Geology and Geophysics, Massachusetts Institute of Technology

DAVIS A. FAHLQUIST, *Associate in Geophysics*
Assistant Professor, A. & M. College of Texas

MICHAEL GARSTANG, *Associate in Meteorology*
Assistant Professor of Meteorology and Research Associate in Oceanography, Florida State University

LOUIS N. HOWARD, *Associate in Mathematics*
Professor of Mathematics, Massachusetts Institute of Technology

ROBERT H. KRAICHNAN, *Associate in Theoretical Physics*
Peterborough, New Hampshire

WILLEM V. R. MALKUS, *Associate in Physical Oceanography*
Professor of Geophysics, University of California, Los Angeles

PAUL C. MANGELSDORF, JR., *Associate in Physical Chemistry*
Associate Professor in Physics, Swarthmore College

NORMAN B. MARSHALL, *Associate in Ichthyology*
Principal Scientific Officer, British Museum (N.H.)

GILES W. MEAD, *Associate in Ichthyology*
Curator of Fishes, Harvard University

ROBERT L. MILLER, *Associate in Submarine Geology*
Associate Professor of Marine Geophysics and Geology, University of Chicago

JAMES M. MOULTON, *Associate in Marine Biology*
Associate Professor of Biology, Bowdoin College

JEROME NAMIAS, *Associate in Meteorology*
Associate Director, National Meteorological Center, U. S. Weather Bureau

GEOFFREY D. NICHOLLS, *Associate in Geochemistry*
Senior Lecturer, Geochemistry
University of Manchester, England

ALLAN R. ROBINSON, *Associate in Physical Oceanography*
Associate Professor of Geophysical Fluid Dynamics and Assistant Professor of Meteorology and Oceanography, Harvard University

ARTHUR K. SAZ, *Associate in Microbiology*
Chief, Medical and Physiological Bacteriology Section, Laboratory of Infectious Diseases, NIAID, National Institutes of Health

WILLIAM E. SCHEVILL, *Associate in Oceanography*
Research Associate in Zoology, Museum of Comparative Zoology, Harvard University

RAYMOND SIEVER, *Associate in Geology*
Associate Professor of Geology, Harvard University

JOANNE SIMPSON, *Associate in Meteorology*
Professor of Meteorology, University of California, Los Angeles

FLOYD M. SOULE, *Associate in Physical Oceanography*

EDWARD A. SPIEGEL, *Associate in Astrophysics*
Research Scientist, Department of Physics, New York University

HENRY M. STOMMEL, *Associate in Physical Oceanography*
Professor of Oceanography, Massachusetts Institute of Technology

THOMAS T. SUGIHARA, *Associate in Geochemistry*
Professor of Chemistry and Chairman of the Department of Chemistry, Clark University

GEORGE VERONIS, *Associate in Mathematics*
Research Oceanographer, Massachusetts Institute of Technology

WILLIAM S. VON ARX, *Associate in Physical Oceanography*
Professor of Oceanography, Massachusetts Institute of Technology

JOSEPH B. WALSH, JR., *Associate in Mechanical Engineering*
Research Associate, Department of Geology and Geophysics, Massachusetts Institute of Technology

PIERRE WELANDER, *Associate in Physical Oceanography*
Docent, Stockholm University, Stockholm, Sweden

ALFRED H. WOODCOCK, *Associate in Oceanography*
Research Associate in Geophysics, Institute of Geophysics, University of Hawaii

Scientific Visiting Committees

Department of Applied Oceanography

ROBERT A. FROSCH, Department of Defense, Washington, D. C.

CLAUDE W. HORTON, University of Texas, Austin, Texas

THOMAS C. SMITH, Daystrom, Inc., Poughkeepsie, New York

Department of Biology

HUDSON HOAGLAND, The Worcester Foundation for Experimental Biology, Shrewsbury, Massachusetts

ERLING J. ORDAL, University of Washington Medical School, Seattle, Washington

JOHN D. H. STRICKLAND, Scripps Institution of Oceanography, La Jolla, California

Department of Chemistry and Geology

HARRY H. HESS, Princeton University, Princeton, New Jersey

WILLIAM W. RUBEY, University of California, Los Angeles, California

LARS-GUNNAR SILLÉN, Royal Institute of Technology, Stockholm, Sweden

Department of Geophysics

MAURICE HILL, University of Cambridge, Cambridge, England

JOHN C. STEINBERG, University of Miami, Coral Gables, Florida

Department of Physical Oceanography

CLIFFORD A. BARNES, University of Washington, Seattle, Washington

GÜNTER DIETRICH, Institut für Meereskunde der Universität, Kiel, W. Germany

ROBERT STEWART, Pennsylvania State College, University Park, Pennsylvania

Department of Theoretical Oceanography and Meteorology

HORACE R. BYERS, University of Chicago, Chicago, Illinois

JEROME NAMIAS, Extended Forecast Branch, U. S. Weather Bureau, Washington, D. C.

ATHELSTAN SPILHAUS, University of Minnesota, Minneapolis, Minnesota

THE DIRECTOR'S REPORT

Those who investigate the laws of the sea to learn its secrets have as a reward the satisfaction of adding to man's store of knowledge. To the scientist, this alone may be adequate compensation for the failures and the heartbreaks which so often are the prelude to success. Our researchers do not work in isolation. Behind them stand research and laboratory assistants, artisans and seamen, accountants and attorneys, janitors and custodians. All of these people working together are vital to the functioning of the Institution.

This list of people would be incomplete without mention of another group who are equally vital even though they work and live throughout the entire length and breadth of this nation. This is the group who have banded themselves together as the Associates of the Woods Hole Oceanographic Institution. Their interest in our work arises from a curiosity about the oceans and a desire to know more about the seas. They are a source of encouragement to the scientists, anxious and willing to give advice and counsel in those areas where they are knowledgable. They lend constructive criticism when asked. They contribute funds of considerable magnitude so that we may venture further into little known areas. They provide fellowships and scholarships so that the ranks of the marine scientists here and abroad may be replenished and increased.

This Annual Report salutes in warmth and gratitude our lay supporters, The ASSOCIATES OF THE WOODS HOLE OCEANOGRAPHIC INSTITUTION.

Many great things have had simple beginnings. And so it was with the Associates. The Institution had come out of the rugged years of World War II greatly strengthened and considerably larger than in the 30's. But even by 1950 it had not lost the wartime reputation of being a secluded place, walled off in the confines of its own work. The general public knew nothing about the purpose or character of our work and few outside a small circle of oceanographers and sponsoring agencies knew of our achievements. As a first step toward correcting this situation, the Director extended an invitation to visit the Institution to a group of summer residents of Woods Hole.

As a result of this visit, Mr. Gerard Swope, Jr., addressed a letter to Edward H. Smith, then Director of the Institution. He expressed his appreciation for having been permitted to learn more about the Institution and stated that he had a desire to help further its work, but did not know how this could be done. Other summer residents, equally sincere in their desire to learn more about oceanography and to help in our studies, joined with Mr. Swope in expressing their interest in the Institution. It was not long after that the Associates of the Woods Hole Oceanographic Institution was formed.

In the beginning, early in 1952, there were ten members. It is a revealing and significant fact that, of the original ten, nine are still carried on the rolls of the

Third annual meeting of the Associates of the Woods Hole Oceanographic Institution held in the ward-room of ATLANTIS on 7 August 1954.

Associates. In the short thirteen-year span of the Associates' Program, this number has risen to well over 400 individual members and over 50 corporate members.

Quite appropriately Mr. Swope served as President for the first four years. In the period from 1955 through 1961, Mr. Noel B. McLean was President and since that time he has served the Institution in a position of even greater responsibility, as Chairman of the Board of Trustees. He was replaced by Mr. Homer H. Ewing who is still active in this post. Mr. John A. Gifford has been the Associates' Secretary since the inception of the Program in 1952 and because of the complexity and extent of the work involved in the position of Treasurer, this post has continuously been filled by the Treasurer of the Institution.

Three committees conduct much of the Associates' business. An Executive Committee is made up of five or more Associates, including the Director of the Institution. The Industrial Committee, which was established in 1954, arranges for corporation participation in the Associates' Program. Mr. Charles Francis Adams has served as its Chairman since that time. The Development Committee, chaired by Captain Paul Hammond, has provided effective assistance to the Institution in developing capital funds.

The Associates embody the spirit of the alumni of a college or university with their sense of loyalty and their desire to provide moral and actual support wherever possible. The work which they do for the benefit of the Institution is widely varied and goes far beyond that of financial assistance alone.

A series of educational fellowships was started in 1955. Under this program, funds were set aside to be awarded as annual grants to promising college graduates who had demonstrated a sincere desire to pursue their advanced education in the earth sciences. Among the first of these was Duncan C. Blanchard, now a member of the Institution's Department of Theoretical Oceanography and Meteorology. The wisdom of his selection for a fellowship has been amply demonstrated by his extensive investigations of the interactions between the air and the sea. Between the years 1955 and 1962 a total of eleven fellowships was awarded. Of these, nine have continued their studies in the field of oceanography. Three have retained their affiliation with the Institution. In addition to Dr. Blanchard, they are Dr. David A. McGill of the Department of Biology, and Dr. Bruce A. Warren of the Department of Physical Oceanography. This is generous repayment indeed for the funds and the efforts expended. In 1962 the Associates' Fellowship Program was expanded by the addition of other Institution funds until now our entire educational budget has increased ten-fold.

During the preparation of this annual report, I found to my interest and surprise that the Associates had proposed that an appropriate medal be awarded annually to the individual making the greatest contribution to oceanography. The Henry Bryant Bigelow Medal, which we established in 1960, has brought this excellent idea to fulfillment. The medal has been awarded three times since its inception. The first award was made to Dr. Bigelow himself. In 1962 the second award was made to Dr. John C. Swallow of the National Institute of Oceanography in England, and last year, the third medal was awarded to Dr. Bruce C. Heezen of the Lamont Geological Observatory.

As a means of furthering interest in oceanography on the part of industrial corporations throughout the country, a series of seminars in which the Associates participated have been sponsored since 1958. The theme of the first seminar, which was repeated in 1959, was Environmental Factors Influencing the Performance of Naval Weapon Systems. Corporation representatives attending the seminar were given briefings by members of our scientific staff. In the following years such briefings for industrial personnel have become very numerous and we consider them a healthy interchange of information from which we derive great benefit.

The Associates have shown great interest in our science. An example of this is the sponsorship of a series of lectures at Woods Hole by prominent oceanographers from this country and abroad. In the first of these in 1954, Dr. Gifford C. Ewing, then associated with the Scripps Institution of Oceanography, presented a series of six Associates' lectures on the subject of physical oceanography. In the years that followed, other lecturers came from many renowned institutions to present learned discussions on a great variety of oceanographic subjects.

During 1964 interest in the Institution and its Associates' Program had grown to a point where a new classification of membership was needed. This is the Club membership. Under this category, yacht clubs, fishing clubs, and other kinds of sports organizations may attain membership. To date, six clubs have joined the individuals and corporations in the Associates.

Contributions of gifts in kind by the Associates have been both generous and varied. In 1955, the General Foods Corporation, a Corporate Associate, donated to the Institution a piece of property located in Boston Harbor. A portable electric piano was contributed to the ATLANTIS to help the morale of the crew during the off-hours on a long cruise at sea. Other gifts have included generators, spars, and last year a gravity meter. Funds provided by the Associates helped to produce the Institution's educational movie, *"Science of The Sea,"* and public education has been furthered by the regular publication of *"Oceanus."* However, no type of contribution has been either more generous or more useful than the boats which have been given to the Institution by the Associates. CARYN, ARIES, SABRINA, SIGMA T and EUGENIE VIII have all seen scientific service in the Institution fleet. Some of the donated boats proved to be too light in construction for the arduous work which oceanography imposes. With the consent of the Associate owner, these were disposed of and the funds realized as a result of sale were put to other oceanographic uses. Two of the boats, NOBSKA and MERGANSER, still ride at moorings at the Institution docks.

On the average, over the past five years, funds contributed by Associates or obtained through their endeavors have provided monies equal to the income of endowment funds exceeding three million dollars. We in the Institution are indeed grateful for the opportunities these funds provide to test new ideas. There is so little that we can say or do in appreciation: the annual dinner, the annual cruise, the subscriptions to *Oceanus* and a royal welcome at all times within the Institution. This is little indeed for the time, the interest and the devotion which the Associates have given to the Institution.

Perhaps the Associates' greatest contribution of all is their recognition of the importance of the work done here. Recognition coming from outside the Institution and from outside the scientific community is a continuing source of encouragement. In the final analysis, despite the innate rewards of scientific research there are few of us, who pursue knowledge for the sake of knowledge alone or conduct scientific investigations for the sheer beauty of abstract knowledge, who do not esteem the recognition and goodwill of our fellow-men. Thus, we are greatly indebted to the Associates for their spontaneous evaluation of our work.

Indeed, we salute our ASSOCIATES. We appreciate their past support, we welcome their continued support, and we urge their even greater participation in our activities.

Department of Applied Oceanography

Cooperative effort at the Institution is standard practice. It would be difficult in many programs to distinguish personnel by their departmental affiliations. The efforts of the Department of Applied Oceanography reflect this situation with the work extending into fields of major interest to all other departments. The computer, for example, is used by all departments and is becoming an important tool in many researches. Other efforts are just as encompassing as the computer. Members from all departments have turned in proposals for the use of ALVIN. These investigators were given preliminary dives in ALVIN during local operations in the late summer and fall. Instrumentation development continued in several areas which involved cruises with members of other departments. The major items are discussed below.

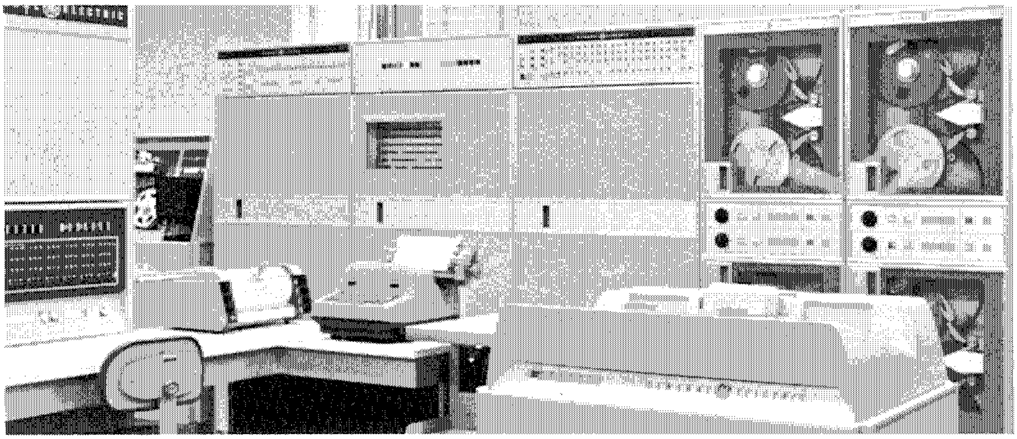
Instrumentation

Much could be learned about oceanic circulation if neutrally buoyant floats (Swallow floats) with identifying acoustic signatures could be scattered throughout the area of interest (hundreds of miles radius), and monitored at a single station or several stations, depending upon mode of location. In lieu of this, which is rather an ambitious program, it seemed sensible to extend the range of Swallow floats by increasing the effectiveness of the output signal and the recording techniques. By lowering the frequency of the output and using the Precision Graphic Recorder as a correlating signal receiver, the effective range of the floats is now approaching 25 km. This enables a ship to track more floats over a widespread area, with less time spent in search to relocate instruments out of range.

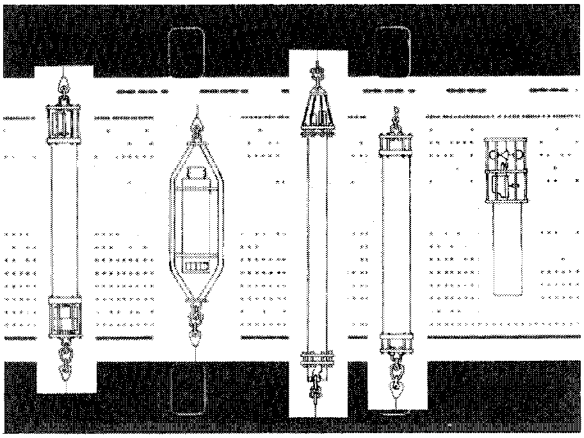
In some areas of the ocean, vertical components of velocity exist in the currents. The magnitudes of these vectors determine the turnover of nutrients and the general circulation pattern but have not been susceptible to direct measurements. A tentative design for a modified Swallow float that senses vertical water motion by vanes has been developed and experiments are to be carried out in early 1965. Although this instrument may create more questions than it answers, it is a step toward a better understanding of the circulation.

The Geology Department used the underwater-photography capability of the Applied Oceanography Department in time-lapse studies of sediment movement, and in the design of a camera-grab sampler. Underwater photographs were also taken of the behavior of a current meter on a mooring.

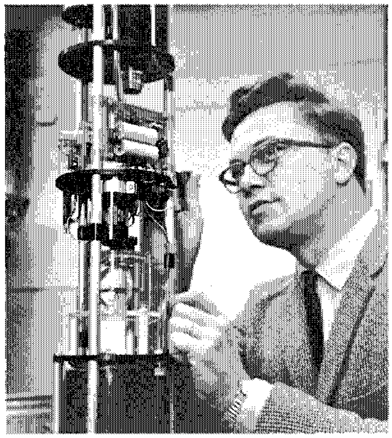
The use of the computer has brought forth a need of appropriate recording techniques so that large amounts of data may be collected in a form easily processed by the computer. Some of this must be converted from analogue to digital form. Such problems have been handled for the Biology Department in plankton counting, for the Geology Department in a sediment analyzer and for the Department of Theoretical Oceanography and Meteorology in atmospheric studies.



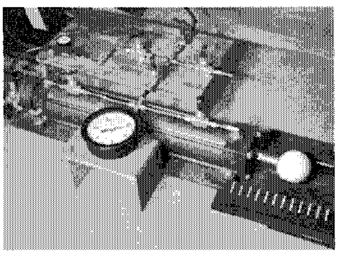
General Electric 225 Computer

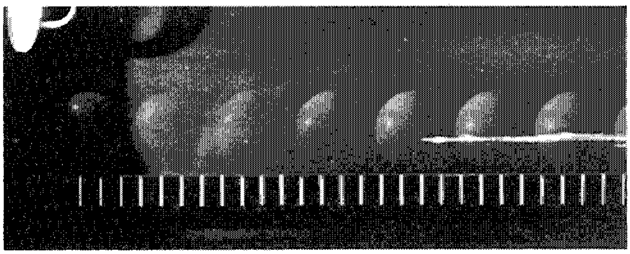


Diagrams of components for oceanographic buoy system on an enlargement of the readout film.



Adjustment of current meter.





Laboratory model of compressed gas drive system for mechanical impact sound source and stroboscopic photo used for velocity determination.

A successful model of an air drive system for the high intensity impact sound source was assembled and tested.

Buoys — Moored and Drifting

The rather obvious problems of keeping a "moored" buoy moored and a drifting buoy located received their share of attention from the Department of Applied Oceanography.

Tests with subsurface floats and wire moorings indicated that two problems in deep current measurements by moored current meters can be greatly reduced. The subsurface float eliminates high frequency noise produced by action of a surface float, and the metallic line must certainly discourage the line "biters" that have raised havoc with the synthetic line moorings.

New problems arise from these improvements, however. Telemetry signals must be brought to the surface for efficient transmission. A system was designed and tested that used a 1000-foot pennant rope to a small low drag surface transmitter. Although digital data from current meters was satisfactorily passed from the subsurface mooring to the surface transmitter, the radio transmission efficiency was low. Recording current meters on subsurface moorings do not need a surface float, and preferably do not have one, provided that an acoustic beacon or transponder on the subsurface float informs the surface retrieving vessel of the mooring's location. Such a device has been developed for use with the subsurface moorings. In addition, tests have been run on acoustical release mechanisms under real operating conditions. The retrieval of a current meter mooring without the anchor weight is reasonably simple, but with the weight it requires real skill. In some cases the anchor weight plus line weight can part the line. Timed releases have worked reliably, but the "on schedule" release of two moorings into the midst of a "not scheduled" hurricane Gladys was convincing evidence that "on demand" releases were preferable.

The efficiency of the Consolan receiving transmitting system for drifting or moored buoys was improved. The radar actuated strobe light was used on five cruises and now successfully fills the need for a bright light on buoys with a long life time.

Some consideration was given to other types of buoy sets, with a long spar buoy being quite attractive for several types of operations.

Deep Currents

Twenty-five moorings were set in 1964 to study mooring behavior, instrument performance and ocean currents. Thirteen of the sets were specifically for current measurements rather than system studies.

Currents near Bermuda were found to exhibit large low frequency shifts above the main thermocline. The periods cannot be associated with tides or inertial motion, but could be eddies set up by the island. Speeds up to 25 cm/sec have been observed at 600 meters depth. Below the main thermocline the currents were consistently weak (5 cm/sec) and rotated with semi-diurnal tidal frequency.

A series of buoys was set near 30°N to examine inertial currents at that latitude. The measurements revealed inertial currents in an apparently isolated subsurface layer, raising questions concerning both their generation and their role in the dynamics of the ocean generally.

Acoustics and Optics

The multiple paths of long range sound transmission in the Eastern Mediterranean were studied in some detail in 1964. This was a continuation of work started in 1961. A precisely controlled repetitive sound source and display on a Precision Graphic Recorder took advantage of the correlation gains in signal to noise ratio. The results showed the effect of bottom topography on bottom bounce paths quite clearly. These measured paths were compared with paths calculated from sound velocity data and known bottom topography.

Although the knowledge of sound velocity profiles is increasing from direct measurements, information from many areas depend upon hydrographic data. Study of methods to obtain the most reliable sound velocity data from hydrographic stations continued.

Pulsed lasers and high speed cameras offer intriguing possibilities in underwater photography, although this idea is still far removed from being a sea-going system. One dive of ALVIN was devoted to preliminary measurements of the polarization of the Zenith ray.

Information Processing Center

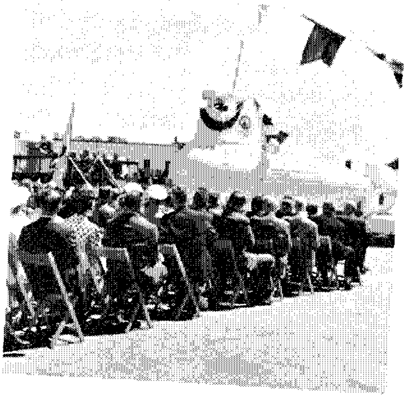
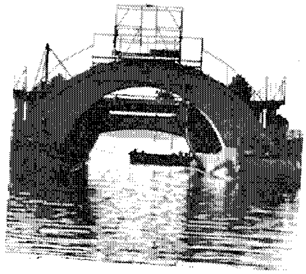
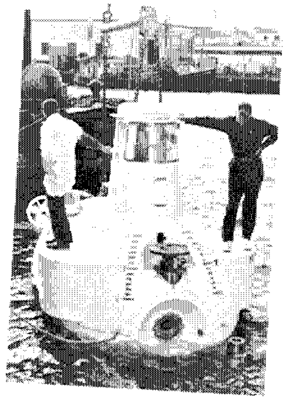
The computers in the Institution are not limited to the GE 225. The Geophysics Department has been operating an IBM 1710 aboard CHAIN for some time, and the Physical Oceanography Department had a G-15 aboard ATLANTIS II for the Indian Ocean cruise of 1963, and are now readying a PDP-5 for the Indian Ocean Cruise of 1965. These sea-going computers are capable of handling much data at sea, and in many cases, completing the processing of the data into final form at sea. Interpretation and analysis often indicates more numerical treatment of the data is needed and this is usually carried out on the GE 225. Equipment modifications and computer programs have been designed to make these several computer systems compatible.

A series of Fortran programming courses and one course in machine language programming were given during the year. These courses introduce the staff to the computer and have accounted for many new users.

As the computer load grows, eventually it will be necessary to make some major changes in equipment. At the same time, the complexity of the problems approached on the computer increases, and the professional programming staff must be augmented.

VLF Navigation

The VLF (Very Low Frequency) Navigation systems were aboard CHAIN and ATLANTIS II for major cruises during the year. This navigation system, which depends on the phase relation between a received signal and a local oscillator, is sensitive to the variations in the ionized layers of the upper atmosphere. At the present time this system is experimental and the cruises in 1964 served to point up the parts of the system that need improving. The possibility of combining this system with a satellite navigation system is very attractive and positive steps were taken in this direction at the end of the year.

Three photographs showing the commissioning of Alvin in June, the catamaran for servicing the vehicle at sea which was built in Woods Hole this winter, and early testing in Woods Hole Harbor.

ALVIN

In June 1964 ALVIN, the two man submersible, constructed for operations to 6000 feet, arrived at Woods Hole. After a commissioning ceremony that attracted a crowd of five hundred people from all over the country, the final diving assembly was completed, and ALVIN entered the water.

The first dive was very successful and brought a feeling of accomplishment to those who had been working on the program. It was rather interesting to note the expressions on the faces of the engineers who knew ALVIN inside and out from design to construction, when the craft behaved just the way they had hoped.

After the first dive, the next phase of the operation was for the pilots to become familiar with handling the craft. The currents and visibility of the waters near Woods Hole are not ideal for submersible work, but are a good training ground. After several weeks of pilot experience, scientists were taken along as observers, to acquaint them with the possibilities of using ALVIN in their work. In the three month operating period, ALVIN made seventy-seven dives and carried fifty-four observers. The observers were quite impressed with the maneuverability, the mechanical arm and the lack of discomfort. The latter is directly coupled to length of the dive, however.

Some of the scientists brought along equipment to make preliminary measurements of subjects of interest to them. A group from the Geology Department had made a grab bucket and scuba survey of the harbor at Woods Hole, and were greatly enthused over the opportunity to check their work from ALVIN.

At the end of the year ALVIN was completely torn down for inspection and minor refit prior to making the deep dives.

EARL E. HAYS, *Chairman*

Department of Biology

Nutrient Chemistry and Microbiology

An understanding of the mechanisms which control the fertility of the sea by necessity involves the study of factors which control the formation, distribution, and fate of organic matter. Considerable emphasis has been placed on these problems in the past, by a number of independent investigators, all working on different aspects of the same overall problem, and at various levels in the trophic structure.

During the past year considerable information has been obtained on the distribution of dissolved organic phosphorus in the Indian Ocean. A pattern of distribution markedly different from that in the South Atlantic was found in which organic phosphorus was largely limited to the upper 1000 meters. In the South Atlantic, by contrast, significant amounts occur to 4000 meters and below. Hopefully at the end of the Indian Ocean program this year these data will not only aid in an understanding of deep water movement but will help in an interpretation of oxidative changes in organic matter which occur remote from the region of formation of the water masses.

The half life of naturally occurring carbon compounds in deep oceanic waters appears to be in the neighborhood of 300 years and, although this estimate is based on several tenuous assumptions, data from both the Atlantic and Indian oceans suggest that this is not an overestimate. The fact that no apparent correlation exists between primary production and the concentration of these substances in surface water suggests that the decomposition of newly formed organic matter is extremely rapid and occurs at the surface. Reservoirs of carbon-containing compounds which are formed, and carried from the surface into deep waters probably consist of a refractory residual which results either from differential decomposition of the sum of producing organisms, or by biochemical transformation of compounds from more labile to refractory forms. This supposition is partly supported by laboratory experimentation with aging cultures of phytoplankton where parallel results were obtained.

Meanwhile experiments on the excretion of organic compounds by marine phytoplankton have demonstrated that growing cells secrete only recently photoassimilated carbon. The proportion of old to new carbon excreted increases rapidly when the algae enter stationary-phase growth. Considerable acrylic acid is stored by the alga *Phaeocystis pouchetii* but little if any of this material is excreted by actively growing cultures in spite of the fact that 30-60% of the photoassimilate is excreted. An additional source of dissolved organic substance is that released by the algae when they are grazed by zooplankton. Feeding experiments showed that approximately 15% of algal carbon grazed appears in the media as dissolved substances.

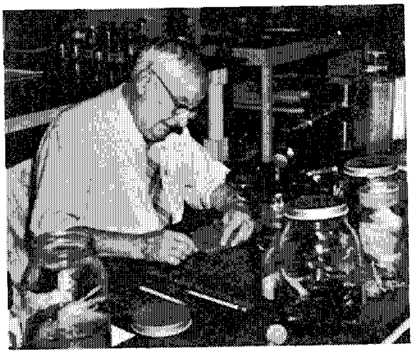
The capacity of phytoplankton to produce alkaline phosphates in a medium depleted of orthophosphate has been demonstrated. Several species grow equally well on glucose 6-phosphate as with the inorganic form, in every case hydrolyzing the ester extracellularly and leaving the glucose intact in solution. Success in staining cells capable of this activity has shown that the enzyme is not produced simultaneously in all cells of the culture but begins with a few cells and then progresses throughout the entire culture.

A study of competition for nutrients by phytoplankton cells of differing sizes, shapes and settling velocities has been initiated. In general it has been found that there is little likelihood of competition between cells for nutrients when the cell concentration is less than 10^8/liter. Concentrations in the western North Atlantic rarely exceed 10^6 cells/liter. Therefore it is concluded that the dominance of a particular species does not result from direct competitive exclusion.

The principal barrier to accurate estimates of the rate of carbon synthesis by phytoplankton has been caused by uncertainties as to the interaction of photosynthesis and respiration. Estimates of respiration have been obtained by back extrapolation of the photosynthesis-light curve to zero light intensity, assuming the curve to be linear. Careful measurements of the photosynthesis: light relationship in phytoplankton at low intensities shows it not to be a straight line but an "s" shaped curve. This finding is new for natural populations and invalidates estimates of respiration obtained by the above method. A further implication is that photosynthesis probably occurs at lower light intensities and consequently greater depth than has previously been assumed.

The action of heterotrophic bacteria in the sea is primarily responsible for the destruction and turnover of organic materials. Thus, the study of these organisms provides a most important link in understanding the rate of biological turnover and the mechanisms involved. Earlier work on this problem has revolved largely around attempts at enumeration of the organisms. More recently controlled open system chemostats have proved more reliable and have permitted enzymatic analysis for the most important energy sources for bacterial growth. Growth constants were determined using lactic acid and glycerol as growth limiting nutrients. The substrate saturation constant was most indicative of the ability of a species to metabolize at low nutrient levels. Under certain conditions bacteria did not grow below minimum cell densities indicating the existence of a threshold concentration of the nutrient. This might explain the presence of readily oxidizable organic compounds in sea water apparently escaping bacterial decomposition, a feature which was noted above from systematic analyses of the deep water distribution of organic carbon in the Indian and Atlantic oceans. An additional aspect of this work, performed independently, has been the use of radioactive isotopes, employing uniformly labelled organic compounds, to determine the heterotrophic potential of organisms *in situ*.

Biochemical studies have been continued in an attempt to discover and isolate the enzyme responsible for the capacity of *Nitrosocystis oceanus* to oxidize ammonia. In a few promising experiments ammonia was oxidized and cytochrome-c reduced. This has encouraged continued pursuit of



Ichthyological studies.

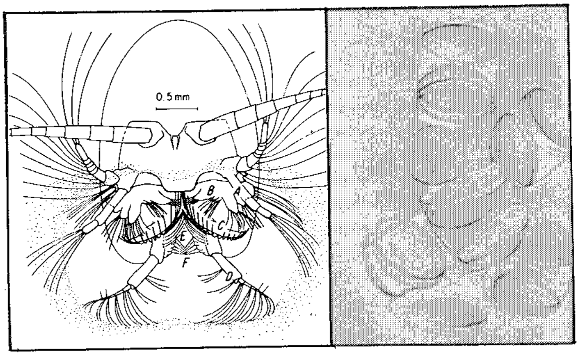
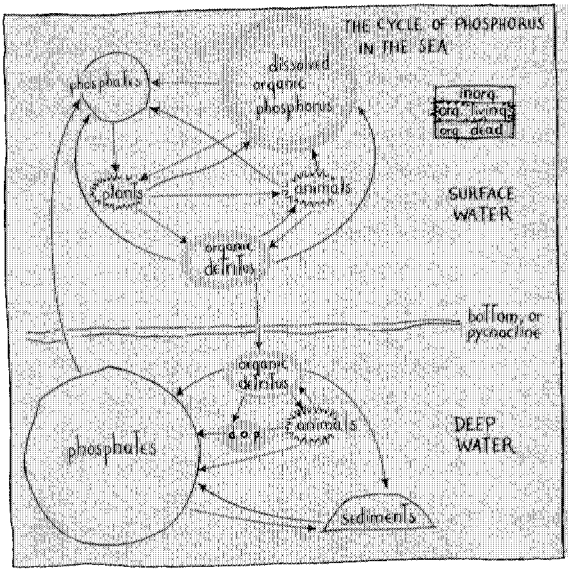
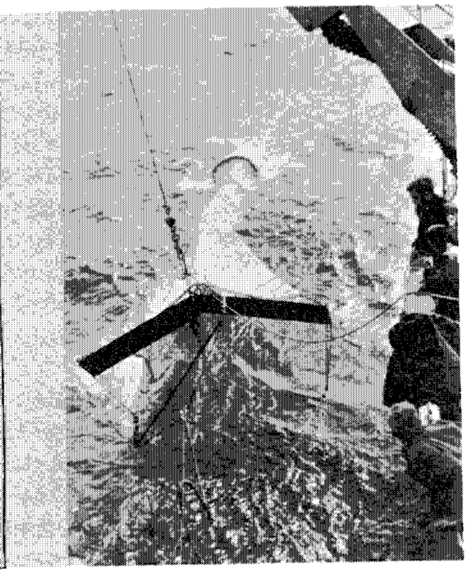


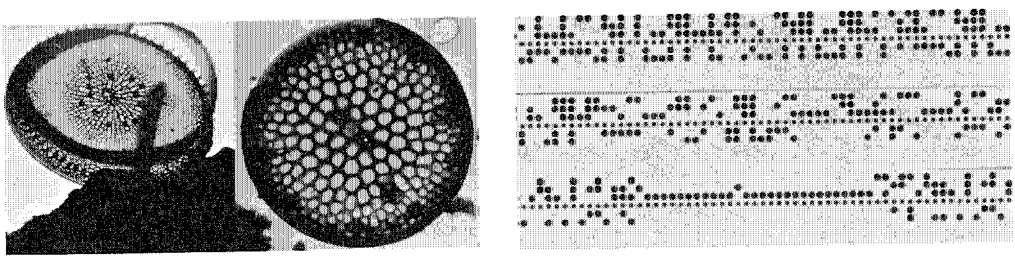
Diagram of Calanus hyperboreus creating water currents for feeding on the diatom Coscinodiscus.



The phosphorus cycle in deep and shallow ocean layers.



A new concept in closing plankton nets.



Electromicrographs of diatoms which may now be counted in the water with other small particles and organisms while underway. Later the data may be analyzed by computer.

an ammonia oxidase system. Recently, ecological studies have been initiated to discover new species of nitrifying bacteria and to determine the rate at which nitrification occurs in the ocean. The latter has been greatly facilitated by the development of new mass culture techniques in which it is possible to obtain essentially pure cultures of single organisms.

It has long been known that many photosynthetic organisms are obligate heterotrophs to a limited extent, such as their requirement for certain vitamins. The most important of these may well be vitamin B_{12}, which occurs in the ocean in concentrations of billionths of a part per billion and in at least three natural forms. Studies have continued to determine the specificity of marine diatoms toward each of these types. Thirteen centric diatoms isolated from different environments have now been examined in some detail. A few species give clear enough responses to each of these analogues of the vitamin to make the differential bioassay of natural waters possible. It is also clear that, while most centric diatoms have absolute requirements for this vitamin, only about half of the pennate ones have this requirement. On the other hand, most pennate diatoms require thiamine, while only one centric species is known to require it.

Invertebrate Zoology

During 1964 a study of North Atlantic epi- and bathypelagic copepods was completed and a comparable investigation initiated of Western Indian Ocean copepods. As a result of the Atlantic work three new genera and seventeen new species were described and a great deal of information obtained on both the vertical and spatial distribution of these organisms. The Indian Ocean studies were undertaken not only to describe the species present, but also, by comparison with Atlantic Ocean species, to determine how widely distributed the bathypelagic forms are and the extent of intraspecific variation found in those common to both oceans. Of the seventeen new species described from the Atlantic, nine have also been found in the Indian Ocean. From studies thus far completed, it appears that most bathypelagic copepods are very widely distributed, a point of some dispute in the literature.

Studies of the feeding behavior and energetics of food conversion by marine copepods have continued. A great deal of information has been obtained on the mechanisms by which *Calanus hyperboreus* and *C. finmarchicus* capture their food. This is accomplished not only by their ability to remove unicellular algae from suspension by filter-feeding but also by "encounter" feeding whereby larger particles are ingested after physical contact. Such particles are seized by coordinated effort of the second maxillae and maxillipeds. Not all individuals capture their prey with equal facility—a great deal depending upon their earlier diet. Animals conditioned to large particle feeding were more deliberate and more likely to ingest large particles than animals conditioned to removing small cells by filter mechanisms. Comparison of respiration to filter-feeding rates indicates that natural phytoplankton populations are seldom sufficient to sustain the animals but a mixed diet of phytoplankton and larger particles may meet this demand.

Investigations of the distribution of benthic organisms have been extended to include shallow waters along the shores of the Indian Ocean in addition to the abyssal depths of the North Atlantic. An epifaunal sled has been constructed and used with success in the Sargasso Sea. Samples obtained by surface skimming in this manner were dramatically different from infaunal studies. A graphic method of measuring faunal diversity has been developed in which a curve is drawn relating the number of species to be expected from a given number of individuals. This permits comparison of samples of different sizes from different regions. Since the points for any given environment are restricted to its own narrow sector of the graph each environment appears to have a unique number-species curve. This lack of randomness implies biological organization, the nature of the organization being different in different environments.

Studies of marine invertebrate larvae has been greatly enhanced by success in maintaining several species of gastropods and sipunculids alive in culture. Thus it is possible to determine the identity of unknown larvae by growing them through metamorphosis until an identifiable form is reached and also to tell something about the length of their larval or free floating life. A large number of samples have been collected from the North Atlantic, and the finding in these of a number of larval forms in the Gulf Stream and throughout the North Atlantic drift provides evidence of the trans-oceanic transport of these species.

Fishes

The past year has proved most successful in terms of the numbers of large pelagic fishes tagged and recovered. Nearly 4,000 fish were tagged and the total of 213 returns far exceeds the previous records of 75 in 1963 and 48 in 1962. A pattern of movements typical of several species has begun to emerge. For example, returns on bluefin tuna and skipjack showed short local movements and will be of value chiefly for estimates of population size and mortality. On the other hand returns from white marlin indicate a distinct migratory pattern. Specimens tagged off Maryland were recaptured off Cuba. Others showed movements from the Straits of Florida into the western Gulf of Mexico and a rapid early summer migration from North Carolina to the southeast part of Georges Bank. Returns for greater amberjack were again numerous. While the majority showed little or no local movement, two revealed migrations longer than have ever been recorded for this species, one covering almost the entire south and east coasts of Florida and the other from Jacksonville, Florida to the vicinity of the Isle of Pines, Cuba.

Investigations into the systematics and internal morphology of tunas and swordfish has been greatly facilitated this past year by the installation of soft and hard x-ray units. Using these techniques studies are now nearing completion of species identification of larval and juvenile tuna by contact microradiograms. In addition a histological study of the two-chambered air bladder unique in 5 of the 6 species of tuna has been carried out. The gross and microscopic morphology of these air bladders is being compared with the uncomplicated air bladder seen in other pelagic fish.

The systematics of rays and skates also continues to receive attention. Collections of skates from the sub-antarctic region and from the Gulf of Mexico-Venezuela region have been obtained this year and provide additional information for a long range study of the zoogeography of these fishes.

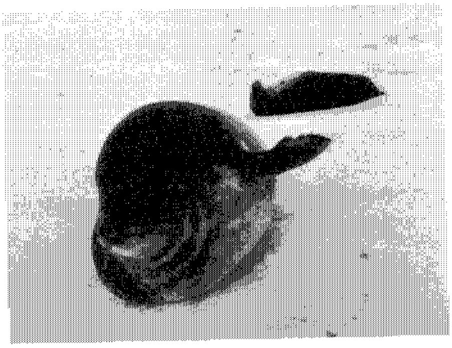
Biophysics and Physiology

Several years ago it was experimentally demonstrated that bubbles rising through a water column concentrate dissolved organic matter and carry it to the water surface. Upon the collapse of the bubble, forces exerted upon the organic film by lateral compression cause these compounds to be transformed into particles. This process may help explain the paradox that primary productivity alone does not appear to provide sufficient food to support existing zooplankton populations. Since particles should be more abundant at the site of surface convergences, it is likely that zooplankton abundance will also be greater in these areas. The development of an *in situ* particle counter coupled with a temperature digitizer has made it possible to detect these convergences as well as obtain counts of the particles from a rapidly moving ship. Preliminary data demonstrated that the plankton is probably distributed in clusters which are in some instances correlated with surface convergences.

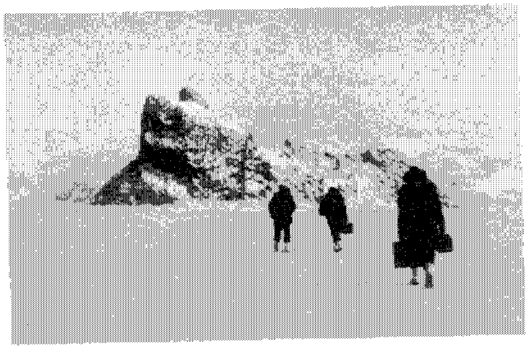
During the past year an investigation of the role of light in the ecology of the sea was extended. Great differences in the transparency of water in different oceanic regions has been demonstrated. As a consequence, considerable variation exists in the depths at which plants can photosynthesize and at which animals can carry out photic responses. In the clearest waters it is estimated that fishes and perhaps some invertebrates can detect daylight at depths as great as 1000 meters. Sensitive photometers are in use which are capable of detecting luminescent flashes and, by adequate shielding from incident light, these measurements may be carried out during the day as well as at night. It has been demonstrated that the amount of flashing varies with locality, depth, and time of day. The diurnal vertical migrations of pelagic populations are closely correlated with changing light conditions. In certain instances more flashing was recorded within the scattering layer than above or below it, particularly during periods of rapid migration.

Spartina, a rooted plant of fresh water ancestry which has adapted to the salt water environment, commonly lives in anoxic muds. It was found that oxygen is supplied to the roots through gas spaces running from the leaves down through the stem. Calculations of diffusion rates based on the size of the gas spaces and measured gradients in the plants agreed with measured rates of gas transport through the intact plant. Mechanisms by which this plant regulates its salt and water balance were also studied. It was demonstrated that sea water salts are excluded at the roots. Those salts which are transported to the leaves are secreted by special glands, making it possible for the plant to transpire without building up internal concentrations of sodium chloride.

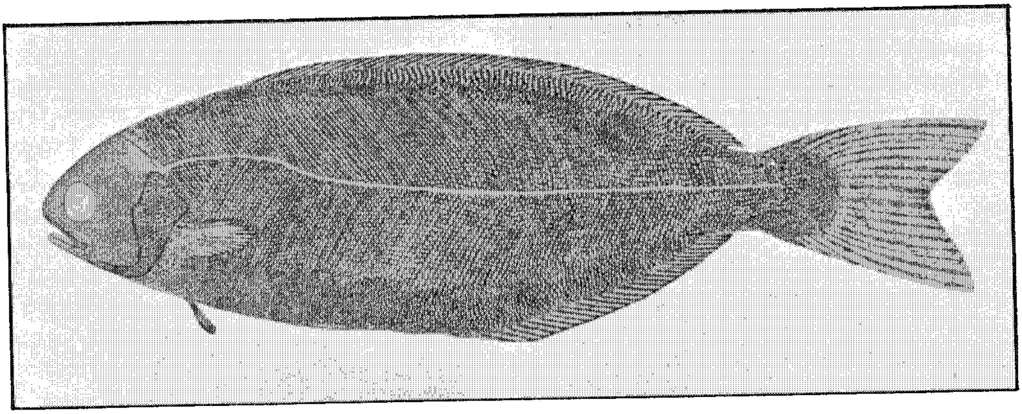
Work has been completed on the thermal physiology of several small species of marine mammals. Telemetering gear was developed with which the temperature and



Weddell seal (Leptonychotes weddelli).



Razor-back, McMurdo Sound, near the seal colony (see page 44).



Adult Schedophilus medusophagus.

heart beat of the animals could be monitored. On diving, a slowing of the heart beat occurred in the harbor porpoise, Greenland seal, harbor seal, bottle-nose dolphin and pilot whale. During the slow phase, however, the animal can apparently induce extra heart beats at will. Earlier experiments were repeated demonstrating that the metabolic heat production of these animals is two to three times higher than comparable sized land mammals.

The thermal tolerance of benthic marine invertebrates has been investigated in order to determine the role of temperature in explaining the zoogeographical distribution of these organisms. In general, thermal tolerance agrees reasonably well with the highest summer monthly mean temperature at the southern limits of their ranges. Best agreement was found for shallow water organisms. Intertidal species show poor agreement, undoubtedly due to the erratic temperature fluctuations they are exposed to in nature.

JOHN H. RYTHER, *Chairman*
DAVID W. MENZEL,
Assistant Chairman

Department of Chemistry and Geology

Geology of the Continental Shelf and Slope

During the second full year of this joint program with the United States Geological Survey the topographic studies of the Atlantic Continental Shelf and Slope were completed, and a model based on the contours was constructed as shown in the accompanying figure. Nearly 1,000 surface samples were collected and about 2,500 kilometers of "sparker" lines were run during the 1964 cruises of the GOSNOLD. The field program in 1965 will concentrate on the lithology and structure.

The Continental Margin from Nova Scotia to the Florida Keys contains many different topographic irregularities. The glacial erosion and deposition which occurred northeast of New York produced an irregular surface on the Continental Shelf and built up a shallower than usual continental rise. From New York to Cape Hatteras sub-aerial erosion on the shelf followed by submarine erosion deeply indented the continental margin. South of Cape Hatteras the topography is controlled by carbonate deposition.

The sediments on the ocean floor were contributed to the ocean by glaciers, rivers, organisms, and authigenic precipates. There appear to be two distinct generations of deposits: present-day sediments and those that are relict from the time that the ocean began to transgress the continental shelf at the end of the last glacial period about 20,000 years ago. The older sediment is coarse grained, iron stained, and solution pitted. It contains shells of ancient near inter-tidal oysters in places as deep as 90 meters. A geological map of the continental shelf and slope shows that Pliocene and Miocene strata dominate the shelf, the upper part of the slope, and the Blake Plateau. Lower on the slope are occasional outcrops of Oligocene to Middle Cretaceous strata. Within the Gulf of Maine are outcrops of Eocene to early Paleozoic rocks, some of which are igneous. Other studies being carried out in this program include the mineralogy and texture of the sediments, the composition of gravel and sand size fractions, the mixing of fresh and salt waters along the coast, organic contents of the sediments, and the distribution of Foraminifera, Ostracoda, and microbenthic fauna on the shelf and slope. In addition analytical facilities are being set up to determine the distribution of major and minor elements in sediments and their interstitial waters. A direct reading emission spectrometer recently acquired by the department under an Atomic Energy Commission Contract will be used for this work.

Coastal Hydrodynamics

This project is concerned with determining the characteristics of breaking waves. Measurements of the horizontal component of velocity has enabled breakers to be classified into three groups based on differences in depth of breaking, wave period and wave phase. These are defined as symmetric, asymmetric, and very asymmetric. The differences in the velocity fields suggest that breakers may be further characterized by one or several vortex systems.

Coastal Geology

These studies have attempted to establish boundary conditions for the dynamic studies. Most successful was the work on outer Cape Cod which showed that a coast has two fundamentally different bottom profiles. One of these, the profile of the sea floor as seen by an echo sounder, is related to the day to day or even hour to hour sea state. The other profile, on which the loose sand lies, is an erosion profile related to an unknown combination of overall sea state and it probably maintains its geometrical shape from year to year. An attempt will be made to relate this geometry to measurable sea state parameters such as wave height or length, amount of storminess, etc. If the behavior of this profile can be predicted it will be possible to advise engineers about many problems where sediment volume is serious.

Fossil Microplankton

Studies of the nature and distribution of late Tertiary and Quaternary dinoflagellates have been continued on sediments from the Yucatan Basin, the Cariaco Trench, and the experimental Mohole drilling on the Guadalupe site. All three areas contained interesting assemblages of dinoflagellates including many new species. Some species from the Yucatan Basin which were known previously only from the Quaternary were also found in Miocene sediments of the Mohole, thereby extending their known age range.

During the initial phases of this program it is planned to make a general survey of fossil microplankton distributions in deep sea cores from various parts of the world. This will provide a framework of the distribution of post-Paleozoic species which can then be used for more detailed stratigraphic comparisons in specific areas.

Gear Development

During the past year a free-falling corer was completed and successfully tested. This is a device which is dropped at the surface free, falls to the bottom, takes a gravity core, then releases its ballast weight and floats to the surface with the core, signaling its position with an electronic flashing light. The advantages of this device are that samples can be taken without interrupting other operations on the ship or requiring the ship to stand by for a long period of time as with conventional coring rigs. On cruise 44 of the CHAIN 21 cores were obtained in 24 coring attempts.

Other gear developments included positive action valves for gravity corers, which yield more undisturbed tops on cores; a recording tensiometer which gives better control of the approach to bottom contact in dredging and coring and a recording, pressure actuated, opening and closing device for plankton nets which was used successfully at depths down to 1,000 meters. A particularly useful device on CHAIN 44 was the radar reflecting moored buoy designed by C. E. Parker. This unit has been greatly improved over the past few years, so that it is now possible to make closely spaced survey lines over fine structures such as are associated with the Mid-Atlantic Ridge.

Radio Isotopes

Water samples for the analysis of fallout radioisotopes are now being collected in the Atlantic by both U. S. and European weather ships. In addition merchant ships are collecting samples along the equator, in Barbados, and the Azores. Large volume water samples in vertical series from surface to bottom were obtained at several stations during cruises 9 and 13 of ATLANTIS II and 44 of CHAIN. In addition collections of plankton were made for the determination of fission products. On CHAIN 44 about 35 cores were taken to ascertain the vertical distribution of radioactivity in sediments.

Vertical profiles of strontium-90 concentration continued to show that fallout to the Atlantic Ocean has been from two to ten times greater than on land at comparable latitudes. Cerium-144 continues to be the dominant fission product in the gamma spectra of plankton and of sediment samples. Certain elements such as antimony-125 are found concentrated in the sediments but are absent in the overlying water. This indicates they leave the water column as rapidly sinking particulate material.

Procedures have been developed for the flame spectrophotometric analyses of calcium, strontium, barium, cesium and potassium. The use of charged particle activations in preference to neutron activations is being investigated for the radiochemical measurement of stable isotope ratios. New approaches are also being used to unravel the contributions of individual elements to the complex gamma ray spectra obtained from many samples. During the International Indian Ocean Expedition of the ANTON BRUUN a series of uptake experiments were made using radioactive cobalt-58 and cerium-144 with freshly collected plankton. The specimens are now being sectioned and autoradiographed to provide a better understanding of the uptake of fallout isotopes by plankton.

Trace Metal-Organic Interactions

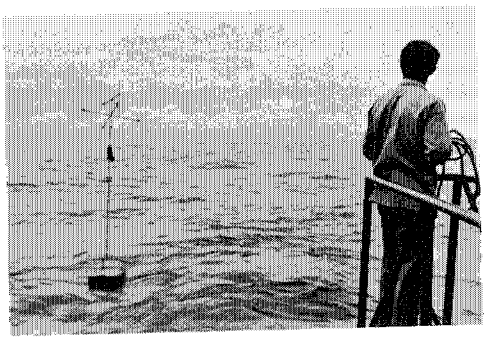
Both zinc and cobalt when complexed with amino acids are taken up by montmorillonite clays. The binding of the monovalent zinc glycine complex is as strong as that of the divalent zinc ion. Some elements are also strongly adsorbed by clays saturated with organic compounds. The adsorption of manganese is three times greater on clays saturated with amino acids compared to untreated clays.

Organic aggregates can be formed from dissolved organic matter in sea water by bubbling. The possibility of incorporating trace metal ions in these aggregates was studied by bubbling filtered sea water with trace levels of zinc-65 and strontium-89. The amount of metal uptake was negligible. However, the problem is still being investigated since the organic matter in this initial study may not be representative of that available in all sea water samples at all seasons.

Chitin Synthesis

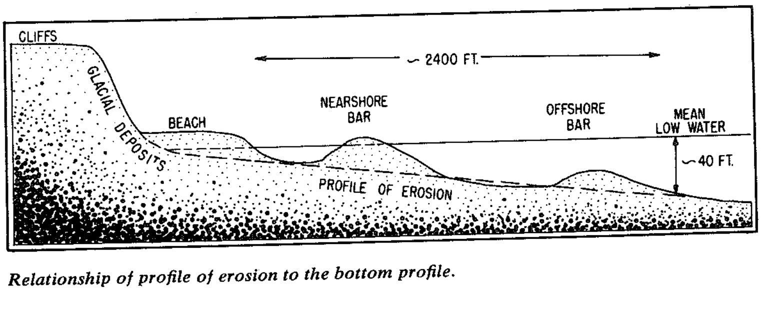
The synthesis of chitin from glycogen in insects has been defined as involving eight enzyme catalyzed reactions. A similar possible pathway is now being investigated in Crustacea. The presence of chitin synthetase, the most important enzyme, has been demonstrated for the first time in Crustacea and a number of factors affecting its activity have been investigated. Some prelimi-

Model of the bottom topography of the continental shelf and slope off the east coast of the United States.

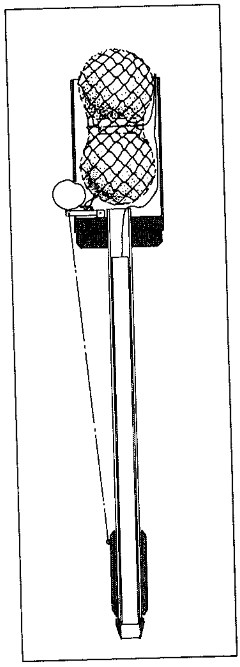


Radar reflecting buoy moored at sea.

Launching radar reflecting buoy over the side of CHAIN.



Relationship of profile of erosion to the bottom profile.

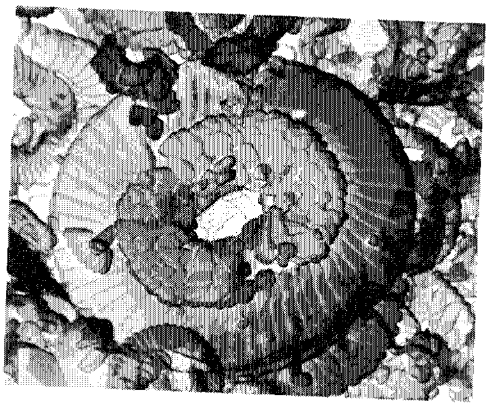


Section through the free-falling corer showing glass floats.

nary work has also been done on two other enzymes, glucamine transamidase and pyrophosphorylase. These three enzymes are among the most important and are being studied most intensively through the intermolt cycle of the Crustacea.

Shell Morphology

Changes in the size and complexity of the shells of gastropods of the same species over short geological periods have been interpreted to be the result of environmental changes such as an increase or decrease in the salinity of the surrounding water. Studies of the amino acid distributions in the proteins of these various forms have indicated that the mechanism of shell alteration first involves the loss of certain acidic and basic amino acids in the protein structure of the shell. The loss of these amino acids leaves molecular holes in the proteins and these are filled by mineralization. As "evolution" progresses the shell proteins become more and more effective mineralizers, so that the more advanced forms contain very little protein compared to the more primitive forms. Other fossil organisms will be investigated to determine if the change in acidic and basic amino acid distribution is a common phenomena associated with alterations in shell morphology.



Electron micrograph of coccolith.

Hydrocarbons in the Sea

The hydrocarbon assemblage of mixed marine zooplankton from the Gulf of Maine has been studied in detail. In addition to pristane, previously reported, a large number of olefinic hydrocarbons in the C_{19} to C_{21} range have been isolated. The C_{19} olefins include mixtures of mono-, di-, and triolefins all with the carbon skeleton of pristane. Four isometric C_{20} diolefins have been isolated and one C_{21} olefin with six double bonds. The latter hydrocarbon appears to be related to the C_{22} hexaenoic acid which has been isolated from menhaden and other fish oils. Further work will determine the fate and approximate half lives of these hydrocarbons both in the food chain and in the sea water. In view of the instability of the highly unsaturated hydrocarbons it is doubtful if many of these polyenes will pass unaltered through the marine food chain.

The recent discovery of organic phosphorus compounds containing a carbon-phosphorous bond has led to a search for such compounds in marine invertebrates. The sea anemone *Metridium dianthus* was found to contain 2-aminoethylphosphonic acid in both its proteins and lipids. In the phyla Coelenterata and Mollusca this compound may account for as much as 50% of the total phosphorus of the organisms. The full biochemical and geochemical significance of these organic phosphorus compounds remains to be established.

JOHN M. HUNT, *Chairman*

Department of Geophysics

Interest in the ocean as a medium for the transmission of sound has continued to be predominant in the program of the department during 1964. Nevertheless, intensive and diverse programs in submarine geology and geophysics, physical oceanography, and submarine bioacoustics have been pursued in the North Atlantic and Indian oceans, in the Caribbean, Mediterranean and Red seas, and off Antarctica. Attention has been chiefly focused on

(1) the acoustic structure and temporal changes of the deep water between Bermuda and Puerto Rico.

(2) the geological structure and composition of sediments and shallower rocks of the lithosphere in the Indian Ocean, in the Mediterranean and Red seas, and within the Puerto Rico Trench.

(3) the effect of mass distribution within the Earth on local gravity in these same regions.

(4) the acoustic properties of the ocean floor and underlying strata in nearly all areas visited.

(5) the behavior and distribution of deep scattering layers and their faunas in the open waters of the North Atlantic Ocean.

(6) the behavior and phonation of cetaceans and seals in Antarctica, New Zealand, and local waters as well as that of certain captive animals. Advantage has also been taken whenever feasible to accumulate additional data when traversing other areas.

Expeditions

The principal cruises were one of six months duration to the Indian Ocean on the CHAIN as part of the International Indian Ocean Expedition, one of six weeks to the Puerto Rico Trench on the ATLANTIS II, one of two months on the CHAIN including a visit to the Mid-Atlantic Ridge at 22°N and a geophysical survey of the Barracuda Escarpment east of the Lesser Antilles. A six weeks' voyage on the ATLANTIS II was also made to the Azores and back, principally to collect fish and to observe the deep scattering layers along the route.

Excellent seismic reflection, gravity, and magnetic profiles were recorded while crossing the Red Sea en route to Aden. In the Indian Ocean, our expedition took advantage of previous work of American and European (largely British) surveys to select meaningful transects of the Somali Abyssal Plain and the Seychelles-Mauritius Ridge. Under a variety of weather conditions, including eighteen consecutive days of tropical storm, the Western Indian Ocean was criss-crossed from Aden across the Somali Plain to the Seychelles, down the Seychelles-Mauritius Ridge to Mauritius and thence back again. During this period, seismic reflection, bathymetric, sea-surface temperature, gravity, magnetic and meteorologic measurements were obtained with the ship underway. Rocks were dredged at many points along the ridges traversed, and long continuous strips of overlapping photographs of the bottom were made. Some of these were over rugged, rocky terrain; others over fascinatingly complex patterns of sand ripples. The heat flow from beneath the ocean floor was measured whenever possible, and cores were taken with them. At one location, an oblique seismic-reflection profile was recorded to determine the seismic velocity of the shallow layers of sediment. Collections of granite were dredged near the Seychelles, where there are anomalous granite outcrops on the islands. Rock of this type rarely occurs except on continents.

Somehow, despite commitments for subsequent cruises, those who participated in the Indian Ocean work have made preliminary analyses of the data. These were presented before a meeting of the Royal Society of London early in December:

"It is considered that the northern portion of the Somali Basin is a deep sedimentary basin partially enclosed to the east by a submarine ridge from which alkaline gabbro has been dredged and to the south by partially buried abyssal hills.

"On the evidence from seven crossings of the Seychelles-Mauritius Ridge, it is proposed that the Ridge comprises two sections. The northern section, composed of nearly horizontally stratified rocks, extends from near the northern part of Saya de Malha Bank to the Seychelles Platform. The southern section is a linear, probably volcanic ridge, that extends from north of Mauritius through Saya de Malha Bank, and may continue as a subsurface feature to the northeast. The two sections abut near Saya de Malha Bank, forming a continuous topographic feature."

On the return, the eastern Mediterranean was criss-crossed for a brief survey with seismic reflection, gravity and magnetic techniques. Off Lebanon there were layers of sediment over a rough basement. The traverse south of Cyprus transected the prograded submarine slope of the Nile delta and another along a course to the northwest revealed complexly fractured deposits of layered rock to a deep, sediment-filled basin southeast of Rhodes. East of Sicily, cores were taken in a deep, flat basin covered with sediment, where their distribution suggests that it is in process of being filled by clastic sediments transported by turbidity currents. Photographs were made across a submarine canyon off southern Italy in an attempt to determine whether such currents were perceptible.

A detailed geophysical survey of the Ligurian Sea was made, where a principal zone of structural change from the ocean-like basin of the western Mediterranean to rocks of obvious European affinities had already been established. Here there are two major north-south striking faults. From seismic reflection evidence the areas between the two faults and also between the easternmost one and Italy are regions of deposition and subsequent folding.

In the flat basin of the western Mediterranean, similar profiles revealed structures that appear to be diapiric and could well be salt domes, if the intermediate rocks of the basin (a layer having velocity of about 5.2 km/sec) consist of sediments resembling those known in Italy.

Continuous seismic, gravity, and magnetic measurements were made between Monaco and Plymouth, England. Emphasis was given (1) to recording seismic reflections across a suspected major fault in Galicia Bank to delineate the principal structures there, (2) to the determination of the thickness of sediments beneath the abyssal plain in the Bay of Biscay and to the magnetic properties of seamounts there, and (3) to the survey of a synclinal structure extending westward from the English Channel. The latter had been examined previously in collaboration with British colleagues in the western approaches to the Channel. In 1960 this synclinal structure could only be traced by seismic reflection to about 100 to 200 meters below sea level, but their age and the types of rock were identified by comparison with cores. It is hoped that traceable reflections have now been recorded to depths two or three times that depth. Possibly even deeper horizons have now been detected — horizons previously detected by refraction.

The Mid-Atlantic Ridge and median rift was intensively examined for a distance of about 120 miles by means of a fine grid of echo soundings, by dredging rocks, and photographing the bottom. Heat flow measurements were unsuccessful because the probes could not penetrate the very rocky bottom.

The principal objective of a cruise of the ATLANTIS II to the Puerto Rico Trench was to cooperate with work aboard the French bathyscaphe ARCHIMÈDE in the Puerto Rico Trench, but the weather conditions limited participation to a search for suitable locations for dives of the submersible, to dredging nearly a ton of rock along the north wall, and to making seismic reflection profiles across the Trench. Both the seismic profiles and the rock sampled are similar to those obtained previously but nevertheless they provide valuable supplemental information about this complex geologic structure.

Observations during this cruise revealed that the shallow thermal front near 30°N had an associated change in deep water extending from the surface to well below the axis of the SOFAR channel. This structure corresponds with a pronounced, but unexplained, anomaly in hydrographic sections made in the early 1930's, which, with other related evidence, suggests that it is a permanent or semi-permanent feature of the North Atlantic circulation.

Additional sound velocity profile determinations were also obtained to learn more about the long-term stability of the acoustic structure over the ocean area between Bermuda and the Antilles. These indicated some change since the earlier survey in July and August of 1962.

Continuous underway geophysical observations (seismic reflections, gravity and magnetic field intensity) were obtained during a cruise of the CHAIN from Woods Hole to the Mid-Atlantic Ridge at 22°N, and thence to St. Thomas, V. I. The necessity for cruising at high speed and other instrumental limitations made these data less useful than those for other recent cruises. Nevertheless, much valuable information on the structure of shallow sediments and on the gravity and magnetic fields as well as some measurements of heat flow were recorded. A short gravity and magnetic survey, together with some seismic reflection records of the Barracuda Escarpment (east of Martinique in the Lesser Antilles) followed. This feature has been considered as a possible Mohole site.

Submarine Geology and Geophysics

The sedimentary structures on the Bermuda Rise, the Outer Ridge north of

Puerto Rico, and the continental shelf, slope, and rise south of New England have, over the years, been examined largely by means of seismic reflection profiles. Supplementing these there have been a series of refraction measurements of the earth's crust beneath the Outer Ridge, and several collections of rocks from the Outer Ridge–Puerto Rico Trench. As a result it appears that two major layered sedimentary series overlie rocks of intermediate compressional velocity (5.2 km/sec) here and there between the Nares Basin and the Puerto Rico Trench. These are interrupted by older protruding rock. Whether the protrusions are intrusions, relict relief, or the result of faulting is unclear. It does seem clear that the latest thick layer of sediments was deposited after most of the tectonic activity had taken place. The recent profiles across the north wall of the Puerto Rico Trench may reveal the succession in the deposition of the sediments and in the formation of the Trench.

A gravity survey of the Republic of Haiti was completed and reported upon as the first step in a considerably larger study around the Island of Hispaniola to delineate the major geologic structures of this portion of the Caribbean region.

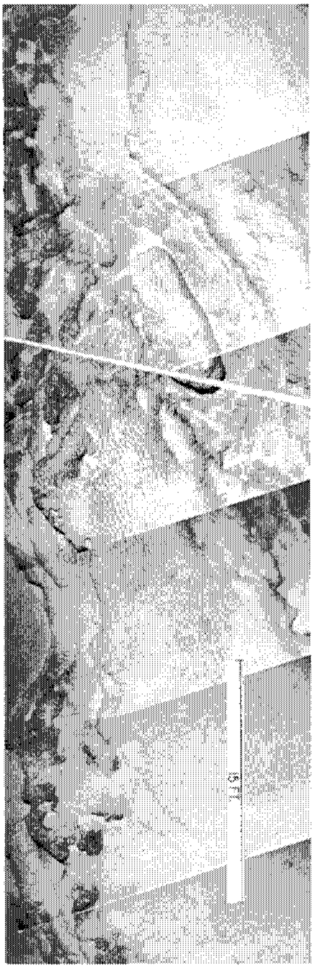
Internal Waves

Data from towed and fixed thermistors at 100-meters depth may in time reveal some of the basic energy transfer processes involved in ocean movements. Preliminary analyses indicate that the directional spectral density of thermal fluctuations obtained from towed transistors decreases roughly inversely with the square of the wave number in the wave-length range 300 to 6000 meters, but that the temporal frequency spectra from fixed thermistors for fluctuation periods between 40 and 1000 minutes varies roughly inversely as the square of the frequency.

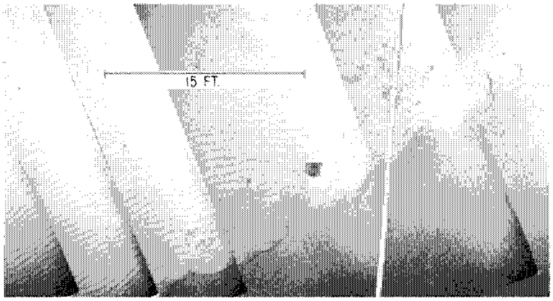
During the ATLANTIS II summer cruise internal waves were measured in the vicinity of Bermuda with a sound velocimeter, suspended in the main thermocline (425 fms). There was some indication that the 20-minute period internal waves were causing some slight motion of the velocimeter. To supplement these observations near Bermuda, a string of thermistors was towed in a star-shaped pattern and the temperature fluctuations were digitally recorded.

Sound Propagation and Reverberation

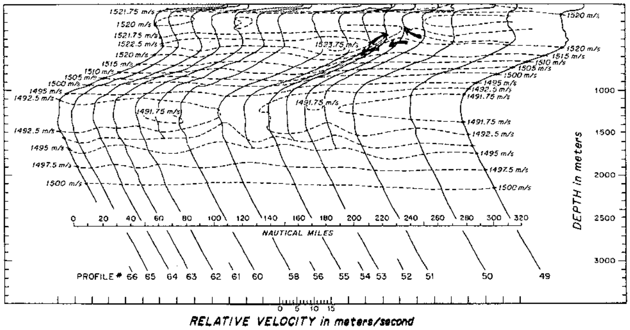
The propagation of sound through sea water is a sensitive indicator of water structure. In the recent past, interest at Woods Hole has centered on various aspects of propagation in natural horizontal sound ducts or channels in the open ocean. In addition to the well-known SOFAR channel (virtually worldwide) other sizable but smaller and less extensive channels are found at various depths within the top 1000 meters of the ocean. In some places two or more channels lie one above another. In 1960 and subsequently measurements have been made to determine the acoustical coupling between such channels. Detailed analysis of these results is continuing. The patterns of observed sound intensities are being compared with theoretical models based on the structure of the water observed by means of the thermistor chain or the sound velocimeter. Much of this year



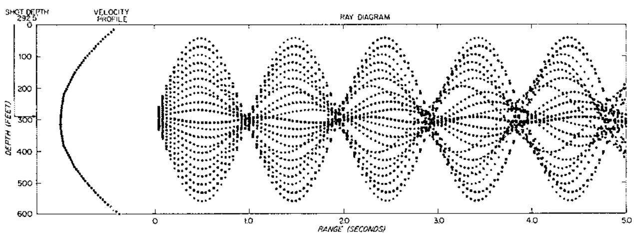
A mosaic of an outcrop of layered rock on the Seychelles-Mauritius Ridge, Western Indian Ocean.



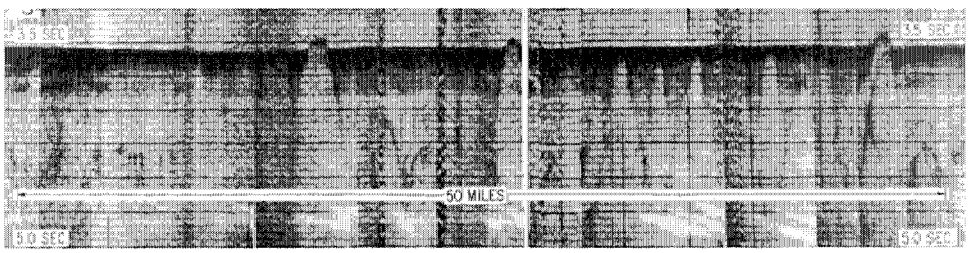
A mosaic of sand ripples on the flank of the Seychelles-Mauritius Ridge.



Contours of equal sound velocity superimposed on sound velocity profiles.



Ray diagram using idealized velocity profiles.



Probable diapiric structures in the Western Mediterranean Sea.

has been occupied with assembling programs (based on the models) for making computations of sound paths and intensities of the sound field.

Sound scattered by the rough surface of the ocean floor provides a means of measuring its shape and certain physical properties. In echo sounding, comparatively little use is made of the acoustical data provided since little more than local water depth is measured. The recent successes with seismic reflection profiling by this and other institutions has provided a rich store of information about sediments and rocks below the sea floor, but, again, little information is gleaned about the sea floor itself.

A program of measurement and analysis of sound scattering by the sea floor was initiated at Woods Hole a number of years ago for the purpose of understanding and making more use of this scattered sound. Extensive measurements of the sound of explosions scattered by the sea floor at various localities over several years in the North Atlantic have been analyzed to provide back-scattering coefficients as a function of the angle of incidence.

In some places where the sea floor appears flat the bottom reflection of the high frequency portion of the sound of an explosion is followed by a smooth decay in the average intensity of scattered sound which appears to follow Lambert's scattering law. There is a wide range in the scattering coefficient presumably caused by differences in bottom roughness or composition. In other places the decay of scattered sound is quite irregular, probably because of large scale topographic features nearby. Even a modest sample of data of this sort requires a major analysis program, which has been largely completed during the past year. This work was greatly facilitated by the use of automatic data reduction and analysis programs in the Institution's digital computer.

Natural Sounds in the Sea

Studies of sound production, principally of whales and porpoises, have long been an adjunct to the development of underwater acoustics. Recently these have included other marine mammals as well. A preliminary account of the underwater sounds of the Weddell seal (*Leptonychotes weddelli*) suggested many interesting questions in connection with these most remarkable sounds. Weddell seals, unlike other Antarctic seals, are non-migratory. During winter, the seas that they inhabit are completely ice-covered, save for small holes used by the seals for breathing. Do Weddell seals use underwater sound to orient themselves in food-getting and in returning to their air-holes under these difficult circumstances? It is hoped that the observations made in Antarctica in the fall will provide an answer. In addition, the sounds of a captive killer whale, *Orcinus orca,* and a captive manatee, *Trichechus latirostris,* were recorded. The former had not been recorded in the work here and the peculiar structure of the sounds of the latter has never previously been reported.

Sound Scatterers

The principal sound-scatterers of the deep ocean are mesopelagic fishes with swim-bladders, and an understanding of their geographical distribution in the North Atlantic should resolve a number of problems in underwater acoustics. What are the areas within which this fish fauna is homogeneous? What is the physical nature of the boundaries separating these areas? Do sound-scattering properties of an area correctly delimit areas of fish-fauna homogeneity?

A method for detecting such faunal boundaries based on fish collections taken over long oceanic transects, when applied to data gathered between the Romanche Trench and Bermuda, indicated that one exists in the southern North Atlantic (ca. 12°N). This coincides not only with the northernmost penetration of South Atlantic Central Water into the North Atlantic, but also a pronounced change in the 12-kcps sound-scattering occurred at the same point.

On the cruise of the ATLANTIS II to the Azores and back, the principal objective was to collect additional data to further clarify the questions asked above. In this connection, the trough southeast from the Grand Banks separating the two North Atlantic gyres was examined as a possible faunal barrier, chiefly by using a midwater trawl along two transects. Continuous echo-soundings of deep scattering layers were also recorded to accumulate more data in order to check the hypothesis that such faunal areas may be delimited from their sound-scattering properties alone. In addition, a novel midwater trawling gear was tested, simultaneous echo-soundings and tape-recordings of the clicks of diving sperm whales were made, and so-called American Scout Seamount was proven to be non-existent.

Of the 300 species of macrourid fishes described, the great majority live over the continental shelf, particularly in the subtropical and tropical parts of the ocean. Strangely enough, the abyssal species do not have drumming muscles on their swim-bladder. This sound-making mechanism is confined to males of slope-dwelling species. Another peculiarity of this family is that their larvae and postlarvae do not inhabit the surface layers as is characteristic of many other groups.

Bioluminescence

The bioluminescence of certain marine micro-organisms has a diurnal rhythm. Maximum activity occurs during hours of darkness, the minimum during daylight. This is true, not only at the surface in shallow coastal waters, but also throughout the euphotic zone of the deep ocean. Below the euphotic zone the diurnal rhythm seems to be feeble. During the solar eclipse in 1963 bioluminescing micro-organisms appear to have responded as if the sun were setting, then rising once more. In short, endogenous rhythms did not over-ride the exogenous factor of changing light.

Underwater Photography

Bottom photography as a method for studying the natural history in the deep ocean was used to describe the population density, diversity of species present and the habits of fishes in the Red Sea and the Gulf of Aden. A similar study was begun using the many fine photographs taken near the site of the sunken submarine THRESHER.

By using well-known photographic developments, it has been possible to obtain photomontages, consisting of hundreds of enlargements of a convenient size, revealing continuous strips of the ocean floor fifteen to twenty feet wide and a mile or more in length. Topographic detail can be scaled from individual stereoscopic pairs of photographs. Thus, large areas of the sea-floor can now be studied with a precision of a fraction of an inch. This new technique is one of the more exciting developments in oceanography in recent years.

Computers

Automation, both in data-taking and in data reduction and analysis continues to be emphasized. The development of an IBM 1710 control system on the CHAIN has continued and has now been augmented by a greatly expanded core memory and by random access disc recorders. This may be used as a recorder and automatic data reduction device, as a scientific log, and as an off-line general purpose computer at sea even while recording new data. Last year, gravity and magnetic observations were successfully reduced to an automatic routine, and navigation, echo soundings and some logging functions were undertaken with some human intervention. This year, echo soundings were recorded automatically and great progress was made toward automatic navigation where suitable navigational aids were available. A complete logging system was used during two long cruises.

Automatic, on-line reduction of seismic reflection observations and measurements of sound velocity in sea water have not yet been successfully programmed at sea. On shore, however, a vast store of digital computer programs has been created and tested for sound-ray tracing through complex water structures for long distances over a rough bottom, updating and reduction of gravity data to get free air and Bouguer anomalies, reduction of sound velocity data, reduction of reverberation data to scattering cross-sections, etc.

Thermistors

The thermistor chain, obsolescent because it cannot feasibly be made much longer than 300 meters, is being replaced by a faired cable. Thus, it is hoped to develop thermistors and several other types of sensors for towing in deep water to about 500 meters at speeds of up to 6 or 8 knots. This is known to be practical, but the exact depth and the speed is not known. New instruments were successfully tested during the year and a cable and snap-on fairing system worked. Temperature can now be recorded automatically and is compatible with digital computers. This system will feed its output directly to the computer on CHAIN and it also records the same data for re-play to a digital computer.

Signal to Noise Ratio

Theoretical investigation employing simultaneous filtering in space and time domains will, it is hoped, improve the signal-to-noise ratio of weak subbottom reflected signals obtained by continuous seismic reflection profiling. In principle, the method of filtering can preserve the signal wave shape but at the same time rejects the noise arbitrarily distributed in the temporal and spatial frequency domains. In addition to the radiated noise interference from the ship (which should be reduced using advanced filtering methods), a study to improve the design of a towed array of hydrophones is also under investigation to reduce flow noise.

J. B. HERSEY, *Chairman*

Department of Physical Oceanography

North Atlantic Circulation

To further our knowledge of the circulation of the North Atlantic it is unfortunately necessary to obtain observations in areas and seasons where it is almost certain that, to put it mildly, the going will be rough. One of these areas is the northern North Atlantic in late fall and winter and during 1964 members of this department found exactly that, "rough-going."

From January to May aboard the ATLANTIS II observations were made of the water masses and currents in that portion of the Gulf Stream System that lies in the western basin of the Atlantic to the east of the Grand Banks of Newfoundland. The oxygen concentration at all sigma-t surfaces was found to be substantially above the Sargasso Sea concentrations and these two portions of the System were separated by a trough of low pressure in the neighborhood of the Southeast Newfoundland Rise. These observations support the two-gyre theory, proposed by Worthington (1962), in which the main circulation of the North Atlantic is divided into a southern gyre, mostly confined to the Sargasso Sea, and a northern gyre extending northward from the Southeast Newfoundland Rise to latitude 52° N., and confined to the west of the 30th meridian. If this picture of the circulation is accepted, then it will be necessary to discard the term "Gulf Stream System" as inappropriate and misleading for naming the main circulation in the North Atlantic.

On this same cruise of the ATLANTIS II current velocity measurements were made in the Norwegian Sea overflow water entering the western basin through a gap in the Mid-Atlantic Ridge near 52° N. This deep overflow water was moving at rates of as much as 8 cm/sec. Dynamic computations using the direct current measurements and temperature and salinity data gave a volume transport of the 4.6 million m^3/sec flowing into the Labrador Basin through the gap.

In June and again in the "rougher" months of November and December the CRAWFORD was used to trace out the constantly changing path of the Gulf Stream in the area south and west of the Grand Banks. A new method was used to track the Stream; temperature and pressure sensors were towed at a depth of 200 meters at speeds around 7 and 8 knots, and these data plus the surface temperature were recorded continuously in the laboratory. The ship was headed so as to follow as closely as possible the horizontal temperature gradient associated with the Gulf Stream, at times following the "middle" isotherm (generally the 15° isotherm), at other times crossing and recrossing the gradient. On the June cruise, gradients of as much as 10°C in one kilometer were observed while the average speed of the surface current was close to 4 knots.

During November and December the pattern of the Gulf Stream meanders was much more complicated than what was observed in June; the gradients were generally less abrupt and the currents weaker. In the 33 days that elapsed between the November and the December cruises a large segment of the Stream moved 100 miles to the eastward.

In an attempt to measure the total volume transport of the Gulf Stream, hydrographic stations were occupied and direct, deep current measurements were made in the Stream from the CRAWFORD in October. The cruise was interrupted by the passage of two hurricanes, however, and the data obtained may not prove sufficient to show the volume transport at that time.

An analysis of surface velocity measurements collected at four locations in the Florida Current shows that eddy motions at the surface produce a transfer of kinetic energy from the eddies themselves to the mean flow. The production of mean kinetic energy by the eddies at the center of the current is sufficient to maintain the surface current against the dissipative action of lateral eddies along the edges.

Not all the studies of the North Atlantic circulation have been confined to the relatively intense western currents. A series of average monthly profiles showing the vertical temperature distribution in the upper 300 meters of the North Atlantic has been produced. Circulation patterns are indicated by the pronounced horizontal temperature gradients.

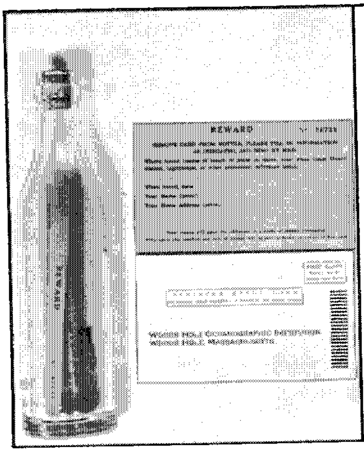
Two Consolan Radio Drogues, with the drogues at 1000 meters, were set out during the first week of June in the Sargasso Sea, 120 miles west of Bermuda. Consolan fixes from the buoys, up to the end of August, showed that they traveled closely parallel for 150 miles to the southwest and then diverged slightly (about 10°), still advancing to the southwest at about 18 cm/sec for another 150 miles. This type of current observation together with observations of the surface thermal fronts and associated currents in the southern Sargasso Sea, although extremely interesting, have yet to be tied to a scheme of the general circulation in the western North Atlantic.

Finally the surface flow on the continental shelf between Newfoundland and Florida has been inferred from drift bottle data for the period 1948-1962. The results of this lengthy and very informative piece of research form Folio 7 of the American Geographical Society's *Serial Atlas of the Marine Environment.*

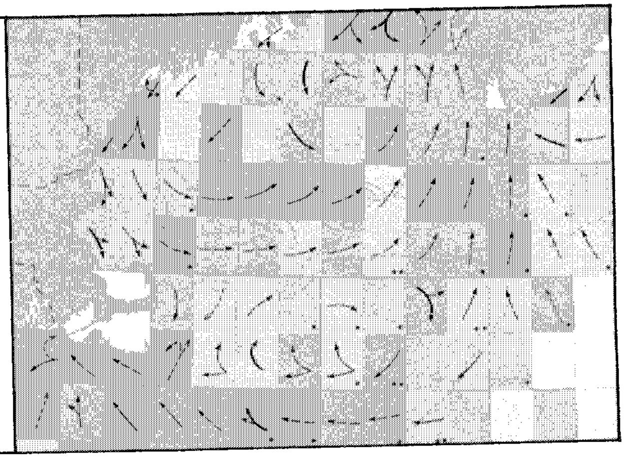
Indian Ocean Currents

An examination of the circulation in the northwestern Indian Ocean during the southwest monsoon, on the basis of hydrographic sections made from the ATLANTIS II in 1963, suggests a strong response of the upper layers to the wind. Geostrophic currents across latitudes 5°N. and 10°N., computed relative to a depth of 1000 m, show alternating bands of northward and southward moving water. The total northward and southward geostrophic transports are of the order of $50 - 100 \times 10^6 m^3/sec$, considerably larger than anticipated, and comparable to transports estimated for the Gulf Stream and the Kuroshio. Direct measurements of vertical shear on the 5°N. section are in agreement with the geostrophic calculations.

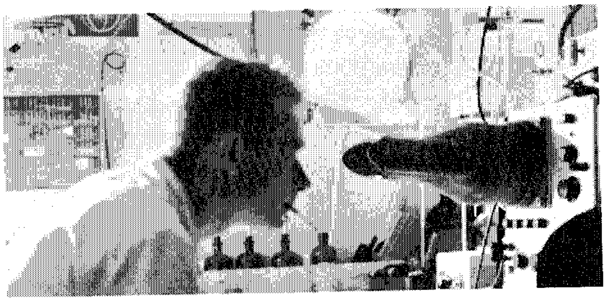
A more detailed survey of the currents near the Somali coast during the same time of year was made in 1964 on a cruise of the R/V ARGO organized jointly by the Massa-



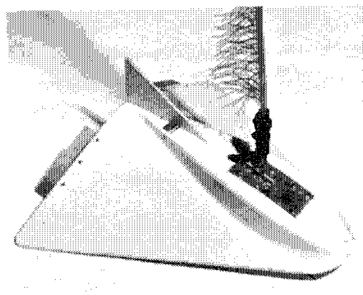
Drift bottle and card used to report its lo cation when found.



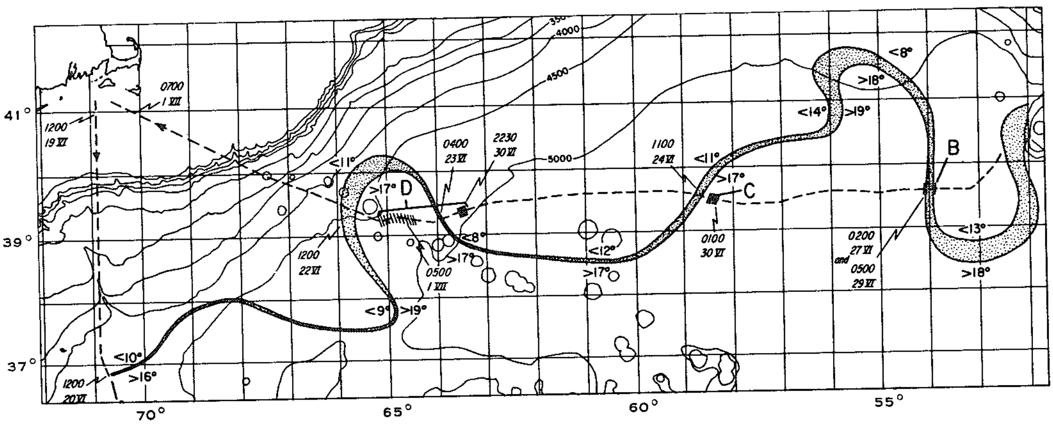
Surface drift in May as determined by bottle records.



Taking a bearing from CRAWFORD on a deep neutrally buoyant float.



V-fin with haired fairing used to monitor 200-meter temperature.



Position of the 200-meter temperature gradient as observed from the 20th to the 28th of June 1964.

chusetts Institute of Technology and the Scripps Institution of Oceanography, with participation by members of this department. Hydrographic sections and direct current measurements were carried out in cooperation with the R.R.S. DISCOVERY. Strong surface currents, up to 5.2 kts, were observed on the western edge of the northeastward-flowing Somali Current.

Atlantic Equatorial Currents

Current meter measurements and serial observations of temperature, salinity and oxygen obtained by the CRAWFORD and the CHAIN during EQUALANT I are greatly enlarging our knowledge of the equatorial currents. These include the North and South Equatorial Currents, the Equatorial Countercurrent (around 4° to 10°N.), the Equatorial Undercurrent at the equator and what appears to be another Equatorial Countercurrent around 5°S.

The major source of the high salinity, high oxygen water which is characteristic of the core of the Equatorial Undercurrent is the area in the Southern Hemisphere just east of the bulge of Brazil. The Equatorial Countercurrent in the North shows some influence from this source as well.

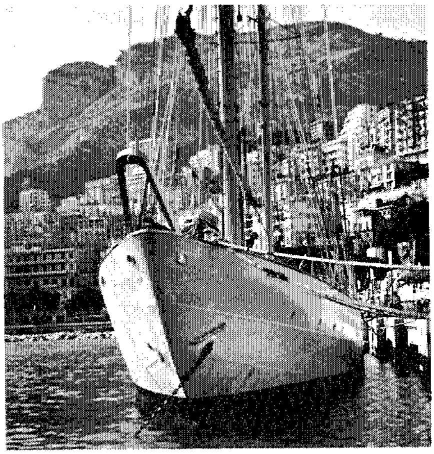
The current meter measurements showed eastward velocity components of up to 69 cm/sec at a depth of 80 meters at the Equator. At most stations, low speeds and random directions at a depth of 155 meters indicated that this level is close to the bottom of the Undercurrent. At 405 meters depth, the measured currents were generally flowing to the west. So far, attempts at calculating the current structure at the Equator from the pressure field, so as to fit it with the currents as measured with the meters, have not been very successful.

The Mediterranean and Red Seas

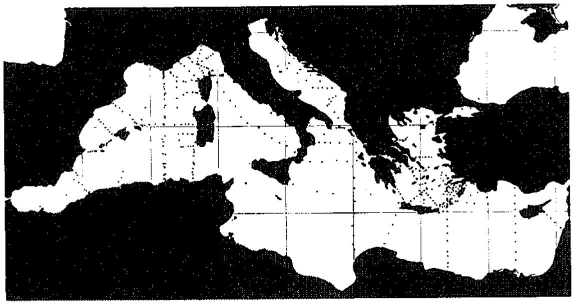
Rounding out the material for an atlas of the Mediterranean Sea, a series of volumetric T/S diagrams have been constructed. These diagrams show the volume distribution of various water masses for discrete sections of the Mediterranean based on data acquired during certain Woods Hole cruises to the area.

Observations in the Red Sea by the ATLANTIS II, the British Research Vessel DISCOVERY and the German Research Vessel METEOR have brought to light a phenomenon of considerable interest to oceanographers. At 21°17.2′N., 38°02.5′E, at depths between 2000 and 2200 meters, water with a salinity above 300‰ and a temperature of 44.5°C was found. In no other area of similar depth in the Red Sea has this anomalous water type been observed.

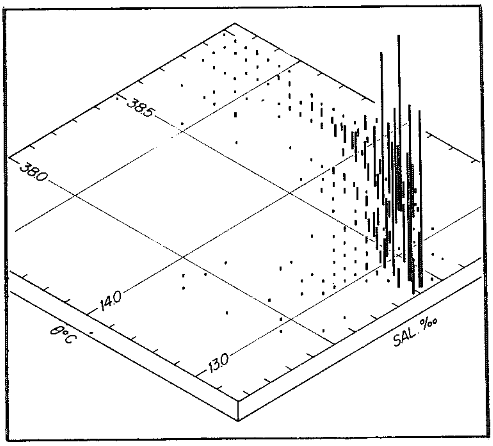
When ATLANTIS II was enroute to the Indian Ocean in July 1963, hydrographic and meteorological data were obtained in the Great Bitter Lakes of the Suez Canal. Their salinity is now about 46‰, and these data, together with data supplied by Professor Morcos of Alexandria University show that the salinity has been decreasing only slightly in recent years. Shortly after the canal was opened, however, the Bitter Lakes salinity was 68‰, and Wüst (1934, 1937) attributed this high value largely to the dissolution of salt beds. A heat budget has been prepared showing that daily evaporation in July can exceed the requirements for increasing the salinity of inflowing Red Sea water to that of Bitter Lakes water. It is possible that the salt beds have either



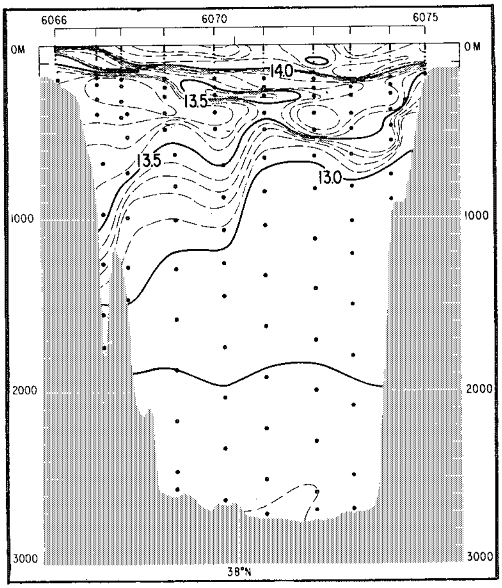
ATLANTIS in Monaco.



Plot of stations used in the Mediterranean Sea atlas.



Volume distribution of various water masses.



Temperature profile from Sardinia to Northern Africa.

leached out or have sealed over and do not now contribute to the characteristics of the Bitter Lakes.

Instrumentation

In several instances oceanographic instruments are being developed to meet specific research needs in this department. Besides the towing gear used in the Gulf Stream work mentioned above, and the development and expansion of the Consolan Radio Drogue system used in the Sargasso Sea, considerable effort has been expended to increase the effective range of Swallow floats, and in the conversion of the *in-situ* salinometer to a conductivity-temperature-depth instrument. In September four of the modified Swallow floats were set out about 100 miles north of Bermuda and a maximum signaling range of 16 miles was achieved. Another significant advance was the use of a rectangular array of three towed hydrophones to fix the positions of the floats from a ship underway; with the ship moving at 10 knots through a moderate sea (sea state 4), 4-kc. float signals were recorded at a range of 10 miles. This new method of locating the floats should greatly facilitate deep current measurements.

Work on the conductivity salinometers has led to investigations of the dependence of the electrical conductance of sea water on pressure and the concentrations of dissolved carbon dioxide, oxygen and nitrogen. Since the precision of existing laboratory salinometers is not better than 0.002-0.003‰, and that of *in-situ* salinometers even less, the effect of varying concentrations of oxygen and nitrogen in sea water is not of much concern for the conductometric measurement of salinity; the carbon dioxide effect, however, while small, is large enough to be taken into consideration.

Rapid Data Processing

In several areas high-speed computers are proving useful both in making possible analyses of observations which would have been prohibitively time-consuming without them, and in greatly accelerating basic, routine data-reduction. Since moored current meters must necessarily collect thousands of measurements on each record, processing these data with a digital computer is unavoidable. A system has been developed which produces a usable digital output from the film records, and in order to make current meter observations generally available, a summary of the data from about fifty records is being compiled. As part of the first stage of a project for studying the spectra of the current measurements, a special-purpose computer program has been written to cover an extremely wide frequency range. Such a program for exploring the records for possible spectral peaks is necessary, since the large amount of data from even a single film could be used to define frequencies over a four decade range.

Analysis has been completed of the frequency and directional spectra of several series of temperature fluctuations due to internal waves on the near-surface thermocline. Observations were made at a depth of 100 meters, on the Atlantic equator and at a location 110 miles northwest of Bermuda.

Computer programs have been written to process original hydrographic-station data, and produce as output tabulations of all observed quantities and computed values of pressure, sigma-t, potential temperature, specific volume anomaly, and dynamic height. Optional provision is made for interpolations of dynamic height and calculation of geostrophic velocity and transport between hydrographic stations. A photo reduction of the typewritten output for each station replaces the typed or handwritten reduced data card formerly placed on file.

FREDERICK C. FUGLISTER, *Chairman*

Department of Theoretical Oceanography and Meteorology

Transport processes are the heart and muscles of the ocean and of the atmosphere as dynamic systems; transport or flux of momentum, of heat, of chemical constituents, of electric charge, and, last but not least, of water in its various states of aggregation going in horizontal and vertical directions in each medium, and across the interface. To be able to understand these processes, laboratory and computer experiments are performed and field studies undertaken. Theoretical models are synthesized, at times complicated, to represent a number of interacting processes, at times simplified to the verge of the unrealistic, to capture the essence of a particular dynamic regime.

Indian Ocean

Within the framework of the International Indian Ocean Expedition members of the meteorological group worked out of Bombay, India, for two one-month periods, one during the Northeast, and one during the Southwest monsoon regime. Objectives were the direct measurement of vertical heat and momentum fluxes as well as the charting of flow conditions both on the seasonal-oceanic and on the diurnal-coastal scales. From the preliminary reduction of data, the outstanding finding is that the cold upwelling waters off the Somali coast cause a strong, low-level-wind jet to form. Drastic reduction of surface friction due to thermal stabilization of the boundary layer seems to be the crucial factor in this phenomenon.

Aruba Project

The first phase of an intensive effort to study the air-sea boundary layer, with particular reference to the effects of the gradual development of the sea state with fetch, was carried out in Aruba in the Dutch Antilles. An instrument system comprising several telescoping towers for shallow water use, and a stable buoy for measurements in deep water, received its first extensive field trial. Data reduction is proceeding, and additional instrumentation (in particular for wave studies) have been developed for a second trip in 1965.

Volcanoes and the Sea

A rare coincidence occurred, shortly after the publication of laboratory results describing an electric charge separation (discussed in the report for 1963), when a volcanic island was born south of Iceland. It thus provided a large-scale test of the applicability in nature of the suggestion that the violent contact zone between molten lava and sea water is a region of intensive production of the positive space charge. Electric field measurements in the vicinity of steam clouds produced by the lava stream pouring into the sea were entirely compatible with the intensity of the charge separation expected on the basis of the laboratory work. Further work to elucidate the mechanisms of the surface interaction is in progress.

Radiation Thermometry and Marine Fogs

Steam fog formation is a manifestation of the vertical flux of heat and water vapor at the ocean surface. With the Institution's C54Q aircraft equipped with an infrared radiometer to measure sea surface temperature, preliminary observations were made of the modification and formation of fog in warm air crossing the Gulf Stream into cooler waters off Nova Scotia. The principal results thus far have been the determination of a proper design for a future series of experiments and of design criteria for modification of the radiometer used (to reduce vapor interference).

Cloud Physics

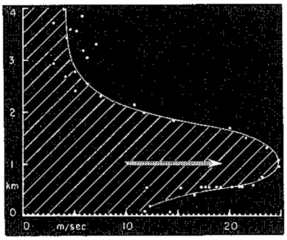
The large volume of data on dynamic and thermodynamic parameters of convective clouds previously collected has necessitated the development of computer techniques for their reduction and analysis. The availability of these techniques makes future use of the instruments for measuring liquid water content of clouds much less formidable a task, and encourages the planning of new tests of various theoretical cloud models. One set of such instruments has been made available to the U. S. Weather Bureau Research Flight Facility for use on its hurricane research missions during 1965.

Studies of Weather Ship Data

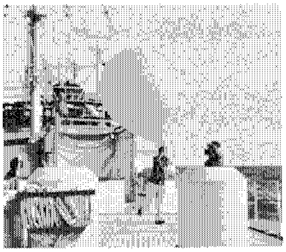
The body of observations obtained aboard weather ships is the chief source of information about long-term fluctuations in air-sea interaction processes. The concept of the oceans acting as thermodynamic flywheels in the combined system has been tested by a statistical study of the deviations of air temperature and dew point from the sea surface temperature. Short-term variations in the flux of heat and moisture from the sea to the atmosphere are found to be almost entirely dependent on atmospheric fluctuations, but the variance of the sea-air temperature difference between the same months of different years depends about equally on sea and air fluctuations.

Climatic Effect of Land-Sea Area Distribution

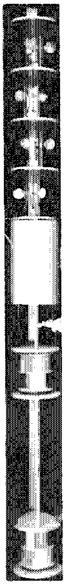
Integration over a simulated period of a hundred years was performed using a mathematical model designed to contrast the influence of land and sea on heating of the atmosphere. The results show that monsoon circulations associated with zonal (east-west) differential heating, particularly in summer, can carry appreciable amounts of heat in a meridional direction. Accordingly, the strength of the mean zonal circulation in the atmosphere for the same latitudinal heating difference is much weaker in the presence of zonal contrasts produced over continents than over a homogeneous, water-covered surface. In agreement with observations in the atmosphere, the model shows a lag in the adjustment of the atmosphere to the seasonal transition in continent-ocean contrast. This leads to a temporary buildup of potential energy in the system, which is released by intensive disturbances, the equinoctial storms.



Profile of the Somali thermal wind jet.

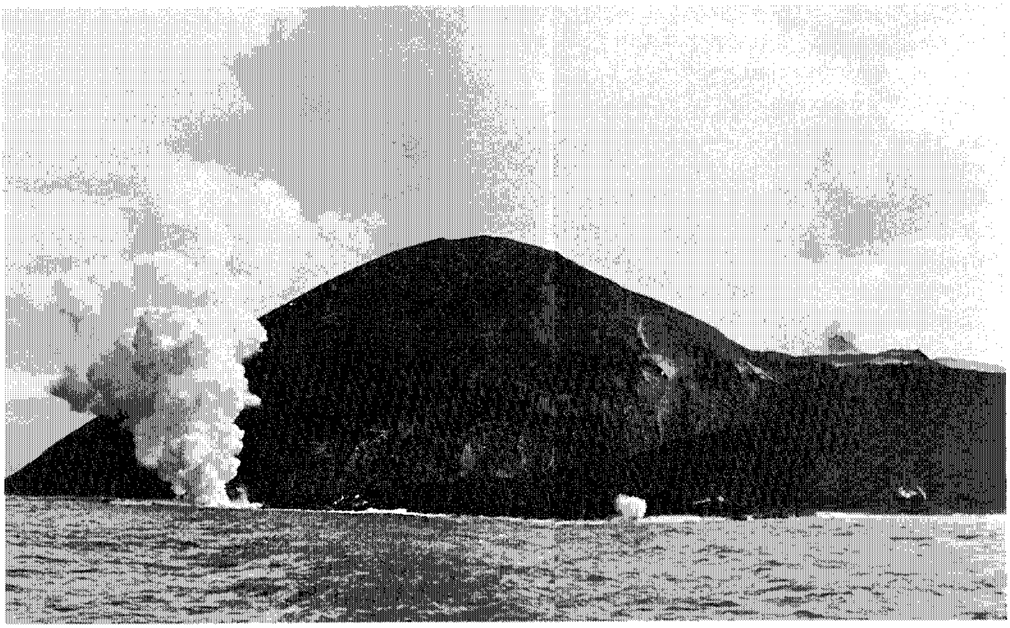


Launching radiosonde at sea.



Low level wind profile buoy.

Time exposure of Surtsey to show lightning during the eruption.



Surtsey, a volcanic island south of Iceland.

Dynamics of the Gulf Stream

A theoretical study of thermal boundary currents, with direct application to the Gulf Stream, has been completed. Exact solutions of similarity form to the full three-dimensional baroclinic boundary layer equations are given, which permits a prediction of the Gulf Stream north from the Strait of Florida. So far only the development of the mass transport has been compared with actual data. Good agreement has been found. Inclusion of topographic effects, coastal slope, is planned as an extension of the theory.

The predictions made by dynamic theories for the ocean pertain in general to fairly large-scale transports of essentially geostrophic character. Direct observations of currents are generally local in character, and hence subject to small scale "noise." Indirect methods are uncertain because an arbitrary reference level must be selected. In an attempt to circumvent this difficulty and to measure small geostrophic currents by direct measurements of pressure gradients, an instrument has been developed consisting of a 6000-foot armored rubber tube attached to a hypersensitive flowmeter. Shallow water experiments with this equipment will be carried out early in 1965.

Hydrodynamics of Rotating Fluids

The complexity of the non-linear interactions in a rotating fluid makes the availability of a high-precision laboratory facility essential for testing theoretical deductions. But equally often experiment has to precede theory. Experiments have been performed this year on the uniform flow past obstacles and on the damping of Rossby-waves in a channel. The important factor in both cases is the extent of the influence of boundary layer effects. These experiments have served to verify theories already developed. On the other hand, a sequence of experiments involving forced convection in a deep rotating body of fluid have provided both qualitative and quantitative information as a basis for theoretical work on the dynamics of water spouts, tornadoes and related phenomena.

Coupled Convection of Heat and Salt

Temperature and salinity are the two basic variables which determine the density of sea water. A statically stable stratification exists in a body of water when the combined effects of heat and salt content increase the density with depth. But a situation, where the temperature and salinity gradients oppose each other (e.g., warm salt water overlying cool fresher water) may be unstable due to differences in the diffusivity of heat and salt. Indeed the case just cited has previously been shown to lead to a mode of convection known as "salt fingers."

It has now been found that the opposite case (i.e., cool fresh water overlying warm salt water) leads to a layered convective system, with a sequence of sharp interfaces separating convecting, and hence well-mixed layers of water. The greater diffusivity of heat, compared with salt, makes the boundary layer on each side of such an interface thermally unstable even when the net stability across it is appreciable. Theoretical as well as experimental work to elucidate the dynamics and the geophysical importance of this process is proceeding.

Kinematics and Dynamics of Sedimenting Suspensions

Theoretical work on the dynamic effects of the weight of a sedimenting suspension has produced results which should be applicable both to downdraft formation in rain clouds and to density currents. This has led to the development of a vortex model for density currents which has received preliminary experimental evaluation. Further experiments with a larger system are planned to follow up the promising initial results.

A by-product of this work is the finding that the arctic atmosphere in summer should act as a trap for extraterrestrial aerosol particles in the size range below one micron. It is suggested that this may be a significant factor in the genesis of that brilliant phenomenon of the high latitude summer nights, the noctilucent clouds.

Summer Courses

In its sixth year the summer program in Geophysical Fluid Dynamics again produced a broad spectrum of student contributions. The interdisciplinary studies ranged from work on antarctic oceanography to hydromagnetic oscillations. As in the past, the staff guided the selection of student topics with several goals in mind. One was to isolate that part of a problem which might become fruitful in the space of approximately eight weeks. The more important goal was to find "open-ended" problems, which would continue to challenge the student after his return to the university.

In addition, a course centered around the dynamic processes of the air-sea boundary was given. About half of the student's time was devoted to formal lectures and seminars, and half to individual research problems, generally of the character of experimental or observational work or evaluation of such work. Several substantial contributions to the research problems reported above were made by this group.

Seminar Activity

The bi-weekly seminars on geophysical fluid dynamics held jointly with Massachusetts Institute of Technology and Harvard University added the University of Rhode Island as a regular participant. A substantial increase in the size of the audience reflected the increase in the number of graduate students and research workers in this field. As usual this Institution served as host to every third seminar, and our staff provided the speakers to half of the seminars held elsewhere.

New this year was a series of working seminars on current theoretical problems held here during the fall with participation by representatives from the Massachusetts Institute of Technology. It is hoped that this also will develop into a regular feature of our activity.

COLUMBUS O'D. ISELIN, *Chairman*
CLÄES G. H. ROOTH, *Assistant Chairman*

Publications 1964

No. 1149. Henry B. Bigelow and William C. Schroeder. Fishes of the Western North Atlantic, Family Osmeridae. *Mem. Sears Found. Mar. Res.*, No. 1, Pt. 3, pp. 553-597. 1964.

No. 1203. Robert L. Miller and John M. Zeigler. A Study of Sediment Distribution in the Zone of Shoaling Waves over Complicated Bottom Topography. In: *Marine Geology: Shepard Commemorative Volume*, R. L. Miller, Editor, MacMillan Co., pp. 133-153. 1964.

No. 1256. Margaret E. Watson. Tunas (Genus *Thunnus*) of the Western North Atlantic. Part 1. Key to the Species of *Thunnus* Based on Skeletal and Visceral Anatomy. *Proc., Symposium, Scombroid Fishes, Jan. 12-15, 1962, Mar. Biol. Assoc., India, Mandapam Camp, Symposium Ser.*, Vol. 1, Pt. 1, pp. 389-394. 1964.

No. 1257. Frank J. Mather, III. Tunas (Genus *Thunnus*) of the Western North Atlantic. Part II. Description Comparison and Identification of Species of *Thunnus* Based on External Characters. *Proc., Symposium, Scombroid Fishes, Jan. 12-15, 1962, Mar. Biol. Assoc., India, Mandapam Camp, Symposium Ser.*, Vol. 1, Pt. 1, pp. 395-411. 1964.

No. 1258. Frank J. Mather, III. Tunas (Genus *Thunnus*) of the Western North Atlantic. Part III. Distribution and Behavior of *Thunnus* Species. *Proc., Symposium, Scombroid Fishes, Jan. 12-15, 1962, Mar. Biol. Assoc., India, Madapam Camp, Symposium Ser.*, Vol. 1, Pt. 1, pp. 411-427. 1964.

No. 1272. Masateru Anraku. Influence of the Cape Cod Canal on the Hydrography and on the Copepods in Buzzards Bay and Cape Cod Bay, Massachusetts. I. Hydrography and Distribution of Copepods. *Limnol. and Oceanogr.*, Vol. 9, No. 1, pp. 46-60. 1964.

No. 1277. Masateru Anraku. Influence of the Cape Cod Canal on the Hydrography and on the Copepods in Buzzards Bay and Cape Cod Bay, Massachusetts. II. Respiration and Feeding. *Limnol. and Oceanogr.*, Vol. 9, No. 2, pp. 195-206. 1964.

No. 1298. Alfred C. Redfield and L. A. Earlston Doe. Lake Maracaibo. *Verh. Internat. Verein. Limnol.*, Vol. 15, pp. 100-111. 1964.

No. 1304. Irving Friedman, Alfred C. Redfield, Beatrice Schoen and Joseph Harris The Variation of the Deuterium Content of Natural Waters in the Hydrologic Cycle. *Reviews of Geophysics*, Vol. 2, No. 1, pp. 177-224. 1964.

No. 1306. Harold L. Burstyn. Theory and Practice in Men's Knowledge of the Tides. *Proc. Tenth Int. Congress, Hist. Sci.*, Hermann, Paris, pp. 1019-1022. 1964.

No. 1323. Duncan C. Blanchard. Charge Separation from Saline Drops on Hot Surfaces. *Nature*, Vol. 201, No. 4925, pp. 1164-1166. 1964.

No. 1332. George D. Grice. Two New Species of Calanoid Copepods from the Galapagos Islands with Remarks on the Identity of Three Other Species. *Crustaceana*, Vol. 6, No. 4, pp. 255-264. 1964.

Publications 1964

No. 1334. David W. Menzel and John H. Ryther. The Composition of Particulate Organic Matter in the Western North Atlantic. *Limnol. and Oceanogr.,* Vol. 9, No. 2, pp. 179-188. 1964.

No. 1344. G. D. Nicholls, A. J. Nalwalk and E. E. Hays. The Nature and Composition of Rock Samples Dredged from the Mid-Atlantic Ridge Between 22°N and 52°N. *Marine Geology,* Vol. 1, No. 4, pp. 333-343. 1964.

No. 1353. Robert R. Hessler and Howard L. Sanders. The Discovery of Cephalocarida at a Depth of 300 Meters. *Crustaceana,* Vol. 7, No. 1, pp. 77-78. 1964.

No. 1358. Howard L. Sanders and Robert R. Hessler. The Larval Development of *Lightiella incisa* Gooding (Cephalocarida). *Crustaceana,* Vol. 7, No. 2, pp. 81-97. 1964.

No. 1359. Joseph Chase. Oceanographic Observations, 1961, East Coast of the United States. *U. S. Fish and Wildlife Service, Bur. Comm. Fish., Data Rept.,* Vol. 1, 176 pp. (Microfiche). 1964.

No. 1362. K. O. Emery and J. Hülsemann. Shortening of Sediment Cores Collected in Open Barrel Gravity Corers. *Sedimentology,* Elsevier Publ. Co., Vol. 3, No. 2, pp. 144-154. 1964.

No. 1371. Peter W. Hochachka and John M. Teal. Respiratory Metabolism in a Marine Dinoflagellate. *Biol. Bull.,* Vol. 126, No. 2, pp. 274-281. 1964.

No. 1377. Robert R. Hessler. The Cephalocarida: Comparative Musculature. *Mem. Conn. Acad. Arts and Sci.,* Vol. 16, pp. 1-97. 1964.

No. 1389. Alan J. Faller and Alfred H. Woodcock. The Spacing of Windrows of *Sargassum* in the Ocean. *Jour. Mar. Res.,* Vol. 22, No. 1, pp. 22-29. 1964.

No. 1392. A. T. Spencer and Alfred H. Woodcock. A Photographic Rain Recorder for Studying Showers in Marine Air. *Jour. Appl. Meteorol.,* Vol. 3, No. 1, pp. 105-109. 1964.

No. 1393. W. E. Schevill, W. A. Watkins and R. H. Backus. The 20-Cycle Signals and *Balaenoptera* (Fin Whales). In: *Marine Bio-Acoustics,* Proc. Symposium, Bimini, Bahamas, April 1963, W. N. Tavolga, Editor, Pergamon Press, pp. 147-152. 1964.

No. 1394. Joseph B. Walsh and William O. Rainnie, Jr. ALVIN — Ocean Research Submarine. *Mechanical Engineering,* Vol. 86, pp. 22-26. 1964.

No. 1395. John M. Zeigler. The Hydrography and Sediments of the Gulf of Venezuela. *Limnol. and Oceanogr.,* Vol. 9, No. 3, pp. 397-411. 1964.

No. 1398. L. V. Worthington. Anomalous Conditions in the Slope Water Area in 1959. *Jour. Fish. Res. Bd., Canada,* Vol. 21, No. 2, pp. 327-333. 1964.

Publications 1964

No. 1402. N. B. Marshall and D. W. Bourne. A Photographic Survey of Benthic Fishes in the Red Sea and Gulf of Aden with Observations on Their Population Density, Diversity and Habits. *Bull. Mus. Comp. Zool., Harvard Univ.*, Vol. 132, No. 2, pp. 225-244, 4 pls. 1964.

No. 1403. E. Massera Bottazzi and A. Vannucci. Acantharia in the Atlantic Ocean: a Systematic and Ecological Analysis of Planktonic Collections Made During Cruises CHAIN 17 and CHAIN 21 of the Woods Hole Oceanographic Institution. 1st Contribution. *Arch. Oceanogr. e Limnol.*, Vol. 13, No. 3, pp. 315-385. 1964.

No. 1404. W. E. Schevill. Underwater Sounds of Cetaceans. In: *Marine Bio-Acoustics*, Proc. Symposium, Bimini, Bahamas, April 1963, W. N. Tavolga, Editor, Pergamon Press, pp. 307-316. 1964.

No. 1405. J. Stewart Turner. The Flow into an Expanding Spherical Vortex. *Jour. Fluid Mech.*, Vol. 18, No. 2, pp. 195-208. 1964.

No. 1406. P. M. Saunders. Sea Smoke and Steam Fog. *Quart. Jour., Roy. Meteorol. Soc.*, Vol. 90, No. 384, pp. 156-165. 1964.

No. 1408. John Schlee, Elazar Uchupi and J. V. A. Trumbull. Statistical Parameters of Cape Cod and Eolian Sands. *U. S. Geol. Surv., Prof. Paper*, 501-D, pp. D118-D122. 1964.

No. 1409. John M. Zeigler. Some Modern Approaches to Beach Studies. *Oceanogr. Mar. Biol., Ann. Rev.*, George Allen and Unwin Ltd., Vol. 2, pp. 77-95. 1964.

No. 1411. David A. McGill. The Distribution of Phosphorus and Oxygen in the Atlantic Ocean as Observed in the IGY, 1957-1958. *Progress in Oceanography*, Pergamon Press, Vol. 2, pp. 129-211. 1964.

No. 1413. Edward M. Hulburt. Succession and Diversity in the Plankton Flora of the Western North Atlantic. *Bull. Mar. Sci., Gulf and Caribbean*, Vol. 14, No. 1, pp. 33-44. 1964.

No. 1414. David A. McGill, Nathaniel Corwin and Bostwick H. Ketchum. Organic. Phosphorus in the Deep Water of the Western North Atlantic. *Limnol. and Oceanogr.*, Vol. 9, No. 1, pp. 27-34. 1964.

No. 1415. J. A. F. Garrick, Richard H. Backus and Robert H. Gibbs, Jr. *Carcharinus floridanus* the Silky Shark, a Synonym of *C. falciformis*. *Copeia*, 1964, No. 2, pp. 369-375. 1964.

No. 1420. John M. Zeigler, Sherwood D. Tuttle, Herman J. Tasha and Graham S. Giese. Pleistocene Geology of Outer Cape Cod, Massachusetts. *Geol. Soc., Amer., Bull.*, Vol. 75, No. 8, pp. 705-714. 1964.

No. 1421. David D. Menzel and Ralph F. Vaccaro. The Measurement of Dissolved Organic and Particulate Carbon in Seawater. *Limnol. and Oceanogr.*, Vol. 9, No. 1, pp. 138-142. 1964.

No. 1422. J. J. Goering, R. C. Dugdale and D. W. Menzel. Cyclic Diurnal Variations in the Uptake of Ammonia and Nitrate by Photosynthetic Organisms in the Sargasso Sea. *Limnol. and Oceanogr.*, Vol. 9, No. 3, pp. 448-451. 1964.

Publications 1964

No. 1423. K. O. Emery. Turbidites — Precambrian to Present. In: *Studies on Oceanography Dedicated to Professor Hidaka in Commemoration of His Sixtieth Birthday,* pp. 486-495. 1964.

No. 1424. B. C. Heezen, E. T. Bunce, J. B. Hersey and M. Tharp. Chain and Romanche Fracture Zones. *Deep-Sea Research,* Vol. 11, No. 1, pp. 11-33. 1964.

No. 1427. J. H. Stanbrough, Jr., and D. P. Keily. Long-Range Relative Navigation by Means of VLF Transmissions. *Deep-Sea Research,* Vol. 11, No. 2, pp. 249-255. 1964.

No. 1428. Peter L. Sachs. A Hydraulically Actuated Safety Device. *Jour. Mar. Res.,* Vol. 22, No. 1, pp. 105-109. 1964.

No. 1429. D. W. Thomas and M. Blumer. The Organic Chemistry of a Fossil — III. The Hydrocarbons and Their Geochemistry. *Geochimica et Cosmochimica Acta,* Vol. 28, No. 9, pp. 1467-1477. 1964.

No. 1430. David W. Thomas and Max Blumer. Pyrene and Fluoranthene in Manganese Nodules. *Science,* Vol. 143, No. 3601, p. 39. 1964.

No. 1431. D. W. Thomas and Max Blumer. Porphyrin Pigments of a Triassic Sediment. *Geochimica et Cosmochimica Acta,* Vol. 28, No. 7, pp. 1147-1154. 1964.

No. 1435. Duncan C. Blanchard and A. Theodore Spencer. Condensation Nuclei and Crystallization of Saline Drops. *Jour. Atmospher. Sci.,* Vol. 21, No. 2, pp. 182-186. 1964.

No. 1436. W. G. Metcalf, B. C. Heezen and M. C. Stalcup. The Sill Depth of the Mid-Atlantic Ridge in the Equatorial Region. *Deep-Sea Research,* Vol. 11, No. 1, pp. 1-10. 1964.

No. 1438. Max Blumer, Michael M. Mullin and David W. Thomas. Pristane in the Marine Environment. *Helgol. Wiss. Meeresunters.,* Vol. 10, Nos. 1-4, pp. 187-201. 1964.

No. 1439. Joseph H. Connell. Territorial Behavior and Dispersion in Some Marine Invertebrates. *Res. Popul. Ecol., Kyoto Univ.,* Vol. 5, No. 2, pp. 87-101. 1963.

No. 1440. Tjeerd H. Van Andel and Peter L. Sachs. Sedimentation in the Gulf of Paria during the Holocene Transgression; a Subsurface Acoustic Reflection Study. *Jour. Mar. Res.,* Vol. 22, No. 1, pp. 30-50. 1964.

No. 1441. Lincoln Baxter, II. A Method for Determining the Geographical Position of Deep Towed Instruments. *Navigation, Jour. Inst. Navig.,* Vol. 11, No. 2, pp. 85-98. 1964.

No. 1442. Richard L. Haedrich. Food Habits and Young Stages of North Atlantic *Alepisaurus* (Pisces, Iniomi). *Breviora, Mus. Comp. Zool.,* No. 201, 15 pp. 1964.

Publications 1964

No. 1443. ROBERT J. CONOVER. Food Relations and Nutrition of Zooplankton. Proceedings of Symposium on Experimental Marine Ecology, *Occ. Publ., Grad. School, Oceanogr., Univ. Rhode Island,* No. 2, pp. 81-91. 1964.

No. 1444. WOLFGANG WIESER. Biotopstruktur und Besiedlungsstruktur. *Helgol. Wiss. Meeresunters.*, Vol. 10, Nos. 1-4, pp. 359-376. 1964.

No. 1449. GEORGE R. HAMPSON. Redescription of a Commensal Pelecypod, *Rochefortia cuneata,* with Notes on Ecology. *The Nautilus,* Vol. 77, No. 4, pp. 125-128. 1964.

No. 1452. C. R. B. LISTER and J. S. REITZEL. Some Measurements of Heat Flow through the Floor of the North Atlantic. *Jour. Geophys. Res.,* Vol. 69, No. 10, pp. 2151-2154. 1964.

No. 1454. K. PARK, P. K. WEYL and A. BRADSHAW. Effect of Carbon Dioxide on the Electrical Conductance of Sea-Water. *Nature,* Vol. 201, No. 4926, pp. 1283-1284. 1964.

No. 1455. ERIC L. MILLS. *Ampelisca abdita,* a New Amphipod Crustacean from Eastern North America. *Canadian Jour. Zool.,* Vol. 42, No. 4, pp. 559-575. 1964.

No. 1456. ALFRED P. FRANCESCHETTI, V. W. DRIGGERS and R. M. O'HAGAN. Physical Oceanography of the Grand Banks and Labrador Sea in 1963. Also, Appendix 1. Permeability of Polyethylene Bottles to Sea Water. *U. S. Coast Guard Bull.,* No. 49, pp. 43-62, pp. 73-80, (App. 1) pp. 81-356. 1964.

No. 1457. DAVID A. MCGILL and NATHANIEL CORWIN. The Distribution of Nutrients in the Labrador Sea, Summer 1963. *U. S. Coast Guard Bull.,* No. 49, pp. 63-71, 341-356. 1964.

No. 1458. GEORGE L. CLARKE and MAHLON G. KELLY. Variation in Transparency and in Bioluminescence on Longitudinal Transects in the Western Indian Ocean. *Bull., Inst. Océanogr., Monaco,* Vol. 64, No. 1319, 20 pp. 1964.

No. 1459. ELIZABETH T. BUNCE, STUART CRAMPIN, J. B. HERSEY and M. N. HILL. Seismic Refraction Observations on the Continental Boundary West of Britain. *Jour. Geophys. Res.,* Vol. 69, No. 3, pp. 3853-3863. 1964.

No. 1460. J. B. WALSH and W. F. BRACE. A Fracture Criterion for Brittle Anisotropic Rock. *Jour. Geophys. Res.,* Vol. 69, No. 16, pp. 3449-3456. 1964.

No. 1461. LOUIS D. QUINN. 2 — Aminoethylphosphonic Acid in Insoluble Protein of the Sea Anemone, *Metridium dianthus. Science,* Vol. 144, No. 3622, pp. 1133-1134. 1964.

No. 1462. FERRIS WEBSTER. Some Perils of Measurement from Moored Ocean Buoys. *Transactions of the 1964 Buoy Technology Symposium, Mar. 24-25, 1964, Mar. Tech. Soc.,* pp. 33-48. 1964.

No. 1463. ELAZAR UCHUPI. Sediments and Topography of Kane Basin. Oceanographic Observations Kennedy Channel, Kane Basin, Smith Sound and Baffin Bay, Summer 1963. *U. S. Coast Guard Oceanogr. Rept.,* No. 5 (CG 373-5) pp. 61-72. 1964.

Publications 1964

No. 1464. Ruth Todd and Doris Low. Cenomanian (Cretaceous) Foraminifera from the Puerto Rico Trench. *Deep-Sea Research,* Vol. 11, No. 3, pp. 395-414. 1964.

No. 1465. Frederick R. Hess. A Shear Pin Weak-Link Assembly for Oceanographic Use. *Deep-Sea Research,* Vol. 11, No. 4, pp. 623-624. 1964.

No. 1469. J. S. Turner. The Dynamics of Spheroidal Masses of Buoyant Fluid. *Jour. Fluid Mechanics,* Vol. 19, No. 4, pp. 481-490. 1964.

No. 1471. C. S. Yentsch, R. H. Backus and Asa Wing. Factors Affecting the Vertical Distribution of Bioluminescence in the Euphotic Zone. *Limnol. and Oceanogr.,* Vol. 9, No. 4, pp. 519-524. 1964.

No. 1472. A. D. Voorhis and J. B. Hersey. Oceanic Thermal Fronts in the Sargasso Sea. *Jour. Geophys. Res.,* Vol. 69, No. 18, pp. 3809-3814. 1964.

No. 1474. George L. Clarke and Richard H. Backus. Interrelations Between the Vertical Migration of Deep Scattering Layers, Bioluminescence and Changes in Daylight in the Sea. *Bull. Inst. Océanogr., Monaco,* Vol. 64, No. 1318, 36 pp. 1964.

No. 1476. Peter L. Sachs. A Tension Recorder for Deep-Sea Dredging and Coring. *Jour. Mar. Res.,* Vol. 22, No. 3, pp. 279-283. 1964.

No. 1477. Vaughan T. Bowen and Thomas T. Sugihara. Fission Product Concentration in the Chukchi Sea. *Arctic, Jour. Arctic Inst., N. Amer.,* Vol. 17, No. 3, pp. 198-203. 1964.

No. 1478. K. N. Sachs, Jr., Richard Cifelli and Vaughan T. Bowen. Ignition to Concentrate Shelled Organisms in Plankton Samples. *Deep-Sea Research,* Vol. 11, No. 4, pp. 621-622. 1964.

No. 1480. John M. Zeigler, Carlyle R. Hayes and Douglas C. Webb. Direct Readout of Sediment Analyses by Settling Tube for Computer Processing. *Science,* Vol. 145, No. 3627, p. 51. 1964.

No. 1482. David W. Menzel. The Distribution of Dissolved Organic Carbon in the Western Indian Ocean. *Deep-Sea Research,* Vol. 11, No. 5, pp. 757-765. 1964.

No. 1486. Bostwick H. Ketchum, and Nathaniel Corwin. The Persistence of "Winter" Water on the Continental Shelf South of Long Island, New York. *Limnol. and Oceanogr.,* Vol. 9, No. 4, pp. 467-475. 1964.

No. 1488. Arthur R. Miller. The Highest Salinity in the World Ocean. *Nature,* Vol. 203, No. 4945, pp. 590-591. 1964.

No. 1492. R. M. Pratt and Bruce C. Heezen. Topography of the Blake Plateau. *Deep-Sea Research,* Vol. 11, No. 5, pp. 721-728. 1964.

No. 1496. Rudolf S. Scheltema. Reproduction of *Nassarius trivittatus* off the Coast of Georgia. *The Nautilus,* Vol. 78, No. 2, pp. 49-50. 1964.

No. 1500. Walter H. Adey. The Genus *Phymatolithon* in the Gulf of Maine. *Hydrobiologia,* Vol. 24, Nos. 1-3, pp. 377-392. 1964.

Publications 1964

No. 1503. PIERRE WELANDER. Convective Instability in a Two-Layer Fluid Heated Uniformly from Above. *Tellus,* Vol. 16, No. 3, pp. 349-358. 1964.

No. 1504. PIERRE WELANDER. Note on the Role of Boundary Friction in the Wind-Driven Ocean Circulation. *Tellus,* Vol. 16, No. 3, pp. 408-410. 1964.

No. 1506. DAVID A. MCGILL and NATHANIEL CORWIN. Observations on the Nutrient Concentrations in the Northern Region of Baffin Bay and the Kane Basin, Summer, 1963. Oceanographic Observations, Kennedy Channel, Kane Basin, Smith Sound and Baffin Bay. *U. S. Coast Guard Oceanogr. Rept.,* No. 5 (CG 373-5), pp. 37-60, 73-98. 1964.

No. 1509. J. S. TURNER and HENRY STOMMEL. A New Case of Convection in the Presence of Combined Vertical Salinity and Temperature Gradients. *Proc. Nat. Acad., Sci.,* Vol. 52, No. 1, pp. 49-53. 1964.

No. 1510. RICHARD C. DUGDALE, JOHN J. GOERING and JOHN H. RYTHER. High Nitrogen Fixation Rates in the Sargasso Sea and the Arabian Sea. *Limnol. and Oceanogr.,* Vol. 9, No. 4, pp. 507-510. 1964.

No. 1514. JOHN SCHLEE. New Jersey Offshore Gravel Deposit. *Pit and Quarry,* Vol. 57, No. 6, pp. 80-81, 95. 1964.

No. 1517. A. J. FALLER. The Angle of Windrows in the Ocean. *Tellus,* Vol. 16, No. 3, pp. 363-370. 1964.

No. 1522. HENRY B. BIGELOW and WILLIAM C. SCHROEDER. A New Skate, *Raja cervigoni,* from Venezuela and the Guianas. *Breviora, Mus. Comp. Zool.,* No. 209, 5 pp. 1964.

No. 1523. DUNCAN C. BLANCHARD. Sea-to-Air Transport of Surface Active Material. *Science,* Vol. 146, No. 3642, pp. 396-397. 1964.

No. 1525. LINCOLN BAXTER, ROBERT BROCKHURST and EARL E. HAYS. Some Deep Water Sound Transmission Paths South of Cyprus. *Jour. Acoust. Soc., Amer.,* Vol. 36, No. 11, pp. 2124-2130. 1964.

No. 1540. JOHN M. ZEIGLER, SHERWOOD D. TUTTLE, GRAHAM S. GIESE and HERMAN J. TASHA. Ch. 26. Residence Time of Sand Composing the Beaches and Bars of Outer Cape Cod. *Proc. Ninth Conf. Coastal Engineer., Amer. Soc. Civ. Engineers,* pp. 403-416. 1964.

No. 1542. ROBERT L. MILLER and JOHN M. ZEIGLER. Ch. 7. The Internal Velocity Field in Breaking Waves. *Proc. Ninth Conf. Coastal Engineer., Amer. Soc. Civ. Engineers,* pp. 103-122. 1964.

No. 1543. RUDOLF S. SCHELTEMA. Feeding Habits and Growth in the Mud-Snail, *Nassarius obsoletus. Chesapeake Science,* Vol. 5, No. 4, pp. 161-166. 1964.

No. 1569. MICHEL I. ROBERSON. Continuous Seismic Profiles Survey of Oceanographer, Gilbert and Lydonia Submarine Canyons, Georges Bank. *Jour. Geophys. Res.,* Vol. 69, No. 22, pp. 4779-4789. 1964.

Ashore and Afloat

A number of meaningful events took place during 1964 in connection with our expansion both ashore and afloat.

Nearly a year after it was first occupied, the Laboratory for Marine Sciences was dedicated on 8 May at a morning ceremony. Dr. Leland J. Haworth, the Director of the National Science Foundation, gave the dedicatory address and was followed by Dr. Jerome Wiesner, who spoke briefly. In the afternoon, four lectures were given by members of the staff. The formal opening was preceded by an open house for the townspeople and school children a week earlier. It is estimated that some six thousand persons took advantage of the opportunity to visit the Institution.

On 19 August, the deed to the Laboratory of Oceanography was recorded in the Barnstable County Court House. This gives ownership of the former "Navy" building to the Institution, subject to certain restrictions that will be binding for a period of twenty years. The transfer to the Institution was approved by the appropriate legislative committees and the General Services Administration.

ALVIN, a deep submergence vessel designed to go to 6000 feet, was commissioned in the parking lot of the Laboratory of Oceanography on 5 June with Mrs. Allyn C. Vine as the sponsor. The principal address was given by the Honorable James H. Wakelin, Jr., Assistant Secretary of the Navy for Research and Development, preceded by some remarks made by Captain Charles B. Momsen USN, Director, Undersea Programs, Office of Naval Research. ALVIN is the culmination of the work of many people — the research scientists who insisted that they be allowed to examine the depths of the ocean by direct observation, the engineers and technicians whose skills made its construction possible, and those in the Office of Naval Research who are convinced that the United States Navy can better fulfill its mission through greater knowledge of the seas. ALVIN offers exciting new possibilities for research at sea.

At about midnight on 18 February, ATLANTIS II was steaming toward her next station some distance north of the Azores, when she was hit by a freak wave. Seven windows on the bridge were broken and the water continued on through the chief scientist's cabin. Although there was considerable damage to the electrical equipment and the bulkhead of the chief scientist's cabin was badly dented, there were no serious injuries to the four men on the bridge at the time. All the repairs were made at the dock in Woods Hole by Institution personnel. The cost of approximately $25,000 was covered by insurance except for the $2500 deductible clause.

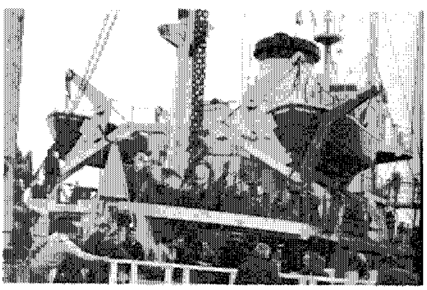
Cruises — 1964

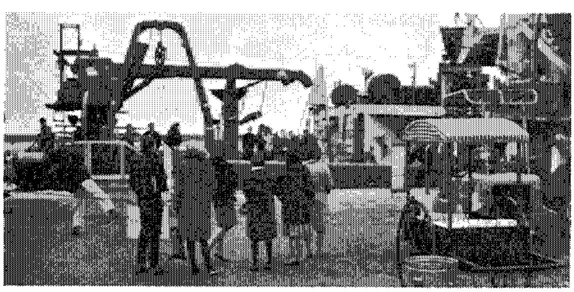
ATLANTIS II Days at Sea – 251 Total Miles Sailed – 37,300 Mi.

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
9	16 Jan.–4 May	North Atlantic–Azores	97	L. V. Worthington
10	6 May–10 June	Munro's Shipyard	- -	- - - - -
11	18 June–8 August	San Juan, Puerto Rico	52	E. Hays
12	20 Aug.–26 Aug.	Bermuda Buoy Line	7	H. Sanders
13	1 Sept.–5 Oct.	North Atlantic–Azores	35	R. Backus
14	20 Oct.–18 Dec.	Brazil, Barbados	60	D. Menzel

CRAWFORD Days at Sea – 224 Total Miles Sailed – 29,304 Mi.

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
103	3 Feb.–4 Mar.	Bermuda	31	R. Walden
104	12 Mar.–20 Mar.	Norlantic Shipyard	- -	- - - - -
105	23 Mar.–30 Mar.	Bermuda	8	R. Parker
106	7 Apr.–19 Apr.	Gulf of Maine	13	R. Conover
107	2 May–20 May	Bermuda	19	N. Fofonoff
108	25 May–8 June	Bermuda Buoy Line	15	C. Parker
109	10 June–11 June	Block Canyon	2	R. Stanley
110	13 June–2 July	Gulf Stream	20	A. Voorhis
111	6 July–9 July	2,000 fathom curve	4	R. Walden
112	15 July–22 July	Hudson River, N. Y.	7	B. Ketchum
113	23 July	Local	1	S. M. Haq
114	3–8 August	39° North–69° West	6	G. Clarke
115	12–22 August, 1964	Gulf Stream	11	P. Mangelsdorf
116	29 Aug.–21 Sept.	Bermuda	24	Fofonoff & Volkmann
117	22–24 Sept.	Munro's Shipyard–Hurricane	- -	- - - - -
118	30 Sept.–22 Oct.	Gulf Stream	23	G. Volkmann
119	2 Nov.–18 Nov.	Gulf Stream	17	F. Fuglister
120	21 Nov.–5 Dec.	Gulf Stream	15	A. Voorhis
121	8 Dec.–15 Dec.	Gulf Stream	14	F. Fuglister





Cruises — 1964

CHAIN Days at Sea – 257 Total Miles Sailed – 42,167 Mi.

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
42	15 Jan.–2 Feb.	70° West longitude	19	A. Voorhis
43	15 Feb.–21 Aug.	Indian Ocean – Mediterranean	189	J. B. Hersey
	22–24 September	Munro's Shipyard – Hurricane	- -	- - - - -
44	29 Sept.–16 Nov.	Barracuda Rise, Abyssal Plain	49	V. Bowen
45	23 Nov.–31 Dec.	Munro's Shipyard	- -	- - - - -

GOSNOLD Days at Sea – 202 Total Miles Sailed – 18,167 Mi.

CRUISE	DATES	AREA OF OPERATION	DAYS	SCIENTIST
34	3 January	Local	1	R. Conover
35	7–12 January	30 Fathom Curve	6	D. Bumpus
	23–27 January	Norlantic Shipyard	- -	- - - - -
36	28–31 January	1,000 Fathom Curve	4	J. Teal
37	1–14 February	Buzzards Bay	9	L. Bennett
38	17–18 February	Wilkinson Basin	2	J. Teal
39	24–29 February	Buzzards Bay	4	L. Bennett
	1–6 March	Buzzards Bay	3½	L. Bennett
40	17–22 March	Gulf of Maine	4	R. Conover
41	30 Mar.–10 Apr.	Off Narragansett Bay	10	Scripps
42	13–15 April	Off Provincetown	2½	L. Bennett
43	16 April–2 May	Norlantic Shipyard	- -	- - - - -
44	7–12 May	Gulf of Maine	6	R. Conover
45	15 May–29 June	Florida Coast	46	R. Pratt
46	6–9 July	Local	4	L. Bennett
47	17–20 July	Local	4	D. Krotser
48	21–29 July	Off Narragansett Bay	9	Scripps
49	1–29 August	New Jersey Coast	26	J. Hülsemann
50	8–10 Sept.	Gulf of Maine	3	S. Haq
51	15–22 Sept.	Continental Shelf of Georges	8	R. Pratt
	22–24 Sept.	Munro's Shipyard – Hurricane	- -	- - - - -
52	24–26 Sept.	Gulf of Maine	3	R. Conover
53	2–31 October 1964	Gulf of Maine	30	E. Uchupi
54	2–6 November	39° North and 69° West	5	R. Walden
55	9–11 November	1,000 Fathom Curve	3	R. Conover
56	16–18 November	Continental Shelf	3	E. Uchupi
57	10 December	Local	1	W. Dow
58	13 December	Local	1	G. Clarke
59	17–20 December	Gulf of Maine	4	J. Teal

Personnel

Eight individuals joined the Research Staff during 1964: John C. Beckerle coming from the Schlumberger Well Surveying Corporation, Richard L. Chase, a former postdoctoral fellow, from Princeton University, Douglas Cormack, from Glasgow University, Egon T. Degens, from California Institute of Technology, Christopher Gatrousis from Clark University, John M. Hunt, from the Jersey Production Research Company, J. Stewart Turner, a former Rossby fellow, from Australia, and David Wall, a former postdoctoral fellow, from the University of Glasgow.

There were three resignations during this same period: David D. Caulfield is at the Electric Boat Company, Johan A. Hellebust moved to Harvard University, and Melvin E. Stern is now at the University of Rhode Island.

Dr. Norman B. Marshall, who was at the Institution as a Visiting Investigator for approximately a year and a half, has returned to London, where he is Principal Senior Scientific Officer at the British Museum (Natural History).

In 1964, also there were for the first time a number of individuals retiring under the Retirement Plan, now ten years old. The eight individuals were honored at a year-end ceremony, as were two others, Ralph H. Bodman who retired on June first and Edwin T. Bryant, neither of whom qualified under the plan: Norman T. Allen after 23 years service, Harold Backus after 33 years, Warren O. Bowman after 18 years, Stanley N. Eldridge after 24 years, Harry L. Hodgkins after 20 years, William C. Schroeder after 32 years, Otto Solberg after 20 years and Mrs. Esther N. Wilson after 17 years.

In response to a petition filed by the Seafarers International Union of North America Atlantic Gulf Lakes and Inland Waters District, AFL-CIO, the National Labor Relations Board conducted during the fall a representation election among the unlicensed seamen on our research vessels. The vote tallied 57 for no union representation and 6 in favor of the SIU.

Sidney T. Knott, Jr., was given the Navy's Meritorious Citation for his work in connection with the THRESHER search.

The Institution continued its scholarship to a graduate of Lawrence (Falmouth) High School. This year the recipient was Wesley E. Stimpson, who is now attending Tufts University.

Scientific Departments and Supporting Services Personnel

PAUL M. FYE . . . . Director
BOSTWICK H. KETCHUM . . . . Associate Director for Biology and Chemistry
DAVID D. SCOTT . . . . Assistant Director for Administration

The following were in the employ of the Institution for the twelve-month period ending December 31, 1964: *Part Time Employment

Department of Biology

Bartlett, Martin R.
Baylor, Edward R.
Breivogel, Barbara B.
Chadwick, Constance W.
Chin, Edward
*Clarke, George L.
Clarner, John P.
Conover, Robert J.
Corwin, Nathaniel
Dean, Mildred W.
*Fraser, Grace C.
Grice, George D., Jr.
Guillard, Elizabeth D.
Guillard, Robert R. L.
Gunning, Anita H.
Hampson, George R.
Hessler, Robert R.
Hulburt, Edward M.
Hülsemann, Kunigunde
Jannasch, Holger W.
Kahler, Yolande A.
Kanwisher, John W.
Koslowski, Jutta G.
Kuenzler, Edward J.
Laird, John C.
Markgren, Louise S.
Masch, David W.
Mather, Frank J., III
McGill, David A.
Menzel, David W.
Mogardo, Juanita A.
Perras, James P.
*Renshaw, Thomas H.
Rogers, M. Dorothy
Ryther, John H.
Sanders, Howard L.
Scheltema, Rudolf S.
Schilling, John L.
Schroeder, William C.
Sears, Mary
Stanley, Helen I.
Teal, John M.
Turner, Harry J.
Vaccaro, Ralph F.
Valois, Frederica W.
Watson, Margaret E.
Watson, Stanley W.
Wilson, Esther N.
Yentsch, Charles S.

Department of Applied Oceanography

Andersen, Nellie E.
Andrade, Marie
Barstow, Elmer M.
Baxter, Lincoln II
Bradley, Mabel D.
Brockhurst, Robert R.
Broderson, George
Chute, Edward H.
English, Jean J.
Fairhurst, Kenneth D.
Fofonoff, Nicholas P.
Freund, William F.
Gifford, James E.
Graham, Russell G.
Hays, Earl E.
Heinmiller, Robert H.
Horn, Henry M.
Howland, Myron P., Jr.
*Jones, Maxine M.
Lyon, Thomas P.
Marquet, William M.
Mavor, James W., Jr.
McCamis, Marvin J.
Michael, Joseph C., Jr.
Morrill, Duncan E.
Norton, Elizabeth
Owen, David M.
Rainnie, William O., Jr.
Reese, Mabel M.
Sharp, Arnold G.
Shodin, Leonard F.
Shultz, William S.
Simmons, Charles F.
Soule, Floyd M.
Stimson, Paul B.
Walden, Robert G.
*Walsh, Joseph B., Jr.
Webb, Douglas C.
Wilkins, Charles H.

Department of Chemistry and Geology

Andersen, Neil R.
Athearn, William D.
Bentley, Harold W.
Blumer, Max
Bowen, Vaughan T.
Burke, Barbara A.
Burke, John C.
Carey, Francis G.
Coppenrath, Agnes I.
Emery, Kenneth O.
*Fitzgerald, William F.
Foley, Robert
Frothingham, Joseph R., Jr.
*Giese, Graham S.
†Hathaway, John C.
Hayes, Carlyle R.
Hülsemann, Jobst B.
Hunt, John M.
Kite, Sherril A.
†Manheim, Frank T.
McAuliffe, Julianne G.
†Meade, Robert H.
Morris, Robert E.
Mott, Norman S.
Noshkin, Victor E., Jr.
Paul, Russell K.
Pratt, Richard M.
Rounbehler, Marcia M.
Sachs, Peter L.
Sass, Jeremy
†Schlee, John S.
Siegel, Alvin
*Sugihara, Thomas T.
†Tagg, A. Richard
Tasha, Herman J.
†Trumbull, James V. A.
Turgeon, Robert R.
Uchupi, Elazar
Watts, John W.
Zeigler, John M.

†Member of U. S. Geological Survey assigned for work at the Woods Hole Oceanographic Institution

Department of Geophysics

Aldrich, Thomas C.
Backus, Richard H.
Bergstrom, Stanley W.
Bowin, Carl O.
Broadbent, Alice G.
Bunce, Elizabeth T.
Cain, Henry A.
Carter, Alwyn L.
Cleary, Kathleen A.
*Collins, Belinda F.
Dow, Willard
Dunkle, William M., Jr.
Feden, Robert H.
*Gallagher, Gloria S.
Grant, Carlton W., Jr.
Hays, Helen C.
Hersey, J. Brackett
Hess, Frederick R.
Johnston, Alexander T.
*Jones, Barbara A.
Knott, Sydney T., Jr.
Lynch, Frank L., Jr.
Mellor, Florence K.
Mizula, Joseph W.
Morehouse, Clayton B.
*Nowak, Richard T.
Payne, Richard E.
Perkins, Henry T.
Peterson, Jane M.
Poole, Stanley E.
Rhoads, Sandra S.
Ruppert, Gregory N.
*Schevill, William E.
Senefelder, Lynne M.
Stetson, Thomas R.
Stillman, Stephen L.
Sutcliffe, Thomas O. L.
Tasko, Edward R.
Vine, Allyn C.
Watkins, William A.
Wing, Asa S.
Witzell, Grace K.
Witzell, Warren E.

Department of Physical Oceanography

Allen, Ethel B.
*Arons, Arnold B.
Bailey, Phyllis T.
Barbour, Rose L.
Barrett, Joseph R., Jr.
Bradshaw, Alvin L.
Bruce, John G., Jr.
Bruneau, Robert E.
Bumpus, Dean F.
Chase, Joseph
Day, C. Godfrey
Densmore, C. Dana
Denton, Edward A.
Frank, Winifred H.
Fuglister, Frederick C.
Hays, Betty C.
Houston, Leo C.
Metcalf, William G.
Miller, Arthur R.
Munns, Robert G.
Pacheco, Marguerite E.
Parker, Charles E.
Phillips, Helen F.
Randall, Vivian H.
Schleicher, Karl E.
Schroeder, Elizabeth H.
Soderland, Eloise M.
Stalcup, Marvel C.
Stanley, Robert J.
Volkmann, Gordon H.
Voorhis, Arthur D.
Warren, Bruce A.
Webster, T. Ferris
Whitney, Geoffrey G., Jr.
Worthington, L. Valentine
Wright, W. Redwood

Department of Theoretical Oceanography and Meteorology

Alexander, Robert M.
Armstrong, Harold C.
Blanchard, Duncan C.
Bunker, Andrew F.
Frazel, Robert E.
Ibbetson, Alan
Iselin, Columbus O'D.
Kraus, Eric B.
Levine, Joseph
Ronne, F. Claude
Rooth, Claës G. H.
Saunders, Peter M.
Spencer, Allard T.
Stevens, Raymond G.
Thayer, Mary C.
Webster, Jacqueline K.

Department of Administrative and Service Personnel

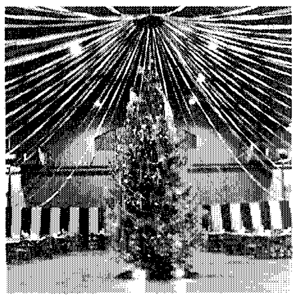
Allen, Norman T.
Anders, Wilbur J.
Backus, Harold
Backus, Jeanne M.
Bard, Wallace R.
Behrens, Henry G.
Bjorkman, William P.
Bowman, Warren O.
Brennan, John
Bryant, Edwin T.
Burke, John E.
Burns, Geraldine M.
Cabral, John P.
Campbell, Eleanor N.
Carlson, Alfred G.
Carlson, Eric B.
Carlson, Ruth H. E.
Carver, Kenneth W.
Chalmers, Agnes C.
Christian, John A.
Clough, Auguste K.
Condon, John W.
Cook, Harold R.
Conway, George E.
Corr, James P.
Crocker, Marion W.
Croft, Donald A.
Cummings, Priscilla J.
Day, Joseph V.
DeCosta, Nancy S.
Dimmock, Richard H.
Doty, Jeanne C.
Eastman, Arthur C.
Eldridge, Stanley N.
Ferguson, Sandra K.
Fernandes, Alice P.
Ferris, George A.
Fielden, Frederick E.
Fisher, Stanley O.
*Fuglister, Cecelia B.
Gallagher, William F.
Gaskell, Fred
Geggatt, Edward E.
Gioiosa, Albert A.
Grant, Carlton W., Sr.
*Hahn, Jan
Hampton, Carolyn
Hatzikon, Kaleroy L.
Henderson, Arthur T.
Hodgkins, Harry L.

Department of Administrative and Service Personnel (cont.)

Hodgson, Sloat F.
Hunt, Otis E.
Ingram, Ruth C.
Innis, Charles S., Jr.
Jenkins, Delmar R.
Johnson, Harold W.
Kania, Martha L.
King, Una T.
Kostrzewa, John A.
Lane, Egbert B.
Leach, David G.
LeBlanc, Donald F.
MacKillop, Harvey
Mangelsdorf, Frederick E.
Martin, David W.
Martin, Olive
McGilvray, Mary K.
McHardie, James
Mitchell, James R.
Morrison, Kenneth
Motta, Joseph C.
Orr, Elizabeth D.
Ortolani, Mary
Pasley, Gale G., Jr.
Patterson, John E.
Pimental, John M.
Reis, Janice A.
Roberts, Harry A.
Rossby, Harriet A.
Rudden, Robert D., Jr.
Russell, Mary L.
Simons, Cecelia M.
Slabaugh, Luther V.
Solberg, Otto
Souza, Thomas A.
Stanbrough, Jess H.
Stansfield, Richard
Stimpson, John W.
*Sullivan, James R.
Teixeira, Morris
Tometich, Louis J.
Veeder, Ronald A.
von Dannenberg, Carl A.
Walker, Jean D.
Watson, L. Hoyt
Weeks, Robert G.
Wessling, Andrew L., Jr.
Wing,Carleton R.
Woodward, Fred C., Jr.
Woodward, Ruth F.
Wright, Hollis F.

Marine Personnel

Allstrom, Frank C.
Babbitt, Herbert L.
Backus, Cyril
Bailey, Peter
Baker, William R.
Bazner, Kenneth E.
Betterly, Robert
Bizzozero, John P.
Bowen, Harold E.
Brereton, Richard S.
Brown, Joseph C.
Bumer, John Q.
Byron, Paul C.
Cabral, John V.
Cahoon, Geraldine B.
Carter, Richard J.
Casiles, David F.
Cavanaugh, James J.
Clarkin, William H.
Colburn, Arthur D., Jr.
Cook, Alden H.
Cook, Hans
Copestick, Louis B.
Cornell, Jack W.
Cotter, Jerome M.
Coughlin, Brooks W.
Crouse, Porter A.
Davis, Charles A.
Devlin, Gerald X.
Edwards, Richard S.
Ewing, William R., Jr.
Goodwin, Steven W.
Grisham, Andrew C.
Halpin, William T.
Hamblet, Dwight F.
Hiller, Emerson H.
Holmes, Roy
Howe, Paul M.
Howland, Paul C.
Hussey, John B.
Jefferson, Albert C.
John, Alfred C.
Karram, Calvin D.
Lacey, Walter H.
Leiby, Jonathan
Matthews, Francis S.
McLaughlin, Barrett J.
Miner, Arnold W.
Mitchell, Peter C.
Moller, Donald A.
Montgomery, Earl C.
Morse, Joseph C.
Mosier, Craig R.
Mysona, Eugene J.
Palmieri, Michael, Jr.
Pennypacker, Thomas R.
Pierce, George E.
Pierce, Samuel F.
Pike, John F.
Ribeiro, Joseph
Rose, Lawrence
Roy, Alfred J.
Seibert, Harry H.
Sointu, Sulo
Stires, Ronald K.
Thurston, Theodore G.
Tully, Edward J.
Vincent, Samuel W.
Wheble, John E.
White, William A.
Williams, Bennett
Williamson, Harvey V.
Woodward, Jan A.



Grants and Fellowships

The following persons were awarded grants, fellowships or honoraria during 1964:

HENRY W. ALTLAND
Gettysburg Collge

NEIL R. ANDERSEN
Massachusetts Institute of Technology

F. A. J. ARMSTRONG
The Laboratory, Plymouth, England

FRANCIS P. BRETHERTON
University of Cambridge, England

RONALD J. BUCHANAN
University of British Columbia, Canada

GEORGE B. BURNETT
Amherst College

HAROLD L. BURSTYN
Brandeis University

ROBERT J. BYRNE
University of Chicago

ANN E. CAMPBELL
Bryn Mawr College

GLEN A. CANNON
Johns Hopkins University

J. N. CARRUTHERS
National Institute of Oceanography
Wormley, Surrey, England

RICHARD L. CHASE
Princeton University

THOMAS M. CHURCH
Colgate University

ERIC D. S. CORNER
The Laboratory, Plymouth, England

PATRICK A. DAVIS
Columbia University

ROBERT G. DONOVAN
University of Notre Dame

URIEL FRISCH
Institut d'Astrophysique
Centre National de le Recherche Scientifique
Paris, France

JOHN D. GAGE
University of Southampton, England

JORIS GIESKES
University of Manitoba, Canada

BJORN N. GJEVIK
University of Oslo, Norway

CYNTHIA T. GRANT
Yale University

HARVEY P. GREENSPAN
Massachusetts Institute of Technology

ANDRÉ GUILCHER
Université de Paris, France

RICHARD L. HAEDRICH
Harvard University

BENJAMIN R. HALPERN
University of California, Los Angeles

JEELANI HAQ
Jamia College, Karachi, Pakistan

SYCD-MAZHAR-UL HAQ
University of Karachi, Pakistan

KLAUS HASSELMANN
Scripps Institution of Oceanography
University of California, San Diego

FREDERICK P. HEALEY
University of British Columbia, Canada

JACKSON HERRING
Massachusetts Institute of Technology

RAYMOND HIDE
Massachusetts Institute of Technology

HARTLEY HOSKINS
University of Chicago

DELBAR P. KEILY
Massachusetts Institute of Technology

KERN KENYON
Scripps Institution of Oceanography
University of California, San Diego

ROBERT A. KNOX
Amherst College

JAMES R. KRAMER
Syracuse University

T. N. KRISHNAMURTI
University of California, Los Angeles

ARVE KVALHEIM
University of Oslo, Norway

Stephen J. Love
Philadelphia College of Pharmacy and Science

William S. Maddux
Princeton University

Willem V. R. Malkus
University of California, Los Angeles

Murray J. Mitchell, Jr.
U. S. Weather Bureau

William R. Moehl
University of Tennessee

Edward C. Monahan
Massachusetts Institute of Technology

Robert F. Morrison
New York University

Stephen P. Murray
University of Chicago

Andrew J. Nalwalk
University of Pittsburgh

David Neev
Geological Survey, Israel

Richard T. Nowak
Massachusetts Institute of Technology

Steven A. Orszag
Princeton University

Hans Panofsky
Pennsylvania State University

Richard W. Paulson
Massachusetts Institute of Technology

Joseph Pedlosky
Massachusetts Institute of Technology

John G. Pierce
University of California, San Diego

Stephen Pond
University of British Columbia, Canada

Lewis D. Quin
Duke University

Carlton Ray
New York Zoological Society

Hans Erick Reineck
Research Institute for Geology
Senckenberg, Germany

Donald C. Rhoads
University of Chicago

J. Colin Robertson
University of Glasgow

Allan R. Robinson
Harvard University

Robert E. Rockwell
University of Massachusetts

Claës Rooth
University of Stockholm, Sweden

Michael M. Rosbash
California Institute of Technology

Murray Rosenblatt
Brown University

Peter L. Sachs
University of Reading, England

David Schlossberg
Massachusetts Institute of Technology

Lars-Gunnar Sillén
Royal Institute of Technology
Stockholm, Sweden

Woollcott K. Smith
Michigan State University

Daniel J. Stanley
University of Ottawa, Canada

James B. Sullivan
New York University

Melvin S. Swanson
Pennsylvania State University

John S. Turner
Commonwealth Scientific and Industrial
Research Organization, Australia

Sten Gösta Walin
University of Stockholm, Sweden

David Wall
University of Sheffield, England

Arthur E. Wegweiser
Washington University

Peter J. Williams
National Research Council
Ottawa, Canada

Donald M. Wilson
Scripps Institution of Oceanography
University of California, San Diego

Arthur T. Winfree
Cornell University

John Woodcock
McGill University, Canada

John R. Yearsley
Massachusetts Institute of Technology

Treasurer's Report

The accounts for the year 1964 have been audited by Lybrand, Ross Bros. & Montgomery.

The book value of endowment funds at December 31, 1964, was $4,155,304, of which $1,582,212 represented accumulated net gain from sales of investments. The market value of endowment assets on the same date, including real estate at book amount, and $169,424 in cash was $6,778,864. Endowment fund investments and income received therefrom are summarized on page 79.

Income received on endowment assets was $221,990 for the year ended December 31, 1964, compared with $209,095 the previous year.

Endowment income represented a return on endowment fund investments of 3.4 per cent at year-end market quotation, 5.6 per cent on book amount and 8.6 per cent on the contributed amount of the endowment fund.

Endowment income was allocated for 1964 operating expenses at the rate of 6 per cent of the contributed amount of endowment funds, or $152,525. Of the remaining balance amounting to $69,465, there was transferred to the income and salary stabilization reserve, $67,790 and to Oceanographic Associates as income from investment of life memberships, $1,675.

The Associates donated a total of $84,232 to the Institution during the year. This provided a very substantial addition to our unrestricted funds. See Directors comments page 21.

During 1964 $200,000 was transferred from the working capital and contingency reserve to the fund for acquisition of capital assets.

The Institution's 1964 contribution to the Woods Hole Oceanographic Institution's Employees Retirement Trust amounted to $184,172.

LYBRAND, ROSS BROS. & MONTGOMERY
ACCOUNTANTS AND AUDITORS

COOPERS & LYBRAND
IN AREAS OF THE WORLD
OUTSIDE THE UNITED STATES

Woods Hole Oceanographic Institution

Woods Hole, Massachusetts

We have examined the balance sheet of Woods Hole Oceanographic Institution as at December 31, 1964 and the related statements of changes in funds and of operating expenses and income for the year then ended. Our examination was made in accordance with generally accepted auditing standards, and accordingly included such tests of the accounting records and such other auditing procedures as we considered necessary in the circumstances. It was not practicable to confirm receivables from United States Government departments, but we have satisfied ourselves as to such accounts by means of other auditing procedures. We previously examined and reported upon the financial statements for the year ended December 31, 1963.

In our opinion, the accompanying statements (pages 76 and 77, inclusive) present fairly the financial position of Woods Hole Oceanographic Institution at December 31, 1964 and the results of its operations for the year then ended, in conformity with generally accepted accounting principles applied on a basis consistent with that of the preceding year.

The supplemental schedules included in this report (pages 78 to 79, inclusive) although not considered necessary for a fair presentation of the financial position and results of operations, are presented primarily for supplemental analysis purposes. This additional information was obtained from the Institution's records and is, in our opinion, fairly stated in all material respects in relation to the basic financial statements taken as a whole.

Boston, Massachusetts
March 2, 1965

Lybrand, Ross Bros. & Montgomery

ASSETS

Endowment Fund Assets:		
Investments:		
Bonds (market quotations $2,179,372)		$ 2,198,940
Stocks (market quotations $4,370,495)		1,727,367
Real estate		59,573
		3,985,880
Cash		169,424
		4,155,304
Plant Fund Assets (note):		
Laboratory plant and equipment		3,240,008
Vessels and equipment		5,727,881
Other property		319,192
Total plant		9,287,081
Plant funds advanced to current		708,729
		9,995,810
Current Fund Assets:		
Cash		686,645
Marketable securities		6,599
Accounts receivable:		
U.S. Government	$252,133	
Other	66,846	318,979
Unbilled costs:		
U.S. Government	944,710	
Other	6,457	951,167
Supplies		49,097
Deferred charges		165,355
Plant funds advanced to current		(708,729)
		1,469,113
		$15,620,227

LIABILITIES

Endowment Funds:		
Unrestricted as to income	$2,100,000	
Unrestricted as to principal and income	53,672	$ 2,153,672
For upkeep of plant		419,420
Accumulated net gain on sales of investment		1,582,212
		4,155,304
Plant Funds:		
Invested in plant (including $4,831,000 for construction of Atlantis II, title to which is conditional upon its continued use for oceanographic research)		9,287,081
Unexpended:		
Fund for acquisition of capital assets		547,100
General plant and equipment reserve		161,629
		9,995,810
Current Liabilities and Funds:		
Accounts payable and accrued expenses		387,768
Contribution payable to employees' retirement plan and trust		184,172
Unexpended balances of gifts and grants for research:		
Government	139,650	
Other	130,228	269,878
Reserves:		
Income and salary stabilization reserve	527,381	
Working capital and contingency reserve	99,914	627,295
		1,469,113
		$15,620,227

NOTE — Depreciation is provided on plant assets, other than vessels ($5,098,000) and the Laboratory of Marine Science ($2,065,000), at annual rates of 2% on buildings and 5% to 33⅓% on equipment. The amount provided is credited to general plant and equipment reserve.

Comparative Statement of Operating Expenses and Income

Years Ended December 31, 1964 and 1963

	1964	1963
Operating Costs and Provisions:		
Direct costs of research activity:		
Salaries and wages	$2,246,960	$1,979,907
Vessel operations	2,084,248	2,078,184
Materials, equipment and services	2,709,546	3,486,402
Travel	352,320	243,099
Aircraft operations	115,276	96,273
Computer center	180,987	119,849
	7,689,337	8,003,714
Indirect costs:		
General and administration	530,495	527,457
Land based operations	368,871	236,509
Miscellaneous	74,025	25,662
Other charges:		
Provision for working capital and contingencies	145,758	186,987
	$8,808,486	$8,980,329
Income:		
For sponsored research (including 1964 — $2,723,248, 1963 — $3,169,821 gifts and grants expended):		
For direct costs	7,546,739	7,909,001
For indirect costs	853,178	751,785
Fees for use of facilities	242,679	205,776
	8,642,596	8,866,562
Endowment income availed of:		
For institution research	142,598	94,713
For institution indirect costs	9,927	12,181
Miscellaneous	13,365	6,873
	$8,808,486	$8,980,329

Statement of Changes in Funds

Year Ended December 31, 1964

	Endowment Funds	Plant Funds: Invested in Plant	Plant Funds: Unexpended	Unexpended Balances of Gifts and Grants for Research	Reserves: Income and Salary Stabilization Reserve	Reserves: Working Capital and Contingency Reserve
Balance, December 31, 1963	$4,104,494	$9,051,567	$494,751	$ 253,391	$459,591	$154,156
Gifts and grants received	4,000		79,898	2,834,654		
Endowment income					221,990	
Net gain on sales of investments	46,810					
Additions from current year's operations:						
Provision for depreciation			170,606			
Provision for working capital, deferred maintenance and contingencies						145,758
Availed of for research costs				(2,723,248)	(152,525)	
Transferred to plant funds from working capital and contingency reserve			200,000			(200,000)
Transferred to unexpended balance of gifts from Oceanographic Associates				1,675	(1,675)	
Invested in plant		187,173	(187,173)			
Capitalization of items expensed in prior years		54,920	(54,920)			
Prior years depreciation on items capitalized			5,723			
Cost of assets disposed of		(6,579)				
Miscellaneous additions (reductions)			(156)	(96,594)		
Balance, December 31, 1964	$4,155,304	$9,287,081	$708,729	$ 269,878	$527,381	$ 99,914

Note — Unexpended balances consist of amounts received in advance of expenditure, and do not include receipts or expenditures under reimbursement type contracts.

Direct Costs of Research Activity

Year Ended December 31, 1964

	Salaries and Wages	Vessel Operations	Materials, Equipment and Services	Travel	Aircraft Operations	Computer Center	Total
U.S. Government:							
Contracts	$1,518,153	$1,337,072	$1,897,059	$129,348	$ 34,453	$155,691	$5,071,776
Grants	677,457	691,390	718,380	208,969	80,761	24,857	2,401,814
Other sponsored research	6.687	21,423	41,359	3,557		123	73,149
Total direct costs of sponsored research	2,202,297	2,049,885	2,656,798	341,874	115,214	180,671	7,546,739
Institution research	44,663	34,363	52,748	10,446	62	316	142,598
Total direct costs of research	**$2.246.960**	**$2.084.248**	**$2.709.546***	**$352.320**	**$115.276**	**$180.987**	**$7.689.337**

*Includes grants and fellowships:

U. S. Government grants	$ 29,678
Other sponsored research	33,622
Institution research	42,458
	$105,758

General and Administration Expenses and Expenses for Land Based Operation

Year Ended December 31, 1964

General Expenses:		
Staff benefits:		
Contribution to retirement plan		$ 22,114
Social security taxes		9,904
Employee health benefits		20,537
		52,555
Provision for depreciation (credited to general plant and equipment reserve)		39,285
Shop services		18,763
Administration Expenses:		
Salaries and wages	$395,084	
Insurance, travel, supplies and other	245,379	640,463
		751,066
Less general and administration expenses included in direct cost of research activity		220,571
		$530.495
Land Based Operation:		
Salaries and wages		$102,381
Contribution to retirement plan		5,965
Social security taxes		3.390
Provision for depreciation (credited to general plant and equipment reserve)		31,862
Shop services		90,106
Other repair costs	25,981	
Heat, light and power	64,439	
Other	44,747	135,167
		$368.871

NOTE — Because of accounting reclassifications some of the amounts above are not directly comparable with the prior year.

Summary of Investments

As at December 31, 1964

	Book Amount	% of Total	Market Quotation	% of Total	Endowment Income
BONDS:					
Government	$ 958,847	24.1	$ 957,642	14.5	$ 38,008
Railroad	403,815	10.1	397,123	6.0	19,649
Public utility	340,715	8.6	329,236	5.0	14,742
Industrial	314,652	7.9	310,010	4.7	15,583
Financial and investment	180,911	4.5	185,361	2.8	9,034
Total bonds	2,198,940	55.2	2,179,372	33.0	97,016
STOCKS:					
Preferred	52,270	1.3	58,275	0.9	4,521
Common:					
Public utility	443,827	11.1	1,183,765	17.9	31,544
Industrial	828,842	20.8	2,403,469	36.3	63,198
Miscellaneous	402,428	10.1	724,986	11.0	23,685
Total common stocks	1,675,097	42.0	4,312,220	65.2	118,427
Total stocks	1,727,367	43.3	4,370,495	66.1	122,948
REAL ESTATE	59,573	1.5	59,573*	.9	2,026
Total investments	$3,985,880	100.0	$6,609,440	100.0	$221,990

*At book amount.