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WOODS HOLE OCEANOGRAPHIC INSTITUTION

REFERENCE NO. 68-6

OCEANOGRAPHIC AND UNDERWATER ACOUSTICS
RESEARCH CONDUCTED DURING THE PERIOD
1 MAY - 31 OCTOBER 1967

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WOODS HOLE, MASSACHUSETTS

WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

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February 1968

TECHNICAL REPORT

*Submitted to the Undersea Warfare Branch,
Office of Naval Research under Contract
Nonr-4029(00) NR 260-101.*

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Approved for Distribution

Earl E. Hays, Chairman
Department of Geology and Geophysics

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ABSTRACT

This is a status report for the period 1 May to 31 October 1967 for Contract Nonr-4029(00) with the Office of Naval Research. Investigations of this contract include oceanic acoustics, physical oceanography, sea floor properties, and advisory activities.

Acoustic, geophysical, and oceanographic cruises by R/V ATLANTIS II, CHAIN, GOSNOLD, ALVIN and LULU in the North Atlantic Ocean and Baltic Sea are described. Continuing analyses of acoustical and geophysical data are discussed; papers, reports and technical memoranda written during this period are listed.

INTRODUCTION

This report is an account of activities during the period 1 May 1967 to 31 October 1967 under Contract Nonr-4029 with the Woods Hole Oceanographic Institution. The major portion of the research has been carried out by members of the Department of Geology and Geophysics.

The program under this contract is directed toward providing basic information about the total oceanic environment with the aim of assisting the Navy carry out its mission. This includes theoretical analysis and field work in acoustics, physical oceanography and sea floor studies and direct liaison with fleet units.

An acoustic, geophysical, and oceanographic cruise of ATLANTIS II to the Baltic Sea and North Atlantic Ocean was undertaken during May, June, and July of 1967 in support of the NATO exercise (MILOC 67) in the Baltic Sea. Magnetic and bathymetric studies were carried out in the North Atlantic. Acoustic transmission experiments, Nansen bottle casts, velocimeter lowerings, echo soundings, bottom cores, and continuous seismic profiles were made in the Baltic sea.

Research submarine ALVIN was used for investigations of mid-water sound-scatterers in the slope water south of Cape Cod (October) and for studies of seafloor fresh water seepages on the Blake Plateau (July).

In addition to our studies in the Baltic aboard ATLANTIS II, an investigation of the thermal front region southwest of Bermuda aboard CHAIN was undertaken by the Geology and Geophysics Department during May and June 1967. Although this cruise was funded by a separate contract with the Office of Naval Research (Nonr-2866), it is reported here since the investigation contributed to the objectives of Contract Nonr-4029.

Also four geophysical cruises of CHAIN and an aeromagnetic study by the WHOI aircraft C54Q, all sponsored by the National Science Foundation, are reported because it is believed these studies are related to the general scope of Nonr-4029.

Analyses of acoustic, geophysical, and geological data from the North Atlantic Ocean, the Baltic Sea, the eastern Mediterranean, and Antarctica have been completed or are underway. Theoretical and experimental work on hydrophone arrays for receiving underwater and seismic reflection signals is continuing. Development of computer

programs for analysis of acoustic transmission results is also continuing.

Papers published or submitted for publication concern scattering of sound, underwater sounds of biological origin, seismic reflection and refraction, magnetic and gravity anomalies over the mid-Atlantic Ridge and Caribbean Sea, geological structure of the sea floor, internal waves, paleomagnetic and paleontologic studies of deep sea sediments, and automatic data processing and control.

PAPERS

The following papers were published during this period under Contract Nonr-4029 and related grants as noted:

Contribution No. 1388. Resonance Scattering of Sound by a Small Gaseous Object of Arbitrary Form by Melvin Steinberg. Jour. Acous. Soc., Vol. 41, No. 5, pp. 1352-1357. (Contract Nonr-1367 and NSF Grant GB-543).

Contribution No. 1699. Seismic Reflection Profiles along the Drill Holes on the Continental Margin off Florida by K. O. Emery and E. F. K. Zarudzki. Geol. Sur. Prof. Paper 581-A, pp. A1-A8, 1967. (Contract Nonr-4029 and NSF Grant GP-4233). (Also WHOI Ref. No. 67-71).

Contribution No. 1855. Structure of the Western Somali Basin by E. T. Bunce, M. G. Langseth, R. L. Chase and M. Ewing. Jour. of Geophy. Res., Vol. 72, No. 10, pp. 2547-2555. (Contracts Nonr-4029 and NSF Grants GP-2370 and GA-283). (Also WHOI Ref. No. 67-38).

Contribution No. 1915. Origin and Development of the Foraminiferal Genus *Pseudo-hastigerina* Banner and Blow, 1959 I, Taxonomy and Phylogeny II, Biometric Analysis by W. A. Berggren, R. K. Olsson and R. A. Reymont. Micropaleontology 13(3):265-288, July 1967. (NSF Grant GS-676).

Contribution No. 1925. Project ADD by F. R. Hess. Jour. of Ocean Technology, Vol. 1, No. 2, 1967. (Contract Nonr-4029). (Also WHOI Ref. No. 67-51).

Contribution No. 1837. A Shipboard Oceanographic Data Processing and Control System. IEEE Transactions on Geoscience Electronics, Vol. GE-5, No. 2, pp. 41-50, by C. O. Bowin, R. Bernstein, E. Ungar and J. R. Madigan, 1967.

Contribution No. 1942. Magnetic Anomalies over the mid-Atlantic Ridge near 27°N by J. D. Phillips. Science, Vol. 157, No. 3791, pp. 920-923, 1967. (Contract Nonr-4029). (Also WHOI Ref. No. 67-68).

Contribution No. 2002. Late Pliocene-Pleistocene Stratigraphy in Deep-Sea Cores for the South-Central North Atlantic by W. A. Berggren, J. D. Phillips, A. Bertels and D. Wall. Nature, 216, 253-254. (Contracts Nonr-4029 and NSF Grant GP-279).

The following papers were submitted during this period under Contract Nonr-4029 and related grants as noted:

Contribution No. 1937. Five Years Experience with a Shipboard Oceanographic Data Processing System: Hindsight and Foresight by C. O. Bowin. Submitted to the 4th U. S. N. Symposium on Military Oceanography. (Contract Nonr-4029).

Contribution No. 1942. Magnetic Anomalies over the mid-Atlantic Ridge and their Effect on MAD System (Confidential). 4th U. S. Navy Symposium on Military Oceanography, U. S. Naval Research Laboratory, Vol. II, pp. 41-71.

Contribution No. 1943. Evidence of Pleistocene Events in the Structure of the Continental Shelf off the Northeastern United States by S. T. Knott and Hartley Hoskins. Submitted to Marine Geology. (Contracts NObsr-72521 and Nonr-1367 and 4029).

Contribution No. 1955. Seismic Refraction Measurements in the Western Mediterranean Sea by D. A. Fahlquist and J. B. Hersey. Submitted to Bull. Musée Océanographique, Monaco. (Contract Nonr-4029).

Contribution No. 1958. The mid-Atlantic Ridge between 22° and 23° North Latitude and the Tectonics of mid-Ocean Rises by T. H. van Andel. Submitted to the Journal of Geophysical Research. (Contracts Nonr-4029, 2216(23); NSF Grants GP-4772, 5170, 5353; and U. S. Atomic Energy Commission Contract AT-30-1, NYO-2174-63).

Contribution No. 1978. Micropaleontology and the Pliocene/Pleistocene Boundary in a Deep-Sea Core from the South-Central North Atlantic by W. A. Berggren. Submitted to the Proceedings of the 4th Session on Mediterranean Neogene Stratigraphy. (Contract Nonr-4029).

Contribution No. 1984. Rises, Trenches, Great Faults and Crustal Blocks by W. Jason Mason. Submitted to Journal of Geophysical Research. (Contract Nonr-4029 and NSF Grant GP-579).

Contribution No. 2004. Underwater Playback of their Own Sounds to Leptoncyotis (Weddell Seals) by W. A. Watkins and W. E. Schevill. Submitted to Journal of Mammalogy. (Contracts Nonr-4029, 4446, and NSF Grant GA-141).

Contribution No. 2005. Swordfish Xiphias gladius Attacks Submarine (ALVIN) by E. F. K. Zarudzki and R. L. Haedrich. Submitted to Deep-Sea Research. (Contract Nonr-4029, Nonr-3484, and NSF Grants GB-4431).

Contribution No. 2010. Geophysical Study of the Cayman Trough by C. O. Bowin. Submitted to Journal of Geophysical Research. (Contract Nonr-4029 and NSF Grants GP-24142 and GP-5353).

Contribution No. 2014. Classification and Phylogeny of Cenozoic Trissocyclidae (Radiolaria in the Pacific and Caribbean Basins I) by R. M. Goll. Submitted to Journal of Paleontology (No contract) - Thesis.

Contribution No. 2015. Classification and Phylogeny of Cenozoic Trissocyclidae (Radiolaria in the Pacific and Caribbean Basins II) by R. M. Goll. Submitted to Journal of Paleontology (no contract). Thesis.

Contribution No. 2016. Tertiary Boundaries by W. A. Berggren. Submitted to Proceedings of S. C. O. R. Colloquium, Cambridge, England. (Contract Nonr-4029 and NSF Grant GS-676).

Contribution No. 2026. Geology of the North Slope of the Puerto Rico Trench by R. L. Chase and J. B. Hersey. Submitted to Deep-Sea Research. (Contracts Nonr-1367 and 4029 and NSF Grants GP-822, GP-1123, and GP-5355).

Contribution No. 2028. The Underwater Song of Erignathus (Bearded Seal) by Carleton Ray, William Watkins and John Burn. Submitted to Science. (Contract Nonr-4446 and NSF Grants GA-126 and GA-234).

Contribution No. 2030. Quantitative Method of Describing the Regional Topography of the Ocean Floor by M. McDonald and Eli Katz. Submitted to Marine Geology. (No contract)

Contribution No. 2033. Early Pleistocene Dinoflagellates from the Royal Society Borehole at Ludham, Norfolk by David Wall and Barrie Dale. Submitted to New Phytologist. (NSF Grant GB-5200).

UNPUBLISHED WHOI REPORTS

The following unpublished reports have been completed during this period under Contract Nonr-4029 and other contracts or grants as noted:

WHOI Ref. No. 66-52. Sound Velocity Profiles between Bermuda and the Antilles. By R. E. Payne and J. C. Beckerle. (Contracts Nonr-4029 and 2866).

WHOI Ref. No. 66-63. Narrative of CHAIN Cruise No. 46. By C. O. Bowin. (Contract Nonr-4029).

WHOI Ref. No. 67-10. CHAIN Cruise No. 60, North Atlantic Ocean, Caribbean Sea, Gulf of Mexico, May 18 - June 30, 1966. Summary Cruise Report prepared by Chief Scientist, Track Charts, Bathymetry and Location of Observations by W. M. Dunkle and K. G. Bumpus. (NSF Grants GP-5319 and GB-4431).

WHOI Ref. No. 67-14. Track Charts, Bathymetry and Location of Observations. ATLANTIS Cruise No. 223, March 7 - June 3, 1956 and BEAR Cruise No. 240, February 27 - June 3, 1956, North Atlantic Ocean and Caribbean Sea by K. G. Bumpus and William Dunkle. (Contract Nonr-4029).

WHOI Ref. No. 67-16. The Normal Incident Reflectivity of the Sea Floor at 12 kc and its Correlation with Physical and Geological Properties of Naturally-Occurring Sediments by L. R. Breslau. (Contract Nonr-1367, 4029, 1841 and NObsr-72521 and 89464).

WHOI Ref. No. 67-26. Second Supplementary Report on the Oceanographic Shipboard Data Processing and Control System (ODPCS) Aboard the Research Vessel CHAIN, October 1963 to December 1966 by C. O. Bowin, W. D. Nichols, T. C. Aldrich, E. F. Dugan, G. N. Ruppert and J. B. Zwilling. (Contract Nonr-4029 and NSF Grants GP-2370, GP-1123, and GP-279).

WHOI Ref. No. 67-28. Track Charts, Bathymetry and Location of Observations, YAMACRAW Cruise No. 3, August 9 - August 26, 1957 and YAMACRAW Cruise No. 6, November 4 - November 19, 1957 by William Dunkle and K. G. Bumpus. (Contract Nonr-4029).

WHOI Ref. No. 67-40. Some Deep-Water Sound Transmission Paths South of Cyprus, Part II. Diffraction Effects by Lincoln Baxter II and Robert Brockhurst. (Contracts Nonr-4029 and 4730).

WHOI Ref. No. 67-53. Underwater Acoustics Wavefront Variations and Internal Waves by J. C. Beckerle, J. L. Wagner and R. D. Worley. (Contract Nonr-2866 and Western Electric Company Nonr-3775).

WHOI Ref. No. 67-55. Track Charts, Bathymetry and Location of Observations. North Atlantic Ocean, Blake Plateau, ATLANTIS Cruise No. 251, November 4 - December 2, 1959 by William Dunkle and K. G. Bumpus. (Contract Nonr-4029).

UNPUBLISHED TECHNICAL MEMORANDA

The following technical memoranda were completed during this period under Contract Nonr-4029 or related contracts or grants as noted:

WHOI Tech. Memo #2-67. Cruise Plan for CHAIN No. 67, 10 May - 10 June 1967 by J. C. Beckerle. (Contract Nonr-2866).

WHOI Tech. Memo #3-67. A Line Amplifier (The Briefcase) by F. R. Hess. (Contract Nonr-4029).

WHOI Tech. Memo #4-67. Cruise Plan for CHAIN No. 70, 12 July - 2 August 1967 by S. T. Knott. (NSF Grant GA-976).

WHOI Tech. Memo #5-67. A Constant Current Bridge for Off Null Measurements by Leonard F. Shodin. (Contract Nonr-4029).

WHOI Tech. Memo #6-67. Cruise Plan for CHAIN No. 73, 6 September - 27 Sept. 1967 by S. T. Knott and E. Uchupi.

WHOI Tech. Memo #7-67. Cruise Plan for CHAIN No. 75. The Lesser Antilles to mid-Atlantic Ridge Area, October 16 - December 20, 1967 by C. O. Bowin. (NSF Grant GA-1209).

CRUISES

Use of Vessels

<u>Cruise # & Sponsor</u>	<u>Date</u>	<u>Work Area</u>	<u>Principal Investigations</u>	<u>Chief Scientist</u>
A-II #32	14 May 1967	N. Atlantic Ocean	Magnetic and bathymetric	J. D. Phillips
Nonr-4029	25 July 1967	Baltic Sea	survey, acoustic experiments,	E. E. Hays
AEC-2176			environmental and acoustic transmission measurements. (Nansen bottle casts, velocimeter lowerings, streaming vertical and horizontal hydrophone arrays, echo soundings, continuous seismic profiling.	V. T. Bowen
CHAIN #67	10 May 1967	N. Atlantic Ocean	Thermal front measure-	J. C. Beckerle
Nonr-2866	9 June 1967	s. w. of Bermuda	ments, velocimeter measurements, internal wave measurements, optical navigation system testing and gravity measuring system testing.	
CHAIN #70	12 July 1967	Continental Rise	Bathymetry, seismic	S. T. Knott
NSF GP-976	2 Aug. 1967	area	profiling, gravity and magnetic measurements, stratigraphic investigation.	
ALVIN	20 Aug. 1967	So. of Nantucket	Acoustic trials	E. Hays.
Nonr-4029				
CHAIN 73	6 Sept. 1967	So. of Cape Hatteras	Same as CHAIN 70	S. T. Knott
NSF	26 Sept. 1967			
GP-976				

Use of Vessels (cont.)

<u>Cruise # & Sponsor</u>	<u>Date</u>	<u>Work Area</u>	<u>Principal Investigations</u>	<u>Chief Scientist</u>
CHAIN 75 NSF GA-1209	16 Oct. 1967 31 Oct. 1967	Lesser Antilles to mid-Atlantic Ridge area	Bathymetry, continuous gravity and magnetic measurements, continuous seismic profiling, heat flow measurements, sediment coring and rock dredging.	C. O. Bowin
ALVIN Nonr- 4029	2 July 1967 8 July 1967	Blake Plateau	Attempted direct observation of submarine fresh water outflows.	E. F. K. Zarudzki
ALVIN Nonr- 4029	2 Oct. 1967 6 Oct. 1967	Continental Slope south of Cape Cod	Direct observation of mid- water sound scatterers.	R. H. Backus

ATLANTIS II - Cruise 32. Woods Hole to Kiel, Germany (Dr. Phillips).

ATLANTIS II departed from Woods Hole on 14 May for Kiel, Germany to participate in the NATO exercise MILOC 67 in the Baltic Sea. Enroute ATLANTIS II steamed to the mid-Atlantic ridge near 44°N. Here a geophysical study using bathymetric and magnetic profiling techniques was made. The scientific objectives of this work was to determine the nature of the total intensity magnetic anomalies over the ridge and their relation to topography and current hypotheses regarding seafloor spreading. This investigation provided the basic information used in planning a more detailed geophysical and geological study of the 44°N latitude area during the last leg of this cruise (Flensburg - Woods Hole).

In addition to our geophysical studies over the mid-Atlantic ridge two station measurements were made in the southern English Channel to test acoustic equipment for our later studies in the Baltic Sea.

ATLANTIS II - Cruise 32. Kiel, Germany - Kalmar, Sweden - Flensburg,
Germany, Dr. Hays.

The measurement of acoustic transmission properties was the major purpose for the Baltic portion of ATLANTIS II, Cruise 32. This investigation was part of a NATO oceanographic exercise, the details for which are given in Operation Plan MILOC BALTIC 67 (NATO Restricted). Three areas in the Baltic were studied for four days each by ships from Denmark, Germany, Italy, Netherlands, and United States. In each area ATLANTIS II ran a pattern that encompassed the stations of all other ships and made environmental measurements near each station and at other designated positions. In this way ATLANTIS II served as the calibration ship in the exercise for the environmental measurements.

Early in the cruise we determined that more accurate salinity-temperature-depth measurements could be obtained by Nansen bottles at the desired locations and depths rather than using certain NATO supplied equipment. Accordingly, we changed our station procedure from that given in the operations plan.

In addition to the station data and cloud cover photographs an automatic digital data recorder was collecting various meteorological and navigational data on a one-minute repetition rate.

ATLANTIS II - Cruise 32 - Flensburg, Germany - Argentia, Newfoundland -
Woods Hole (Dr. Bowen).

This portion of the cruise was largely supported by the Atomic Energy Commission (Contract AT(30-1)-2174). However, certain scientific objectives of the investigation were relevant to the aims of Contract Nonr-4029. These included a detailed examination of a section of the mid-Atlantic Ridge, in terms of its bathymetry, magnetics, petrology, sedimentology, heat flow, and hydrography. The ridge study was successfully completed in a rectangular area normal to the ridge axis and between 42°10'N, 27°53'W and 43°55'N, 29°50'W, selected after study of the bathymetric and magnetic profiles made during the earlier Woods Hole - Kiel portion of this cruise.

A summary of the acoustic, hydrographic, magnetic and bathymetric measurement made during this cruise, including the mid-Atlantic studies is given in the ATLANTIS II-32 Cruise Summary (WHOI Ref. No. 67-47).

CHAIN Cruise 67 - Woods Hole - Bermuda - Woods Hole (Drs. Beckerle and Katz).

CHAIN departed Woods Hole on 10 May 1967 for the area south of Bermuda. The major scientific objectives of the cruise included an investigation of the thermal front region near 30°N latitude and environmental measurements of the ocean during acoustical transmission studies. Although this cruise was supported largely by Contract Nonr-2866, it is reported here since the investigations were relevant to the general scope of Contract Nonr-4029.

This cruise also afforded preliminary experiments with the GEON system to measure the tilt of the ocean surface relative to local gravity vertical. Engineering efforts were also an important part of the cruise. These included development tests of a multi-sensor (SVP) underwater instruments package with an on-line computer output in cooperation with Sylvania Electronics Company and testing of a new vibrating string gravity meter by Massachusetts Institute of Technology scientists.

The thermal front study was carried out with the help of Weather Reconnaissance Squadron Four from Jacksonville, Florida. They made airborne infrared surveys of the sea surface in order to help locate and define the thermal front over a larger area than possible from CHAIN. As it turned out we found the frontal region ourselves using a towed temperature sensor at a depth of 112 meters.

The towed observations allowed us to define the meandering shape of the front for over 110 miles. In the region of the front we observed large meandering surface slicks. The aircraft survey also showed a number of photographs with long meandering slicks during the period of our observations.

Our environmental measurements during the acoustic transmission experiments were conducted in cooperation with the USS MISSION CAPISTRANO, USS PENOBSCOT, the Bell Telephone Laboratories, and the U. S. Navy Underwater Sound Laboratory. The main objective of CHAIN in this joint effort was the measurement of internal ocean waves at a location between a sound source and hydrophone. During this work we recorded environmental data between 50 and 650 meters for greater than 30 hours. Unfortunately, after completion of this first joint experiment the seas picked up considerably and it became too difficult to allow continuation of the joint experiment.

CHAIN Cruises 70 and 73, Woods Hole - Woods Hole (Mr. Knott).

During July and September two geophysical cruises were made aboard CHAIN to investigate the continental rise between Nova Scotia and Cape Hatteras. This study was largely supported by the National Science Foundation (GP-976). However, the support of the Office of Naval Research (Contract Nonr-4029) enabled the new computer and data storage system to be used for recording and compiling gravity data. The Office of Naval Research also provided the major equipment used in the continuous seismic profiling, bathymetric and magnetic studies. In addition bottom reflectivity data were collected.

The purpose of this investigation was to relate the continuous seismic profiles with stratigraphic information previously obtained from dredgings, piston cores, offshore oil wells, the JOIDES drill holes off Florida and seismic refraction velocities. About 4300 miles of bathymetric, seismic reflection, gravity, and magnetic measurements were obtained. Seismic velocity data were obtained by use of expendable sonobuoys periodically along the ship track. A more complete discussion of each cruise is given in the Cruise Plans (WHOI Tech. Memo #4-67 and #6-67).

ALVIN - Woods Hole - Woods Hole (Dr. Backus).

ALVIN departed Woods Hole 2 October for an area over the continental slope south of Cape Cod. ALVIN was accompanied by LULU and GOSNOLD. The purpose of the cruise was the direct observation of some mid-water sound-scatterers in the slope water. In all eight dives were made to investigate the sound scattering feature known as

"Alexander's Acres". Sonarscope photographs, underwater photographs, and netted specimens showed that schools of lanternfish are probably responsible for this particular sound scattering feature.

ALVIN - Blake Plateau - West Palm Beach, Fla. - Charleston, S. C.
(Mr. Zarudzki).

During the period 2 July - 8 July ALVIN, accompanied by LULU, made several dives to investigate the seafloor of the Blake Plateau. The purpose of these dives was direct observation of previously reported, possible fresh-water outflows. However, no fresh-water outflows were detected.

TASK UNIT I - OCEANIC ACOUSTICS

Work Unit - Sound Transmission

Acoustic Transmission in a Non-Layered Medium (Dr. Katz, Messrs. Brockhurst and Douth).

A project was initiated to do ray tracing and spreading loss computation in the presence of variations of the sound velocity profile with range. Our purpose is threefold:

- (i) To perform parametric numerical experiments to predict the qualitative importance of range variations in models of known conditions.
- (ii) To have the capability of converting our oceanographic data, exactly as taken during an acoustic experiment, to acoustic predictions as an aid to analysis and interpretation of data.
- (iii) To study the equivalence of different numerical techniques which have been brought to bear on this general problem in the last few years.

Two distinct computer programs are in the process of being completed. The first employs the Runge-Kutta method to do ray tracing in a field where the velocity is everywhere specified by an input function. Given the velocity field, the approximation is in the solution of the eikonal equation. This program is particularly suited for studies of type (i). The second is an extension of the linear gradient technique to another dimension. The approximation is in the specification of the field at intermediate points, the ray path solutions then being exact. Its input is in the form of station data and will be used for (ii). Comparison studies between the two will provide perhaps the first contribution towards (iii). The two programs will be summarized below.

The first computer program uses an asymmetrical Epstein sound velocity profile. The depth of the sound channel axis of the velocity profile may be varied with range by any suitable equation. Results of this program have been compared with those published by Eliseevnin (1965). It was found that the horizontal axis of his figure is mis-labelled. It is correct if units on the horizontal axis are multiplied by 0.1 and if the axis of the sound channel be redrawn to this new scale.

Since the sound velocity varies by a factor of 10% in the velocity profile used by Eliseevnin, his results are unrealistic as applied to the SOFAR channel, where the velocity of sound may typically vary by 2 or 3%. Sound velocity profiles have been calculated and ray diagrams drawn for the ATLANTIS Cruise 215 crossing of a boundary of the Gulf Stream. In this particular area the sound velocity profile varied by 2% and the sound channel axis was depressed 680 meters. An example of the ray trace for this case is presented in Figure 1.

The analysis of different sound velocity profiles and different axis displacement functions is being continued.

The second program is designed for use with measured sound velocity profiles and depth along an experimental track. It is assumed that sound velocity with depth is available at sufficiently small intervals in range so that linear interpolation will adequately describe the two dimensional velocity field. It is also assumed that the bottom contour can be approximated to sufficient accuracy by a series of straight line segments of arbitrary length. The effect of the curvature of the earth will be approximated by adjusting the velocities and depths at each range using Watson's approximation to Horton's method. Ray quantities are

Figure 1. Sound propagation across Gulf Stream.

calculated along short segments by locally rotating the coordinate system so that the velocity gradient is normal to the initial direction of the ray at each point. In this system, one can locally apply Snell's law to a good approximation. Magnetic tape output at prespecified range intervals will permit subsequent intensity calculations and off line ray tracing.

Diffraction and Interference Effects in Underwater Sound (Messrs. Baxter, II, and Dow and Dr. Hays.

An investigation of the Baltic Sea sound channel was carried out on ATLANTIS II Cruise 32 in May and June, using for the first time the new vertical sectionalized array. Three separate areas in the southern Baltic were surveyed. Velocimeter records showed that the channel as predicted on the basis of the 1966 Danish measurement of strong gradients in temperature and salinity was present. The five hydrophones of the vertical array were spaced in numerical order through the channel with #1 and #2 near the surface, #3 and #4 approximately at the channel axis and #5 near the bottom. Since the data from each hydrophone is fed to a separate channel, characteristics of the signals at the various depths can be analyzed and compared. Several sound transmission runs with spark and explosive sources were made in each area at ranges up to about 19 miles. The data from 17.5 hours of sparking and 789 explosive charges are recorded on 75 reels of 4-channel magnetic tape. Sound spectrograms of some of the shots were made with a Kay Electric 7029A sound spectrograph. Wave induced noise in the recording was kept low by positioning the array between weights and combinations of submerged and surface floats. Preliminary inspection of the recordings and sound spectrograms indicates that their quality is sufficiently good to permit a study of ray and normal mode transmission and bottom reflectivity in the frequency range from about 50 Hz to 10 KHz.

After the cruise, the following actions were taken: (a) Further sound spectrograms were made on the Kay Electric 7029A sound spectrograph. (b) The E. A. I. Oceanographic Computer was taken out of storage and refurbished and (c) programming for edited digitization was investigated. The results are respectively (a) The sound spectrograms give a good overall picture of dispersion and intensity as a function of frequency. Dispersion below 1000 Hz is readily seen in those that we

have made to date. Although the record is not clearly resolved into discrete normal mode patterns, there is a great deal of consistent detail to be studied and explained. (b) The Oceanographic Computer is nearly ready to give us some quantitative spectrum levels in the shortest possible time. (c) It would be best to do the complete analysis digitally once programming and editing is worked out, but this would be a long range project. For the present we are planning to digitize two of our tapes to use in development of programs for analysis.

Modal Analysis for Dispersion Effects Observed in the Baltic Sea
(Dr. Murphy).

The sound spectrograms for the AII-32 Baltic Sea data show dispersion effects. However, no distinct or individual modal curves appear in the records. A preliminary analysis of some of the modal aspects of the sound propagation problem for conditions appropriate to the Baltic Sea experiments is now in progress.

Although methods for making machine computations for modal analysis have been extensively discussed in the literature, it was decided, in this preliminary analysis, to avoid elaborate calculations until some feel for the implications of the Baltic Sea sound spectrograms is obtained. Therefore the analysis in progress has been based on closed form solutions that more explicitly show the physical aspects of the problem rather than on elaborate numerical analysis. For example, the procedure discussed by Deavenport (1966) which used hypergeometric functions and a sound velocity profile of the form ("Epstein profile")

$$\frac{1}{c^2(z)} = A \operatorname{sech}^2\left(\frac{z}{H}\right) + B \tanh\left(\frac{z}{H}\right) + D \quad (1)$$

has been applied where z is the depth coordinate; A , B , D and H are profile parameters. Parameter values appropriate to the Baltic Sea experiments, have been used to construct modal solutions, dispersion relations, modal excitation functions, etc.

For simple boundary conditions, calculations can be carried out readily. For example, with the boundary condition that the z-independent part of the sound field goes to zero for $z \rightarrow \pm \infty$, the dispersion relations and excitation functions have been computed for parameters appropriate to the Baltic data. The results show that for frequencies above 700 or 800 cps, the z-dependent part of the sound field for lowest order modes becomes negligible before either the sea surface or sea bottom is reached. Therefore, the results should have some validity at frequencies above 700 or 800 cps. In fact, these results predict practically unobservable dispersion above these frequencies, which does agree with the observations. For lower frequencies, where the interesting dispersion effects occur, it is necessary to use more elaborate boundary conditions, and calculations along these lines are in progress.

Work Unit - Sound Scattering

Direct Observation of Mid-water Sound -scatterers from ALVIN (Dr. Backus and Colleagues).

A study aimed at making direct observations and sampling of certain mid-water sound-scattering phenomena was undertaken using DSRV ALVIN during 3-6 October. The special sound-scattering feature known as "Alexander's Acres", peculiar to the Slope Water, was found to be present at the diving site, 39°48'N, 70°33'W. This layer has been under study at the Institution for 12 or 13 years. A good deal has been learned about the distribution, behavior, and acoustical characteristics of this layer, but the big question has always remained, "What was the animal responsible?" Because of its acoustical properties, some swimbladdered, schooling fish was thought most likely.

On the first dive ALVIN descended to 625 meters, near the bottom of the scattering layer as observed by surface echo-sounder. ALVIN's sonar was put in operation, a conspicuous target was chosen, and ALVIN closed it with lights off. At range "zero" the lights were turned on and the submarine was in the midst of a large school consisting of a lanternfish 50 - 60 mm long, there being 2 or 3 fish per cubic meter, and thousands of them in view. A net had been rigged up on ALVIN's basket. The submarine was driven through the school, catching dozens of specimens. This procedure was repeated at this and at other depths

always with the same result. We decided the lanternfish was Ceratoscopelus maderensis and this identification was verified upon surfacing with the specimens.

Subsequent dives were spent in verifying the nature of these fish schools and studying their behavior. Photographs of ALVIN's sonarscope were made for studying the spatial distribution of the schools of Ceratoscopelus in comparison with the spatial distribution of the sound-scatterers observed with the surface echo-sounder. Pictures of the fish schools were made with ALVIN's cameras. A report on these observations is in preparation.

Midwater Sound-scattering Integrator (Dr. Backus and Mr. Wing).

We have described this apparatus in earlier reports. It has been built in order to study the geographic variation in the intensity of mid-water scattering 12 Hz count in the upper 400 fathoms of the sea.

Sea trials of this unit were conducted on CHAIN 72 (August) and showed several troubles directly related to unregulated ship's A. C. power and failure of ship's air conditioning. Further, there was only one spare UQN transducer available for the integrator's use (it cannot be used on the UQN that is required for the PGR). Since the transducers used were widely separated, the quality and amplitude of the returned signal was low. Because of these difficulties it was decided to make tape recordings at sea suitable for integrator analysis at leisure ashore. This was done on GOSNOLD 106 (October).

A special calibration box was built for making standard 12 Hz calibration sections and ambient noise sections on each tape (10 minutes calibration, 10 minutes ambient noise, and 10 minutes of volume reverberation data). Some difficulties with the GOSNOLD's PDR (Westex) prevented good records during the first two days, but the four tapes made on the following two days look very good, although the analysis has not yet been made.

It is felt that tape recordings should be made at sea even though the integrator is also being used. This provides a permanent record, which can be re-examined at any time and re-evaluated as the integrator is improved or a new design conceived.

Work Unit - Ambient Noise (Messrs. Schevill and Watkins).

The seasonal and geographic distribution of ambient noise is still imperfectly known. It is the major element in natural background noise. Its level, changing from time to time and from place to place, has often limiting effect on underwater acoustic efforts. Its study has included analysis of ambient recordings from widely separated locales as well as animal recordings of widely divergent species.

The Antarctic records of the under-ice ambient noise continue to be of interest. Sound-ray propagation to hydrophones at varying depth were compared with the sounds received. This confirmed the very low level of reflection from the sea-ice. Shallow hydrophones had relatively long range listening capabilities and hydrophones on the bottom had short ranges at these 300 m depths; this was due to the low level of reflection from the ice cover and a consistent upward sound refraction pattern.

A comparison was made of the sounds of Arctic bearded seals, Erignathus barbatus and the sounds of the Antarctic Weddell seals Leptonychotes weddelli. Both seals were recorded during the early spring season. The bearded seal produces a long (up to a minute or more) frequency modulated song that is characterized by rapid sinusoidal excursions in frequency. The overall song has a dropping frequency characteristic. The Weddell seal also may produce a long trilling call (40 seconds or more) of dropping frequency; the Weddell trill, however, is composed of discrete pulses rather than being frequency modulated. Both these animals contribute heavily in their respective regions.

Playback of their own sounds to Weddell seals effected a positive response from these animals. They responded vocally to good fidelity playback as if another seal were present. We recognized three broad categorical meanings derived from the hours of working with these seals: (a) trills probably dominance, (b) low pulses, evidently threats, and (c) chirps, possibly inquiry. The latter may also have had some navigational value, since they were the sounds consistently though intermittently used while swimming between holes.

Killer whale (Orcinus orca) sounds were again the subject of study, to determine if the reported differences in the calls of male and female animals did indeed exist. We found both types of calls from

one animal and so conclude that evidence is lacking for the existence of secondary sexual characters in the calls of these animals.

Contract Nonr-4446 shared in the support of these studies.

TASK UNIT II - PHYSICAL OCEANOGRAPHY

Work Unit - Sound Velocity Distribution

Sound Velocity Profiles from the Eastern Mediterranean Sea (Messrs. Payne, Levine and Zarudzki).

During CHAIN Cruise 61 thirty-five sound velocity profiles were made in the Eastern Mediterranean (Fig. 2). During the past summer the analysis of these data was initiated; computer programs were written to obtain calculated profiles from the raw data and to plot the profiles. The analysis of all profiles was carried out in three steps:

- 1) The sound velocity and Inverted Echo Sounder (IES) data were transcribed from printed paper tape and Precision Graphic Recorder (PGR) records to punched cards. The sound velocity data were then transferred to digital magnetic tapes.
- 2) Calculations of sound velocity, temperature, and depth were performed on the GE-225 computer.
- 3) Profiles of calculated sound velocity and temperature were plotted on the Calcomp plotter attached to the GE-225 computer.

Steps 1 and 2 have been completed and there are five profiles still to be plotted in Step 3.

A Hewlett Packard quartz crystal thermometer was attached to the sound velocimeter instrument package to simultaneously measure the water temperature. However, it was later discovered, that the instrument had too long a time constant to be useful at the lowering speeds used during Cruise 61. Differences between the indicated temperatures

Figure 2. Location of Sound Velocity Profiles in the Eastern Mediterranean Sea.

at a given depth on the ascent and descent were as much as five or more degrees, particularly above 200 m. depth.

Below 750 m. sound velocity function was constant within 0.2 m/sec. throughout all the lowerings. The major variations were principally above 200 m. within and above the zone of thermocline. The data are being further processed and will be reported shortly.

Water Temperature Profiles from CHAIN 61 (Messrs. Levine and Zarudzki).

During the R/V CHAIN Cruise 61 over nine thousand miles of continuous water temperature profiles were obtained. These were taken with three sensors towed through the water while the ship was underway. The instrumentation consisted of: (a) surface water temperature probe (thermistor), (b) a hull mounted quartz crystal thermometer recording water temperature at 5 meter-depth, (c) a towed fish with a Hewlett-Packard quartz thermometer and a Ross tow depth recorder to give the water temperature at variable depths. It was towed mainly above the thermocline at a depth of 30 to 40 meters. The locations of our water temperature profiles are shown in Figure 3.

The analog data gathered during the cruise was sorted and studied. The objectives of the studies were: (a) the relationship between the temperature curves obtained simultaneously at the surface, 5 m and 35 m depths, (b) the spatial distribution of water temperature patterns, (c) correlation of the sound velocity and temperature stations by a continuous temperature profile.

The work has progressed to the point where we can visually analyze the curves. In this way we have located 14 crossings of strong (4 - 5°C) thermal fronts in the Levantine Basin and the Ionian Sea.

Oceanic Front and Sound Velocity (Drs. Katz and Beckerle).

During CHAIN Cruise 67, the oceanic front in the Sargasso Sea was extensively studied. The front, a meeting of cold and warm surface waters, extended down some one hundred and fifty meters and resulted in the expected rapid change in sound velocity profile across the front near the surface. Unexpected, however, was a sharp difference in

Figure 3. Temperature Gradient Positions from CHAIN Cruises 61 and 21.

sound velocity at an isolated location thirty-five miles to the east and on the warm side of the front (Figure 4). This anomalous profile was repeated three times and must be considered as good data. The difference in sound velocity at 900 m (20 m/s) is roughly half as large as differences across the Gulf Stream. Our initial feeling is that the mechanism involved here is quite different. As a preliminary explanation we offer the following: the driving together of waters from both north and south will require a removal of this water. This occurs through both a quasi-geostrophic flow easterly along the front, established by the density differences in the two surface waters and by a downwelling. The slope of the interface points down into the warm water, thus warm water sinking (sliding) on top of the cold water at the interface would appear in the general direction where the anomaly is found. Such a mechanism could thereby explain the warm water, and consequently high sound velocities, found at this depth in the vicinity of the front.

In about the same season and general location, Beckerle (1965) reported a shifting of the 1520 m/s level which, in relative position to the front and direction of the shift, was a weaker mirror image of this observation. This activity north of the front remains unexplained.

Successful Prediction of Current Meter Measurements on Buoy "P"
at 30°N 70°W (Dr. Beckerle).

At a number of scientific meetings during the past two years Beckerle (1966) has suggested that predictions of certain features of temperature or current fluctuations observed as time series from buoys in the Sargasso Sea area might be seen from spatially distributed observations of the ocean using lowered instruments from ships. During the recent CHAIN Cruise 67 (see Section on Cruises, p. 10) a portion of the thermal front in the Sargasso Sea that was located using a towed temperature sensor presented an opportunity to forecast the time the frontal zone would pass by the deep moored Buoy P at Station #238 (30°N 70°W) of CHAIN Cruise 66.

It was proposed that the thermal front is part of a 240-mile wavelength internal Rossby wave (Beckerle, 1966). Accordingly, the front's speed of advance should be about 1/10 knot. Aboard CHAIN 67,

Figure 4. Sound Velocity Profiles about the Front.

during the week after May 15, the date of the first encounter with the frontal zone, portions of the front were found to be shifted about 10 miles westward or southwestward from where it was located earlier. An approximate speed of advance of the front based on these observations appears to be under 1/10 of a knot (maximum and minimum speed 0.08 to .05 knots). These estimates of magnitude and direction of propagation are reasonable for an internal Rossby wave; however, to confirm that the front is propagating in accordance with theory would require observations lasting over a much longer period than that of our cruise.

A prediction of the movement of the frontal line based on Rossby wave theory made aboard CHAIN indicated that the front would cross the vicinity of the near surface current meter in Buoy P about two or three weeks after May 15, the date CHAIN first crossed the frontal line (i. e., between 28 May to 6 June.) As indicated in the Summary Cruise Report and Track Charts CHAIN 67 the passage of the frontal zone in the 10 meter deep current meter data should show up as an abrupt switch in the current direction. Recent examination of the 10 meter deep current measurements shows the switch in current direction near the 28th of May as predicted. Preliminary examination of the current pattern permits an interpretation of the frontal passage. Interpretation of most buoy current meter patterns has been very difficult because of their complexity. Inertial loops on virtual displacement plots of current data have been about the only easily recognized and understood patterns. The recent success with a frontal passage, measured aboard CHAIN 67 and predicted to pass by and influence current data of a deep moored buoy, adds another kind of observable pattern to moored current meter observations that can be interpreted.

Doppler Shifts and Internal Waves at the Thermal Front (Dr. Beckerle and Mr. Suarez).

During CHAIN Cruise 67 some efforts were made while studying the thermal frontal region to observing Doppler shifts in the spatial frequencies of internal waves using a towed temperature sensor. The results of this effort confirm and augment observations of April 1965 aboard CHAIN on Cruise 47 when Doppler shifts were observed on crossing the thermal front using a towed sound velocimeter (Beckerle, 1966). Considerable thought and a number of experimental checks were made in order to assure ourselves that the observed fluctuations in the

temperature were produced by internal waves and other changes in temperature structure and not merely by vertical motions of the towed body through a thermal gradient. Spectra of the towed temperature measurements were calculated and these indicate Doppler shifts. However, a most striking Doppler effect was observed between the fluctuations of the temperature series obtained in towing up to the front and those of the series obtained after reversing course. Expanding one record by about 20% made the two recordings strikingly similar in appearance. Even small details in the temperature fluctuations appeared preserved on the expanded recordings near the turning point.

Unlike the results of CHAIN 47, where the Doppler shift observed indicated the internal gravity waves were approaching the front from both sides, the results from CHAIN 67 indicated that the waves are moving away from the front. This difference in observations might be due to zones of horizontal convergence and horizontal divergence along the front. Accordingly, one might expect the different direction of Doppler shift, depending on whether the tow was across a region of convergence or divergence.

Work Unit - Sound Field Dynamic Anomalies

Deep Instrument Package (Messrs. Dow, Whalen, Scott, Guild and Grant).

The deep instrument package described in the previous report has undergone sea trials off Bermuda during CHAIN Cruise 67.

Briefly the package consisted of velocity, temperature, pressure, salinity, and depth sensors, the output of which were multiplexed for transmission to the surface vessel through 20,000 feet of 1/4 inch single conductor logging cable. The depth sensor consisted of an inverted echo sounder. Two velocimeters were used for cross checking.

The sea trials indicated that the over-all volume of the package should be reduced for greater ease in handling over the side, particularly with the type of rigging system used on R/V CHAIN. Also a more streamlined shape is required to permit faster lowerings with less trapped water, and better control. However, to meet these requirements

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it was deemed necessary either to change the physical configuration of some of the commercial sensors or reduce their number. The shape of the external battery stack should also be modified. Because of these and other considerations it has been decided that for the time being at least, only velocity, temperature, pressure, and depth (Inverted Echo Sounder) will be sampled. This permits streamlining the package with approximately a 60% reduction in overall cross-sectional dimensions. However, provision is being made for adding other sensors with suitably modified pressure cases and a hydrophone at a later date.

Some connectors are also being changed and circuit improvements made in the Inverted Echo Sounder, commutation system (Sylvania), summing amplifier and cable driver.

Deep Hydrophones (Messrs. Dow and Scott).

A deep hydrophone unit designed to operate down to 2000 fathoms has been constructed. This unit, an updated version of the design used in sea spider, was used successfully in a recent dive of the submarine ALVIN to measure self noise background during underwater operations.

The unit consists of a Harris Z 3-A transducer coupled to a low noise high gain wide band amplifier contained in a high pressure aluminum case. Four such units, designed to be suspended from surface vessels by single conductor logging cable, are being assembled here. Circuit design has been modified by the addition of a power amplifier capable of driving long lengths of the high loss cable, and by an arrangement to permit powering the unit from the surface using the same conductor as transmits the signal. The deep units also contain a circuit which automatically impresses calibration pulses in series with hydrophone at 8 second intervals.

Horizontal Sectional Array (Messrs. Dow, Grant, and Scott).

Construction of the horizontal sectional array has been completed and limited sea trials were undertaken on ATLANTIS II Cruise 32 to the Baltic Sea. This array is similar to the vertical system summarized elsewhere in this report except that the array is designed for horizontal towing. The design has a number of advantages over the common arrangement of numerous elements strung together in a long oil filled tube: 1) The hydrophone and spacer sections plug into one another in any order. In case of failure or damage, the inoperative section may be quickly located by the substitution method, a spare plugged in and the array deployed again with minimum loss of ship time, 2) with appropriate spares, changes in the overall length of the array, number of hydrophone elements, and spacing between them can be made quickly at sea as dictated by the nature of the experiment, the signal/noise ratio, and the required directivity, 3) the system employs five separate channels. Therefore, five hydrophones (or groups of five if it is desired to extend the present array) may be read out separately, and the array electrically steered by variable delay networks if required. Alternatively, the direction of a transmitting source or reflector with respect to the line of the array could be determined, provided the operator knows whether the source lies to port or starboard.

Unfortunately the Atlantic crossing last spring had to be made at full speed in order to meet ship schedules in the Baltic. No deep water tests of the completed system have been made by personnel familiar enough with its operation to make an evaluation. However, in March (CHAIN Cruise 64) a portion of the array was tested briefly in 2000 fathoms of water using a sparker sound source. In spite of a heavy sea, multiple bottom returns were received with good signal/noise ratio.

Signal to Noise Improvement by Summing the Outputs of Separately Towed Arrays (Mr. Knott).

It was suggested by Knott, et. al. (1967) that a significant improvement in the broadband signal to noise ratio of seismic reflections could be realized by summing the outputs of a number of simultaneously towed hydrophone arrays. Several arrays of continuous sensor configuration towed in a spread across the stern of a research

vessel was envisioned. We seek to improve the reception of broadband, low-frequency reflected signals in the presence of broadband, low-frequency tow noise. An examination of simultaneous outputs from separate sensors in a multi-element array which is towed behind a ship indicates that much of the troublesome low frequency (less than 200 Hz) noise is coherent or is nearly so. When the coherence of the noise is examined by comparing the output of a 10 element, 50 foot array with a secondary standard hydrophone built into the center of the array structure, the low frequency noise again appears to be essentially (within a $1/4$ wave length of being in phase) coherent. Although some noise spikes may sweep the length of the array and be received successively at each sensor, generally the high-level, low frequency tow noise is virtually in phase so that it is additive.

When the output from one array is compared with that of another towed simultaneously nearby from a separate cable, the two arrays appear to exist in separate near field noise environments that are generally random in relation to one another. Since in these studies the wanted signals are expected to be coherent at the outputs of the arrays, a considerable improvement in signal to noise may therefore be realized by adding the outputs of separately towed arrays. Such a simple expedient appears obvious, but it is not a technique in general use. This technique and extensions of it are now standard practice for continuous seismic profiling. Since much of the noise that is reduced by summing the outputs of the arrays is at frequencies below 100 Hz, the weak lower frequency seismic returns are more easily perceived.

Successful Interim Approach to a Continuous-Sensor, Line-Hydrophone
(Mr. Knott).

Three 100 foot, line arrays of 200 Geospace MP7 hydrophone elements have been constructed on other grants at Woods Hole (Prada, 1967). We consider these arrays to be interim devices because the MP7 transducers, which are of a "bender" configuration, appear to change sensitivity with use and handling in an unpredictable way. Some measure as much as 12 db below others in sensitivity. The WHOLINE is one possible approach for future work. For general seismic profiling it may also be necessary to induce industry to make similarly inexpensive elements in ceramic cylinders or crystal blocks

which have been consistently more reliable than "benders". The difficulty is finding units of less than .75 inch diameter which can be easily connected and inserted in the towing tube. The 200 element array, which now is very convenient to use, could then be easily and inexpensively constructed and its acoustical performance would be stable and predictable.

Use of a Secondary Standard Hydrophone in an Array (Mr. Knott).

The reception of a discrete bottom reflected signal at a towed array is often far from simultaneous along a moderate-length array. The signal wavefronts may simply approach the array off the perpendicular because the array is not horizontal. To remove the ambiguities of shifts in output frequencies due to the wavefronts sweeping along the array, we have inserted in our routinely-used arrays a separate receiving channel from a calibrated secondary-standard phone, an LC-32, whose output is tape recorded continuously for various reflectivity measurements.

TASK UNIT III - SEA FLOOR PROPERTIES

Work Unit - Bottom Structure and Reflectivity.

Preliminary Results of Continuous Seismic Reflection Profiles on the North America Continental Rise (Mr. Knott and Dr. Emery).

A preliminary examination has been made of the continuous seismic reflection profiles obtained during CHAIN Cruises 70 and 73 across the North American continental rise (NSF GP-976). It appears that "basement" and composite reflectors related to Horizon A (Ewing and Ewing, 1962) can be traced under the rise and slope showing tentative correlation with on-shore well data and seismic refraction studies. Generally, the composite reflectors of Horizon A and the sediments above and below are flat lying which suggests that the rise has been stable since pre-Cretaceous time. Abyssal hills on the Hudson Fan appear to have resulted from down-slope slipping of Pleistocene and younger sediments. Beneath these and nearer shore shallow sediment structures there is evidence of similar structures.

Basement reflection times are commonly as much as 3.5 seconds below the seafloor. Considerable detailed data about the intervening reflectors was revealed. Preliminary comparisons of the seismic with the gravity and magnetic observations indicate that some of the large internal relief in the rise structure off Nova Scotia is probably due to sediment slumping rather than the intrusion of dense, magnetic bodies.

Preliminary Results of Seismic Refraction Measurements in the
Baltic Sea (Miss Bunce).

Seismic refraction measurements were made in two areas of the Baltic Sea in June 1967. The refraction data were obtained in the course of the acoustic transmission measurements program of Operation MILOC BALTIC 67. Three end-to-end profiles, 10 to 14 km long, were obtained, two in the area south of Oland Island, Sweden, the third to the east, north of the peninsula of Hel, Poland.

The results of shipboard analysis of the data show rather different seafloor structure for the two regions. South of Oland Island (60 meters water depth) the compressional wave velocity of the deepest observed sub-bottom layer is 6 km/sec, at 720 meters depth. Above this a layer of 4.1 km/sec velocity material, 600 meters thick, is overlain by thin layers of sedimentary material. In the area to the east, where the water depth is 90 meters, the top of the deepest layer, velocity 5.7 km/sec, is at 2600 meters depth. Above this layer lie, in turn, 700 meters of 4.6 km/sec, 1000 meters of 4.1 km/sec, and 600 meters of 3.2 km/sec materials. Thin layers of sediments form the top of the section.

The layer velocities and thicknesses described here are preliminary values. . Detailed analysis is almost complete and a paper containing the results is in preparation.

Flat Areas of the Seafloor (Dr. Chase, Mr. Denman and Miss Kramer).

Abyssal plains and smaller valleys known as sediment ponds where the seafloor is almost a horizontal plain, occur beneath the sea in many regions. These flat areas of the seafloor are important to underwater acoustics because they reflect sound regularly in the same way a mirror reflects light. Many of the flat areas are characterized by flat sub-seafloor reflectors. Continuous seismic reflection profiles show that in places sequences of such reflectors extend down to a depth beneath the seafloor equivalent to up to several seconds of return travel-time of acoustic energy. However, the vast majority of the flat areas we know only from 12 kHz echo-soundings. The latter commonly reveal reflectors in the first 10 fathoms below the seafloor.

In the past year, the positions of plains and ponds crossed by WHOI ships and recorded by the 12 kc precision echo-sounder have been compiled onto BC plotting sheets, and the depth of each plain or pond and the depth to which subbottom layers are visible has been listed.

Attempted Direct Observation of Fresh Water Seepages on the Blake Plateau (Mr. Zarudzki and Dr. Mannheim, USGS).

Fresh water aquifers are known to extend seaward under the Atlantic continental shelf of the United States. The JOIDES drilling program on the Blake Plateau penetrated a very large aquifer near the seafloor surface. Recently, DSRV ALUMINAUT during a survey of the Blake Plateau encountered a low temperature water environment near the seafloor which suggested a fresh water seepage.

During July DSRV ALVIN, specifically outfitted to investigate possible fresh water seepages, made a study of the Blake Plateau seafloor. Attempts to locate the fresh water were made using a resistivity probe mounted on the hull and an ambient water temperature probe. An additional criterion of fresh water was an expected loss of buoyancy. Unfortunately, we could not locate the appropriate seafloor depressions which we believed associated with fresh water outflows. Consequently, no fresh water seepages were detected.

Underway Seismic Reflection and Refraction Profiling (Mr. Hess,
Mr. Knott and Miss Bunce).

During CHAIN cruises #70 and 73 a system for obtaining seismic oblique reflection and refraction measurements was tested and put to use. The system utilizes expendable radio sonobuoys dropped from the ship as seismic signal receiver, simultaneously with the continuous seismic profiling (CSP). Oblique reflection and refraction profiles of up to 20 miles were successfully obtained although 12-15 miles range was more common. The system consists of: (1) a seismic profiling sound source; (2) a towed hydrophone array for CSP; (3) military type SSQ-41A sonobuoys; and (4) suitable radio receiver and graphic and magnetic tape recorders. Good refraction arrivals were received in water depths ranging from 40 meters on the shelf to over 4500 meters on the Sohm Abyssal Plain. Preliminary measurements show that refracted arrivals were received from deep structures having apparent compressional wave velocities of up to 4.5 km/sec.

Improvements of the Chesapeake Type Array (Messrs. Knott and Hess).

The basic Chesapeake-type array used by WHOI was rebuilt for CHAIN cruise 70 and 73. In addition to refurbishing, several improvements in design were accomplished: (1) bulkhead designs were changed so that each transducer section can now be disconnected and interchanged without oil loss; (2) all conical seated, high-pressure sealed electrical connectors were replaced by simple molded insert connectors; (3) a two-channel preamplifier has been incorporated to allow continuous monitoring of the LC-32 secondary standard hydrophone of the center transducer section; the hydrophones of the array can now be connected to the preamplifier separately or in parallel by means of a shipboard selector switch. The performance of the refurbished, redesigned array during subsequent cruises appears to be improved. However, actual measurements of signal to noise have not been compared. This work was supported by the National Science Foundation (GP-976).

Seismic Source Improvements (Messrs. Knott, Witzell, Hess,
Young and Church).

Recently we have had available on the R/V CHAIN both our 100,000 joule underwater spark and a 10 cubic inch, Bolt Air Gun. Each had been used separately; the air gun only intermittently because of a now-corrected design flaw. In July and September both sources were operational for a study of the Atlantic continental rise of North America (CHAIN cruises 70 and 73). The preparation and maintenance of the equipment for these cruises was supported for the most part by the National Science Foundation (GP-976).

During the first part of CHAIN cruise 70, each source was triggered alternately at a 10 second repetition rate. We found, however, that both sources could be triggered simultaneously and used to advantage. As a result "basement", a rough continuous surface of varying depths below layer A (Ewing and Ewing, 1962), could be followed to over three seconds, reflection travel time, below the seafloor of the continental rise.

During CHAIN cruises 70 and 73 the air gun operated continuously (generally at a 10 second repetition rate) for about 16 days of each cruise without being shut down. After this period of time various seals, springs, and the solenoid valve had to be replaced. The air compressor, an Ingersol Rand 15T3, after approximately five weeks of continuous use on both cruises, required new valves and cleaning of the final compressor stage and air lines.

Prior to these cruises both the sparker and its diesel generator which also powered the air gun compressor had been refurbished. A new capacitor bank had recently been installed for the spark energy storage. The poor speed regulation of the generator and other problems which caused the over-voltage interlocks of the spark power supply to operate irratically were corrected. These improvements allowed the sparker power and energy storage system to operate routinely above 9 kilo-volts. The lowest useful frequency of the spark system using a single electrode was thus shifted downward from about 50 hz to about 40 hz with a bubble pulse period of 25 ms. A further increase of more than 10 db in the peak pressure of the discharge pulse was obtained with a triple electrode assembly; however, the shift in frequency brought the lowest useful frequency of the output

once again up to 50 hz (the bubble pulse period being 20 ms.). With this increase in peak pressure the signal to noise ratio of reflections from the spark source alone was, without question, better than air gun alone. Since the waveforms of the spark (20 ms bubble pulse period) and of the air gun (40 ms period) complemented one another, their summation by synchronizing their outputs could be used to obtain deeper penetration.

To determine the output waveforms of each source, blast gauges, LC-32 standard hydrophones, were towed routinely near the sources. We have not yet, however, monitored routinely the downward radiated energy from below the sources. The combined waveform of the two sources was inferred from the blast gauge measurements and by an examination of signals from the first bottom reflections received by another LC-32 in the hydrophone array and from the arrays in general.

Work Unit - Physical Properties of Rocks and Sediments.

Investigation of Mediterranean Sediment Cores (Mr. McCoy and Dr. Chase).

In 1966 thirty sediment cores were taken during CHAIN Cruise 61 in the eastern Mediterranean. The coring program was part of an investigation of the sedimentary processes and tectonic history of the Mediterranean carried out in conjunction with an investigation of underwater acoustic characters of the same region. Ten cores have been split, photographed and described. Measurements of the natural remanent magnetization on six of the cores with the fluxgate magnetometer suggested that all are younger than 700,000 years, the time of the last reversal of the earth's magnetic field, and that post-depositional chemical changes in the sediment have produced a scatter in the directions of remanent magnetism.

The cores are characterized by thin beds of volcanic ash, beds of saprolitic sediment rich in organic matter, hydrogen sulphide, pyrite, and foraminifera. These beds were laid down during times of stagnation of the bottom water of the Mediterranean during the Pleistocene. More normal oxidized sediments, mainly foraminiferal oozes and red muds, lie between the saprolitic beds. Beds coarse at

the base grading up to fine sediments at the top indicate that dense sediment-laden currents periodically sweep down slopes of the eastern Mediterranean seafloor and across the abyssal plains and sediment ponds.

Bathymetric information from the eastern Mediterranean is being compiled in order to better understand present-day sediment dispersal patterns and tectonic features in the eastern Mediterranean.

A brief lithologic description was made of fifteen cores taken in the Baltic Sea during cruise AII-32.

Rock Magnetism (Dr. Phillips, Mr. Ladd and Mrs. Brown).

A study of the remanent magnetization of 18 cores from the North Atlantic near the Vema Fracture Zone (10°N) was completed. The magnetic declination of 17 cores was found to be uniform down the core lengths suggesting that the sediment is of Late Pleistocene age. In fact, they are probably much younger than the Brunhes/Matuyama polarity reversal .7 million years ago. Only one core (ATLANTIS II-32, Station 6) showed a reliable magnetic declination reversal pattern. The inferred geomagnetic polarity reversals indicate an age of about .9 million years for the bottom of the core. Minimum sedimentation rates for the 17 cores showing no reversals ranged from 2 - 12 mm/1000 yrs. The sedimentation rate for the ATLANTIS II-32, Station 6 core was 5 mm/1000 yrs.

A similar analysis of 12 cores recently obtained from the mid-Atlantic Ridge near 44°N aboard ATLANTIS II (Cruise 32) has been initiated.

Micropaleontology (Dr. Berggren).

A comprehensive survey was completed of the geologic epochs of the Tertiary system. The boundary problems associated with each of the periods and stages was discussed from the historical point of view and a general summary of the paleontological characteristics of each of the units involved was given. An attempt to relate Tertiary biostratigraphic zones (based on planktonic foraminifera) to the

standard chronostratigraphic scale was also made. This investigation was presented orally at the S. C. O. R. Symposium in Cambridge, England.

A similar study was made on the Quaternary geologic boundaries and presented orally at the S. C. O. R. Symposium. A historical synthesis of criteria used to determine the **Pliocene/Pleistocene** boundary in land and deep-sea sections was made. It was found that the various criteria do not delineate an isochronous surface. Recent data have allowed the recognition of the **Pliocene/Pleistocene** boundary based on paleontologic criteria and an estimate of its absolute age (1.85 my) with the help of paleomagnetic studies on deep sea cores.

New Sediment Corer (Mr. Boutin, Dr. Von Herzen, Dr. Chase, Dr. Phillips and Mr. Wooding).

A new sediment corer has been developed. Funding has come partly from NSF and partly from ONR funds. The corer was tested in October during CHAIN cruise 75. Bottom-cameras, strobe-lights, telemetering pinger, and a heat-flow recorder are mounted in the weight-stand of the corer, and a special compass is attached to the upper barrel. When it is lowered to the seafloor, the corer is operated in the same way as an ordinary piston-corer, but in addition, a series of bottom photographs are taken, the vertical heat gradient beneath the ocean floor is measured, and the orientation of the compass in the photographs allow the core to be oriented. In addition, the telemetering pinger transmits to the surface the heat flow and magnetic orientation information.

Work Unit - Geomagnetism (Dr. Phillips, Mrs. Brown and Mr. Aldrich).

Geomagnetic measurements were made with towed proton precession magnetometers in the North Atlantic Ocean and Caribbean Sea.

Over 4000 miles of magnetic and bathymetric profiles were obtained aboard ATLANTIS II (Cruise 32), primarily over the mid-Atlantic Ridge, while enroute to the Baltic Sea to participate in the NATO exercise - MILOC 67. Analysis of five profiles, 450 - 180 km long, spaced 20 - 40 km apart and intersecting the mid-Atlantic Ridge between 45° and 43°N, showed that a symmetrical north-south magnetic pattern parallel to the ridge axis is recognizable over the two southernmost profiles. Here the ridge is

characterized by a well developed central rift valley. The three northernmost profiles do not contain obvious magnetic symmetry elements and are over a portion of the ridge characterized by rugged topography without a central rift. A smaller, detailed magnetic, bathymetric, heat flow and geologic survey was also made across the ridge crest between 42°30'N and 43°30'N. This survey spanned the region of apparent change in its character. Here a narrow zone transverse to the ridge axis showed abrupt termination of the symmetrical north-south magnetic trends and the central rift valley, each well developed in the southern part of the survey area. North of this zone there is little evidence of a symmetrical magnetic pattern or central rift valley.

Dredged rock and heat-flow measurements in the respective areas also showed striking differences. Basalts and relatively low heat flow ($0.6 \mu\text{cal}/\text{cm}^2\text{sec}$) characterized the southern area, even in the median valley; whereas, serpentinitized peridotites and very high heat flow ($3 - 7 \mu\text{cal}/\text{cm}^2\text{-sec}$) were observed in the northern area. Model studies suggest that the configuration of magnetic bodies that could account for the symmetrical magnetic pattern of the southern area supports the sea-floor spreading hypothesis. A spreading rate of about 1.2 cm/yr active over the last 5-6 million years is indicated.

Nearly 4300 miles of magnetic profile were completed along the east coast of the United States (CHAIN Cruise 70 & 73) as part of a general geophysical study of the continental rise and slope of North America (supported in part by NSF Grant GP-976). Several large anomalies (greater than 500 gammas - peak to peak amplitude) appear to trend sub-parallel to the shelf-slope break. Other anomalies associated with large opaque sub-bottom reflectors were also observed. Model studies have recently been initiated to determine the nature of the magnetic bodies which may account for these anomalies.

Approximately 2000 miles of magnetic profile across the Antilles Island Arc have been collected during this report period aboard CHAIN (Cruise 75 - NSF funded). Measurements on this cruise will continue until December 1967 in the area east of the Lesser Antilles.

An analysis of magnetic profiles previously collected in the Mediterranean Sea (CHAIN 61) is continuing. Large magnetic anomalies (greater than 300 - 500 gammas - peak to peak amplitude) are found over the Sicilian Escarpment east of Malta and certain seamounts associated with the escarpment. Model studies are presently underway to determine the nature of the magnetic bodies responsible for the observed anomalies.

As part of our geomagnetic profiling program an airborne proton precession magnetometer with an automatic digital recording system was mounted in the WHOI aircraft C54Q (supported largely by NSF Grant 1209). Plans were formulated during this report period for aeromagnetic studies east of the Lesser Antilles Island Arc and over the mid-Atlantic Ridge.

Work Unit - Gravity

Gravity Field over Ocean Areas (Dr. Bowin, Messrs. Nichols, Aldrich, Dugan, and Miss Wertheimer).

During this reporting period gravity measurements at sea have been conducted on three cruises of the R/V CHAIN. All of these have been supported by grants from the National Science Foundation. CHAIN cruise 70 and 73 investigated the continental rise off the northeastern seaboard from Virginia to the Grand Banks. CHAIN Cruise 75 (October to December, 1967) began near the end of this reporting period. The purpose of this cruise is to determine crustal structure sections across the Lesser Antilles Island Arc and between the Island Arc and the mid-Atlantic Ridge to the east.

Gravity measurements were made using both a LaCoste and Romberg gimbed meter (S-13) and a gyrostabilized vibrating string meter developed by the Massachusetts Institute of Technology.

TASK UNIT IV - ADVISORY ACTIVITIES

Cooperation with Navy Activities (Mr. Vine and Dr. Hays).

The major advisory activity during this period was the six weeks participation of Dr. Hays and Mr. Vine in an ONR-NAS sponsored ASW study group held at La Jolla, California during June and July. As in the last reporting period Dr. Hays and Mr. Vine continued occasionally to spend a day or two at a time at ONR, Washington with representatives from other laboratories to help ONR prepare special studies or reports. In particular, Dr. Hays participated in two working sessions on long range sound propagation studies.

Several members of the Woods Hole group attended the Fourth Navy Symposium on Military Oceanography at Washington in May to present papers and exchange information on problems of military value and their possible solutions. Mr. Vine visited the submarine command at Charleston, South Carolina to discuss their oceanographic and acoustic training programs.

There were a dozen or more less directly but we believe important types of liaison and educational activity in which some of the scope of Navy oceanographic activities and philosophy were included. Several staff members gave formal or informal lectures to a wide variety of groups that included Navy, Naval Reserve, Navy laboratories, technical society sections, industrial, college engineering classes and high schools. Such talks and lectures with their associated and usually lively discussions broaden the general awareness of the country's Naval and other maritime interests and sometimes serve as a starting point for university theses work on ocean oriented problems.

JOIDES, Committee Meetings (Dr. Phillips).

As part of the planning for the National Science Foundation's program for drill coring in the deep sea, Drs. Berggren, Phillips and Von Herzen have participated in several JOIDES panel meetings. These meetings have concerned the selection of sites for the drill holes and the paleomagnetic, micropaleontologic and heat flow observations to be made on the core materials.

TASK UNIT V - SHIPBOARD DATA PROCESSING

Work Unit - Shipboard Data Processing (Dr. Bowin, Messrs. Nichols, Woodside, Aldrich, Mrs. Zwilling and Miss Wertheimer).

Gravity, magnetic and bathymetric measurements obtained during this report period (CHAIN Cruises 70, 73, and 75), as well as previous data, are to be processed by the new Hewlett-Packard 2116A computer. The writing of reduction, correction, editing, plotting, and analysis programs for the computer has begun. A digital read/write magnetic tape drive and interface for the HP-2116A was purchased with Institution and NSF funds. This magnetic tape drive greatly facilitates the reduction of the gravity data measured in 1967, and in the continued processing of previous gravity information.

A real-time data acquisition and reduction program (SYSTEM III MOD Ø) was written for the HP-2116A computer. The requisite hardware items were also implemented, and inputs from the LaCoste and Romberg gravity meter, Varian magnetometer, ship's speed log and gyrocompass were connected to the computer. This program was completed and successfully tested during CHAIN Cruise 70. Unfortunately, before the end of the cruise a combination of intermittent failures in the computer and in the test oscilloscope allowed only part of the core memory to be available for use. These failures were remedied upon return to Woods Hole and they have not reoccurred since.

The presently available core memory (8,192 memory locations) has proven to be insufficient for storing both the acquisition and reduction program, and a plotter program for the real-time graphic display of the calculated values. Since we consider the graphic record to be one of the most significant reasons for having a computer aboard the ship, program development was shifted to concentrate on implementation of off-line programs for the reduction, correction, analysis and plotting of data previously acquired or that obtained by manually reading chart records recorded during the 1967 cruises of CHAIN. When sufficient funds are available for acquiring additional core memory, real-time acquisition and plotting will be resumed.

Preliminary reports presenting reproductions of profile plots of free-air and Bouguer gravity anomalies, total magnetic intensity, and bathymetry for WHOI sea-gravity measurements, 1962 through 1966, have been submitted to the Office of Naval Research for transmittal to the U. S. Naval Oceanographic Office, and the Gravity Branch, Aeronautical Chart and Information Center.

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APPENDIX

Personnel

SENIOR SCIENTISTS

Backus, Richard H.
Hays, Earl E., Dept. Chairman
Vine, Allyn C.

ASSOCIATE IN OCEANOGRAPHY

Schevill, William E.

ASSOCIATE SCIENTISTS

Beckerle, John C.
Berggren, William A.
Bowin, Carl O.
Bunce, Elizabeth T.
Murphy, Edward L.
Von Herzen, Richard P.

RESEARCH SPECIALISTS

Baxter II, Lincoln, Physics
Brockhurst, Robert R. Physics
Dow, Willard, Electronics Engineer
Knott, Sydney T., Hydroacoustic Engr.
Zarudzki, Edward F.K., Seismic Engr.

ASSISTANT SCIENTISTS

Chase, Richard L.
Davis, James A.
Giese, Graham
Haedrich, Richard L.
Katz, Eli
Phillips, Joseph D.
Wall, David

RESEARCH ASSOCIATES

Bergstrom, Stanley W.
Dunkle, William M.
Hess, Frederick R. (Lv. absence)
Hessler, Robert J.
Owen, David M.

Small, Herbert
Watkins, William A.
Wing, Asa A.
Witzell, Warren E.
Young, Earl M.

RESEARCH ASSISTANTS

Aldrich, Thomas C.
Bertels, Alvine
Boutin, Paul R.
Cain, Henry A.
Dale, Barrie
Dollinger, Irwin
Doutt, James A.
Hays, Helen C.
Jones, Maxine
Lowell, Victoria

Lyons, Jay K.
McCoy, Floyd W.
Nichols, Walter D.
Nowak, Richard T. (PhD Cand.)
Payne, Richard E. (PhD Cand.)
Poole, Stanley E.
Ruelon, Diana (temp.)
Ruppert, Gregory N.
Wertheimer, Alice
Whalen, Thomas L.
Wooding, Frank

LABORATORY ASSISTANTS

Brown, June (part time)
Carter, Jane C.
Church, William J.
Denman, Mark (part time)
Dugan, Everett F.
Gallagher, Gloria (part time)
Grant, Carlton, Jr.

Guild, Ritchey
Hillard, Channing
Howbert, Martha
Ruiter, Robert G.
Scott, Carl W. Jr.
Shores, David L.
Witzell, Grace M.
Zwilling, Judith

DOCTORAL CANDIDATES WORKING ON THEIR
DISSERTATION IN THIS DEPARTMENT

Nowak, Richard T. (M.I.T.)
Payne, Richard E. (U. of Rhode Island)

VISITING INVESTIGATOR

Kissinger, Paul B.

POST DOCTORAL FELLOW

Goll, Robert M.

COOPERATIVE STUDENTS

Bzdyl, Robert
Turcotte, Richard B.

ADMINISTRATION

Morehouse, Clayton B. - Stock Expeditior
Stetson, Thomas R. - Project Coordinator
Sutcliffe, Thomas O. Equipment Custodian

SECRETARIES

Gurney, Elaine
Mellor, Florence
Peterman, Carol I.
Peterson, Jane M.
Stone, Louise D.

SUMMER

Curtis, Lorenzo I.	Visiting Investigator
Morgan, Jason	" "
Boersma, Anne	Fellow
Fink, Arthur	"
Hinckley, Gregory K.	"
Ladd, John W.	"
Suarez, Alfredo A.	"

SUMMER STUDENTS

Appleman, Jack M.
Bennett, Linda
Burry, Virginia
Byrne, Hugh M.
Cratsley, Dennis W.
Delnore, Victor E.
Field, Michael E.
Golden, Julia
Hutchinson, Joan P.
Kramer, Leslie

Kraus, Nigel
Laine, Edward D.
Leonard, Peter D.
Levine, Edward R.
Royer, Thomas C.
Sargent, F. William
Vieira, Margaret A.
Wood, Lawrence A.
Wood, Pamela
Woodside, John

Visitors

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Director Hudson Laboratories of Columbia University 145 Palisade Street Dobbs Ferry, New York 10522	1	Underwater Warfare Division Norwegian Defense Research Establishment Karljohansvern, Horten, Norway	1
Director Marine Laboratory University of Miami #1 Rickenbacker Causeway Miami, Florida 33194	1	Director Defense Research Laboratory University of Texas Austin, Texas 78712	1
Director Department of Oceanography and Meteorology Texas A & M University College Station, Texas 77843	1	Bell Telephone Laboratories, Inc. Attn: Mr. E. E. Sumner, Div. 54 Whippany, New Jersey 07981	1
Head, Department of Oceanography Oregon State University Corvallis, Oregon 97331	1	Anti-Submarine Warfare Research Center La Spezia, Italy	1
Director Arctic Research Laboratory Point Barrow, Alaska 99723	1	U.S. Naval Schools, Mine Warfare U.S. Naval Base Charleston, South Carolina 29408	1
Head, Department of Oceanography University of Washington Seattle, Washington 98105	1	Hawaii Technical Information Center 567 South King Street Honolulu, Hawaii 96813	
Geophysical Institute of the University of Alaska College, Alaska 99735	1		

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