LEVEL II

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ATLANTIC OCEANOGRAPHY

VOLUME I

Report

for the period of

January 1, 1978 to December 31, 1978

Rept for 1 Jan-31 Dec 78

Renewal Proposal

for the period of

January 1, 1979 to December 31, 1979

For the continuation of Research under

Contract N00014-74-C0262; NR 083-004

submitted to the

Department of the Navy

Office of Naval Research

Ocean Science and Technology Division

by the

Woods Hole Oceanographic Institution

Aug[redacted]78

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VOLUME I

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GEOLOGY & GEOPHYSICS

INTRODUCTION AND SUMMARY

While our proposal to ONR covers a broad spectrum of research currently undertaken within the Institution, it also includes several new initiatives. For administrative covenience and efficiency, we have broken the proposal into six categories, the five scientific departments and the Gulf Stream Ring Study. Nonetheless, many of the programs transcend this arbitrary breakdown. Perhaps the best example is the study of the bottom boundary layer, which in total extends through all of the departments.

The budget for the programs proposed exceeds somewhat that received during the past contractural year. In part this reflects the increasing costs to do research, partly the new initiatives and also a substantial increase in ship time use over the past year. Even so, ship costs have been held down by using other institutions' vessels in the Pacific and Indian Oceans. Another substantive difference from last year comes about through Dr. Robert Ballard's tranfer from the Geology and Geophysics Department to Ocean Engineering. Within the Geology and Geophysics Department two major thrusts- Projects ROSE and HEBBLE - account for a large increase in the budget.

In an attempt to make the proposal more wieldy and useful, we have broken it into two volumes. Volume I contains the 1979 proposal, budgets and 1978 annual report. Volume II contains supplementary information such as: vita, publications and other sources of support. Hopefully, this will make it easier to find things and less bulky to carry.

ONR N00014-74-C-0262

1 January - 31 December 1979

	Biology	Chemistry	Geology and Geophysics	Ocean Engineering	Physical Oceanography	Other	Total
Gross Regular Salaries (includes allowance for vacations, holidays, sick pay of $125,244, which is accounted for as employee benefits)	$ 26,285	$ 5,983	$ 41,499	$ 30,775	$ 20,702		$ 125,244
	$245,440	$54,133	$367,283	$282,602	$208,809		$1,158,267
Cruise Leave, Sea Duty Vacation and Overtime (Includes Premium Pay of $17,279)	213	109	4,852	8,311	3,794		17,279
	2,409	684	28,786	40,672	17,979		90,530
TOTAL SALARIES	247,849	54,817	396,069	323,274	226,788		1,248,797
Other Employee Benefits	66,772	14,527	107,421	92,076	65,853		346,649
TOTAL SALARIES AND BENEFITS	314,621	69,344	503,490	415,350	292,641		1,595,446
Permanent Equipment	13,672	37,654	37,413	126,971	2,019		217,729
Expendable Supplies and Equipment	19,253	13,300	40,803	89,829	46,253		209,438
Travel							
Domestic	12,443	2,880	23,350	12,828	7,028		58,529
Foreign	4,739	2,260	17,872	15,568	48,383		88,822
	17,182	5,140	41,222	28,396	55,411		147,351
Publication Costs							
Graphic Service	4,615	1,170	13,117	7,637	4,810		31,349
Page Charges	2,860	1,250	9,550	2,000	5,120		20,780
Reprint Charges	1,175	1,450		200	560		3,385
	8,650	3,870	22,667	9,837	10,490		55,514
Ship Costs							
Large		32,376	145,680			26,890	204,946
Medium			6,866	130,454	27,464		164,784
Small	360	600					960
Computer Technicians				25,092	3,936		29,028
	360	32,976	152,546	155,546	31,400	26,890	399,718
Computer							
Sigma 7	4,340	1,550	11,315	14,880	40,145		72,230
VAX 11/780			48,625				48,625
Other	500		4,750	2,925	2,000		10,175
	4,840	1,550	64,690	17,805	42,145		131,030
Miscellaneous							
Shop Services	3,900	2,730	10,686	18,330	3,055		38,701
Programming	1,764	1,568	1,568	9,408	2,548		16,856
Shipping & Communications	3,150	1,900	12,525	9,289	37,940		64,804
Laboratory Overhead	66,026	14,539	104,713	85,479	60,657		331,414
Xerox Charges	800	150	400	1,380	700		3,430
Graduate Research Assistants	3,210	6,675	46,080		6,505		62,470
GC-MS System		11,200					11,200
Ship Charter	18,300						18,300
Plane Charter	2,160						2,160
GEOREF Services			300				300
VAX 11/780 Disc Lease			15,000				15,000
Other	5,600	1,600	7,000	1,500	23,550		39,250
	104,910	40,362	198,272	125,386	134,955		603,885
Direct Costs	483,488	204,196	1,061,103	969,120	615,314	26,890	3,360,111
Indirect Costs	72,523	30,629	159,167	145,367	92,297	4,047	504,030
TOTAL COSTS	$556,011	$234,825	$1,220,270	$1,114,487	$707,611	$30,937	3,864,141
						Fee	102,134
						Total	$3,966,275

W.H.O.I. Proposal No. 1224
8 August 1978

I. BIOLOGY

DEPARTMENT OF BIOLOGY

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INTRODUCTION

Seven proposals are offered for consideration from the Biology Department. Six represent requests for continuing support of previous funded research while one is a new initiative. The proposal from Jannasch, Taylor and Wirsen concerns experiments on microbial conversion of organic compounds at the edge of the continental slope (2500 m) and in several other deep sea environments in the western North Atlantic off Woods Hole. Scheltema's efforts relate to the development of culture techniques for certain fouling organisms and experiments on food requirements of barnacles and the effect of temperature and salinity on larval survival. Backus expects to complete his charts of volume reverberation regions in the world's oceans. A self-contained sound recording instrument was constructed by Haedrich and successfully used. He plans to deploy it at several places in the ocean next year. Watkins and Schevill will devote time to improving the radio tag for whales and continue to record and analyze sounds especially those produced by sperm whales and finback whales. Kalmijn proposes to investigate the biological significance of the electric and magnetic fields in natural waters through behavioral and biophysical studies in fishes and bacteria. The newly proposed research by Mann concerns the comparison of the energy budgets of two wood boring molluscs that have dissimilar nutritional modes, one species utilizes the wood, the other does not.

Backus and Wiebe, presented in the Gulf Stream Ring Section, are also members of the Biology Department.

DEPARTMENT OF BIOLOGY

Budget Summary*

1 January 1979 - 31 December 1979

A.	Gross regular salaries (including allowance for vacations, holidays, sick pay of $26,285 which is accounted for as employee benefits)	$ 245,440	
	Cruise leave, sea duty vacation and overtime (including premium pay of $213)	2,409	
	Total Salaries	247,849	
B.	OTHER EMPLOYEE BENEFITS	66,772	
	Total Salaries and Benefits		$ 314,621
C.	PERMANENT EQUIPMENT		13,672
D.	EXPENDABLE SUPPLIES & EQUIPMENT		19,253
E.	TRAVEL		
	Domestic	12,443	
	Foreign	4,739	
	Total Travel		17,182
F.	PUBLICATION COSTS		
	Graphic Services	4,615	
	Page Charges	2,860	
	Reprints	1,175	
	Total Publication Costs		8,650
G.	SHIP COSTS - Small ship		360
H.	COMPUTER COSTS		
	Sigma 7	4,340	
	HP 2100	500	
	Total Computer Costs	4,840	4,840
I.	MISCELLANEOUS COSTS		
	1. Shop Services	3,900	
	2. Programming	1,764	
	3. Shipping & Communication	3,150	
	4. Laboratory overhead at 21% of Total Salaries & Benefits	66,026	
	5. Xerox costs	800	
	6. Other Costs	29,270	
	Total Miscellaneous Costs		104,910
J.	TOTAL DIRECT COSTS		483,488
K.	INDIRECT COSTS at 15% of Total Direct Costs		72,523
L.	TOTAL COSTS		$ 556,011

W.H.O.I. Proposal No. 1224

*Includes Wiebe and Backus from Gulf Stream Rings

1. MICROBIAL TRANSFORMATIONS IN THE DEEP SEA BENTHIC BOUNDARY LAYER

Holger W. Jannasch
[redacted]

Carl O. Wirsen
[redacted]

Craig D. Taylor
[redacted]

Background

Our previous work on microbial activities in the deep sea has indicated that the combined effect of elevated hydrostatic presssure and low temperature reduces the rates of nutrient regeneration and other biologically mediated reactions considerably (Jannasch and Wirsen, 1973, 1977a, b; Jannasch *et al.*, 1973, 1976; Wirsen and Jannasch, 1976). The bulk of this information consists of data obtained by *in situ* incubation studies conducted on the sea floor with the aid of DSRV ALVIN. This approach eliminates decompression effects. On the other hand, it is subject to a number of limitations inherent to the use of the submersible, e. g., relatively few diving operations curbed quite often by weather conditions, the submersible's depth capacity, the small number of feasible permanent bottom stations and the limited choice of *in situ* incubation periods.

The present project uses free vehicles in sea floor incubation studies in order to overcome those limitations and to add some new aspects to this research, especially the study of interactions between the activity of scavengers and their microbial gut flora.

The ONR relevance of this research relates to the fact that all processes involving microbial activities such as decomposition of organic materials, natural or man-made, reductive and oxidative corrosion, fouling, etc. are strongly affected by deep sea conditions especially high pressure. These effects as well as the consequences with regard to the durability of deep sea moorings and other structures, the role of specific pollutants in these processes, and the persistence of dumped organic and metallic waste materials are unknown at this time.

Long Range Research Plans

The biological transformations of organic materials measured during this and the coming research period (1978/1979) will be extended later to include (a) transformations of sulfur compounds (important in the creation and maintenance of oxic/anoxic interfaces and corrosion effects)(b) the transformations of nitrogen compounds (ammonification, denitrification, nitrification; important in microbial nutrient regeneration) and (c) the anaerobic reduction of CO_2 to methane as effected by pressure and the competition by sulfate reduction . Corrosion studies under aerobic and anaerobic conditions will be quantified (Ailor, 1971; Uhlig, 1971). Later studies will include the effect of pollutants on the above mentioned processes or, as far as corrosion is concerned, protective materials inhibitory to microbial transformations which induce corrosion. Special emphasis will be paid to another very important part in the transformation of solid organic materials: the rate of digestion by scavenging animals and the role of gut microorganisms in this process (see below).

Over the next 3 to 4 years work will be extended over a wide variety of geographically and geochemically different locations such as shelf, slope, canyons, abyssal plains and deep sea trenches. Also areas of characteristic type and rate of sedimentation, low and high bottom currents, high heavy metal deposits and dump sites will be investigated.

The free vehicles used in this work are equipped with simple time releases and cost in the range of $2,000 each and appear to be a most efficient and reliable approach to the benthic boundary layer studies as envisioned in this proposal. Their deployment in larger numbers and at a greater variety of locations and depths constitutes a distinct advantage over fewer, more sophisticated and costly units. Acoustic recall devices are envisioned in this project only if less expensive instruments become available.

Work Done During the 1978 Research Period

Our ONR funded work started in January of this year. Since we were scheduled for a most suitable (NSF funded) cruise in the Puerto Rico Trench in Feb-March of 1978, we started the construction of our first free-vehicle in November of 1977. It was deployed on Feb. 22 to a depth of 5330 meters (OCEANUS Cruise #40) and successfully recovered after a 6 day incubation time on Feb. 28. In this first test, six core tubes were either injected automatically with radiolabeled acetate shortly after insertion into the sediment or they contained radiolabeled fish meat confined on the sediment surface in the core tube. Immediately after recovery the cores were fixed for later analysis of the transformation products in the laboratory by scintillation counting.

The intention of these experiments was to measure the rate of microbial conversion of simple as well as complex organic compounds in the upper layers of the sediment. The controls were freshly retrieved cores incubated at *in situ* temperature but at 1 atm (ship's refrigerator). Both the technical and the microbiological part of the experiment were successful.

A second vehicle deployment was carried out on OCEANUS Cruise #44 on April 29, 1978, for a short-term incubation experiment. The vehicle was retrieved on May 2 with all cores filled and injection mechanisms successfully released. The data of these two first experments are being computed.

On OCEANUS Cruise #40 we also ran a preliminary experiment on capturing and incubating amphipods for a given time period in the presence of a radiolabeled food source. Our plans for working in this area during the next research period are based on our results of this preliminary test of a newly conceived trapping and incubating device.

Proposed Research for the Coming Year (1979)

1. Vehicle deployments.

(a) For the remainder of 1978, we are planning to deploy one more vehicle using OCEANUS Cruises #49 and #51 in piggy-back fashion for a 5 weeks' incubation period (July 27 to about September 2). As a suitable site, the edge of the continental slope southeast of DOS #1 at about 2500 m depth has been chosen.

(b) A minimum of four deployments are planned for the 1979-80 research period to encompass a wide range of incubation periods. We are scheduled for two 10 day OCEANUS Cruises during June and September which would allow for two incubations of 4 to 6 days and one incubation for about 8 weeks. Two suitable locations for this study are areas of distinctly different sediment accumulation and different organic carbon content. They were studied by E. Laine and C. Hollister (sediments) and by J. Farrington (chemistry) and are less than one day sailing time apart and about 3 1/2 days sailing time from Woods Hole (ca. 34°N, 57°30'W, 4300-5600 m). In addition, a long term incubation (8 months) will be started during the September cruise to be terminated during the spring of 1980.

2. Procedures

(a) Two more tripods will be built. No major change of the present design is planned.

(b) Sediment cores are taken by the tripods and incubated *in situ* (i) after automatic injection of liquid radiolabeled materials (acetate, glutamate, glucose) and (ii) with a given amount of solid radiolabeled food material on the core surface (fish meat or commercially available labeled proteins in a solified carrier such as agar). After retrieval the cores are frozen and later analyzed in sections for radiolabeled transformation products using procedures analogous to those described by Jørgensen (1978). Parallel cores retrieved and injected at the surface will serve as controls.

(c) A newly designed amphipod trap and incubation chamber will be used for measuring the uptake of labeled food materials (see above) by the scavengers as well as their microbial gut flora during a set time period. The technical details will be given at the oral presentation.

Justification of Budget

Permanent equipment requested includes three timer-release units @$700, five blocks of flotation @ $267 and two strobe lights @ $290 for night recovery.

Expendable equipment and supplies include the materials for two amphipod traps ($350) and for nine injection core units ($880), 1000 lb of descent weights ($250), four compression springs (@$17), radiolabeled substrates and scintillation supplies ($714), batteries, nuts and bolts, aluminum stock for frames, PRG paper, cables, clamps, mecca cables, etc. ($350).

Shop services (@ $13 per hour) are needed for tripod construction and welding (10 hrs) and the building of amphipod traps and injection core units (100 hrs).

Four one-way flights to Bermuda with one per diem each is requested for joining or leaving the cruises scheduled for us (NSF funded) during 1979. Our main operating area (see above) is at a 3 1/2 day distance from Woods Hole and a 2 day distance from Bermuda. One of us (H. W. J.) has been asked to organize a session on marine microbiology at the U. S. - Japan Intersociety Microbiology Congress at Honolulu, May 8-11, 1979 and suggested an emphasis on deep sea boundary layer research. The round trip is $600 plus 4 days' expenses.

Literature Cited

Ailor, W. H. 1971. *Handbook on Corrosion Testing and Evaluation.* John Wiley & Sons, New York.

Jannasch, H. W. and C. O. Wirsen. 1973. Deep sea microorganisms: *in situ* response to nutrient enrichment. Science 180: 641-643.

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Jørgensen, B. B. 1978. A comparison of the methods for the quantification of bacterial sulfate reduction in coastal sediments. I. Measurement with radioactive tracer. Limnol. Oceanogr. (in press).

Uhlig, H. H. 1971. *Corrosion and Corrosion Control.* John Wiley & Sons, New York

Wirsen, C. O. and H. W. Jannasch. 1976. Decomposition of solid organic materials in the deep sea. Envir. Sci. Tech. 10: 880-886.

MICROBIAL TRANSFORMATIONS IN THE DEEP SEA BENTHIC BOUNDARY LAYER

1 January 1979-31 December 1979

		ONR Funded Man Months	Actual Man Months
Professional:			
	Holger W. Jannasch - Co-Principal Investigator	1	1
	Craig D. Taylor - Co-Principal Investigator	2	2
	Carl O. Wirsen	2	2
Other Personnel:			
	Stephen Molyneaux - Research Assistant	1	1
	Secretary (To be assigned)	2 wks	2 wks
A.	Gross regular salaries	$12,515	
	Cruise leave, sea duty vacation and overtime (including premium pay of $213)	1,984	
		14,499	
B.	OTHER EMPLOYEE BENEFITS	6,090	
	TOTAL SALARIES AND BENEFITS		$ 20,589
C.	PERMENENT EQUIPMENT		
	1. Construction of 2 free vehicles		4,015
D.	EXPENDABLE SUPPLIES AND EQUIPMENT		2,700
E.	TRAVEL - Domestic (1 R.T. Honolulu)	830	
	- International (4 one-way trips to Bermuda)	871	
	TOTAL TRAVEL		1,701
F.	PUBLICATION COSTS		
	1. Graphic services (35 hrs @ $13.00/hr)	455	
	2. Page charges: 20 @ $20	400	
	TOTAL PUBLICATION CHARGES		855
I.	MISCELLANEOUS COSTS		
	1. Shop services (130 hrs @ $13.00/hr)	1,690	
	2. Shipping and Communication	800	
	3. Laboratory overhead at 21% of Total Salaries and Benefits, exclusive of premium pay	4,279	
	TOTAL MISCELLANEOUS COSTS		6,769
J.	TOTAL DIRECT COSTS		36,629
K.	INDIRECT COSTS AT 15% OF TOTAL DIRECT COSTS		5,494
L.	TOTAL COSTS		$ 42,123

W.H.O.I. Proposal #1224

2. PELAGIC DEVELOPMENT AND SETTLEMENT BY LARVAE OF MARINE FOULING ORGANISMS

Rudolf S. Scheltema
PII Redacted [redacted]

Abstract

The discovery of techniques for the routine rearing of pelagic larvae belonging to the encrusting species of fouling organisms has been undertaken. The possibility of growing larvae in the laboratory opens up opportunity for the study of environmental characteristics which control larval mortality and the duration of pelagic development.

Experiments thus far completed suggest that the species and concentration of algal food is important in determining the per cent survival and length of development of the nauplii larvae of two species of barnacles, *Balanus amphitrite* and *Balanus eburneus*. Results on the effect of temperature on larval development in these same species are still inconclusive and further study is needed.

Similar research on the effect of environmental characteristics upon the encrusting calcareous-tube-making polychaete worm *Hydroides dianthus* has been begun, and it is anticipated that encrusting bryozoa will also be investigated as the work proceeds.

The role of settling-responses of larvae will be investigated to discover if such reactions will result in the "inhibition" or "attraction" of new colonizers and hence contribute to determining the species composition of fouling communities.

Long Range Scientific Objectives

The overall long-term goal of our research remains unchanged, namely a better understanding of the role played by pelagic larvae in the recruitment of species into the fouling community. The influence of larval survival and settlement responses upon the abundance of particular fouling species and upon the composition of the fouling community as a whole should be distinguished from other biological interactions such as predation and intra- or inter-specific competition that can occur after settlement. Predation and competition on the attached juveniles and adults can best be studied by careful intermittent non-destructive examination of submerged panels (*vide*, Sutherland, J. P. 1976, pp. 137-153, *In* The ecology of fouling communities. J. D. Costlow, Editor, Proc. U.S.-U.S.S.R. workshop, "Biological production and biochemistry of the world's oceans"). On the other hand, larval survival and settlement responses can be more readily examined by laboratory experimentation even though the relevance of such results in the natural environment may later need to be assessed by further field study. By rearing larvae of species that are important in the fouling community one can examine some of the requirements for larval growth, development, and mortality and also the larval behavior at the time of attachment.

Progress on Current Research

Considerable progress has been made upon our originally proposed goal to study the food requirements for developing larvae of fouling species. Research has been largely centered upon two balanomorph barnacles common on the east coast of the United States, namely *Balanus amphitrite* and *Balanus eburneus*. The former species, *B. amphitrite*, is a very widely distributed form found in warm temperate and tropical harbors throughout most of the world; the latter, *B. eburneus*, was selected because of its distribution into estuaries. The initial step has necessarily been the establishment of culture techniques for these two barnacle species. The development of culture methods has led to some interesting observations which bear importantly upon the interpretation of later experiments. For example, we have noticed differences in survival that are seemingly related to the volume of the rearing chambers or to some correlated factor such as density of the larvae or the water-surface area. Therefore, when making comparisons between different experiments it is important that identical culture chambers are used and that larval densities are held the same in every instance.

Feeding experiments with *Balanus amphitrite* have permitted some tentative conclusions regarding the importance of both the quality and quantity of the algal food required for the growth and survival of larvae. *Quality* here refers to the species, the culture conditions, and the age of the unicellular algae used as food for larvae. *Quantity* denotes the concentration of algal cells used as food.

A comparison of different algal species when used as food for developing nauplii of *B. amphitrite* showed that survival to settlement with the flagellate *Isochrysis galbana* was twofold greater than with *Monochrysis lutheri*. However, if the two algae *Monochrysis* and *Isochrysis* were mixed at a ratio of 1:1, better survival was obtained than with either algal species alone, but the rate of development was not substantially altered. A third species, the diatom *Skeletonema costatum*, when used as food for *B. amphitrite* gave about the same survival as *Isochrysis* but the length of development on the average was substantially shortened for most larvae. These data are summarized in the accompanying Table I. The conclusion is that some algal species are better than others when used as food for *Balanus amphitrite* larvae, and that the food available to a larva may importantly affect both its survival and rate of development.

Table I. Duration of development and percent survival of *Balanus amphitrite* when fed diets of various algal species at 10^6 cells/ml at 25°C.

Algal food species	% survival to cyprid	Time to cyprid (days)	% survival to settlement	Time to settlement
Monochrysis lutheri	22	10-13	18	13-15
Isochrysis galbana	44	9-14	40	10-16
1:1 mixture of *Monochrysis* and *Isochrysis*	60	9-13	60	11-19
*Skeletonema costatum**	59	4-8	45	5-12

*Nauplii grown from different parents than in the preceding three feeding experiments. Better growth was obtained with *Skeletonema* at somewhat lower concentration (5 x 10^5, 65% survival to cyprid, 52% to settlement; time to settlement 5-11 days).

Why some algal cells are better food for nauplii than others is not immediately evident; it may be that some species of algae can be more effectively harvested because of their size or shape (*vide*, Paulson, T. C. and R. S. Scheltema 1968. Biol. Bull. 134: 481-489) or alternatively that the "food value", e.g., the ratio of proteins, carbohydrates and lipids, may differ in the various algae so that some species more nearly fill nutritional requirements of the larvae.

The use of different quantities of algal food cells resulted in different percentages of survival in *Balanus amphitrite* but did not appear to alter in any systematic way the rates of development to the cyprid stage. Concentrations of 10^5 cells/ml of *Isochrysis* did not support development of *Balanus amphitrite* to the cyprid stage, whereas at a similar concentration 20% survival beyond the cyprid stage to settlement was obtained with *Skeletonema*. When the concentration of either algal species was increased, better survival of *Balanus amphitrite* resulted. Data for survival and the time required until settlement are summarized for *Balanus amphitrite* in the accompanying Table II.

Table II. The relationship of food concentration to the percentage survival and the duration of pelagic development in the acorn barnacle *Balanus amphitrite*, grown at 25°C.

Algal species and concentration	% survival to cyprid	Time to cyprid (days)	% survival to settlement	Time to settlement
Isochrysis				
1×10^5	0	-	0	-
5×10^5	12	5-10	4	6-14
1×10^6	31	5-11	21	6-19
Skeletonema				
1×10^5	39	5-15	20	7-15
5×10^5	65	4-8	52	5-11
1×10^6	59	4-8	45	5-12

The second barnacle species, *Balanus eburneus*, has also been successfully reared to settlement. Of ten diets tested (three of which are still in progress), four have, so far, produced cyprids competent to settle. These include a *Skeletonema* culture infected with bacteria, the green alga *Duniella tertiolecta*, the diatom *Thalassiosira pseudonana* (3H) and a 1:1 mixture of *Dunaliella* and *Thalassiosira*. Using larvae from a single hatch of 25°C and 25‰ salinity, *Thalassiosira* alone gave far better survival to cyprid and settlement (80% to cyprid and 24% to settlement) than *Dunaliella* alone (8% to cyprid and 4% to settlement). The 1:1 mixture of these two species was superior to either alga alone (100% to cyprid and 70% to settlement). Larvae from two additional hatches have also responded well to the 1:1 *Dunaliella/Thalassiosira* mixture, yielding 61% and 84% to cyprid. In general, *B. eburneus* larvae show greater survival at 25°C than at 20°C and with an algal cell concentration of 2×10^5 rather than 1×10^5 cells/ml.

The low percent survival to cyprid produced by *Dunaliella* was accompanied by a somewhat slower rate of development. No cyprids appeared in the *Dunaliella* cultures until day 5, while the *Thalassiosira* and *Dunaliella/Thalassiosira* diets produced cyprids by day 4, indicating better culture conditions. Thus, as for *Balanus amphitrite*, both quality and quantity of algal food affect culture success in *B. eburneus*.

In spring 1978, work was initiated on rearing the larvae of the calcareous encrusting tube worm *Hydroides dianthus*. Preliminary experiments have resulted in successful culture from the spawning of gametes to metamorphosis of larvae. In seeking optimal laboratory rearing conditions, it has been tentatively shown that: 1) these tiny larvae develop and survive best on small algal cells, i.e., *Isochrysis* and *Thalassiosira pseudonana*, although the larger cells of *Dunaliella* are also adequate for development and metamorphosis; 2) larvae cultured in large (per larva) volumes of continuously aerated seawater appeared to survive better than those grown in smaller volumes of unaerated seawater sieved and renewed frequently; 3) more rapid growth rate and better survival were obtained at 25°C than at 20°C; and 4) on a mixed diet of *Isochrysis, Thalassiosira* and *Dunaliella* at 25°C, settlement of larvae commenced as soon as 10 days from the formation of trochophores. Further experimentation will be aimed at determining the best types and density of algal cells and other culture factors such as temperature and salinity for improving survival rate through metamorphosis.

A comparison between the concentration of algal cells used for growing larvae in the laboratory with published figures for phytoplankton concentration reported for coastal waters shows a possible discrepancy between these two values. Mean cell densities found in natural coastal waters vary greatly from 2.1×10^1 to 2.23×10^5 cells/ml (*vide*, Lillick, L. 1937. Biol. Bull. 73: 488-503; Hulburt, E. 1963. J. Mar. Res. 21: 81-93; Smayda, T. 1973. Marine Pub. Series No. 2, Univ. Rhode Island, pp. 3-1 - 3-100); algal concentrations used in the laboratory are far greater than natural densities at the lower end of this range. At present there are no ready explanations for this paradox. However, two possibilities present themselves.

(1) Laboratory study has consistently shown that for barnacles as well as for a wide variety of other invertebrate larvae, a mixture of algae results in better growth than a single species of algae when offered as food. Perhaps the wider variety of phytoplankton species found in natural populations will support better growth and survival because collectively they furnish a more 'balanced' diet.

(2) The size range of algal cells easily consumed by nauplii larvae is less than 25 microns in diameter. However, methods of sampling nannoplankton in the sea are inadequate and probably underestimate the actual number of cells that occur in natural waters. Perhaps barnacle larvae are more efficient in collecting nannoplankton than the sampling methods presently in use by marine biologists! The species and numbers of nannoplankton cells that actually co-occur with barnacle larvae under natural conditions need further study if the two suggestions above are to be tested.

These possible solutions suggest new directions of research at some time in the future.

Experiments to determine the relationshop between physical factors and larval development are still inconclusive. To observe the effect of temperature on the survival and duration of larval development presents subtle difficulties that in the past have often been ignored (*vide*, Scheltema, R. S. 1967, Biol. Bull. 132: 253-265). For example, when *Balanus amphitrite* nauplii have been grown at 20° and 25°C, survivals of 74.5% and 83.4%, respectively, resulted after four days of culture, whereas at 30°C only 7.5% survived. This result suggests that nauplii do not tolerate the temperatures often found in coastal tropical waters where this barnacle species is nonetheless commonly known to occur. On the other hand the initial rate of ecdysis is much higher at 30°C than at 25° and 20°C and these data suggest that high developmental rate is related to high water temperature. How is this paradox, the co-occurrence of high mortality and at the same time high developmental-rate explained? The difficulty in interpreting the results of larval mortality at 30° arises from the fact that one does not know whether the high larval death rate results directly from the elevated temperature or whether the unicellular algal food organisms are somehow altered in their 'food value' (as defined above) or alternatively killed before they can be eaten. Stated differently one may ask if the larvae are not actually dying of malnutrition or starvation. The use of an algal species with a wide temperature tolerance is one possible way to partly overcome this difficulty.

<u>Program for 1979</u>

(1) To continue to develop culture routines for additional fouling organisms. When the culture methods for serpulids are well in hand, we propose next to begin work with encrusting bryozoa.

(2) To conduct further experiments on the food requirements of *Balanus amphitrite* and *Balanus eburneus*. Because of the paucity of information on food requirements of barnacle larvae, we regard these experiments as important and of considerable interest. (The only previous work is that of J. Moyse, 1963. J. du Conseil 28: 175-187; Moyse and E. W. Knight-Jones, 1967. Proc. Symp. Crustacea. Ser. 2, Mar. biol. Assoc. India, Pt. II, pp. 595-611; and W. H. Lang, 1977. Ph.D. Dissertation, Univ. South Carolina, U.S.A.) However, from published work and our own research, it is apparent that there are large variations inherent in feeding experiments and that considerable replication will be required before generalizations can safely be drawn. Feeding experiments with the serpulid *Hydroides* will be continued.

(3) To continue work on the effect of temperature and salinity upon the development and survival of larvae belonging to the coastal species, *Balanus amphitrite* and *Hydroides dianthus* and the estuarine barnacle, *Balanus eburneus*. Some of the difficulties inherent with this work and a possible solution have already been briefly suggested above (*viz.* using algal food that is known to have wide tolerances for the physical factor being tested).

Geographic differences in the effect of temperature on embryonic ('pre-planktonic') development of *Balanus balanoides* have been described by H. and M. Barnes (1976. J. exp. mar. Biol. Ecol. 24: 251-269), and very likely such differences may also occur in the pelagic stages as well. It will eventually, therefore, be necessary to make comparisons between geographically separated populations of widely distributed fouling organisms and for this reason we propose as a modest beginning a comparison between populations of *Balanus improvisus* and *Balanus eburneus* from Woods Hole, Massachusetts, with those of Beaufort, North Carolina. Differences in temperature response at different regions in the range of fouling species may have important and obvious practical consequences for their control under certain applied circumstances.

(4) To conduct experiments on interspecific settlement responses. Goodby (1961, Nature, Lond. 190: 282-283) noticed that when clean, new panels were placed in proximity to those previously submerged and with 'mature' fouling communities, that fouling was inhibited in the newly submerged panels. It has been suggested in this instance, and in a number of anecdotal accounts, that larval settlement is inhibited by the proximity of an established fouling community.

On the other hand there are accounts that describe the 'attractiveness' and the 'induction' of larval settlement by the presence of a pre-existing fouling community. For example, Cole and Knight-Jones (1949, Fishery Investigations, Lond., Ser. 2, 17: 1-39) described the preferential settlement of oyster larvae on previously fouled oyster cultch. The subject of inter-specific settlement responses was reviewed in the original proposal that initiated the present research (*vide* also, Scheltema, R. S., 1974. Thallasia Jugoslavica 10: 263-296) and need not be further elaborated here.

An experimental test of the settlement 'inhibition' or 'attraction' can be made by introducing larvae of fouling organisms into the presence of an attached and established fouling species. This kind of experiment was performed by Ryland (1959, J. exp. Biol. 36: 613-631) to determine the preference of certain bryozoa larvae for particular preferred species of intertidal thallus algae. The types of experiments to be performed by us have been identified and described in detail in our original proposal. Briefly, these are (1) the simple two-culture method in which there is one experimental culture containing a stimulus for settlement and another as a control with filtered sea water only (e.g., *vide* Scheltema, 1961. Biol. Bull. 120: 92-109) and (2) the 'multiple choice' experiment in which larvae are allowed to choose between several different substrates in a single dish (e.g., *vide* Ryland, 1959 *op. cit.*).

Included in the budget is a request for funds to accomplish the necessary field work. Also we request continued part-time support of a post-doctoral investigator.

PELAGIC DEVELOPMENT AND SETTLEMENT BY LARVAE OF MARINE FOULING ORGANISMS

1 January 1979-31 December 1979

		ONR Funded Man Months	Actual Man Months
Professional:			
	Rudolf Scheltema - Principal Investigator	3	3
	Alison Ament - Postdoctoral Investigator	6	6
Other Personnel:			
	Isabelle Williams - Research Assistant	5	5
	Secretary (To be assigned)	0.5	0.5
A.	Gross regular salaries (including allowance for vacations, holidays, sick pay of $2,292 which is accounted for as employee benefits)	$ 19,562	
B.	OTHER EMPLOYEE BENEFITS	4,961	
	TOTAL SALARIES AND BENEFITS		$ 24,523
C.	PERMANENT EQUIPMENT		-
D.	EXPENDABLE SUPPLIES AND EQUIPMENT		500
E.	TRAVEL - Domestic		2,345
F.	PUBLICATION COSTS		
	1. Graphic services (20 hrs @ $13.00/hr)	260	
	2. Page charges: (10 @ $50) Reprints	500	
	TOTAL PUBLICATION CHARGES		760
I.	MISCELLANEOUS COSTS		
	1. Shop services (40 hrs @ $13.00/hr)	520	
	2. Shipping and Communication	100	
	3. Laboratory overhead at 21% of Total Salaries and Benefits, exclusive of Premium Pay	5,150	
	4. Xerox costs	50	
	TOTAL MISCELLANEOUS COSTS		5,820
J.	TOTAL DIRECT COSTS		33,948
K.	INDIRECT COSTS @ 15% OF TOTAL DIRECT COSTS		5,092
L.	TOTAL COSTS		$39,040

3. THE ENERGY BUDGET OF MARINE WOOD-BORING MOLLUSCS.

Roger Mann (Principal Investigator)
Department of Biology
Woods Hole Oceanographic Institution
PII Redacted
[redacted]

Ruth D. Turner (Consultant)
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Harvard University

Abstract

The objective of the proposed research is to compare the energy budgets of two oviparous, wood-boring molluscs, *Bankia gouldi* and *Martesia striata*, throughout their life cycle. The components of the energy budget equation (consumption, growth, respiration, faecal losses, excretion) would be assayed, and a description of gross biochemical composition (% carbon, nitrogen, carbohydrate, lipid, ash) made, at regular intervals throughout larval development, metamorphosis and growth to mature adults. Data will provide a basis for controlling fouling through inhibition of the biochemical and physiological processes accompanying development, metamorphosis and growth.

Introduction and Research Objectives

The development and natural history of the wood-boring marine molluscs have received considerable study (Turner and Johnson, 1971). Investigations have also been made of nitrogen fixation in these organisms (Carpenter and Culliney, 1975). However, despite the fact that considerable evidence exists that these organisms are important in nutrient cycling in the sea (Turner, 1973, 1978), comparatively few studies have examined their physiology and biochemistry. Furthermore, a knowledge of the biochemical and physiological changes accompanying larval development, metamorphosis and growth in wood-boring molluscs would provide a basis for control of their fouling activity through inhibition of these processes. The objective of the research described in the present proposal is to compare the energy budgets of two species of wood-boring molluscs, *Bankia gouldi* and *Martesia striata*, throughout larval development, metamorphosis and growth to mature adults. These two species have been chosen because they are both oviparous and phylogenetically closely related, but differ in that *B. gouldi* utilizes the wood into which it bores for nutritional purposes, whereas *M. striata* does not.

The proposed research would assay the components of the energy budget equation for each species. Using the I.B.P. terminology of Ricker (1968) this equation may be described as:

$$C = P + R + F + E$$

where C: consumption

P: production or growth (sum of somatic growth, Pg, and reproductive tissue, Pr)

R: energy loss through respiration

F: faecal losses

E: excretion and secretions

Such a study will differ from published material on energy budgets of the more extensively studied lamellibranchs (see Bayne 1976 for review) in that it will emphasize the following questions:

(i) What are the relative roles of phytoplankton and wood in the nutrition of *B. gouldi* when both are available in excess?

(ii) How do the relative roles of wood and phytoplankton vary in the nutrition of *B. gouldi* as phytoplankton availability is reduced?

(iii) Does the use of wood as a nutritional source in *B. gouldi* result in a storage metabolism that differs significantly from that observed in *M. striata,* and marine bivalve molluscs that do not utilize wood for food?

(iv) What, if any, effect does the use of wood as a nutritional source have on the biochemical reserves incorporated into the gametes, and the subsequent development of the larval forms?

Review of Relevant Literature

Larval forms

Wood-boring molluscs exhibit developmental characteristics similar to those of other bivalve molluscs (see Loosanoff and Davis, 1963, Chanley and Andrews, 1971 for review of bivalve mollusca; Turner and Johnson, 1971 for wood boring molluscs). A range of reproductive habits are evident varying from oviparous (e.g. *B. gouldi, M. striata*) to lengthy brooding periods in larviporous forms (e.g. *Teredo furcifera, Lyrodus pedicellatus*).

It is generally recognized that bivalve mollusc larval forms predominantly utilize phytoplankton as a food source (Loosanoff and Davis, 1963, Wilbur and Yonge, 1964) and exhibit a protein-lipid based respiratory metabolism (Holland and Spencer, 1973, Holland and Hannant, 1974, Bayne, 1976). Thus large droplets of lipid within the larva not only represent a much higher energy reserve per unit weight than protein and carbohydrate (9.5 cal/mg vs. 5.7 and 4.2 cal/mg respectively) but also provide buoyancy to these pelagic individuals. It is notable that phytoplankton are similarly rich in proteins and lipids (Parsons, Stephens and Strickland, 1961). Thus, specific lipid requirements in developing larvae can probably be fulfilled by comparatively minor structural changes in digested material rather than de novo synthesis *per se*.

Both *B. gouldi* and *M. striata* utilize phytoplankton during larval growth and development (Loosonoff and Davis, 1963, Boyle and Turner, 1976). However, the author can find no studies examining their biochemical composition during this period. The larviparous shipworm *Lyrodus pedicellatus* exhibits a short, free-swimming larval period. Pechenik *et al.* (1978) have demonstrated that, during this period, the larvae do not feed, being totally dependant upon parentally derived reserves. Greenfield (1953) reported that "unborn" larvae of *L. pedicellatus* contain 10-15% dry weight (shell inclusive) of glycogen derived from parental reserves, this being reduced to 5-8% after 24 hours in the free swimming state. This is considerably higher than that recorded for oyster larvae (Holland and Spencer, 1973), and suggests that the larvae of *L. pedicellatus* differ significantly from the majority of pelagic molluscan larvae both behaviorally and physiologically. The specific gravity of glycogen ($\sim$1.56) is considerably greater than that of either sea water or lipid ($\lesssim$1.0), and will thus require a much greater energy expenditure for swimming than would otherwise be expected. While such a strategy may be of little consequence in species with short pelagic larval periods, the use of such a strategy in oviparous species would be markedly disadvantageous.

<u>Metamorphosis and Growth to Mature Adults</u>

In oysters, probably the most intensively studied of the molluscs from the biochemical aspect, metamorphosis and subsequent juvenile development is accompanied by a gradual change from a protein-lipid based respiratory metabolism to a protein-carbohydrate metabolism (Holland and Hannant, 1974, review by Gabbott, 1975). In these filter feeders nutrition is derived primarily from suspended particulate material and phytoplankton. However, in the marine boring molluscs nutrition is more complex. With the exception of the sub-family Martesinae of the family Pholadidae, wood borers (i.e. Teredinidae, Xylophagainae) require wood for successful metamorphosis and growth (Turner and Johnson, 1971).

Following settlement Teredinids and some Pholads ingest considerable quantities of wood as a result of boring activity. Wood in the marine environment may originate from both man-made structures and natural sources. Hungate (1940) has examined the nitrogen content of sound and decayed coniferous woods and found it to be very low (<0.05% of the dry weight) indicating that material ingested by wood borers from this source is predominantly carbohydrate in the form of cellulose. Successful utilization of this material is highly dependent upon cellulolytic enzyme activity. Whether this is associated with bacterial gut flora or the digestive cells of the mollusc *per se* has yet to be fully evaluated (Barington, 1962, Dean, 1975). Although the absolute efficiency of such a process may be low in terms of assimilation (see Greenfield, 1953 for discussion), the quantity of material processed suggests that ingested wood represents a major energy source for these molluscs (Dean, 1975). Walne (1973) has suggested that nitrogen assimilation may be a growth limiting factor in juvenile *Saxidomus giganteus*. It is relevant to ask whether or not a similar situation exists in wood borers that utilize ingested wood for nutritional purposes, and whether sufficient nitrogen may be obtained from this source to fulfill metabolic requirements.

Reproductive activity in bivalve molluscs is closely linked with both seasonal temperature change (review by Sasty, 1975) and biochemical storage cycles (reviews by Giese, 1969, Gabbott, 1975, Bayne, 1976). Rapid gametogenesis is often evident as water temperatures increase. At this time glycogen reserves are depleted and protein becomes increasingly important as a respiratory substrate (Bayne,1973, 1976, Mann, 1978, Widdows, 1978). Lipid-rich eggs are common in bivalve molluscs (see Holland and Spencer, 1973, Bayne, 1976). The work of Greenfield (1953), discussed earlier in the present text, suggests the importance of parentally derived carbohydrate in the gametes of wood borers. However, should lipid rich eggs be evident in oviparous wood borers, as is suggested by the energetically disadvantageous habit of a pelagic larvae reliant upon carbohydrate, then questions arise as to the source of dietary lipids in marine borers. It does not seem unreasonable to suggest that these are derived primarily from lipid rich phytoplankton taken during filter feeding.

Proposed Program

Rearing of Experimental Organisms

Larval culture of *B. gouldi* has been described by Sigerfoos (1908) and Culliney (1975). Comparable data for *M. striata* is given in Turner and Johnson (1971) and Boyle and Turner (1976). Both species, together with many other marine borers, have been reared on a regular basis in the laboratory of Professor R. D.

Turner at the Marine Biological Laboratory, Woods Hole, Mass. This program has involved continual development of larval rearing techniques since its inception. While mass rearing (10 L - 100 L vessels) of the larval stages of marine boring molluscs has not been attempted on a regular basis an abundance of literature on the mass rearing of commercially valuable, edible bivalves (e.g. Walne, 1966, Dupuy *et al.*, 1978) provides adequate guidelines for re-scaling present methodology. This is considered necessary because procedures involving biochemical assay of larvae, and subsequent programs involving the regular sacrifice of juvenile and adult organisms for growth and biochemical assay, require substantial numbers of organisms.

B. gouldi is endemic from northern New Jersey south to Panama, and can either be collected when required, or maintained in the running sea water facility to be used for the proposed study and to be described later in the present text. *M. striata* does not occur as far north as Woods Hole, however, specimens can be collected in the region of Beaufort, N.C. and subsequently maintained in the Woods Hole facility.

Phytoplankton culture for larval feeding has been carried out by the author at frequent intervals over the past six years using methods described in Walne (1966) and modified, where required for simplicity, to closely resemble those recently described by Dupuy *et al.* (1978). A large number of suitable food species are maintained at Woods Hole Oceanographic Institution in the collection of R. R. L. Guillard, and are available to the author on request.

Experimental Protocol

This is identical for both *B. gouldi* and *M. striata*, and will consist of a long term growth experiment extending from larval release to attaining maturity. At regular intervals throughout larval development, and growth following metamorphosis, a number of experimental organisms (sufficient to give *ca.* 10-20 mg of dry material) will be sacrificed for estimation of morphometric parameters, mean live and dry weight and biochemical composition (percentage carbon, nitrogen, carbohydrate, lipid, ash as described in the following section). Prior to sacrifice estimates will be made of consumption (= filtration rate in larvae, filtration and wood ingestion following metamorphosis), respiration, faecal production and excretion. Production will be estimated from gross growth data during the interval between sampling. During larval development food will consist of the diatom *Thalassiosira pseudonana* (3H) and the flagellate *Isochrysis galbana*, both of which have been shown to be excellent foods for larval forms (Boyle and Turner, 1976 and unpublished data). Following metamorphosis three experimental protocols will be attempted for each species, namely filtered (1 μ) water and wood only, and the same conditions supplemented with a low (25 cells/μl), and high (100 cells/μl) concentrations of phytoplankton.

Biochemical Analysis of Molluscs, Phytoplankton, Wood and Faeces.

Larvae will be collected from culture vessels on a suitable size nylon mesh (Culliney, Boyle and Turner, 1975) Phytoplankton will be filtered on to a pre-ashed, 22 mm Gelman A/E glass fibre filter (∿1 μ porosity) in a Millipore apparatus. Both larvae and phytoplankton will be freeze dried prior to analysis. Adult molluscs, wood and faecal samples will be freeze dried prior to analysis, organisms being separated from the wood containing them following drying. Separated specimens will be ground to a powder in an unglazed pestle and mortar to facilitate subsampling.

Carbon, and nitrogen assays will be effected with a Perkin-Elmer CHN analyzer. Glycogen will be assayed as anthrone-reactive material, following trichloroacetic acid extraction (5% w/v), by the method of Strickland and Parsons (1968). Lipid will be assayed by the charring method of Marsh and Weinstein (1966) following extraction in 2:1 v/v chloroform:methanol (Holland and Gabbott, 1971). Ash is defined as that material remaining after combustion to constant weight at 450°C.

Consumption

Previously Walne (1966), and Pechenik *et al.* (1978), have used radioactively labelled phytoplankton to estimate filtration rates in mollusc larvae. The many problems with this methodology have been discussed by Conover and Francis (1973). The proposed research will estimate phytoplankton consumption in both larval and adult molluscs by monitoring depletion of algal cells in a closed culture system by the method of Jorgensen (1949). Cell counts will be made with a Coulter electronic particle size counter and checked by optical counts made with a hemacytometer. Relevant controls will be included as required.

Consumption of wood following metamorphosis would be estimated from burrow size either by X-raying or culturing animals in thin wooden panels sandwiched between plexiglass plates.

Respiration

Respiration will be assayed manometrically in all but the larger adult organisms. The major problem to be overcome in manometric assay is to minimize error inherent to the apparatus in comparison to the oxygen consumption of the organisms. A standard Gilson respirometer has an error of ± 2 μl per reading, too great for accuracy in the case of larval molluscs. Thus, respiration in larval forms will be assayed using the microrespirometer of Grunbaum *et al.* (1955). Following metamorphosis on wooden dowels, cuts sufficiently small to fit into the respirometer flasks, respiration will be assayed by microrespirometers, a Gilson respirometer equipped with 15 ml flasks, or a Gilson equipped with 50 ml flasks as growth of the animal requires. Respiration in large adults will be assayed by incubating specimens in B.O.D. bottles and monitoring oxygen depletion using either a polarographic oxygen electrode or a Winkler titration.

Faecal Production

Due to the minute quantities and concentrations of material involved it is not feasible to assay this component for larval molluscs. Faecal production in organisms following metamorphosis will be assayed by encouraging specimens to metamorphose in the ends of wooden dowels, and subsequently suspending these vertically in a vessel of filtered seawater enriched with phytoplankton where the experimental protocol requires. Faecal material will be allowed to accumulate over a period not exceeding 24 hours, thus minimizing bacterial degradation (see Newell, 1965), and subsequently collected using a Pasteur pipette, filtered onto a Gelman A/E filter and assayed as described earlier. Relevant controls will be included as required. True faeces, and wood particles resulting from boring action alone, cannot easily be separated, however, providing comparative biochemical analysis of the deposited material and the original wood are completed then the quantitative removal of any chosen biochemical component can be assayed.

Excretion

Dissolved excretory material is predominantly in the form of ammonia with minor contributions from amino acids and urea (Potts, 1968, Bayne, 1976). Excretion will be assayed in conjunction with respiration measurements using the colorimetric techniques of Solorzano (1969) and Newell *et al.* (1967) for ammonia and urea respectively, and the fluorescence technique of North (1975) as modified by the present author (unpublished) for amino acids. Simultaneous measurement of respiration and excretion allows calculation of the oxygen consumption:ammonia excretion ratio. This, in turn provides strong inferrential data on the nature of the predominant respiratory substrate (review in Bayne, 1976) which can be substantiated by biochemical assay as described earlier.

Conversion of data to caloric values

In order to compute an energy budget equation from the data collected relevant conversion factors must be applied to give caloric content. These are as follows: protein, estimated as nitrogen content x 6.25, 5.7 cal/mg; lipid 9.5 cal/mg; carbohydrate 4.2 cal/mg (Ansell, 1972); respiratory losses, 483 cal/ml O_2 (Hughes, 1970); ammonia 30 k cal/mole, urea 79.6 k cal/mole, amino acids 722 k cal/mole (Hutchens, 1970).

Relevance to other projects supported by O.N.R.

The office of Naval Research presently supports two other projects on the biology of wood boring molluscs. These are natural history and larval development (R. D. Turner and C. J. Berg; Harvard University), and nitrogen fixation in shipworms (J. J. McCarthy, R. D. Turner, C. J. Berg, and J. Waterbury; Harvard University and Woods Hole Oceanographic Institution). The proposed research complements both studies by investigating an area which is of direct relevance to both, but covered by neither.

Experimental Facility

The proposed work will be carried out at the Environmental Systems Laboratory of the Woods Hole Oceanographic Institution. This facility has a 25 x 12 m indoor wet laboratory fully equipped with a variety of wet tables and tanks for experimental work and holding specimens. The wet laboratory has a running seawater capacity of 100 L/min of heated water plus 200 L/min of ambient temperature water. Seawater heating is effected by means of a fossil fuel boiler. Heat may be applied up to a maximum of 35°C, and is monitored by an automated alarm system, together with other laboratory equipment, on a 24 hour per day basis. Attached to the wet laboratory is a temperature controlled algal culture laboratory and three dry laboratories. Much of the equipment necessary to effect the proposed work (e.g. spectrophotometer, fluorometer, microscope, centrifuge, balances, CHN analyzer, filtration equipment, freeze drier, muffle furnace) is available either in this laboratory complex or within the Woods Hole Oceanographic Institution. The author is presently requesting a Coulter Counter from another agency.

Funding Request

Funds are requested to cover the Principal Investigator for three man months and a research assistant grade III (T.B.A.) full time. One month of secretary time, plus 40 hours of graphic arts services are requested to cover the production of reports and publications.

One week of salary time is requested to cover J. P. Clarner for C.H.N. analysis.

Professor R. D. Turner (Harvard University) has agreed to act as a consultant on the research project at no cost.

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1 January 1979 - 31 Decmeber 1979

Professional:	ONR Funded Man Months	Actual Man Months
Roger Mann - Principal Investigator	3	3
Other Personnel:		
J.P. Clarner - Senior Research Assistant	0.25	0.25
To be assigned - Research Assistant III	12	12
Secretary	1	1
A. GROSS REGULAR SALARIES (including allowance for vacations, holidays, sick pay of $2,349 which is accounted for as employee benefits)	$20,891	
B. OTHER EMPLOYEE BENEFITS	5,439	
Total Salaries and Benefits		$26,330
C. PERMANENT EQUIPMENT - *Microrespirometers*	450	
Gilson Respirometer	2,272	
Total Permanent Equipment		2,722
D. EXPENDABLE SUPPLIES AND EQUIPMENT		1,553
Coulter Counter Service Contract		500
E. TRAVEL - Domestic		1,000
F. PUBLICATION COSTS		
Graphic services: 40 hrs @ $13.00/hr	520	
Reprints: 300	300	
Total Publication Charges		820
H. COMPUTER COSTS		
Sigma 7: 2 hrs @ $155/hr		310
I. MISCELLANEOUS COSTS		
1. Shipping and Communication	150	
2. Laboratory overhead @ 21% of Total Salaries and Benefits	5,529	
3. Xerox costs: 5000 x .06	300	
Total Miscellaneous Costs		5,979
J. TOTAL DIRECT COSTS		39,214
K. INDIRECT COSTS @ 15% of Total Direct Costs		5,882
L. TOTAL COSTS		$45,096

4. NATURAL OPERATING AREAS

Richard H. Backus

[PII Redacted] [redacted]

Abstract

It is possible to relate volume reverberation (midwater sound scattering) to midwater animal distribution to general ocean circulation and to predict, to a considerable extent, the pattern of any one of the three from the pattern of any other. For the world ocean, the general circulation is the best known of the three domains, volume reverberation the least known. Beginning with the general circulation, the writer has partially prepared a chart of volume reverberation regions and provinces (which, alternatively, can be called "biogeographic regions and provinces" or "natural operating areas"). He proposes to finish the chart in 1979.

Long-Range Scientific Objective

In 1970 we described a division of the tropical and western North Atlantic Ocean into faunal "regions", a system based on the distribution patterns of mesopelagic fishes, mainly species in the families Myctophidae and Gonostomatidae (Backus, Craddock, Haedrich and Shores, 1970). Following this, it was argued (Backus, 1972) that because mesopelagic fishes with swim bladders are important contributors to midwater sound-scattering (volume reverberation), a division of the ocean into faunal regions based on midwater fish distribution could be taken also as a division of the ocean into sound-scattering regions[1]. In the latter paper the average displacement volume of midwater fishes caught per hour of effort was calculated for each faunal region; volume reverberation levels were calculated for the several regions using one as a reference region and assuming that a doubling of fish catch would result in a three-decibel increase in reverberation. These regional reverberation averages were then compared to actual reverberation measurements made in various parts of the Atlantic by Chapman, Bluy, and Adlington (1970); some agreement was found.

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[1]There is no reason for thinking that a division of the ocean into biogeographical units based on the distribution of mesopelagic fishes with swim bladders would give a different result from one based on mesopelagic fishes in general or on mesopelagic animals in general. The generalizations made by McGowan (1974) for the Pacific Ocean pelagial were derived from and apply to a great variety of kinds and sizes of plants and animals.

Later, Chapman, Bluy, Adlington, and Robison (1974) compared an extensive body of sound-scattering data with faunal zonations of the Atlantic, mainly as set forth by Backus *et al.* (1970), and eastern Pacific as described by Kort (1967). Chapman *et al.* (1974) concluded in part that "Spectra of column strength have been used as a tool for comparing reverberation conditions in a wide range of ocean areas. As the spectra often maintained consistent features over distances of hundreds of kilometers but changed dramatically in the neighborhood of known faunal or oceanographic boundaries, the present study supports the concept of dividing the world's oceans into reverberation provinces".

Recently, a scheme of faunal regions and provinces based on myctophid fishes was set forth for the Atlantic Ocean (from the borders of the arctic to the subtropical convergence at 35°S) by Backus and Craddock (1977) and Backus, Craddock, Haedrich, and Robison (1977). In the latter, the nature of the physical (ocean circulation) changes that take place at each of the faunal boundaries is described as well as the faunal and physical properties that are common to the provinces of each region. The results of this work show that the biogeographic structure of the Atlantic and that of the Pacific, as shown by the earlier work of McGowan and colleagues (McGowan, 1974), have a more or less common set of determinants. Data from the much-less-studied Indian Ocean suggests that this ocean is like the others.

Thus, it seems possible to relate volume reverberation to animal distribution to ocean circulation and to predict to a considerable extent the pattern of any one of the three from the pattern of any other. We propose to construct for the world ocean a chart of volume reverberation regions and provinces using principally the data of physical oceanography, that is to say, to describe the least-known of the three domains by means of the best-known one. Such a chart is not only of considerable theoretical interest, but also can be used by acousticians in planning experiments and observational programs. Furthermore, it is apparent, although not gone into here, that *many* properties of the marine environment are relatively unvarying within these same provinces and regions while changing more or less rapidly at their boundaries. Some examples in addition to sound-scattering spectrum are wind and weather, speed of underwater sound, sound velocity profile, conditions of ice, and water transparency. Thus, these regions and provinces can be thought of as "*natural* operating areas" of interest to naval and other marine operators. Finally, because of the equivalencies noted earlier, the chart given can be viewed as describing the biogeographic structure of the world ocean.

Present Status and Progress for the Year

The method for drawing this chart is to choose isotherms or other isopleths that delimit the circulationally separate areas that zoogeographic studies show to be distinct. The general regional foundations of this chart are (1) *subtropical* regions in the North and South Atlantic, North and South Pacific, and South Indian Oceans; these correspond to the so-called "central gyres" of these oceans, (2) *tropical* regions between the subtropical regions in all three oceans (in the North Indian Ocean, there are no regions north of the tropical region, however), (3) *temperate* (or "*transitional*" as it has been called in the North Pacific) regions poleward of the subtropical ones, and (4) *subpolar* and *polar* regions successively poleward of the temperate regions.

Some of the general bases for division of the regions into provinces are these: (1) the *subtropical* regions are divisible into northern and southern parts by the boundary between the west winds and the trades; in the North Atlantic, at least, the subtropical region is divisible also into a western (Sargasso Sea) and an eastern part; thus, the North Atlantic Subtropical Region is divisible into four provinces, (2) the tropical regions are divisible into eastern (cooler, more productive, upwelling) and western (warmer, less productive, non-upwelling) parts; there are also narrow equatorial zones to be set off from the rest of the tropical regions. These examples of bases for dividing the regions into provinces are given mainly for showing the *degree* of division that this chart will have.

Our division of the Atlantic north of 35°S was done earlier. The dividing of the Southern Ocean is fairly straight-forward and has been done. We have mostly done the North Pacific and the eastern parts of the tropical South Pacific. Remaining to be done is the bulk of the South Pacific and the Indian Ocean and, of course, manuscript preparation. We are drawing this chart on a Mollweide equal-area projection of the world centered on 160°W (approximately the longitude of Hawaii). The chart was especially prepared using a NavOceano computer program.

This work has gone somewhat more slowly than was hoped originally. One of several difficult problems are the so-called "subtropical convergences". Much confusion surrounds these features. For example, clearly different phenomena have been given this name in the North and South Atlantic Oceans and greatly different ways of drawing it have been used in the South Pacific. Veronis (1973) says: "from our study here it appears that the established classifications are misleading". It is not mere tidiness that encourages us to draw such inter-ocean homologies as these correctly. Chapman *et al.* (1974) found, for instance, that sound-scattering spectra in the subtropical

Atlantic were more like spectra from the subtropical Pacific than spectra from adjacent parts of the Atlantic.

There are also difficulties in drawing homologies between the temperate and subarctic parts of the North Atlantic and North Pacific. This is due to the fact that the influx of arctic water into the North Atlantic is considerable but into the North Pacific almost nil; thus, not only is the real situation very different in the two oceans, but the much-used term "subarctic" has wholly different meanings in the literature of the two.

Program for 1979

We plan to finish the preparation of the chart during 1979, prepare an accompanying manuscript, and submit the product to the Journal of the Acoustical Society of America.

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NATURAL OPERATING AREAS

1 January 1979-31 December 1979

		ONR Funded Man Months	Actual Man Months
Professional:			
	Richard H. Backus	2	2
A.	Allowance for vacations, holidays, sick pay of $ 711 which is accounted for as employee benefits		
	TOTAL SALARIES AND BENEFITS		$ 7,404
F.	PUBLICATION COSTS		
	1. Graphic services (30 hrs @ $13.00/hr)	390	
	2. Page charges: (7 @ $60.00) Reprints	420	
	TOTAL PUBLICATION CHARGES		810
I.	MISCELLANEOUS COSTS		
	1. Shipping and Communication	50	
	2. Laboratory overhead at 21% of Total Salaries and Benefits	1,555	
	3. Xerox costs	50	
	TOTAL MISCELLANEOUS COSTS		1,655
J.	TOTAL DIRECT COSTS		9,869
K.	INDIRECT COSTS AT 15% OF TOTAL DIRECT COSTS		1,481
L.	TOTAL COSTS		$11,350

W.H.O.I. Proposal #1224

5. SOUNDS MADE BY DEEP BENTHIC FISHES

Richard L. Haedrich
PII Redacted [redacted]

This project, initiated in mid-1977, had as its short-term goal to build a self-contained, light-weight recording system for use on deep ocean free vehicles. This goal has been met. The instrument and all its appurtenances were completed in early 1978, and preliminary tests show it to function as planned.

Our long-term scientific goals remain the same. They are to answer the following questions:

-- Are there sounds associated with feeding on bait by deep-ocean fishes?

-- Do these fishes, on locating food, make particular noises which might serve to attract others?

-- In the absence of bait, are the same, different, or in fact any noises heard?

-- Are there diel patterns in sound production?

-- Is there a seasonality in the types of sounds recorded?

-- Are there different patterns in different faunal (bathymetric) zones?

Why is this matter of interest? For about six years now we have been studying aspects of the distribution and natural history of large animals on the continental slope and rise south of New England. Support has come from the National Science Foundation. Pertinent, and important, points that emerge from this work are a) the fishes (and other megafauna) are strongly zoned with depth (Haedrich *et al.*, 1975), b) some fishes, particularly the dominant ones in very deep water, depend on falls of large carcasses for food (Haedrich and Henderson, 1974), and c) a significant fraction of the biomass of deep-ocean animals (megafauna and macrofauna) is contained in fishes (Haedrich and Rowe, 1977).

Deep-water fish species that figure prominently in our samples are members of the families Macrouridae (rattails) and, less importantly, Brotulidae. Representatives of both families have obvious drumming muscles associated with the swimbladder, and are assumed to be major contributors to the variety of mysterious hoots, clicks, and thumps that hydrophone lowerings in deep water have revealed (Marshall, 1971). These fishes also are among the main species that quickly gather at baited cameras (Dayton and Hessler, 1972; Isaacs and Schwartzlose, 1975), and gather at rates greater than one would expect were water-borne chemical cues the stimulating agents. One can easily imagine that sound plays a role here.

Since animals are zoned, and since the responses of fishes to bait vary from zone to zone, we expect characteristic sounds and acoustic patterns will tend to typify different zones. This will depend on the role that sounds play. The observations above suggest a role in feeding. The fact that sound-producing organs are found in only one sex of some species suggests a role in reproduction. Where sound is associated with behavior, we would expect to hear it throughout the year; where it is tied to reproductive behavior, we would expect it only seasonally. Since, for the most part, scavenging fishes are found on the rise and seasonally spawning fishes are found on the slope, the postulated acoustic differences should characterize rather different depth strata. Observing patterns like this would be of great interest to us. Combined with other data, they would imply different ecologies at different depths, and, we hope, the whole would move us nearer an understanding of what actually causes the observed zonation patterns.

The Instrument

The recorder is a Sony TC-150 cassette model. Switching circuitry, designed and put together by S. G. Page at W.H.O.I. turns the recorder on after a selected time period (2 to 17 hours) and allows it to record for again selected periods of time (one minute to full tape, by one-minute increments). The recorder, the switch circuits, and a battery pack fit in an aluminum pressure case rated to about 5000 m. To avoid condensation inside the case, air is excluded by the use of a foam plug that fits snugly inside the case and in which the components fit in cut-out slots. Before the case is closed, about 60 cc of Drierite are sprinkled in the bottom. The hydrophone, with separate preamplifier, is an ITC model 1010A with frequency range 4-4000 Hz. Its operating depth is unlimited. Gain in the preamp can be varied: 0, 20, or 40 db. The hydrophone cable plugs into the end of the recorder pressure case, and the hydrophone, preamp, and pressure case are all fastened in a simple stainless steel cage. The cage, to be used as a free vehicle, has eyes for attaching floats at one end and an anchor, via a Williams Pinger Release, at the other. A report describing the instrument is in preparation.

Status and Immediate Plans

In April of this year we took the instrument to sea on OCEANUS 43. Our object then was to test the operation of the switching circuitry under actual conditions. Two lowerings, to 655 and 1800 m, were made with the instrument on the hydrowire. The settings were for a two-hour delay and then continuous (full tape) operation.

During the deployment, we "pinged" at regular intervals with the ship's echosounder. The instrument worked perfectly. The two 45-minute records we made contain no unusual noises; they are dominated by wire strumming and rumble from the ship (which we expected) and occasional porpoise squeals on one of them. These we had also heard around the ship at the same time. The tests showed us we will need to experiment a bit with the gain before another deep ocean trial.

Accordingly, we plan shallow-water deployments during August. These will be done in Great Harbor, Woods Hole, where some associates will be diving for other purposes. The setting and retrieval of the recording instrument will involve virtually no extra time. We will try several long term (several days) sets, and expect to record the squawks and clucks that sea robins make when they are spawning (Fish and Mowbray, 1970). These we think should be quite appropriate for calibrating the instrument to record rattail sounds. If the shallow water tests are successful, and we have no reason to feel that they will not be, we will press ahead with deep-water deployments as opportunity avails.

Program for 1979

With the instrument now built and functioning, we plan to gather as much data as we can by "piggy-backing" on cruises with others. We would like some of this to be in conjunction with ALVIN/LULU trips where there might be a chance to visually check the attitude of the deployed instrument. It will be important to do as many lowerings as possible with the baited time-lapse camera. If the camera work cannot be arranged, however, we will bait the recording instrument itself. We will prepare simple descriptions and analyses of the sounds obtained, but ultimately will work together with W. Watkins of W.H.O.I. in making sonographs and other more sophisticated analyses that he has developed over the years during his work on cetacean sounds.

Our original request to ONR was for money to build the recording instrument. ONR has been quite generous in its support of this effort, and, for the moment, we feel that enough has been spent on it. Therefore, we are asking only for moral support during 1979. If the data that we assemble by "piggy-backing" look promising, we will return with a more tangible request in 1980.

Bibliography

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6. MARINE BIOLOGICAL SOUNDS

PII Redacted

William A. Watkins
[redacted]

William E. Schevill
[redacted]

Long Range Scientific Objectives

Our study of marine biological sounds has focused particularly on the environmental biology of cetaceans and other soniferous animals. Emphasis is placed on (a) their contribution to oceanic ambient sound, (b) correlation of their sounds with behavior, and (c) investigation of the movement and distribution of these populations. This includes the study of techniques for tracking animals (photography, marking, radio-tagging, and sound), techniques for studying their sounds (broad-band listening and array recording), and techniques of analysis of acoustic and distribution data.

Background and Description of Program

The study of the behavior of these animals provides understanding of the importance of the sounds they produce and the relationship of these sounds to the ambient ocean sound. Reasonable predictions of the distribution of animal sounds are not possible without careful studies of the animal populations. The sound characteristics of each species vary with location, behavior, population size, seasonal activity. and maturity of the animals. Very little of this is known. It is important to the Navy to have reliable assessments of marine biological sounds.

Beginning with the first cetacean sound identification by Schevill and Lawrence in 1948, our project has progressed from the discovery and basic analysis of underwater sound produced by more than 40 species of marine animals, through studies of their hearing capabilities and of sound production, their use of echolocation, directionality of sound propagation, voluntary level variations, seasonal differences in sounds, and correlation of the acoustics with both behavior and distribution of the animals. New techniques have had to be developed for each new step, and methods adapted to suit each study. These included design and fabrication of hydrophones, amplifiers, recorders, analytic equipment, quiet propulsion, and tagging and tracking gear. Techniques were devised for field study of animals at sea, underwater and aerial photography, acoustic recording and analysis, and tracking. Our study of underwater animal sounds has had the benefit of a long series of successful investigations into the acoustic behavior of marine animals.

Bioacoustic studies are based on high quality recordings of marine animal sounds to permit a careful scrutiny of the characteristic sounds of individual animals, and those common to a species, as well as comparisons of sounds from other species. We record in the field with as broad a bandwidth (180 kHz) and as large a dynamic range as we can arrange, then the data can be manipulated to specific analysis parameters in the laboratory. Recently we have emphasized multiple hydrophone recordings from arrays to provide acoustic locations for sound sources as well as details of three-dimensional sound fields.

High quality bioacoustic recordings require direct acoustical observation, which depends largely on unscheduled meetings between the investigator (with the right equipment and sufficient experience to use it wisely) and animals producing the sounds. Since contacts with animals cannot often be planned, the study of animal sounds does not lend itself to a structured program. But instead, a studied readiness for eventualities is attempted. Field equipment is kept as portable as possible, with the hope of taking advantage of the unexpected animal contact. In addition, prospecting trips are planned to areas where the particular animals under study are more likely to be found. Experience has reduced the probability of missing the animals, so that in spite of the odds, our trips usually have been very productive. We have been able to obtain good data from short exposures to the animals. Repeated exposures and repeated positive correlations have given us confidence in our acoustic results.

Our studies have provided good assessments of behavior in wide ranging marine animal populations as well as local Cape Cod cetacean groups. These local studies have continued each year for more than 20 years and have provided good observations of animals that occur regularly in our waters, including right whales, finbacks, humpbacks, sei whales, minke whales, and a wide assortment of smaller cetaceans. Both aerial and shipboard photography has provided good records of individual animals, and has permitted us to follow changes and stability in color markings, parasitic growths, and sizes as well as behavioral patterns and local distributions of the animals. The cumulative effect of such a continuing program has proved valuable in assessment of distribution, movement, and repeated visits of these cetacean species.

Efforts to trace the movement of individuals and migratory patterns of populations have been complicated by the difficulties of identifying individual animals. Many species appear to have characteristic uniformity of appearance, and individuals are not easily separable by size, color, or behavior. Therefore we have attempted various marking techniques, and in 1962 began experiments with radio-tags for whales. Current radio systems have developed from our experiences in several subsequent tagging experiments. For the past several years, paint-marking has been under study and so has the feasibility of using natural skin marks, trying to assess relative permanence and ease of differentiation of, for example, the bonnet patterns of right whales, and white patches on humpbacks.

Our analyses have permitted studies of the sounds of pinnipeds, manatees, and other soniferous marine species, as well as ambient noise in a wide variety of environments. These analyses have included ice-generated noise, effects of reverberation, and shallow water propagation. Analysis of each sound sequence is varied to fit the salient characteristics of the particular acoustical experiment. Our field recording equipment is unique - giving us a potential bandwidth of less than 1 Hz to 180 kHz. We continue to be among the few investigators that are equipped for both high frequency and very low frequency recording. We may still be the only ones that habitually work from ships with such low frequency sounds as the 20 Hz finback pulses.

Progress This Past Year

Our program of development of a radio whale tag for large whales has created wide interest. It grew out of our 1962-1965 experiments on the feasibility of tagging free-swimming whales with a radio tag, and has progressed step-by-step until we now have a radio tag that appears to be ready for final testing (WHOI-Ref. 77-58). Because of the importance of assessments of cetacean population dynamics to our own program as well as to national and international regulatory programs, we found that we had to concentrate much of our effort last year on the development and testing of the radio whale tag. We did not want the tag to be used until we were certain that it was well tested and reliable. Yet we also wanted the tag ultimately to be useable by all those that needed the behavioral data that a radio tag could give.

We obtained good cooperation from the other interested groups (National Marine Fisheries, Johns Hopkins Univ., Naval Ocean Systems Center, etc.) and were able to organize meetings to discuss the tagging program in November 1976 and December 1977. We conducted tests on whale carcasses in Iceland in 1976 and 1977, and others tested the tagging and attachment mechanisms on live whales in 1976 and 1977. The next obvious need was a definitive test of the tag longevity on a whale, and so we proceeded to organize and design an experimental series beginning in June 1978 to find out how well a whale would wear a radio tag. ONR has made it possible to set up an effective test sequence.

This proposal has been written in May so that the outcome of these experiments is unknown. It is expected that both finback and humpback whales will be tagged and tracked for as long as the tag continues to operate in the whale - from 2 to 12 or more weeks. The life of the tag batteries is 16 weeks or more, and is dependent on the behavior of the whales since the transmitters shut off when the antennas are underwater. The experiment will be conducted in Prince William Sound, Alaska, and will utilize two boats and aerial tracking. It is a cooperative experiment with individuals participating from NMFS/Marine Mammal Division (Seattle), Ocean Applied Research Corp (San Diego), U.S. Fish and Wildlife Service (Sacramento), Johns Hopkins University (Baltimore), and WHOI (Woods Hole). Personnel from other organizations are also standing by to help. Funding for the basic experiment is largely from ONR, with contributions from each of the programs, as well as equipment from Johns Hopkins and substantial additional help from NMFS/Marine Mammal Division (Seattle), and, depending on the longevity of the experiment, additional support is to be made available by WHOI/Marine Policy Program, and the Marine Mammal Commission. The organization of this experiment has taken a great deal of our effort in the first months of 1978, but we have enjoyed superb cooperation from all the participants.

Our sound analyses have emphasized the sounds of four species: the pulse sequences of sperm whales, the low frequency 20 and 40 Hz sounds of finback whales, the breeding season calls of the harp seal, and the calls of the Antarctic Ross seal.

Sperm whale repetitive pulsed sequences (codas) that appear to be unique to individual whales within an acoustic area have been studied from both old and new recordings of these whales. The sequence of pulse patterns appears to be important to sperm whales.

Individual sperm whales were often found to be silent when swimming alone, several miles distant from other sperm whales, but would join in and noisily contribute their click series when they met a group of these whales. The pulsed sounds of sperm whales apparently serve a communicative function. We do not find evidence for echolocation in sperm whales.

Our cruise in October 1977, in deep water south of Sable Island and Nova Scotia, gave good opportunities to study both groups of sperm whales and isolated individual sperm whales. Besides *Physeter* (sperm whales) our observations and recordings from this cruise include: perhaps a thousand *Globicephala* (pilot whales), *Orcinus* (killer whales), *Grampus*, *Delphinus*, *Stenella* (three species), and *Balaenoptera physalus* (finback) and *Balaenoptera borealis* (sei whale).

We continue to have opportunities to study the sounds of finback whales. Recordings of a variety of pulse rates at 23 to 18 Hz and at 75 to 40 Hz were recorded during our October 1977 cruise, and on our spring day trips in Cape Cod Bay. Another interesting sound heard from finbacks was a loud (source level estimated as high as 85 dB re. 1 dyne/cm^2) broadband slap-like sound that occurred during strenuous near-surface feeding. It occurred when the whale was well below the surface, and was accompanied by surface disturbance - like that of a fluke pressure disturbance against the surface. Though we may have some hints, we have not been able to associate many of the very low frequency sounds with particular behaviors.

During aerial observation as well as shipboard work we have had many opportunities to compare behaviors of different whale species. Two groups of observations in which four species of baleen whales were seen feeding in the same water were used to correlate our past observations of feeding behavior. Right and sei whales were seen to feed on concentrations of plankton and ignore nearby fish schools, while finbacks and humpbacks fed on schooled small fish and ignored the plankton concentrations. Each of the four baleen whale species fed differently. The whales with grooved throats were able to encompass large amounts of water and food so that the throat distension particularly in the finbacks was sometimes enormous - enlarging to fully twice their normal size.

During the late winter breeding season, the unusual acoustical composition of the majority of the calls of the harp seal (*Phoca groenlandica*) provides the distinctiveness apparently needed for a breeding season call (such as many other seals produce). In the harp seal, this takes the form of a "reversed" characteristic of amplitude and frequency (Hz) relative to ambient noise, abrupt endings, and redundancy of consistently repetitive call sequences. Together these characteristics create sound patterns that contrast sharply with most other sounds in their environment. These calls of the harp seal command attention and cut through background noise.

Work Planned for 1979

The shift in our emphasis from acoustic behavior to radio tagging during the last part of 1977 and 1978 was a response to the immediate need for completion of the development of the radio whale tag and for thorough testing of the attachment system. We did not want the tag used on animals before it was ready. The wide interest in the radio tag had already precipitated premature attempts to use the system. We hope, therefore, that the tests in Alaska during the summer of 1978 will have demonstrated that the radio whale tag is a reliable instrument ready to be used by others in solving a variety of cetacean population problems. Additional work is needed to make the tag useable on sperm whales. We expect to use the radio tag for some of the problems of whale movement in our own research program. Detailed plans for this will also depend on the results of the Alaskan tests, and the amount of equipment that survives those experiments.

A variety of acoustic problems, temporarily postponed by the tag development, can again be pursued. The new recorder obtained in 1978 will increase our confidence in the field studies. The four-hydrophone array technique which provides useful locations of underwater sound sources can now be more reliably arranged at sea.

We anticipate continued study of sperm whale sounds, both from our substantial collection of previous recordings of these whales and from new observations at sea. We want to investigate the sequence of sounds produced by individual whales over prolonged periods. The varied behavior of individuals can perhaps be related to the sounds that we hear from them. Our sperm whale studies have utilized observations from only one general area, and therefore they may represent a very limited population and behavioral cross section. We need to sample other sperm whale areas.

Our offshore cruises have continued to be productive, and so as in previous years, we request funds for two weeks in a suitable vessel, particularly to try and find different segments of the offshore whale populations. We also request that these funds be made available for a charter vessel. Our previous charters have produced excellent results and we have been able to build on our experiences with particular vessels such as the yawl MARUFFA and organizations (Educational Experiences, Inc.) that have provided experienced crews and handy sailing vessels to take advantage of specific research requirements and different areas at sea (SE of Sable Is., NE of Bermuda). We hope to be able to dovetail our program with these organizations in order to take advantage of trips in areas that we have not previously studied -- as for example in the waters between Iceland and Norway. The use of sail in our acoustic program has worked well.

The very low frequency sounds that we continue to find associated with finback whales also needs to be investigated. We have data on these sounds that goes back to 1952 and we have records from most seasons and a wide variety of locations, including Cape Cod Bay through 1978. We would like to continue this low frequency (Hz) analysis.

The day trips in Cape Cod waters during the spring weeks have proved to be highly productive. This year they have given us good looks at 8 to 10 species of cetaceans. The cruises give a good balance to our aerial observation and they allow work at sea with the same animals we have been watching from the air. The aerial observations have provided continuity in our studies of local cetaceans -- a study that has continued productively since 1956. Funds for both the local medium ship charter and the aerial observations are requested.

Efforts to follow individuals by recognition of natural marks requires a high degree of excellence in photographic records. We need to know the relative stability of natural marks. For aerial as well as shipboard photography we are experimenting with gyro stabilization of the equipment. We continue to have good chances to obtain very good pictures of identifying marks.

We are happy to participate in a variety of Navy related programs and we continue to serve in advisory and cooperative capacities with both research and regulatory groups. We expect to help particularly in acoustic analyses of sounds from midwater fish recordings, sounds recorded from Arctic bowhead whales, sounds of rare South African porpoises (*Sousa*) and sounds of Antarctic seals. We share our data on sightings and individual whale recognitions with other area workers.

MARINE BIOLOGICAL SOUNDS

1 January 1979 - 31 December 1979

Professional:	ONR Funded Man Months	Actual Man Months
William Watkins - Coprincipal Investigator	12	12
William Schevill - Coprincipal Investigator	6	6
Other Personnel:		
Karen Moore - Research Assistant	12	12
Secretary	1	1
Cruise and Aircraft help	4 wks	4 wks
A. GROSS REGULAR SALARIES (including allowance for vacations, holidays, sick pay of $5,688 which is accounted for as employee benefits)	$49,646	
Cruise leave, sea duty vacation and overtime	425	
Total	50,071	
B. OTHER EMPLOYEE BENEFITS	12,953	
Total Salaries and Benefits		$63,024
C. PERMANENT EQUIPMENT Gyro-stabilizer		1,212
D. EXPENDABLE SUPPLIES AND EQUIPMENT		6,400
E. TRAVEL - Domestic: Seattle, Washington; Barrow, Alaska	4,397	
International: Bergen, Norway	3,868	
Total Travel		8,265
F. PUBLICATION COSTS		
Graphic services 60 hrs @ $13.00/hr	780	
Page charges: 15 @ $60.00 JASA	900	
Reprints: 3 @ $125.00	375	
Total Publication charges		2,055
G. SHIP COSTS - Small ship: 3 @ $120		360
H. COMPUTER COSTS		
Sigma 7: 8 hrs @ $155/hr		1,240
I. MISCELLANEOUS COSTS		
1. Shop Services: 40 hrs @ $13.00/hr	520	
2. Shipping and Communication	1,000	
3. Laboratory overhead @ 21% of Total Salaries and Benefits	13,235	
4. Other Costs (see attached)	21,310	
Total Miscellaneous Costs		36,065
J. TOTAL DIRECT COSTS		118,621
K. INDIRECT COSTS @ 15% OF Total Direct Costs		17,793
L. TOTAL COSTS		$136,414

OTHER COSTS

1.	Charter of Medium Ship	
	15 days @ $1,000/day	$15,000
2.	Local day charters	
	6 days @ $550	3,300
3.	Small airplane hire	
	40 hrs @ $24.00/hr	960
	20 hrs @ $60.00/hr	1,200
4.	Rental of ADF receiving system	850
	TOTAL OTHER COSTS	$21,310

7. ELECTRIC AND MAGNETIC DETECTION IN MARINE ORGANISMS

Adrianus J. Kalmijn

[PII Redacted] [redacted]

Introduction

Sharks, skates, and rays are extremely sensitive to weak electric fields, detecting dc and low-frequency voltage gradients of less than 0.01 μV/cm. The receptor system comprises the ampullae of Lorenzini, which are mainly located in the animals' protruding snouts. The elasmobranchs' electric sense plays an important role in predation, enabling these fishes to zero in on the bioelectric fields of their prey. They also are able to orient themselves to the electric fields of ocean currents, and to establish their compass heading presumably by electromagnetic means. Thus, the elasmobranchs present us with a sophisticated electrical detection system, and thereby give evidence of the biological relevance of the oceanic electromagnetic fields.

Certain mud bacteria are equipped with intrinsic magnetic dipole moments, and when separated from the substrate swim north following the steeply inclined field lines at our latitude. The bacterial magnets consist of strings of magnetite crystals showing single domain properties. The behavior of these bacteria is very much dependent on the ambient magnetic field and can be drastically changed by the application of strong magnetic pulses. These findings are not only of great microbiological interest, but also prove the feasibility of ferromagnetic orientation in higher organisms, and bear upon the magnetics of sedimentary rocks and the study of biomagnetic materials.

Scientific Objectives

1. To determine the biologically relevant aspects of the electric and magnetic fields in natural waters. Specific data are obtained from the geophysical literature and by direct field measurements.

2. To establish the significance of these fields in the animals' daily life. This is achieved in behavioral studies, both under well controlled laboratory conditions and in the animals' natural habitat.

3. To study the physical principles of electric and magnetic reception. Measured are the electric and magnetic coupling between the animals and their environment leading to the detection of the

pertinent stimuli.

4. To analyze the electric and magnetic sensory systems from an engineering point of view. Advanced electrophysiological techniques are applied to follow the data flow and central processing.

5. To apply our scientific expertise toward a better use of the oceans of which the animals form an integral part. They had already mastered the oceans long before man came into being.

<u>Progress Report</u>

In earlier years, the elasmobranchs' electrical sensitivity was determined by recording the heartbeat of free-swimming sharks and skates. Upon application of uniform, 5-Hz squarewave fields, the animals showed unconditioned cardiac decelerations down to voltage gradients of 0.01 μV/cm, thus exhibiting the highest electrical sensitivity known in the animal kingdom. This year, we have been conducting protracted series of behavioral experiments to establish the elasmobranchs' ability of orienting to such steady dc fields as induced by ocean currents flowing through the earth's magnetic field. The stingray *Urolophus* was trained to secure food from an enclosure positioned to the far right with respect to the voltage gradient and not to enter a similar enclosure at the opposite side of the pool. The animals did very well ($p < 0.001$) over the whole range of fields commonly occurring in oceanic waters (0.05 to 0.5 μV/cm), thus proving the P.I.'s case.

After we progressively lowered the voltage gradients of the imposed electric fields, the above mentioned stingrays kept orienting down to a level of 0.01 μV/cm, the old heartbeat threshold sensitivity value. One specimen even became significant ($p < 0.0025$) at a field strength of a mere 0.005 μV/cm. In the earlier heartbeat experiments, the animals responded to the onset of a 5-Hz squarewave field. In the present tests, however, they not only detected steady dc fields, but also determined the direction and the polarity of these fields, to make learned right/left decisions and to set out for the food-containing enclosure. Even more remarkably, they did so while inducing at the same time up to at least ten times stronger electric fields by crossing the vertical component of the earth's magnetic field; the horizontal component of the earth's magnetic field had been canceled to eliminate the use of the animals' previously established magnetic compass sense.

The behavioral tests which led to the confirmation of the elasmobranchs' unique electric and magnetic orientational abilities all have been conducted in a small, well-controlled setup in the quiet woods of the Institution's Quissett campus. The electric fields were generated by a micro-ampere current source and passed into the water by means of a specially designed salt-bridge system. The horizontal component of the magnetic field was nulled in the electrical, and randomly reversed in the magnetic experiments by means of Helmholtz coils mounted to the outside of the hut. Up to the present time, the vertical component of the local earth's magnetic field was left undisturbed. For more specific experiments on the animals' detection mechanism, we now have added another set of Helmholtz coils to control the vertical component of the magnetic field as well. Though primarily conceived as a pilot setup for future facilities, our small hut has yielded the very best electric and magnetic data the P.I. could hope for.

Now that we know that sharks, skates, and rays are able to interpret the various field configurations and behave accordingly, the time has come to approach the receptor system from an engineering point of view. The elasmobranchs are not simply transparent to electric fields as is commonly maintained; neither are the receptors merely sensing the line integral of the voltage gradient along the length of the ampullary canals. Instead, the skin resistance plays a crucial role, especially in the detection of local dipole fields. The great lengths of many of the ampullary canals rather subserve a convergence of the potentials at the widely distributed skin pores onto the densily packed sensory clusters, enabling the animals to sense the relevant stimuli differentially and to treat interference as common-mode signals. These physical considerations are based upon the actual measurement of field potentials and impedance ratio's in the sensory areas of the dogfish shark *Mustelus*. By these studies, the P.I. wishes to emphasize the importance of understanding the physical principles on which the biological detection systems operate.

While the peripheral receptor system determines which stimuli the animals detect, it is the central nervous system (CNS) that processes the information the animal receives. To define the sensory input upon which the CNS acts, I have first recorded the nervous activity of the ampullary fibers with ultra-fine, intracellular, glass-pipet microelectrodes. During these experiments, the animals remained completely under water and were left intact as far as possible, allowing us to stimulate the receptor system in the most natural way and to record from the same sense organ for many hours. We then proceeded with exploring the CNS itself in order to analyze its integrative action. The first basic question was whether indeed the CNS treats the incoming data differentially, ignoring their common-mode content, as is suggested by the layout of the peripheral system. That is, we do not just probe the CNS to find out empirically what it does, but we specifically try to establish whether it operates as we may expect from an engineering point of view.

In testing the electrical sensitivity of fish, some authors express their stimulus fields in terms of voltage gradients, others in terms of current densities. This is alright as long as they also give the resistivity of the water, which for weak dc and low-frequency fields is purely ohmic for all practical purposes. Yet, from earlier studies it has become evident that electroreceptors have the properties of voltmeters rather than current meters. However, whether the animals as a whole act as either the one or the other remained an open question. We therefore trained the catfish *Ictalurus* to orient to uniform electric fields, first in water of 2 kohm • cm and thereafter in water of 20 kohm • cm, more similar to that of their native ponds. The crucial question was: will we find a threshold sensitivity at the same current density, i.e at a ten times higher voltage gradient, or will we find a threshold at the same voltage gradient, i.e. at a ten times lower current density. The latter appeared to be the case, proving that the animals act as voltmeters rather than current meters and that the fields should be expressed in terms of voltage gradients rather than current densities.

For the present season, we are in the midst of an extensive field program to be carried out on the project's RV Boston Whaler (donated and equipped by the Eppley Foundation). In addition to the earlier modifications, we have installed an echosounder/fish-finder for our nightly excursions. After establishing the feasibility of evoking and observing the feeding attacks in the shallow-water dogfish, we are now running long series of experiments to quantitatively document last year's findings (attack pattern, distance of response, source discrimination, alternative cues, etc.). Concurrently, we are working on the blue sharks off Cape Cod in order to conduct the first experiments on the electric sense of a pelagic species. At night the blues seem to enter shallower areas, which would very much facilitate our research. In addition to analyzing the animals' feeding behavior, we will initiate studies on their electric and magnetic orientational performances at sea. In the fall, we intend to continue our field work in the Florida waters on invitation of the Mote Marine Laboratory and the Rosenstiel School. There, we will concentrate on the lemon shark, which we tested cursorily before and plan to introduce into our Woods Hole program upon completion of the new facilities.

Our studies on the magnetic mud bacteria are advancing very well. The "magnet lab" in the wine cellar of the Fenno House is now in full operation. Both our Zeiss dissecting microscope and a new Zeiss dark-field/phase-contrast compound microscope have been modified and adapted for this particular project (thanks to additional O.N.R. support and the great skill of Mr. Ralph Dixon, the Boston Zeiss instrument maker). All parts affecting the magnetic milieu of the bacteria while on the microscope stage have been replaced by non-ferromagnetic materials. The bacteria tracks are recorded by means of either a still or a movie camera directly attached to the microscope. A versatile digital time base (designed in collaboration with Mr. Richard Nowak) controls the camera shutter, the ambient magnetic field reversals, and the imposed magnetic pulses. The pulser has been optimized with a new high-voltage power supply and redesigned coils to give stronger pulses (up to almost 1,000 gauss) of longer duration (10 μs zero-to-peak). The pulses are monitored on an extremely fast storage oscilloscope. Small, fully controlled magnetic incubation chambers are being built to study the long-term effects of field reversals and to follow the fate of the pulsed, intrinsically reversed (i.e. southbound) mud bacteria.

The results Dr. Richard P. Blakemore and the P.I. obtained thus far from their bacterial studies may be summarized briefly. Certain mud bacteria when separated from the substrate consistently swim to the north, following the steeply inclined field lines. These bacteria appear to be equipped with permanent, ferromagnetic dipole moments. Upon reversal of the ambient magnetic field, they make U-turns several cell diameters wide to align themselves again with the field in the northward (i.e. the opposite) direction. Upon the application of very short (1-10 μs), monophasic magnetic pulses of sufficient strength and antiparallel to the steady ambient field, the bacteria make similar U-turns, now heading south, as a result of the reversal of their intrinsic dipole moments. To affect 50% of the bacteria, pulses of 375-400 gauss were needed for the freshwater specimens from Cedar Swamp, and 525-550 gauss for the marine ones from Eel Pond. Similar coercive forces were found by Dr. Charles R. Denham, a geophysicist at our Institution, with conventional alternating field demagnetization procedures.

The bacterial magnets are composed of linearly arranged strings of iron-rich crystals located within the cell bodies (Blakemore, WHOI). They seem to consist mainly of magnetite (in collaboration with Dr. Richard Frankel, MIT). In our Fenno House experiments, the bacteria act as if the crystals form a chain of tightly coupled single domains. In the first place, after pulsing the bacteria, they either remain northbound or become southbound. We have not seen any of them becoming completely demagnetized. Secondly, the strength of the intrinsic dipole moments is the same before and after reversal, independent of the strength of the applied magnetic pulse, as follows from the constant diameter of the U-turns. Thirdly, though possible, it is much more difficult to magnetize the bacteria transversely than longitudinally.

As expected, the transversely magnetized bacteria are confined to a plane perpendicular to the ambient magnetic field, though within that plane they are free to move about randomly. A comprehensive study of the bacteria's magnetotactic behavior and its biological significance is under way and will be reported on at the September site visit.

Plans for the Coming Year

There is a great need for complementing the geophysical data with more specific measurements on the electric and magnetic fields in the marine and freshwater habitats of electrosensitive fish. These measurements require ultra-stable, low-noise dc electrodes of the kind the principal investigator and other scientists (Sanford, Cox, a.o.) have been making and improving over the years. Some types are now also commercially available, and new materials promise further improvement. However, the physical characteristics of these electrodes (stability, noise, dc and low-frequency impedance) are usually not adequately described if determined at all. The P. I. has therefore initiated a comparative study of the various electrodes following up on his earlier work in order to establish the present state of the art and to evaluate and implement new technological developments. These studies not only are strictly necessary for the present project, but also will be of great benefit to the many people (both scientists and Navy engineers) who have consulted the P.I. on these matters.

We will continue the behavioral experiments on the electric and magnetic orientation of the stingray *Urolophus* in our small electromagnetic facilities in the woods of the Quissett campus. Having established the animals' electric and magnetic abilities, we will next concentrate on a quantitative assessment of their performances and a thorough analysis of the underlying physical principles. Although the electromagnetic theory prompted the P.I. to conduct the original experiments and fully explains the results, the actual nature of the animals' magnetic orientation mechanism still needs to be confirmed. This will be accomplished on the one hand by offering the animals electromagnetic fields of specific configurations, and on the other hand by either masking or eliminating the animals' electric sensitivity. The completion of these experiments will eventually hinge on the presence of the planned biophysical facilities, of which the realization is in sight. In addition, we will continuously endeavor to substantiate our laboratory results in field tests.

After a good start on the biophysical/neurophysiological studies of the elasmobranchs' electroreceptor system, we will pursue this exciting line of research with the ultimate goal of fully describing the animals' electromagnetic detection system in engineering terms. In the current year, the P.I. has largely completed his sophisticated electronics setup and proven the feasibility of the approach. Except for Waltman's beautiful studies in the sixties and the P.I.'s later measurements, the physics of the receptor system have not been worked out to any extent. Even worse, the simplistic concept of the animals' electrical transparency has been perpetuated until the present. Furthermore, the electrophysiological studies have almost exclusively been conducted on isolated sense organs. For a system analysis, one has to record the nerve and brain potentials in intact, submerged animals, stimulating them with electric fields administered through the surrounding seawater. In this way, one can combine the power of the biophysical/neurophysiological method with the biological validity of the whole-animal approach.

Our field work conducted in the coastal waters off Cape Cod from the R/V Boston Whaler keeps the project in direct contact with the real world. Our oceanic efforts heavily rely on previous laboratory studies of which they form a logical extension. Certainly, the field work is very much dependent on the weather, underwater visibility, and other uncontrolled factors. On the other hand, it allows us to verify our laboratory data on free-roaming animals in their natural setting. In this respect, the well-equipped, non-galvanic Boston Whaler offers us great opportunities. Next year, we will again spend many nights on the water to elaborate earlier observations and to implement new ideas and findings. The Whaler will also be used for a more detailed study of the geophysical and electrochemical fields in the animals' natural habitat. Of these, the microstructure and variability fields are particularly important parameters from a biological point of view.

The bacterial studies will branch out in many different directions. Some laboratories will concentrate on the purely physical properties of the magnetic crystals; others will study their occurrence in sediments and evaluate their contribution to rock magnetism. Blakemore will further elaborate the basic microbiological aspects: culturing, identification, iron-metabolism, etc. Applied studies will investigate the importance of these new findings with respect to fouling. In this concerted effort, the P.I.'s laboratory takes a unique position, allowing him and his collaborators to observe the behavior of individual, live bacteria under a wide range of well-defined magnetic conditions, and thus enabling them to combine the biology and the physics of this challenging topic. Beyond the quantitative description of the bacteria's magnetic performances and their tightly-coupled single-domain properties, we will take several routes to determine the magnetic dipole moments of single specimens. Thus, we will apply rotational magnetic fields to compare the magnetic torque and viscous drag in these organisms, and set up non-uniform magnetic fields to balance the magnetic and gravitational forces. The biological significance of the magnetotactic response will be studied by incubating the bacteria in normal, inverted, and nulled magnetic field conditions, and by comparing the magnetic properties of bacteria from northern, southern, and equatorial regions. These studies will be conducted in close collaboration with Dr. Richard P. Blakemore at the University of New Hampshire.

At last, before the end of the present year, we hope to begin construction of the planned biomarine research facilities. The total cost is estimated at $290,000. The Arthur Vining Davis Foundation donated the first $150,000; The Institution added $25,000; and we recently received a pledge for another $50,000, contingent on which we will proceed in the expectation of matching funds to come through in due time. The facilities were conceived in 1974, at a time when the P.I. predicted the electric and magnetic orientational abilities of marine elasmobranchs on theoretical grounds, backed up by preliminary experimental evidence. In the meantime, the P.I. has conducted introductory experiments in a small-scale setup in the woods of the Quissett Campus, which in fact proved the elasmobranchs' inferred electromagnetic abilities. This firmly established the great need for more versatile and permanent research facilities to bring the P.I.'s biophysical and behavioral studies to a par with the very best in the field of sensory reception.

The new biomarine research facilities will be located in a remote part of the Institution's Quissett Campus where electromagnetic interference and traffic noise are negligibly low. One circular tank, 24' in diameter, will be used for orientation studies on the larger, more active elasmobranchs. Another tank, 15' in diameter, will house the smaller, bottom-dwelling species. Both the 24' and 15' tanks will be equipped with sophisticated electric and magnetic field control systems. In a third setup, we will conduct our biophysical/neurophysiological studies, presently carried out in the Loeb teaching building by courtesy of the Marine Biological Laboratory. These three setups will be separated sufficiently to prevent mutual interference. The heater plant, utilities, and control systems will be enclosed in a fourth building far down the access road. The facilities have been designed in collaboration with the Institution's building office (Mr. Mitchell) and an outside architect (Mr. Wilson). Several engineering firms have been consulted on unconventional construction methods. For further details, see the pertinent proposals and the architect's blueprints. The P.I. will also be delighted to go over the plans and answer any further questions.

Other Activities

The P.I. has taught two courses on Sensory Biophysics and Behavior in the Marine Biological Laboratory, and has given several invited lectures (Philadelphia, Scripps, Point Loma, Stanford, Monterey, New Hampshire). He also participated in a Conference on Biomagnetic Effects at Berkeley and in a similar Symposium at M.I.T.

Budget Justification

Personnel:

The P.I. requests 10.5 months on the project, whereas he will be teaching for the remaining 1.5 months. The Research Specialist will work with the P.I. full-time, assisted by a half-time Electronics Assistant. The full-time Research Assistant will be heavily involved in the training experiments, while the part-time helper will take care of the experimental animals. The secretarial help will consist of typing letters, manuscripts, and proposals.

Permanent Equipment:

The permanent equipment is requested to support the P.I.'s growing electrophysiological activities.

Other Funding:

We will seek matching funds for the completion of the biomarine research facilities from private sources.

ELECTRIC AND MAGNETIC DETECTION IN MARINE ORGANISMS

1 January 1979 - 31 December 1979

		ONR Funded Man Months	Actual Man Months
Professional:			
	Adrianus J. Kalmijn - Principal Investigator	10.5	10.5
Other Personnel:			
	Research Specialist	12.0	12.0
	Research Assistant II - Electronics	6.0	6.0
	Research Assistant I - Biology	12.0	12.0
	Part-time helper	4.0	4.0
	Elaine Ellis - Secretary	1.0	1.0
A.	Gross regular salaries (including allowance for vacations, holidays, sick pay of $8,017 which is accounted for as employee benefits)	$ 69,465	
B.	OTHER EMPLOYEE BENEFITS	17,791	
	Total Salaries and Benefits		87,256
C.	PERMANENT EQUIPMENT (See Attached)		4,313
D.	EXPENDABLE SUPPLIES & EQUIPMENT		5,500
E.	TRAVEL - Domestic		750
F.	PUBLICATION COSTS - Reprints		300
I.	MISCELLANEOUS COSTS		
	1. Shop Services: 30 hrs. at $13.00/hr.	390	
	3. Shipping & Communication	180	
	4. Laboratory overhead at 21% of Total Salaries and Benefits	18,324	
	5. Xerox costs	50	
	6. Other Costs: Data Processing;	550	
	Service, Maintenance & insurance on Boston Whaler	1,200	
	Total Miscellaneous Costs		20,694
J.	TOTAL DIRECT COSTS		118,813
K.	INDIRECT COSTS at 15% of Total Direct Costs		17,822
L.	TOTAL COSTS		$ 136,635

W. H. O. I. Proposal 1224

PERMANENT EQUIPMENT

1.	Oscillographic recorder		$ 2,475
	Astro-Med, Model Dash-II		
2.	PET Printer		550
	Commodore Business Machines		
3.	Microelectrode beveler		495
	W-P Instruments, Model 1200		
4.	Stimulus isolation unit (2)		414
	W-P Instruments, Model 305-2		
5.	Fiber optic light pipet set		379
	Dolan-Jenner, Model 170 D		
		Total	$ 4,313

II. CHEMISTRY

DEPARTMENT OF CHEMISTRY

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Volume I

INTRODUCTION

The major thrust of the research program proposed by the Chemistry Department for 1979 is the continued investigation of the formation, cycling, and fate of organic compounds in the oceans. We also seek to initiate a complementary program to investigate the marine chemistry of iron, including the nature and role of organic-metal complexes.

The program proposed by Dr. Farrington is a natural and logical development of his studies carried out over the past few years. In 1979 he and Dr. Wakeham will primarily concentrate their efforts on the studies of an extensive collection of water column particulates recovered during last year's field program in the productive coastal waters off Peru. Field studies proposed for 1979 include the sediment trap intercalibration experiment in the Panama Basin and a cruise to the Bermuda Rise (jointly with investigators from the Biology Department) for detailed studies of organic matter influxes and distribution in the benthic boundary layer.

Dr. Lee, who last year collaborated with Dr. Farrington, proposes to initiate studies in a novel and exciting aspect of marine organic geochemistry. Specifically, she will investigate the origin and fate of multi-nitrogen organic compounds with emphasis on those produced during metabolic activities. This study is extremely important in indicating mechanisms of biological and chemical regeneration of organic nitrogen, and fluxes and processes governing transport of nitrogen between geochemical reservoirs.

Dr. Zafiriou's program seeks to increase our understanding of the processes involving iron, especially dissolved iron, in the marine environment. Initially experiments will be performed to test the hypothesis that dissolved species are important intermediates in various transformations of iron in seawater.

CHEMISTRY

DEPARTMENTAL BUDGET SUMMARY

12 Month Period

1 January 1979 - 31 December 1979

A.	SALARIES		$ 54,817
B.	OTHER EMPLOYEE BENEFITS		14,527
	TOTAL SALARIES & BENEFITS		69,344
C.	PERMANENT EQUIPMENT		37,654
D.	EXPENDABLE SUPPLIES & EQUIPMENT		13,300
E.	TRAVEL		
	1. Domestic	$ 2,800	
	2. International	2,260	5,140
F.	PUBLICATION COSTS		
	1. Graphic Services	1,170	
	2. Page Charges	1,250	
	3. Reprint Charges	1,450	3,870
G.	SHIP COSTS		
	1. R/V KNORR - 6 Days @ $5,396	32,376	
	2. ASTERIAS - 5 Days @ $120	600	32,976
H.	COMPUTER COSTS		
	1. 10 Hrs. @ $155	1,550	
	2. Programming & Analysis	1,568	3,118
I.	MISCELLANEOUS COSTS		
	1. Laboratory Overhead - 21% of A,B	14,539	
	2. Shop Services - 210 Hrs. @ $13	2,730	
	3. GC-MS System	11,200	
	4. G.R.A. - S. Henrichs - 3 mo. @ $1,070; 3 mo. @ $1,155	6,675	
	5. Xeroxing	150	
	6. Shipping and Communications	1,900	
	7. Other	1,600	38,794
J.	TOTAL DIRECT COSTS		$204,196
	INDIRECT COSTS @ 15%		30,629
TOTAL COSTS			$234,825

Biogeochemistry of Seawater Particulates and Surface Sediments

John W. Farrington (617) 548-1400, ext. 316

(1) Abstract

We propose to continue our investigations of the biogeochemistry of organic matter in seawater particulates and surface sediments. We focus our attention on the lipid class compounds, fatty acids, fatty alcohols, wax esters and hydrocarbons. Quantitative and semi-quantitative data on a large number of specific compounds are used to elucidate influence of planktonic, benthonic and microbial processes on oceanic organic matter. We compare different oceanic areas, e.g. upwelling areas vs. central oceanic gyres to study the influence of various sources of organic matter and depositional conditions.

Our major emphasis this year will be the analyses of sediment trap, in situ pump and large volume water sample particulates, and surface sediments from the upwelling area off Peru obtained on R/V KNORR Cruise 73-2. We will also participate in the sediment trap intercalibration experiment in the Panama Basin.

(2) Long-Range Scientific Objectives

The study of the biogeochemistry of organic matter in seawater particulate matter and surface sediments. These studies are important for understanding several important processes in the marine environment:

(i) the carbon cycle of the water column and benthos;
(ii) the influence of organic compounds on nutrient chemistry, trace metal chemistry, and other inorganic compounds;
(iii) the influence of organic matter on the resuspension, transport, and deposition of mineral particles;
(iv) the influence of near-shore continental shelf processes on mid-water processes removed from continental margin areas.

These studies also contribute to understanding:

(i) how early diagenetic transformations in surface sediments influence the organic geochemistry of ancient sediments;
(ii) the distribution, reactivities, and fates of anthropogenic compounds in the sea.

(3) Present Status and Progress Over the Past Year

a) Engineering, Technology, and Analytical Methodology

1) In Situ Pump Systems. Mr. Fritz Hess of the Ocean Engineering Department has proceeded with the development and building of the hydrowire deployed in situ pumps with funding from both this project and that of Dr. V. T. Bowen (DOE) with some additional funds from Dr. R. B. Gagosian (NSF). Full scale field testing of the pumps was completed during R/V KNORR Cruise 73 - Panama to Callao - with deployments of up to three pumps at a time on the wire and lowerings to depths of 4500 meters. Several excellent samples were obtained.

Based on this experience, several modifications have been suggested and larger pumps capable of 20 l/min. throughput are now being designed and built for Dr. Derek Spencer with NSF and DOE funding.

The initial development and deployment work is completed and we do not request a large effort this year to modify the pumps. We will use them with minor modifications while awaiting the outcome of the efforts funded by others.

ii) Sediment Trap Technology. Mr. Hans Jannasch will complete work this summer on a rotating, timed, sediment trap collector cup with acrylamide gel as a "fixative". The design and prototype was completed last summer and several are being built this summer in a cooperative effort with Dr. John Milliman of the Geology Department. The two traps built for our use in Buzzards Bay will also be used in the Sediment Trap Intercalibration Experiment (STIE) in the Panama Basin.

iii) Glass Capillary-Gas Chromatography-Chemical Ionization-Mass Spectrometry. Dr. Nelson Frew of the Chemistry Department GC-MS Facility has applied glass capillary gas chromatography-chemical ionization-mass spectrometry to analyze for fatty acids in seawater particulates and surface sediments. With this powerful tool we are now capable of quantitative or semi-quantitative measurement of between 100 and 150 individual compounds. In principle this method of analysis can be readily applied to several other classes of compounds in oceanic samples.

iv) Data Systems. Marine Organic geochemists now have available a combination of sampling devices and analytical methodology which allows measurement of hundreds of specific organic compounds in a fairly large number of samples in a relatively short time compared with two to three years ago. This is useful data wherein slight changes in ratios of compounds of similar structure can be powerful indicators of processes operating in the oceans. Data management systems must keep pace with these developments in order to fully utilize the data.

We have been involved with others funded by EPA and DOE to investigate and apply these systems to environmental quality data. Thus, we are now in a good position to develop and apply these systems to marine organic chemistry research in general. This will be a long-term effort.

b) R/V KNORR Cruise 73, Leg 2 - Panama to Callao, Peru (joint with R. B. Gagosian, N. Staresinic, G. Rowe et al.)

This cruise was one major effort of our work during the past year. At a series of stations on a transect ranging from 45 meters on the continental shelf to 5300 meters in the Peru-Chile Trench we obtained:

(i) 15 box cores at a total of 11 stations;
(ii) 21 floating sediment trap samples (main effort by N. Staresinic);
(iii) 15 _in situ_ pump lowerings - many in conjunction with floating sediment trap deployments;
(iv) several samples of particulates from large volume water sampling (main effort by R. B. Gagosian et al.);
(v) pore water samples for nutrients and amino acid studies from six box cores (main effort by S. M. Henrichs);
(vi) T, S, O_2, nutrients, POC from all water profiles (main effort by R. B. Gagosian).

A cruise report with more complete details is being prepared. It is safe to state that this cruise was more successful than we had hoped. We now have on hand an extensive collection of water column particulates from large volume water samplers and _in situ_ pumps, sediment trap samples, box cores of surface sediments, and ancillary data.

Analysis of these samples with the powerful analytical tools at hand should provide a large step forward in our understanding of organic geochemistry of highly productive coastal areas.

c) Walvis Bay-Namibian Shelf-Slope Studies

We continue our analyses of sediment cores from another upwelling area - the Benguella Current area of Walvis Bay - Namibia. These samples were obtained during R/V ATLANTIS-II Cruise 93, Leg 3 - 1975-1976. We reported on our efforts in more detail last year. This year we slowed our analyses somewhat to tackle other problems. However, we have completed a subset of studies and extractions and compound isolations, and analyses are now in progress at a more steady pace. We are beginning to publish on the data for organic compounds. Our first major findings for sediments are as follows:

STERENES IN SURFACE SEDIMENT FROM THE SOUTHWEST AFRICAN SHELF AND SLOPE, R. B. Gagosian and J. W. Farrington

Surface sediment samples collected from southwest African (Namibian) shelf and slope have been analyzed for their hydrocarbon content. In the surface samples a class of olefinic isoprenoid hydrocarbons, the sterenes, have been found to represent 20-40% of the total hydrocarbons. To the best of our knowledge sterenes have not been reported in surface marine sediments in such high concentrations.

Cholest-2-ene, cholestadiene, cholestatriene, 24-methylcholest-2-ene, 24-methylcholestadiene, 24-ethylcholest-2-ene and 24-ethylcholestadiene were found in the sediments and identified by high resolution glass capillary gas chromatography-mass spectrometry.

The formation of sterenes from sterols via microbiological processes or chemical autooxidation, followed by subsequent dehydration mechanisms and double bond isomerizations are postulated.

d) Western North Atlantic Sediments

As with the Walvis Bay-Namibian shelf sediment studies progress has been slowed this year but has kept at a steady pace by the efforts of Dr. Cindy Lee. Fatty acid and hydrocarbons are now being analyzed in several cores from areas where sterol analyses are completed and submitted for publication.

STEROL GEOCHEMISTRY OF SEDIMENT FROM THE WESTERN NORTH ATLANTIC OCEAN AND ADJACENT COASTAL AREAS, C. Lee, J. W. Farrington and R. B. Gagosian

Core sections from coastal bay, continental slope, and continental rise surface sediments of the western North Atlantic were analyzed for sterols. Changing rate or type of sediment input, bioturbation, and chemical conversion appear to be processes important in controlling the distribution of sterols in these sediments. Comparisons of individual sterol distributions and variations in the ratio of Soxhlet-extractable to non-extractable saponified sterols indicate that for the western North Atlantic, the extent to which each process is dominant varies with proximity to shore. Evidence is presented to show that sterols in the deep sea may be at least partially terrigenous in origin and not all biogenically derived in the surface waters. These sterols, and by analogy other labile organic compounds, may serve as a source of carbon for benthic organism metabolism.

e) Atlantic Sediment Trap Samples

We have received two Parflux sediment trap samples from the Parflux site in the North Atlantic off Bermuda and six samples from the equatorial site through the courtesy of Drs. Honjo, Brewer and Spencer. These samples have all been extracted. Lipid class analyses have been completed for the Parflux site off Bermuda. An exciting and important observation is the presence of wax esters in the samples. These compounds are not present in large amounts in surface sediments analyzed to date. They are found in large amounts in certain zooplankton and mid-water fish. The implications are that the ester bond is cleaved during or shortly after deposition.

Fatty acid and sterol data show that the composition of both these classes of compounds are different for particulate matter and surface sediments of the deep sea. This implies extensive reworking or alteration of material once deposited to the benthic boundary layer and/or significant inputs to sediments by benthic fauna. These studies continue and are part of our continuing investigation of the dynamics of the organic matter in oceanic particulates.

f) Pore Water Organic Geochemistry

Ms. Susan Henrichs, a Joint W.H.O.I./M.I.T. Graduate Student, has been pursuing thesis research under Dr. Farrington's direction which investigates pore water organic geochemistry focusing on amino acids. During this past year samples were obtained for these studies during the cruise off Peru. On board measurements of ΣCO_2, pH, NO_2^-, $NO_3^=$, NH_3, and initial $S^=$ analysis steps were completed. Analytical methodology for amino acids in pore waters has been investigated. Analyses are now underway for Gulf of Maine and the Peru samples. We have an excellent start in a new area of research.

g) Cooperative Investigations

Given our extensive surface sediment sample collection for organic geochemistry studies we have several requests for samples each year. We have endeavored to assist others where possible. Extensive cooperation with Dr. R. A. Hites of M.I.T. has resulted in the publication by Dr. Hites et al. of aromatic hydrocarbons data for deep sea sediments. We have also collected samples for Dr. John Hunt of our department for volatile hydrocarbon analyses.

(4) Program for 1979

a) Peru Cruise Particulate, Sediment Trap, and Surface Sediment Analyses

Our major effort this year will be analyses of the samples from the Peru cruise. As previously mentioned, we have an excellent set of samples which will allow us to investigate the dynamics of the organic carbon cycling in this area. Our approach, as in the past, will focus on specific organic compounds and in particular on fatty acids, fatty alcohols, wax esters, and hydrocarbons. Sterols and cholesterol esters are investigated by our colleague Dr. Gagosian. Our previous work over the past several years as reported in the literature, has provided new insights into organic geochemical processes. By using the approach of analyzing chemically related and yet distinct compounds we can investigate such questions as:

a) What are the relative roles of microbial and planktonic populations as sources for organic compounds in particulates and sediments?

b) What is the relative importance of marine and land sources for organic matter in sediments?

c) What are the rates of transformation of organic compounds once deposited to sediments or incorporated into particulate matter?

d) What are the pathways of transformation?

e) How do benthic communities influence organic matter diagenesis in surface sediments and exchanges with the overlying waters?

Dr. Cindy Lee will be analyzing many of these samples for organic nitrogen compounds. This is an area of organic geochemistry we think is very important and exciting (see her proposal). We have enjoyed having Dr. Lee as a colleague in formal collaboration and look forward to continued collaboration in the future as she continues to develop her oceanic organic nitrogen and sediment sterol geochemistry efforts.

Dr. Stuart Wakeham will join us in August, 1978. He brings to our efforts an excellent background in analytical organic chemistry and a knowledge of organic geochemistry in lacustrine environments. Dr. Wakeham will focus his efforts on the analysis of fatty alcohols, fatty acids, and wax esters in sediment trap and <u>in situ</u> pump samples. We anticipate he will spend most of his time on GC mass spectral analyses and data interpretation.

b) Sediment Trap Intercalibration Experiment (STIE)

We will participate in the sediment trap intercalibration experiment now scheduled for 1979 in the Panama Basin. Our participation in terms of deployment of traps and <u>in situ</u> pumps is funded via the overall proposal to NSF (as coordinating agency).

Fatty acid, wax ester, and fatty alcohol analyses of the expected 10 to 15 samples will be conducted as part of this ONR-funded effort. The rationale for the experiment is presented in the overall proposal to NSF which was passed on to ONR for review.

c) Pore Water Organics Studies

This will be the last year we request funding for Ms. Henrichs in support of these studies. We are preparing a proposal to NSF to fund the remainder of her thesis research. During this next year she will complete the analyses of the Gulf of Maine and Peru Cruise samples and with Dr. Farrington present the results for publication. Only six months salary for Ms. Henrichs and modest supplies funds are requested.

d) Western North Atlantic Near Bottom Particulates

We propose a modest participation with Dr. Jannasch in a cruise to the Bermuda Rise area and the initial Parflux site where we have previously sampled surface sediments. During this cruise we propose to deploy our <u>in situ</u> pumps in near bottom areas to sample particulates within 50 to 500 meters of the bottom. Analyses of these samples will allow us to compare suspended particulates and surface sediments with respect to organic compound compositions. Our previous work in this area suggests that land-derived organic matter may be transported to these areas by near bottom transport processes. Furthermore, the floc at the sediment-water interface should undergo substantial exchange with the near bottom suspended matter. We will focus on the influence of this process on organic matter distributions in the benthic boundary layer. The proposed cruise is staged in and out of Woods Hole and our efforts would require six days ship time in addition to that requested by Dr. Jannasch.

Personnel:

Dr. Farrington has overall responsibility for the project and will primarily focus his attention on the fatty acid analyses. He will also work in conjunction with Dr. Wakeham on fatty acid, fatty alcohol and wax ester analyses, and with Ms. Henrichs on pore water amino acid analyses.

Dr. Wakeham's and Ms. Henrichs' efforts have been described above.

Equipment:

We request a glass capillary gas chromatograph and integrator to complete the conversion, which we began two years ago, of our instrumentation from eight year old instruments to modern instrumentation.

Travel:

We request funds for Dr. Wakeham and Dr. Farrington to attend the International Organic Geochemistry Conference in Newcastle-Upon-Tyne to present papers describing our research supported by ONR over the past several years. Neither Dr. Farrington or Dr. Wakeham have attended the last three such conferences. We think we have important and interesting data to present and discuss with our colleagues.

We also request travel funds for a trip to California to discuss our research with colleagues at Scripps Institution of Oceanography and the University of California, Los Angeles. We have maintained informal collaboration with these colleagues for the Walvis Bay and Peru shelf and slope geochemistry investigations.

BUDGET

10/262.37

1 January 1979 - 31 December 1979

SALARIES

Senior Personnel:	ONR Man Mos.	Actual Man Mos.
1. John W. Farrington	4	4
2. Stuart G. Wakeham	6	6
Other Personnel:		
1. Richard M. Sawdo	1	1
2. Alan C. Davis	6	6
3. Peter P. Bates	4	4
4. Helen A. Jacobson	2	2
5. Christine N. Johnson	3	3

A. 1. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay, etc. of $3,710 which is accounted for as employee benefits)		$34,269
2. Cruise Leave, Sea Duty Vacation and Overtime (including premium pay of $109)		684
TOTAL		$34,953
B. Other Employee Benefits		9,412
C. TOTAL SALARIES & BENEFITS		$44,365
D. PERMANENT EQUIPMENT		
1. Glass Capillary GC System		14,849
E. EXPENDABLE SUPPLIES & EQUIPMENT		8,000
F. TRAVEL		
1. Domestic - Two Round Trips to S.I.O.	$ 1,380	
2. International - Two People to Newcastle - Upon-Tyne and return	2,260	3,640
G. PUBLICATION COSTS		
1. Graphic Services - 40 Hrs. @ $13	520	
2. Reprint Costs	700	
3. Page Charges - 10 Ea. GCA @ $45; JGR @ $80	1,250	2,470
H. SHIP COSTS		
1. R/V KNORR - 6 Days @ $5,396	32,376	
2. ASTERIAS - 5 Days @ $120	600	32,976
I. COMPUTER COSTS		
1. 10 Hrs. @ $155	1,550	
2. Programming & Analysis - 80 Hrs. @ $19.60	1,568	3,118
J. MISCELLANEOUS COSTS		
1. Laboratory Overhead - 21% of A,B Less Premium Pay	9,294	
2. Shop Services - 60 Hrs. @ $13	780	
3. Shipping & Communications	1,000	
4. G.R.A. - S. Henrichs - 3 mo. @ $1,070; 3 mo. @ $1,155	6,675	
5. GC-MSSystem - 100 Units @ $100/Unit	10,000	
6. Service Calls for GCs	600	$ 28,349
K. TOTAL DIRECT COSTS		137,767
L. INDIRECT COSTS @ 15%		20,665
M. TOTAL COSTS		$158,432

An Investigation of Multi-Nitrogen Organic Compounds in Seawater and Sediments

Cindy L. Lee (617) 548-1400, ext. 453

(1) Abstract

This proposal is a request to initiate an investigation of multi-nitrogen organic compounds in the marine environment. Specifically, metabolic wastes such as those produced during purine and pyrimidine catabolism will be investigated in seawater and sediments. Such an investigation should give some insight into mechanisms of transport of nitrogen between geochemical reservoirs and mechanisms of biological and chemical regeneration of organic nitrogen.

(2) Long-Range Scientific Objectives

The general long-range objective of this research is to understand the role of organic nitrogen compounds in the marine environment. Nitrogen is one of the most biologically important elements in natural waters and can control biological productivity through its role as limiting nutrient. For this reason, the regeneration of nutrient N from organic nitrogen compounds is extremely important in the estuarine, marine coastal, and upwelling systems which play such a major role in world biological production.

Particular emphasis will be placed on determining the sources of production, the transition behavior, and the ultimate fate of certain classes of important multi-nitrogen compounds, beginning with the products of purine and pyrimidine catabolism. This study must eventually include investigations of seawater, sediments, particulate matter, and sediment trap material, since the geochemical cycle of organic nitrogen involves transport between these various geochemical reservoirs. Since most nitrogen remineralization occurs in the upper ocean or at the benthic boundary layer, these will be the areas of primary focus.

(3) Present Status and Progress Over the Past Year

This is a new proposal. Previous ONR-sponsored work was carried out under the direction of Dr. John Farrington. See his proposal for a summary of that research.

(4) Program for 1979

I propose to study multi-nitrogen organic compounds released into the marine environment as metabolic wastes, such as those produced during purine and pyrimidine catabolism. The decomposition of marine plankton (C/N $\approx$ 6) is thought to release high-N products in large amounts to produce low C/N ratios ($\approx$ 3) found in the bulk of seawater DOC. The presently characterized organic nitrogen compounds known to exist in seawater cannot account for this low ratio. Amino acids (C/N $\approx$ 3) and amino sugars (C/N $\approx$ 5) are present in too low concentrations and have too high C/N ratios to compensate for this. Interestingly, urea (C/N = 0.4), which is present in seawater in relatively high amounts (0.3-5 μg-atoms N/liter) is an end-product of purine catabolism (as well as some other metabolic processes). Other multi-N catabolism products may be present as well.

These catabolism products present in seawater may be an important nutrient source for phytoplankton in the nitrogen-limited waters which make up a major part of the world oceans. A large variety of phytoplankton can use hypoxanthine, as well as urea and ammonium (all products of purine catabolism) to support growth under nitrogen-limited conditions. Even so, very few measurements of N-rich organic compounds have been made in natural waters.

Because multi-N, organic purine/pyrimidine catabolism products are important in the metabolic cycles of most organisms, and because certain catabolites are somewhat specific to the type of organism, determining the relative quantitative importance of these compounds in seawater and Recent sediments will help in understanding the relative importance of different biological N regeneration pathways. Sediments are thought to play an important role in nitrogen remineralization processes, especially in the coastal zone. The sediments act as both a source and a sink to the overlying waters in response to changes in availability of various forms of inorganic and organic nitrogen, thus acting as a control on the total biological productivity where nitrogen is limiting. As in seawater, much of the organic nitrogen fraction in sediments is uncharacterized. Amino acids and amino sugars apparently make up a larger fraction of the total organic nitrogen in sediments than in seawater, but 25-50% is still uncharacterized.

In addition to the biological significance of the multi-nitrogen metabolites, they may take part in trace-metal interactions or humification processes in seawater and sediment. The carbonyl, amine, and double-bonded carbon functional groups of these compounds are highly reactive and would likely participate in these processes.

With funding from the National Science Foundation, I have just begun a study of amino sugars present in sediments and sediment trap samples in an attempt to learn more about remineralization processes of organic nitrogen compounds, particularly chitin. During initial work-ups of Buzzards Bay sediment samples in conjunction with this NSF-sponsored work, I found over 25% of the total organic nitrogen present in the water-soluble fraction of the benzene-methanol extract. The multi-N metabolites discussed above could be extracted in this fraction.

Because concentrations of the catabolites are probably higher in sediments than in seawater, coastal sediments would be used for the development of methodology. This development would involve separation and collection of individual compounds from the solvent extracts by high pressure liquid chromatography (HPLC) followed by identification using probe-distillation mass spectrometry. Some of the purine catabolites have been previously separated using both reverse-phase and cation-exchange HPLC.

The low volatility, high polarity, and insolubility in common organic solvents of these compounds makes cation-exchange HPLC preferable to gas chromatography as a separation device. HPLC collection of pure compounds would allow structural identification by probe-distillation MS, and by UV, IR and UV-fluorescence spectroscopy, and comparison with authentic standards. Or, the preparation of volatile derivatives of some catabolites may allow identification by GC-MS. Once retention times of the desired components have been established, routine HPLC analysis of samples without additional mass spectrometry should be sufficient. The HPLC separation and quantification method could then be adapted to seawater, hopefully taking advantage of new direct seawater injection techniques developed for similar amino acid analysis systems.

Sediment and sediment trap samples collected by John Farrington and Robert Gagosian are presently stored in Woods Hole. These samples are from a variety of coastal and open ocean environments and are available to me as long as the proposed extraction procedures are compatible with present uses of these samples. Opportunities to collect both seawater and sediment from the Massachusetts coastal area also exist.

Budget Justification

Funds are requested for the purchase of a high pressure liquid chromatograph equipped with gradient elution and variable wavelength detection. Another HPLC in the Department (Farrington's) was used for preliminary studies to determine the usefulness of the instrument for multi-nitrogen compounds, but is not available for more extensive or routine use. Also, this preliminary work showed the necessity of gradient elution capability not available with Farrington's instrument.

Funds requested for the GC-MS Facility are to cover operating expenses shared on a recharge basis. Structural determination and verification is an important part of the proposed research and is not easily carried out by any other method.

BUDGET

An Investigation of Multi-Nitrogen Organic Compounds in

Seawater and Sediments

SALARIES

		ONR Man Mos.	Actual Man Mos.
Senior Personnel:			
1.	Cindy L. Lee	3	3
Other Personnel:			
1.	Peter P. Bates	4	4
A.	1. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay, etc. of $1,051 which is accounted for as employee benefits.)		$ 8,759
B.	Other Employee Benefits		2,186
C.	TOTAL SALARIES & BENEFITS		10,945
D.	PERMANENT EQUIPMENT		
	1. HPLC System		22,805
E.	EXPENDABLE SUPPLIES & EQUIPMENT		2,700
F.	TRAVEL		
	1. Domestic - West Coast Meeting		750
G.	PUBLICATION COSTS		
	1. Graphic Services - 25 Hrs. @ $13	$ 325	
	2. Reprint Costs	300	625
H.	MISCELLANEOUS COSTS		
	1. Laboratory Overhead - 21% of A,B	2,298	
	2. Shop Services - 50 Hrs. @ $13	650	
	3. GC-MS System	1,200	
	4. Instrument Maintenance	400	
	5. Communications	425	
	6. Xeroxing	75	5,048
I.	TOTAL DIRECT COSTS		42,873
J.	INDIRECT COSTS @ 15%		6,431
K.	TOTAL COSTS		$49,304

Marine Chemistry of Iron

Oliver C. Zafiriou (617) 548-1400, ext. 342

(1) Abstract

We propose to study the behavior of filterable iron species in seawater using radiolabelled compounds to test the hypothesis that dissolved species are important intermediates in various transformations of iron in the marine environment. Initially, Fe^{59}(II) and Fe^{59}(III) will be used to follow such processes as adsorption to inorganic and organic particulates, formation of filterable particles, and possible formation of organic-iron species. Later we propose to address more complex and realistic systems using tracer iron added to natural samples to evaluate such interactions as adsorption onto naturally occurring particles, complexation by organic ligands and interaction with living organisms.

(2) Long-Range Scientific Objectives

The marine chemistry of iron is important, but complex and poorly understood (Brewer, 1975; Kester et al., 1975). Nevertheless, it is virtually certain that many processes involving iron in the marine environment proceed through the formation of small soluble species which react in turn with other materials to yield products. Our goal is to increase our understanding of processes involving iron, especially dissolved iron, in the marine environment. We seek to test the hypothesis that dissolved species are important intermediates in various transformations of iron in seawater. Initially, we operationally define dissolved iron as that which is capable of passing through Millepore PSAC-10 ultrafilters or filters of pore size 0.05 μm.

Known or plausible inputs of dissolved iron into the ocean include: dumping by man, corrosion of ferrous materials, input by rivers, dissolution of amorphous oxyhydroxides (Langmuir and Whittemore, 1971; Byrne and Kester, 1976), release of biochemically bound iron during decay processes (Brewer, personal communication, 1977), and liberation of iron by chemical/biochemical reactions; especially, release within sediments followed by diffusion into the overlying water. Oxidation of iron sulfides and reduction of insoluble iron by organic matter are two such sedimentary sources.

According to our hypothesis, these sources of dissolved iron species feed a variety of sinks. Polymerization and self-aggregation of iron leads to insoluble iron phases, adsorption or reaction with clays leads to iron bound in minerals, and interaction with organic chelators may lead to organo-iron species. Adsorption on various surfaces, including minerals, organic coatings on minerals, and living and dead organic matter is probably a major process. Knowledge of the rates at which these processes are operating would have an important impact on our understanding of the cycling of many reactive trace metals, in addition to iron, in the upper layers of the ocean. The work of this proposal would lay the foundation for such knowledge.

The formation and behavior of soluble iron species is also an important, poorly understood aspect of the corrosion of ferrous materials in the marine environment (Kester, 1976). Achieving our goal will thus advance sadly deficient basic knowledge in an area that is related to Navy interests and needs.

(2) Present Status - Preliminary Results

This proposal suggests using radiolabelled iron to study interactions of dissolved iron in seawater, a conceptually obvious approach which appears to have been overlooked because it has generally been assumed that iron in solution would adsorb so readily to apparatus surfaces that useful data could not be generated. For example, in determining the solubility of iron hydroxide precipitates in a recent study, Byrne and Kester (1976) assumed that as soon as iron in solution was separated from the solid phase, massive adsorption occurred; they took detailed precautions to prevent this phenomenon from distorting their results.

We have preliminary results which show that a sizeable fraction of the Fe^{59} in solution as generated by the procedure of Byrne and Kester (1976) does not adsorb readily. Special filter holders were constructed which avoided contact of solution with surfaces except the filters themselves. When solutions of Fe^{59} in seawater at pH 8.1 were prepared by separating the particulates from the dissolved material by passage through a single 0.05 micron Millepore filter, the concentrations of dissolved iron in the filtrates (Table 1, column 2) were similar to the results of Byrne and Kester (1976) using a comparable procedure. In a parallel experiment where Fe^{59} solutions were immediately run through a second filter of the same type, less than half of the soluble iron was lost on refiltration (Table 1, column 3), a process that affords intimate contact of solution with the filter medium.

In a similar experiment using filtering centrifuge tubes, we measured the dissolved iron passing through Millepore PSAC-10 ultrafilters; this iron is of truly molecular dimensions. In this preliminary work, precautions to avoid radio-contamination caused us to use some leak-prone apparatus; nevertheless, in replicate experiments where no leakage occurred, we obtained similar soluble iron concentrations in the filtrates from membrane filters and from ultrafilters (Table 2). For the parts of this procedure comparable to Byrne and Kester's, the agreement with their results is good.

We verified that our results are not artifacts in several ways: (1) the supplier's data implies a maximum level of impurities in the filters too low to account for our results; (2) gamma spectrometry of representative samples showed the radioactivity detected was Fe^{59}; (3) the filtration technique is validated by the similarity of results to those of Byrne and Kester (1976); (4) random defects in filters are ruled out by the good reproducibility among experiments.

Our results to date indicate that Fe^{59} solutions in seawater can be prepared by appropriate filtration methods so that sufficient activity remains in the soluble fraction to permit further experimentation. We have shown that the majority of dissolved Fe^{59} is not rapidly and irreversibly adsorbed, even during procedures such as filtration through cellulosic materials which, because of their higher surface area, are expected to be among the worst performers in this respect.

(3) Proposed Program for 1979

We propose to prepare dissolved Fe^{59} solutions in seawater by adding known Fe^{59} compounds, such as Fe(II) and Fe(III) salts to seawater and filtering or ultrafiltering these preparations. The chemical behavior of the filtrates with respect to Fe^{59} will be studied. These experiments will be carried out in apparatus designed to reduce adsorption by minimizing surface area, and by using materials determined in early experiments to be least adsorbing. Additionally, Fe^{59} adsorption will be monitored routinely by recovering wall-bound material.

Initial experiments will stress the simplest possible systems and evaluate various potential construction materials for minimal soluble iron(III) adsorption. The experiments will be designed to study the kinetics of disappearance of various soluble Fe^{59} preparations in filtered seawater. The rate of self-aggregation under various conditions will be measured by counting the formation of filterable particles as a function of time. Adsorption onto the wall material will simultaneously be evaluated by counting the container walls. These experiments will be done with soluble iron preparations made by adding Fe^{59}(III) to prefiltered seawater and filtering off the particulate phase, or alternatively by adding Fe^{59}(II) to prefiltered seawater. The latter should quickly oxidize to Fe^{59}(III) (Kester et al., 1975). If the soluble Fe(III) species are in thermodynamic equilibrium, these solutions should behave identically. We will additionally ask whether the Fe^{59}, initially added as an inorganic species, is behaving unusually with respect to adsorption because of the formation of organic-iron species. Experiments using seawater pretreated to remove potential iron-chelating organic compounds by photooxidation and/or active charcoal adsorption will be used to pursue this question.

These experiments will demonstrate the usefulness of the proposed approach and provide information needed as a basis for further studies for characterizing the chemical nature of the soluble iron and of more complex interactions, such as the adsorption of iron onto naturally occurring organic and inorganic particulates, the complexation of initially inorganic Fe^{59} by organic ligands, and the interaction of Fe^{59} with living organisms.

Methods

Achieving our objectives will depend heavily on using adequate methods to study this complex system. The major difficulties anticipated are:

1. Iron is ubiquitous and contamination can be a problem.
2. Iron(III), the thermodynamically stable oxidation state is very insoluble in seawater. Low levels of soluble iron and concomitant sensitivity problems are expected.
3. Iron(III) species may readily adsorb onto surfaces from seawater, so the apparatus itself could remove iron and seriously distort the results.

Since procedures for decontaminating materials with respect to iron and for measuring total iron are available (Strickland and Parsons, 1972), the first problem is a nuisance, not a fundamental limitation. The recent work of Byrne and Kester (1976) (among other studies, e.g. Davies, 1970) shows that by using Fe^{59} radiotracer "soluble" iron(III) in seawater can easily be prepared by amorphous hydroxide dissolution (an analog of a natural process) and subsequent filtration at levels readily quantified by gamma spectrometry (or, in our hands, scintillation counting). The tracer is available in high chemical and radiochemical purity and activity, and the high penetrating power of the emitted gamma radiation facilitates counting Fe^{59} in a variety of physical and chemical forms. We shall use radiotracers, especially Fe^{59}, to solve the quantification problem. In later years, use of other isotopes and/or simultaneous quantification of stable iron may be used in more complex experiments.

The third difficulty, adsorption, has been assumed to be so severe as to make studies almost impossible (e.g. Byrne and Kester, 1971), but actual measurements (discussed in section (2)) suggests this assumption is wrong. We propose to surmount this difficulty by a combination of two approaches:

(1) Utilizing apparatus made of materials with low potential to adsorb iron and with minimal surface area to minimize adsorption.

(2) Measuring and accounting for the amount of Fe adsorbed by apparatus surfaces themselves. Adsorbed iron may be recovered by chemical leaching (as Lewin and Chen, 1973), or the surfaces may be counted directly in some experimental designs.

Initial experiments will explore further the most suitable materials; however, we find that polycarbonate is excellent. Since polycarbonate is easily fabricated and is available as strong, thin, solvent-weldable sheets and as filtration media (Nuclepore filters), it alone could be used to make apparatus (except sealing gaskets). If apparatus can be lined with polycarbonate film, the container surface can be counted directly to measure adsorption.

In section (2) we presented evidence that ordinary cellulose acetate filters (Millepore) only adsorb about half the soluble iron(III) in seawater passing through them. As Figure 1 shows, we expect a dramatic decrease in adsorption with the use of polycarbonate filters (Nuclepore) also available in small pore sizes.

Facilities:

The proposed work requires a "hot lab", a waste storage facility, licensing for Fe^{59} acquisition, a sodium iodide well-type scintillation counter for routine counting, and occasional access to a Ge-Li gamma spectrometer for verification of activity as Fe^{59}. All of these facilities are currently available in the Chemistry Department at Woods Hole.

Personnel:

Dr. Zafiriou's background in physical chemistry and recent work on photoprocesses in seawater involving trace constituents are a suitable background to undertake the proposed work. Ms. True has performed the preliminary experiments with iron and is familiar with the problem, techniques, and approach. Additionally, Ms. Anne Thompson, recent physical chemistry Ph.D. and W.H.O.I. postdoctoral fellowship recipient, will join Dr. Zafiriou's group for a year in June, 1978 (at no salary cost to the projects on which she works). We will also have the opportunity to consult with Dr. R. C. Mantoura, who will join the W.H.O.I. Chemistry staff in the fall of 1978 as an Assistant Scientist; his thesis work on metal-organic interactions qualifies him outstandingly to aid in this work. We are thus well equipped to focus a variety of relevant talents on this complex, challenging, important problem.

References

Brewer, P. G. (1975). Minor elements in seawater. In: Chemical Oceanography, 2nd Ed., Vol. 1, pp. 415-497 (J. P. Riley and G. Skirrow, eds.). Academic Press, New York.

Byrne, R. H. and D. R. Kester (1976). Solubility of hydrous ferric oxide and iron speciation in seawater. Marine Chemistry, 4: 255-274.

Davies, A. G. (1970). Iron, chelation, and the growth of marine phytoplankton. J. Mar. Biol. Assoc. U. K., 50: 65-86.

Kester, D. R. (1976). Improving the chemical behavior of metals in the marine environment. In: Science, Technology and the Modern Navy, pp. 509-516 (E. I. Sholkovitz, ed.). Office of Naval Research, Arlington, Virginia.

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Langmuir, D. and D. O. Whittemore (1971). Variations in the stability of precipitated ferric oxyhydroxides. In: Non-equilibrium Systems in Natural Water Chemistry, pp. 209-233 (R. F. Gould, ed.). ACS Symposium Series No. 106, ACS, Washington, D. C.

Lewin, J. and C.-H. Chen (1973). Changes in the concentration of soluble and particulate iron in seawater enclosed in containers. Limnol. Oceanogr., 18: 590-596.

TABLE 1

Fe^{59} in pH 8.1 Sargasso Seawater 0.05 μ Millepore Filtration.

Experiment Number	Fe in Filtrate, M[a]	Fe in Filtrate After Refiltration, M[b]	% Loss on Refiltration[c]
1	7.1×10^{-10}	4.3×10^{-10}	39
2	7.0×10^{-10}	4.7×10^{-10}	33
3	1.4×10^{-9}	9.6×10^{-10}	31
4	7.0×10^{-10}	2.7×10^{-10}	61
5	1.1×10^{-9}	5.6×10^{-10}	49

[a] Slow filtration through unsupported 0.05 μ Millepore membranes; Fe added = $1.3 - 1.5 \times 10^{-6}$ M.

[b] Slow filtration through second 0.05 μ membrane, about 10 - 30' after first filtration.

[c] Error due to counting statistics ≤ 15%.

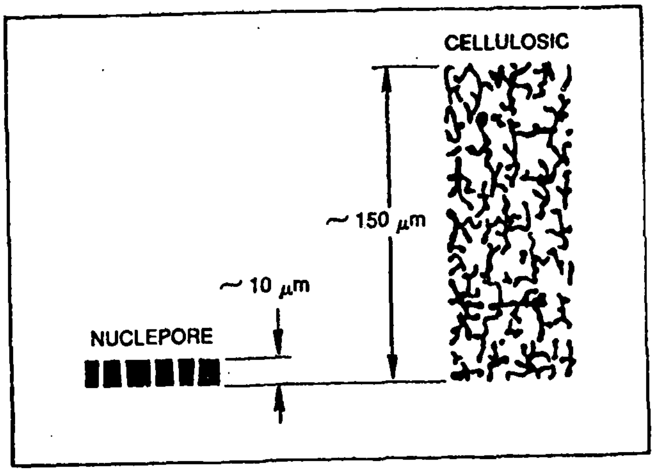
TABLE 2

Filtration and Ultrafiltration of Fe^{59} in Sargasso Seawater Using Centrifugal Filter Holder Filtrate Iron Concentrations.

Experiment Number	Filter	Replicate 1	Replicate 2
1	0.05 μ Millepore	1.2×10^{-9}	2×10^{-9}
2	0.05 μ Millepore	1.9×10^{-8} (leak?)	2.0×10^{-9}
3	0.05 μ Millepore	1.9×10^{-9}	3.9×10^{-8} (leak?)
4	Ultrafilter	Leak	1.3×10^{-9}
5	Ultrafilter	6.8×10^{-9}	
6	Ultrafilter	2.0×10^{-9}	

FIGURE 1

Comparison of Polycarbonate (Nuclepore) and Cellulosic (Millepore) Filter Structures.



For a given size filter, Nuclepore filters have thirty times smaller surface area than Cellulosics.

(Source: Nuclepore LAB-20 Catalog, pp. 4-5).

BUDGET

Marine Chemistry of Iron

SALARIES		
Senior Personnel:	ONR Man Months	Actual Man Mont
1. Oliver C. Zafiriou	3	3
Other Personnel:		
1. Mary B. True	3	3
2. Christine N. Johnson	1	1
A. 1. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay, etc. of $1,222 which is accounted for as employee benefits)		$11,105
B. Other Employee Benefits		2,929
C. TOTAL SALARIES & BENEFITS		14,034
D. EXPENDABLE SUPPLIES & EQUIPMENT		2,600
E. TRAVEL		
1. Domestic Meetings		750
F. PUBLICATION COSTS		
1. Reprint Costs	$ 450	
2. Graphic Services - 25 Hrs. @ $13	325	775
G. MISCELLANEOUS COSTS		
1. Laboratory Overhead - 21% of A,B	2,947	
2. Communications	475	
3. Shop Services - 100 Hrs. @ $13	1,300	
4. Instrument Maintenance	600	
5. Xeroxing	75	5,397
H. TOTAL DIRECT COSTS		23,556
I. INDIRECT COSTS @ 15%		3,533
J. TOTAL COSTS		$27,089

III. GEOLOGY AND GEOPHYSICS

GEOLOGY AND GEOPHYSICS
1979

TABLE OF CONTENTS

GEOLOGY AND GEOPHYSICS

PROGRESS REPORTS

1979

1. INTRODUCTION

Our proposed programs in Geology and Geophysics are focused to a large degree on two broad research objectives. The first objective includes application of the methods of seismology, magnetics and gravity, and detailed mapping of accretionary plate boundaries to improve our understanding of the structure, composition and evolution of the oceanic lithosphere. We consider this to be a well-integrated approach to the solution of the overall problem, inasmuch as each element of the study is strongly dependent upon and supportive of other elements. For example, we cannot properly use seismological methods to do the required high-resolution, quantitative measurements necessary to an understanding of seismic wave propagation in oceanic lithospheres without the information on plate tectonics and accretionary processes supplied by magnetics and by the geologic studies of spreading ridges. Similarly, we cannot expect to understand fully the nature and causes of important variations in the earth's gravity field without the supportive evidence from seismology and the other geophysical disciplines. Techniques of measurement and of interpretation are improving steadily in all of these disciplines, and we anticipate a continuing high level of productivity in the future as specific objectives become more clearly defined and as our ability to attack them improves.

Another strong focus in our research is concerned with the sediment layer and its interaction with the water column. Our studies in this area cover a broad range of topics and techniques directed towards better understanding of processes that determine the shape and composition of the sea bed. Major components of the overall effort are concerned with vertical and horizontal sediment movement and the resultant effects on sea floor morphology and bed forms and on the internal structure and physical properties of the sediment layer. This part of our research program is strongly interdisciplinary, with significant contributions from physical oceanography, biology and acoustics to supplement a broad suite of sedimentological studies.

Continuation of research on the geological and geophysical characteristics of marginal seas is proposed at a modest level of funding. We also propose to continue the essential maintenance of our sea floor sample library and of our digital data library, both of which are necessary to the pursuance of our research goals. Progress reports are included for all previously funded programs, including those for which no additional support is sought.

DEPARTMENT OF GEOLOGY AND GEOPHYSICS
BUDGET SUMMARY
1 January - 31 December 1979

A.	Gross Regular Salaries, including an allowance for holidays, vacation and sick pay of $ 41,499 which is accounted for as employee benefits		$ 367,283
	Cruise Leave, Sea Duty Vacation and Overtime, inc. premium pay of $ 4852		28,786
			$ 396,069
B.	Other Employee Benefits		107,421
C.	TOTAL SALARIES AND BENEFITS		$ 503,490
D.	PERMANENT EQUIPMENT		37,413
E.	EXPENDABLE SUPPLIES AND EQUIPMENT		40,803
F.	TRAVEL: Domestic	$ 23,350	
	Foreign	17,872	41,222
G.	PUBLICATION COSTS:		
	Graphic Arts	$ 13,117	
	Page charges	9,550	22,667
H.	SHIP COSTS:		
	RV OCEANUS (2 days)	$ 6,866	
	RV ATLANTIS II (30 days)	145,680	152,546
I.	COMPUTER COSTS:		
	Sigma 7	$ 11,315	
	VAX11/780	48,625	
	Hewlett Packard	4,750	64,690
J.	OTHER MISCELLANEOUS COSTS:		
	1.Shop Services	$ 10,686	
	2.Shipping and comm.	12,525	
	3.Programming	1,568	
	4.Lab. overhead of 21% of Sal.+ Ben.excl. of premium pay	104,713	
	5.GRA support	46,080	
	6.Other costs	22,700	198,272
K.	TOTAL DIRECT COSTS		$ 1,061,103
	Indirect Costs @ 15% of TDC		159,167
L.	TOTAL COSTS		$ 1,220,270

SEISMOLOGY I

BASIC SUPPORT FOR ONGOING PROGRAMS

G. M. PURDY, R. A. STEPHEN, E. T. BUNCE, J. I. EWING

G. M. Purdy	Tel. (617) 548-1400 Ext. 574
R. A. Stephen	Ext. 575
E. T. Bunce	Ext. 221
J. I. Ewing	Ext. 265

Introduction

As an introduction to the five proposals included on the following pages, a brief overview will be presented here of all our efforts and plans in seismology, including those not currently supported by ONR. The long range objective of all our programs is to better determine the structure and physical characteristics of oceanic crust and upper mantle and of the ocean's major tectonic features. To achieve this aim, we can view our research efforts as taking four directions.

1. First and foremost, the solution of specific geologic and structural problems. Two such programs are proposed for support by ONR: the Kane Fracture Zone project (Seismology II proposal) and the ROSE project (Seismology III proposal). In a broad sense, both these projects are aimed at understanding the structure of, and tectonic processes occurring at, ridge axes and fracture zones and defining and understanding the structure and evolution of oceanic lithosphere.

2. The primary barrier to the achievement of the above aims using seismological techniques is our lack of a quantitative approach to seismic wave propagation through oceanic lithosphere. To improve our expertise in this field, we have added an Assistant Scientist to our group, Ralph Stephen, who will be working on the application of amplitude and waveform analysis techniques to our refraction data, and we are continuing our studies of propagation through heterogeneous structures using simple ray tracing techniques (Seismology I proposal).

3. Another method by which we can better achieve our geologic goals is by the development of improved experimental and data collection techniques. A major advance has been made during the past two years in this respect through the ONR sponsored development of our ocean bottom hydrophone system (Seismology IV). In addition, we have ongoing programs studying the usefulness of a deep towed hydrophone for airgun seismic reflection profiling (IPOD supported),

the design of a deep low frequency implosive source (Seismology V proposal) for fine scale refraction studies of Layer 2, the use of multi-component seismometers emplaced down DSDP drill holes within Layer 2 to carry out oblique seismic experiments to better determine the physical properties of the upper crust and relate them to drilling results (NSF), and the investigation of seismometer package configurations to learn how (or if it is possible) to better record both the vertical and horizontal components of ground motion using recoverable OBS packages emplaced on the sea floor (Seismology I).

4. As our understanding of seismic wave propagation improves and as we devise better experimental and data collection techniques, our interpretation methods must improve in parallel. Our work on statistical methods of interpreting travel times (Delay time function technique) will continue and is proving to be a powerful approach to rigourously interpreting the large datasets produced by our OBH refraction experiments (Seismology I and II). The addition of Ralph Stephen to our group and the imminent arrival of Bob White from Cambridge University on a postdoctoral scholarship for one year, will significantly accelerate our efforts in the routine application of waveform analysis and travel time inversion methods.

Current Status Report

The proposed programs in our 1978 proposal were directed towards advancing our expertise in three major areas of seismic refraction: instrumentation, data reduction and interpretation. The following brief report on our activities during the past year will focus on each of these three areas in turn.

1. Instrumentation Development: With the success of our ocean bottom hydrophone system on the Kane Fracture Zone cruise (see Seismology II proposal), our instrumentation testing and development program has been restricted specifically to the work described in our 1978 proposal: i.e. to the study of noise levels, resonances and coupling efficiency of various designs of seismometer packages. These tests are scheduled to be carried out during the last week of July at the same location as those described in last year's proposal.

Our primary objective is to determine experimentally the parameters which control the noise levels, resonances and coupling efficiency of different seismometer packages. In an attempt to devise a systematic approach to this problem, we have constructed several sensor packages, each fitted with identical vertical and horizontal seismometers and based on two simple designs. The first is the probe that proved so noise-free in last year's tests. This time it will be a hollow 2m long tube fitted with vertical and horizontal seismometers at both the top and bottom and arranged so that a 200 kg mass can be removed from the top. The tests will then consist of monitoring ambient noise levels and shots on all four sensors with and without the detachable 200 kg mass. The second basic configuration will be a 12 cm diameter, 12 cm long cylinder in which are installed vertical and horizontal seismometers. This will be deployed on its own and with 30 cm, 60 cm and 120 cm diameter baseplates. By the addition of weights to each baseplate by divers the effect of both the surface area and mass of each package on resonance and coupling effeciency can be determined. The output of each sensor will be monitored and recorded on an OBH tape recorder on board the surface vessel via a cable. Preliminary results of these tests should be available for display at the September Site review. We hope these data will complement those collected at the pre-ROSE calibration tests and prove sufficient to isolate the key design parameters needed to improve future OBS designs.

2. Data Reduction: A major effort has been applied to the implementation, improvement and expansion of the digital data reduction system described in last year's proposal. Excellent progress has been made since the initial implementation of the system for the Kane Fracture Zone cruise last November. It is now a routine process to convert analog OBH tapes into computer plotted record sections with travel time corrections applied and with amplitudes corrected for replay gains and shot size. The digitised seismograms are stored on disc to allow real-time display and processing on a graphics CRT terminal. The refracted wave travel times picked from the record sections are also stored on disc in a standardised format compatible with our travel-time vs. distance plotting programs, travel-time modelling, travel-time inversion, topographic correction calculation and delay-time function analysis programs. Such a disc oriented system has proved a great advantage, significantly accelerating the tedious data correction and editing procedures. By storing the digitised seismograms on disc, the data is accessible quickly and cheaply to anyone with a graphic CRT terminal. To date, this has proven important primarily for data quality assessment and checking procedures but as the system is becoming debugged, it is used increasingly for random data inspection and comparison, allowing any given shot or set of shots on any of the eight receivers to be viewed and their amplitude spectra calculated quickly and easily. Without this system, for the 'T' experiment alone, such straightforward comparisons would entail

sorting through two filing cabinets full of paper records.

3. <u>Interpretation:</u> Our interpretation technique development efforts have been primarily directed toward solving specific problems in the Kane Fracture Zone data. Our more general efforts have concentrated, as described in our 1978 proposal, on studying the usefulness of ray tracing methods for the study of propagation through heterogeneous structures, gaining basic capabilities in waveform analysis and modifying and improving our delay time function analysis methods.

At the time of writing, progress in all these matters has been disappointingly slow and in consequence, our efforts will be intensively directed towards these problems for the remaining six months of the contract year. The routine use of the ray tracing program has been delayed because of attempts at minimizing its cost and making it more reliable and easier to use. These developments have recently been completed but the very preliminary results we have at this time will not be presented in this proposal. More definite results from this work should be available for the September review and a specific effort will be made to present them in detail at that time.

Ralph Stephen joined our group only a few weeks before the time of writing this proposal, thus it is premature to report honestly on our progress with establishing a basic capability for amplitude analysis. Stephen brought with him from Cambridge copies of the Fuchs-Müller reflectivity program for the computation of synthetic seismograms and a first step will be to get this program running on the new VAX computer (when it is delivered in the fall). This program is too slow for routine use for studying amplitude vs. distance relations on large datasets; but we view it as a necessary basic tool to be used sparingly to supplement less complete but faster ray theory amplitude calculation methods. Perhaps the most important step in this field we wish to make during the next few months is to formulate a plan for what role we can most effectively play in this fast-moving field of seismology. This will involve not only a more detailed study of the exact strength, capabilities and cost of the new computer system, but also considerable interaction with colleagues at other institutions.

So far this year, we have published or have in press four papers prepared under either total or partial ONR support:

Purdy, G. M. and R. Detrick, 1978. A Seismic Refraction Experiment in the Central Banda Sea. Jour. Geophys Res., <u>83</u>, 2247.

Purdy, G. M. and Kristin Rohr, 1978. A Geophysical Survey within the Mesozoic magnetic anomaly sequence south of Bermuda. Jour. Geophys. Res., in press.

Koelsch, Donald E. and G. M. Purdy, 1978. An ocean bottom hydrophone instrument for seismic refraction experiments in the deep ocean. Marine Geophys. Res., in press.

Purdy, G. M. and David Twichell, 1978. Sediment Distribution around the Bouvet Triple Junction. Marine Geology, 28, 53-57.

Proposed Program

During the past two years of ONR support, a large effort has been directed towards the development of hardware for the ocean bottom hydrophone system. This development, except for minor improvements and modifications described in proposals III and IV, is essentially complete. Our work will now be re-directed at the development and improvement of our data reduction and interpretation methods. The Kane Fracture Zone experiments and the ROSE project will result in a huge data base of high quality data deserving of careful analysis for the next two to three years. In this proposal, we request support for developing and maintaining the computational tools necessary for making the most effective use of these data in solving fundamental geologic problems.

The arrival of the Institution's new VAX computer system this fall will significantly increase our computational capabilities: it will inevitably, however, require an increased programming effort on our part to modify and convert our existing programs to the new system. The VAX is a time sharing disc oriented system and during the past year, our existing data reduction system on the Sigma 7 computer has been modified to use a disc stored data base and be controllable through typewriter and graphic terminals. This has been facilitated by the temporary partial lease of a private disc drive for the Sigma 7 and the purchase of a Texas Instruments hard copy terminal. Thus the structure of our system will not have to be modified and is ideally suited to the VAX computer. Nevertheless, the Sigma 7 system dependent sections of our programs will have to be changed, and it is vital that these conversions be completed before the ROSE data needs to be processed. Efforts are currently being made to learn as much about the new system as possible to speed up conversion procedures, but it is unfortunately inevitable that some delays and problems will be experienced. We request support for a computer programmer and research assistant to work on the conversion and re-documenting of our programs. We also request funds to purchase a Tektronix graphics terminal which will be hard wired to the VAX from our lab and funds to cover 1/4 of the lease cost of a 176 megabyte disc pak. These budgetary items are important not only to achieving a smooth conversion to the new computer system, but also to maintaining a flexible and well documented data reduction and interpretation system that will not be choked by either the ROSE data or by any future major data collection effort.

The single most important new effort we wish to make in the next couple of years is the application of amplitude analysis (synthetic seismogram) techniques to our refraction data. We judge this to be a good time to enter this field as the problem of computing synthetic seismograms for laterally homogeneous media seems to be well solved (e.g. Fuchs & Müller 1971, Wiggins & Madrid 1974, Wiggins, 1976, Helmberger 1977). By the beginning of 1979, we will have the full wave reflectivity method operating on the VAX computer. This program, providing as it does a complete solution taking into account all possible wave paths and conversions, is a necessary basis for our future work in this field. It is, however, too expensive to use for routine data analysis and is slow compared with some available ray theory methods which may be adequate for the study of most problems. As has been mentioned previously, we plan during the next six months to research in detail the available ray theory techniques with the aim of being in a position at the beginning of 1979 to write (or convert an existing) program which will provide us with the capability for routinely modelling amplitudes at reasonable computing cost. This will then be available for application to the Kane Fracture Zone and ROSE project data.

This interest in amplitude analysis will not detract from our continued interest in improving our travel time analysis methods. The delay time function techniques will continue to be our most important and basic interpretation method, particularly in dealing with the large Kane fracture zone and ROSE experiment data sets. One major problem with current delay time function techniques is that as the number of polynomial or Fourier coefficients describing a refracting interface increases, the stability of the solution decreases, particularly at the edges of the area of study or where data is relatively sparse. Thus in practice, one is restricted to fairly low order polynomials or Fourier surfaces which may not accurately reflect the true configuration of the refracting interface. We are exploring improved analytical techniques which will increase the stability of these higher order solutions. A second major problem with current delay time methods involves devising more rigorous statistical tests to provide better bounds on the validity of the delay time solutions, and this will also be a major goal of our effort to improve our delay time function analysis programs.

Budget Justification

In addition to the modest support requested for the principal investigators (2 months each for Purdy and Stephen, 1 month for Bunce), we request 3 months for W. E. Witzell Sr. (Research Specialist) to provide routine technical and logistical support for the seismology group as a whole and to provide the necessary supervision of our other techniques. To carry out the conversion of our programs to the VAX computer, to re-document them, to assist Stephen with the development of the amplitude analysis programs, and to maintain our standard data reduction system, we request 2 months support for a computer programmer and four months support for a research assistant. We also request one month for Helen Hays (Senior Research Assistant) for general drafting and administrative support and 5 months of secretarial support (3 for Ewing).

We request $6,350 to purchase a Tektronix Model 4012 Graphics computer terminal. At present real time access to our data is hampered by the heavy use of the graphics terminals linked to the Sigma 7. The proposed Institution VAX system will have only one graphics terminal available to general users. We anticipate that this will be so heavily used that access to our data will be significantly impaired. As eight people will be using the system heavily on a day to day basis (i.e. Purdy, Stephen, Detrick, White (Post-Doc), Dean (Res. Assistant), Programmer, and two Joint Program Students, Trehu and Rohr), we consider it justified to request these funds.

We request $1,586 for mostly computer related expendable supplies. Travel: we request funds to allow Ewing, Purdy and Stephen to attend the spring AGU and 2 trips to the West Coast for Stephen to meet with colleagues at Scripps and Cal Tech to discuss ray theory based amplitude modelling methods and to attend the fall AGU meeting.

We request 10 hrs. of Sigma 7 computer time so our work can continue during the conversion phase and 220 hrs. of VAX time for conversion of all our programs, the development of amplitude analysis techniques and the continued development of delay time function methods.

The three months GRA support is for Kristin Rohr (Joint Program student) to continue her exploratory work on time series analysis of our digital data. To enable us to maintain all our programs and a large portion of our data permanently on disc, we plan to lease our own 176 megabyte disc drive, one quarter of the cost of which ($3,000) we request in this proposal.

SEISMOLOGY I
Ongoing Support
1 January - 31 December 79

		ONR Man/Months		Actual
A.	SALARIES AND WAGES:			
	Professional:			
	John I. Ewing, Sr. Scientist	N/C		
	Elizabeth T. Bunce, Sr. Scientist	1.0		
	G. Michael Purdy, Asst. Scientist	2.0		
	Ralph Stephen, Assistant Sci.	2.0		
	S. T. Knott, Res. Specialist	N/C		
	W. E. Witzell, Sr., Res. Spec.	3.0		
	Support:			
	Programmer, TBA	2.0		
	Res. Assistant, TBA	4.0		
	H. Hays, Sr. Res. Assistant	1.0		
	J. Bear, Secretary	5.0		
	Gross Regular Salaries (includes allowance for holidays vacation, and sick pay of $ 2908 which is accounted for as employee benefits)			$ 26,601
B.	OTHER EMPLOYEE BENEFITS			7,043
C.	TOTAL SALARIES AND BENEFITS			$ 33,644
D.	PERMANENT EQUIPMENT			
	1. Tektronix Graphics Computer Terminal Model #4012			$ 6,350
E.	EXPENDABLE SUPPLIES AND EQUIPMENT			
	1. Pens, Paper and Mylar for Calcomp		$ 397	
	2. 25 reels Memorex 9T digital tape		332	
	3. UV Oscillograph paper (20 rolls @ $ 37/roll)		740	
	4. Thermographic paper for T.I. computer (25 rolls and 10 floppy discs)		117	$ 1,586
F.	TRAVEL (Domestic)			
	1. 3 R/T Washington (AGU) with 10 days exp. A/F - $360, T/E - $525 cars $160		$ 1,045	
	2. 2 R/T WH-West Coast with six days expenses A/F -$944, T/E $300, cars $100		1,344	$ 2,389
G.	PUBLICATION COSTS			
	1. Graphic Arts: 80 hrs @ $13		$ 1,040	
	2. Page charges: 10 @ $80		800	$ 1,840
H.	SHIP COSTS (None)			
I.	COMPUTER COSTS:			
	1. 10 hrs Sigma 7 @ $155		$ 1,550	
	2. 220 hrs. VAX 11@ $45		9,900	$ 11,450
J.	OTHER MISCELLANEOUS COSTS:			
	1. Shipping and communications		$ 1,500	
	2. Shop Services: 80hrs @ $13		1,040	
	3. Lab. overhead of 21% of C		7,065	
	4. Grad.Res. Asst.(3 mos. @ $1155)		3,465	
	5. 1/4 cost of leasing 176 megabyte disc drive for VAX computer		3,000	$ 16,070
K.	TOTAL DIRECT COSTS			$ 73,329
	Indirect Costs @ 15%			10,999
L.	TOTAL COSTS			$ 84,328

SEISMOLOGY II

KANE FRACTURE ZONE PROJECT

G. M. Purdy

Tel: (617) 548-1400 Ext. 574

Long Range Objectives

Using the high quality seismic refraction data collected during our cruise in November 1977, we hope to gain fundamental new information on the major structural elements within a large Atlantic fracture zone. The long range objective is to understand the formation and evolution of one of the ocean's largest and most common tectonic features: fracture zones.

Current Status Report

Our data collection cruise from which we returned in mid-December was extremely successful. The new version of the bathymetry contour map of our work area, including the data from our cruise, is shown in Figure 1. This figure also shows location of the ocean bottom hydrophone (OBH) instruments and the shooting lines for the two experiments. No instruments were lost and good data were recorded by all OBH units. Our newly constructed shipboard systems, the shot instant data logger and the acoustic homing system, also performed excellently and the latter system, which allowed us to navigate our shooting lines relative to the deployed receivers, was particularly invaluable, allowing us to accurately duplicate our shooting lines. A total 560 explosive shots varying in size between 8 and 512 lbs were fired, together with 8,600 airgun shots providing us with a huge data base from which we are confident that we can determine well controlled structural solutions. So far, our efforts have been concentrated on the fracture zone ('T') experiment for which we now have a complete set of corrected record sections (five of which are shown in Figure 2). At the time of writing, six months after completion of the cruise, our geological answers are few as our efforts have been concentrated on routine data reduction. Preliminary travel time analyses have been carried out on six of the OBH in the T experiment using simple slope intercept and one dimensional delay time methods and indicate thin oceanic crust, low MOHO velocities (7.7 kms/sec), significant crustal thinning beneath the fracture zone trough but no major structural discontinuity south of OBH 4, and a suggestion that the crustal section north of the fracture zone (older) is consistently thicker than that to the south.

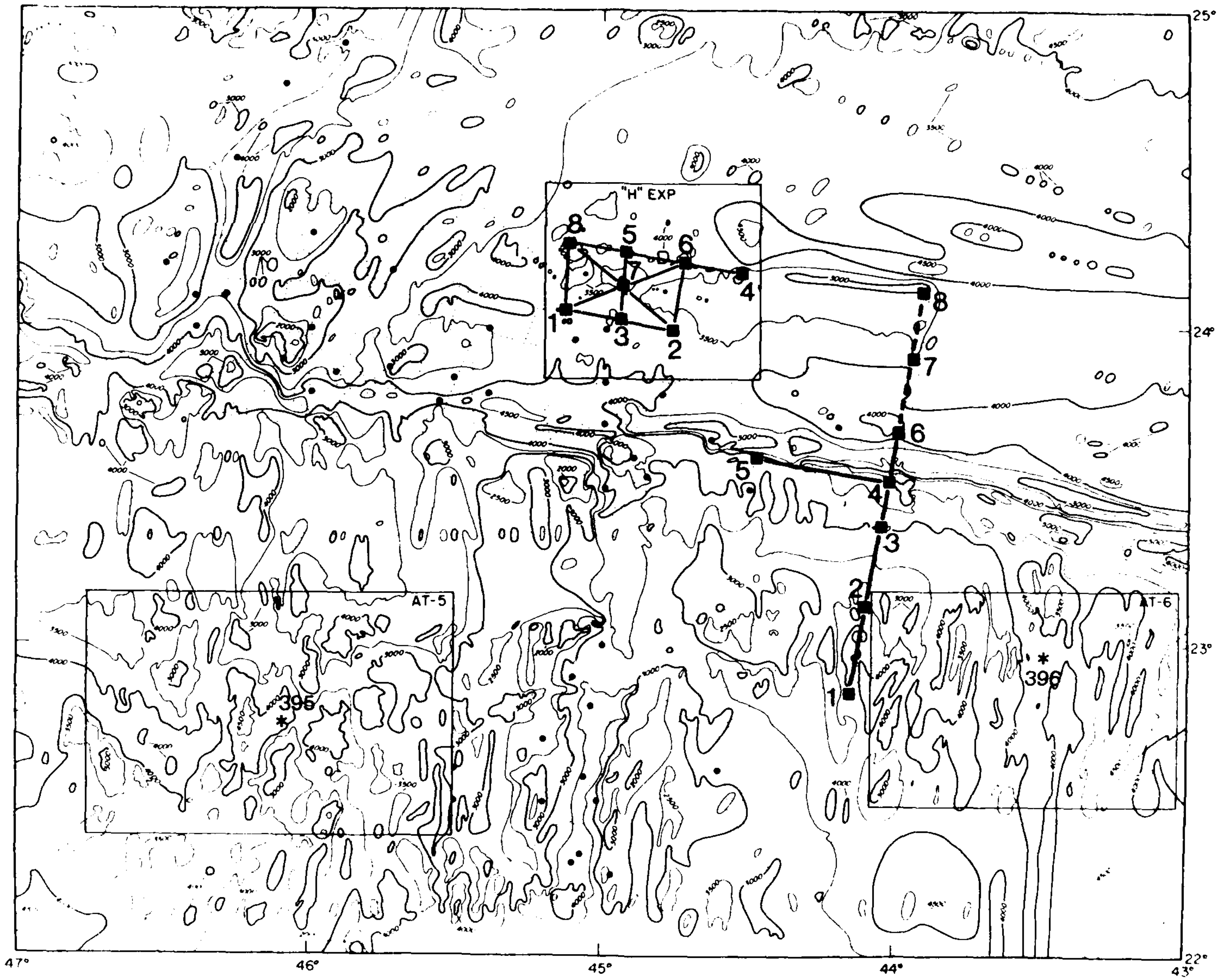


Figure 1. Revised bathymetric map of the Kane Fracture Zone area showing the location of the two major seismic refraction experiments completed Oct./Nov. 1977. Numbers indicate receiver locations, solid lines are shooting lines. Contour interval 500 corr. m. Small dots are teleseismic earthquake epicenters.

Figure 2 shows corrected record sections for five of the eight OBH's deployed in the 'T' (fracture zone) experiment. The locations of these receivers are shown in Figure 1. OBH 1 and OBH 2 were situated on normal oceanic crust south of the Kane Fracture Zone, OBH 4 was located in the fracture zone trough while OBH 7 and OBH 8 were located well north of the fracture zone. The record sections have been plotted so that in each case the southernmost shots are located at the left hand side of the diagram. With the exception of four 240 lb shots in the fracture zone itself, only 32 lb shots are plotted. The record sections have been corrected for clock drift and shot instant, but not topography. Amplitudes have been normalized for shot size and have been scaled using an empirical factor proportional to R^{-1}.

Clear refracted wave arrivals are apparent out to ranges of 60-70 km and often to ranges of 80-90 km. While the amplitude of arrivals with ray paths crossing the fracture zone province are attenuated, clear first arrivals are apparent even for 32 lb shots (see OBH 7 and 8). The travel time/distance curves of the OBH's located away from the fracture zone are typical of normal oceanic crust with crustal velocities of 5-6.5 km/sec breaking over into mantle-type velocities at ranges of 15-20 km. At OBH 4, however, the breakover to mantle velocities occurs at a range of only about 10 km, suggesting that significant differences exist between the crustal structure in the fracture province and normal oceanic crust.

The record sections shown in Figures 2 and 3 also display a number of interesting second arrivals and amplitude variations. A large amplitude phase is apparent on OBHs 1 and 2 coming in 1-4 sec. after the first arrival. The slow apparent velocity of this phase suggests it is some type of converted shear wave arrival. Though less obvious, a similar arrival exists on OBHs 7 and 8 north of the fracture zone. On several of the instruments, but particularly on OBH 4, two discrete packets of energy follow the first arrival at about 1 sec. intervals. These arrivals occur over about a 10 km range, 25-35 km south of OBH 4. These arrivals, including the first arrival, are strongly attenuated between 35 and 40 km range, coming in strong again beyond 40 km. A similar amplitude relationship exists on OBHs 1 and 2 with large amplitude first and second arrivals between 20 and 35 km and very low amplitudes around 40 km range. These amplitude variations are likely to be the result of velocity gradient variations in the mantle and may offer a very fruitful area for synthetic seismogram/ray tracing type studies.

While the sea floor topography was relatively subdued outside the fracture province, changes in water depth along the shooting

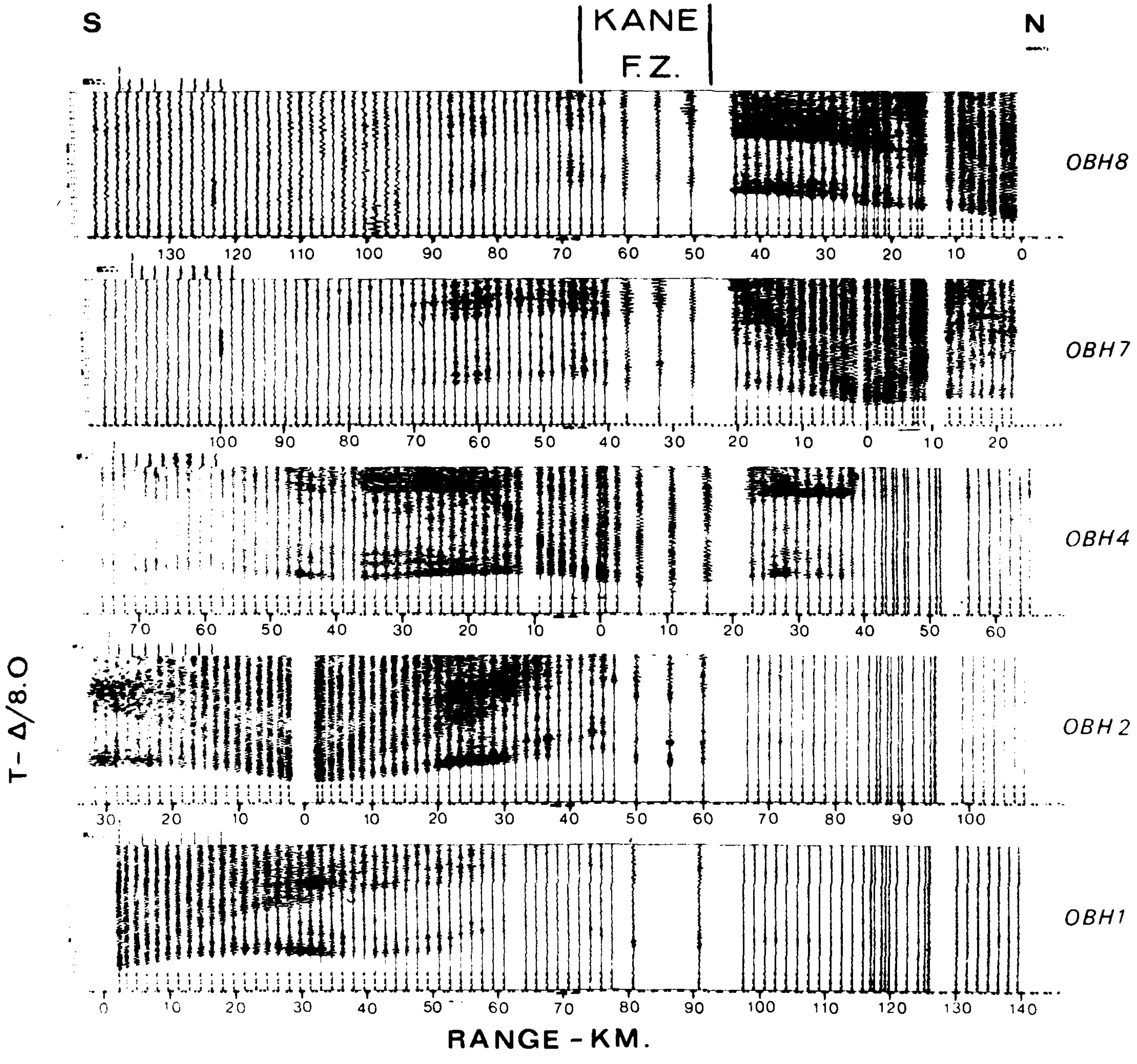


Figure 2. Corrected record sections for five of the eight receivers deployed in the "T" experiment. Travel times have been corrected for shot instant and clock drift, but not topography. Amplitudes have been normalized for shot size and scaled according to an empirical weighting factor proportional to 1/R. With the exception of four shots in the fracture zone province, only 32 lb. shots are shown. Record sections are arranged so that the southernmost shots are located at the left-hand side of the diagram and the southernmost receivers are at the bottom of the page. See text for discussion of seismograms.

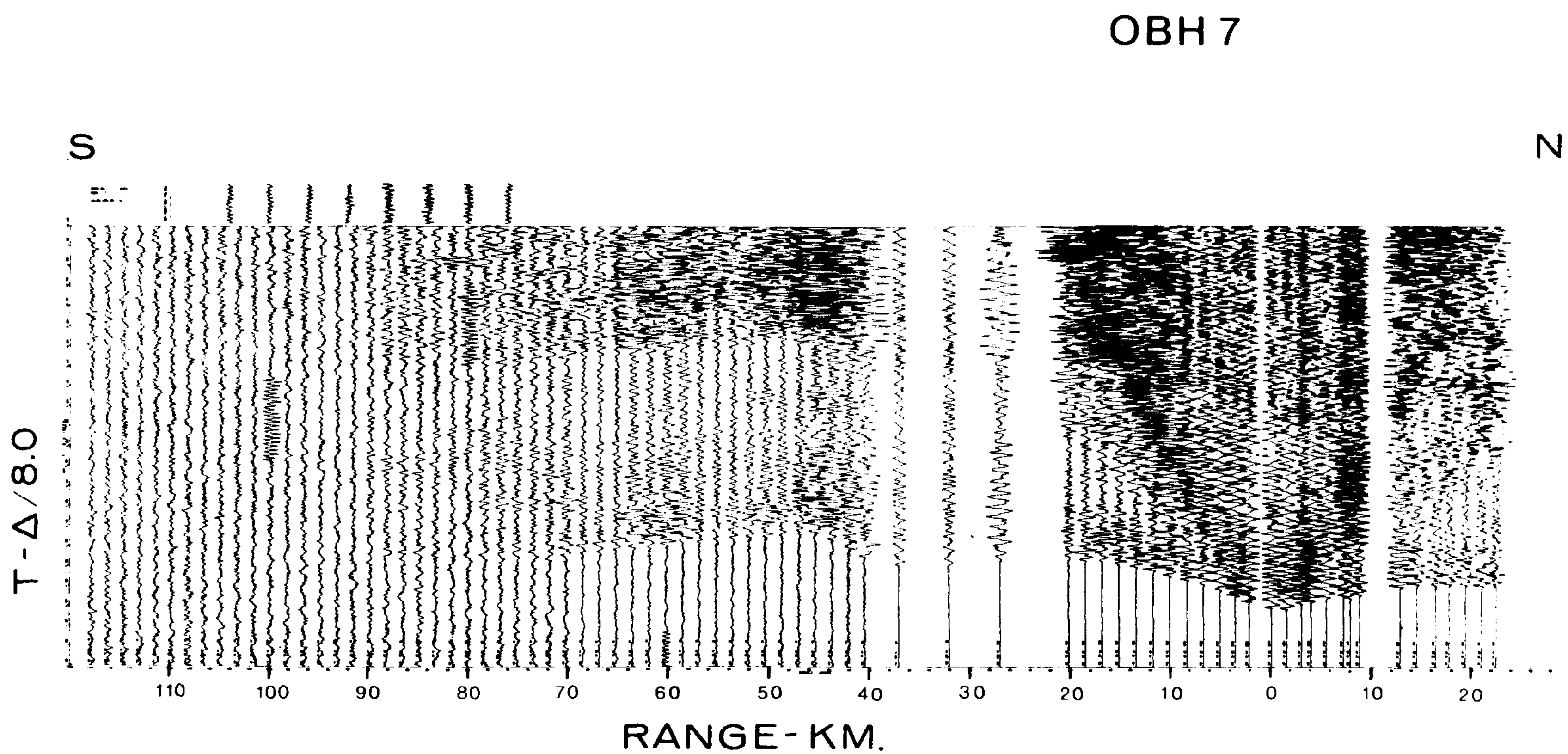


Figure 3. Corrected record section for OBH7, Kane Fracture Zone 'T' experiment Caption same as that in Figure 2, eight 1 sec calibration pulses plotted at the top left margin of the record section enable one to translate arrival amplitudes into dynes/cm^2. Note the large topographic effects associated with the fracture zone (25 <R< 45) and the large variation in amplitude of first and latter arrivals between ranges of <u>50</u> and <u>70</u> hm.

lines have significantly affected the observed travel times. For example, the undulating nature of the MOHO arrivals on OBHs 1 and 4 south of the fracture zone (Figure 2) are topographic effects. One simple method for making topographic corrections is to flatten the sea floor to a convenient horizontal datum. The magnitude of these topographic corrections is particularly sensitive to the velocity assumed for the sea-bed material. Whitmarsh (1975) has suggested a method in which this velocity is estimated by determining the value of $\Delta t/\Delta h$ which minimizes the root mean square residuals for a least-squares line fit to a set of arrivals with the same apparent velocity. We have applied this method to MOHO arrivals from each of the receivers shown in Figure 1. The estimates of $\Delta t/\Delta h$ determined in this manner varied quite significantly from receiver to receiver. This was true even when MOHO arrivals from the same shots were used at different receivers. We believe that this is due to the sensitivity of the method to which shots are included in the least-squares fitting procedure. Thus, while the rms residuals can be minimized for a particular value of $\Delta t/\Delta h$, that value of $\Delta t/\Delta h$ can vary by at least a factor of two depending on which shots are used to determine the residuals. Interestingly, this result was only obvious because we had data from the same shots at several different receivers that could be compared. We hope to use the shallow crustal structure determined from the 300 cu in and 1000 cu in airgun data to place better constraints on the $\Delta t/\Delta h$ value most appropriate for this area.

With the large number of travel times available from this experiment, the delay time function technique of Morris et al., (1969) can be applied to both Layer 2/Layer 3 and MOHO arrivals. The principle advantage of this technique is that all the travel times from each receiver can be combined into a single data set which can be solved both for the refractor velocity and the configuration of the refracting interface. Preliminary delay time surfaces have been calculated for the MOHO south of the Kane Fracture Zone using the 141 MOHO arrivals observed at OBHs 1,2, 3, and 4. The solutions are generally stable, although the RMS errors are rather large. The delay time surface is relatively flat beneath OBH 1, 2 and 3, but deepens considerably beneath OBH 4. This increase in delay time to MOHO beneath the fracture zone may not be real; the polynomial is not well constrained at either end of the profile and high dip values in this region are not uncommon in delay time studies. Even if the larger delay times are real, the depth to MOHO is probably not greater beneath the fracture zone; the larger delay times actually reflecting lower velocities in the shallower crustal layers. With the addition of the travel time data north of the fracture zone and the better control on shallow crustal structure, we expect from analysis of the airgun data, these problems should be resolved. We are also working on an improved analytical technique for computing the delay time surfaces which will minimize the instability problems inherent in more conventional delay time solutions.

During 1978, papers outlining the preliminary results of the 'T' experiment will be presented at meetings of the European Geophysical Society and the American Geophysical Union, and a paper will be prepared for publication describing the experiment and giving the results of our travel time analyses of the structure to the north and south of the fracture zone and the line between OBH's 4 and 5 shot within the fracture zone trough.

A concentrated effort on interpretation of the 'H' experiment will begin in September when Bob White joins our group as a Post-doctoral Scholar (funded by the WHOI Education Department). During his 12 months working with us, he will concentrate solely on the 'H' experiment and provide a valuable acceleration to our efforts.

Proposed Work

We request support to continue our interpretation of these excellent data. Our preliminary travel time analyses and a study of the large number of clear seismograms recorded during the 'T' experiment convinces us that we shall be able to place some rigourous constraints on the seismic structure of a typical Atlantic fracture zone, as well as determining complete crustal sections to the north and south sufficiently well to define the systematic differences in structure due to the 10 m.y. age difference. The 'H' experiment yielded data of an equal quality to that recorded during the 'T' experiment and the eight closely spaced receivers deployed within a $\sim$ 50 km square provide a sufficient number of wave paths to define the shallow crustal structure with unusual accuracy and resolution; and thus allow us to focus on our original objectives of studying the structure of 'typical' Atlantic basement topography and its degree and scale of lateral homogeneity.

We consider the quality of these two data sets justifies a continuing major interpretation effort. During 1979, our work on the 'T' experiment will consist of a) refining our knowledge of the shallow structure using the airgun wide angle reflection data; b) carrying out a study of the travel times to OBH 5 from shots fixed between OBH 1 and OBH 8 using 2-D delay time and ray tracing techniques in order to better constrain the structure and geometry of the fracture zone province; c) we plan to use the synthetic seismogram techniques (which will be developed by Ralph Stephen under our Seismology I proposal) to study the apparently consistent patterns of amplitude variations, (particularly those seen at the three OBHs south of the fracture zone and which can be clearly seen in Figure 2) to define the vertical velocity gradients within the crust outside of the fracture zone province.

Bob Detrick recently completed his Ph.D. and is now a post-doctoral investigator working only on the interpretation of the 'T' experiment. As predicted in last year's proposal, we now request a further 9 months support for him as a post-doc so he can continue to devote 100% of his efforts to these data. Because of the success of the experiment, the high quality of the data and the interesting nature of the preliminary results so far available, we feel such a high level of commitment is amply justified. This 9 months support for Bob will guarantee that the 'T' experiment data receives the detailed analysis that we feel it deserves.

Bob White has recently completed his Ph.D. at Cambridge University and, as previously mentioned, will join our group for 12 months starting September 1, 1978. We request no salary support for White. White's Ph.D. thesis is concerned with amplitude and travel time studies of wide angle reflection and refraction data to make more detailed determinations of the shallow structure of oceanic crust: thus he is particularly well qualified to complete the interpretation of the 'H' experiment, which is specifically directed towards the study of these problems. We request funding for computer time and expendable supplies to permit White to concentrate on the thorough interpretation of the 'H' experiment data.

Although Purdy will remain intimately involved with all aspects of the work described here, we are particularly concerned that our heavy committment to the ROSE project will not interrupt or delay the completion of our interpretation of the Kane Fracture Zone data. By clearly defining the responsibilities as we have done above, we hope to avoid this. Neither Detrick nor White are involved with the ROSE project at this time, nor do they plan to become involved in the foreseeable future.

Nineteen hundred seventy nine will be the third year of the Kane Fracture Zone project: the data were collected in late 1977, 1978 has been a year of data reduction and preliminary interpretation and 1979 will be a year of concentrated interpretation to produce at least two major papers on the results of the 'T' and 'H' experiments. We do not foresee this project continuing beyond 1979: should our work during the next 12 months produce problems which deserve closer investigation, support will be requested in 1980 to study them specifically as well defined and separate tasks. No further support for the 'general' interpretation of these data will be requested.

Budget Justification

The levels of support requested for Detrick and White are justified in the text of the proposal. We request one month support for C. Grant, electronics technician, for maintenance of the replay and digitization electronics. We request four months each for a research assistant and a computer programmer to assist Purdy, Detrick and White with the intensive interpretation effort. Unfortunately, last year we underestimated some of the problems of handling such large digital data sets and did not request sufficient research assistant/programmer support to ensure the smooth flow of data through our system. To prevent reoccurrence of such delays, we request 4 months of research assistant support specifically for this project. We anticipate considerable program development during this final year of interpretation and, especially as we will be using the new VAX computer with which we are unfamiliar, we request 4 months programmer support to provide the necessary expertise to quickly solve our problems. Again, we ask for 4 months support for a summer student employee. This proved extremely successful this year providing a significant acceleration to our work at low cost. In fact, our summer employee this year is Anna Sundberg who has since been accepted as a joint program Ph.D. student and, as her interest in seismology will continue and as she is already familiar with the Kane Fracture Zone data, we request 3 months support for her as a GRA so she can return to us next summer.

We request no permanent equipment and $1,147 for mostly computer related expendable supplies. Travel funds of $330 are requested to allow Detrick to attend the spring AGU meeting. $4,720 for publications costs is needed for the preparation and publication of our results. Ten hours of Sigma 7 computer time is requested so our work can continue through the period in which our programs are being converted to the VAX, and 200 hours of VAX time are requested for carrying out the bulk of our interpretation.

The Kane Fracture Zone data are currently stored on a private disc pak on the Sigma 7 computer. To allow these data to be smoothly transferred to the new VAX machine, we request 1/4 of the cost of leasing 176 megabyte disc drive to be fitted on the VAX.

SEISMOLOGY II

Kane Fracture Zone Interpretation
1 January - 31 December 1979

		ONR Man/Months	Actual
A.	SALARIES AND WAGES		
	Professional:		
	G. M. Purdy, Asst. Scientist	N/C	
	R. A. Stephen, Asst. Scientist	N/C	
	R. S. Detrick, Post Doc. Invest.	9.0	
	R. S. White, Postdoctoral Fellow	N/C	
	Support:		
	C. W. Grant, Sr. Res. Asst.	1.0	
	Res. Assistant, TBA	4.0	
	Programmer, TBA	4.0	
	Summer Student Employee	4.0	
	Gross Regular Salaries (includes allowance for vacations, holidays, sick pay of $ 2494 which is accounted for as employee benefits)		$ 23,231
B.	OTHER EMPLOYEE BENEFITS		6,216
C.	TOTAL SALARIES AND BENEFITS		$ 29,447
D.	PERMANENT EQUIPMENT (None)		
E.	EXPENDABLE SUPPLIES		
	1. Pens, paper and mylar for Calcomp	$ 397	
	2. 25 rolls 9T digital tape	332	
	3. 10 rolls UV oscillograph paper @ $37/roll	370	
	4. Thermographic paper for T. I. computer terminal (25 rolls)	48	$ 1,147
F.	TRAVEL (Domestic) 1 R/T Washington D.C. for A.G.U. (4 days) A/F - $120, T/E - $210		$ 330
G.	PUBLICATION COSTS		
	1. Graphic Arts: 240 hrs @ $13	$ 3,120	
	2. Page charges: 20 pages @ $ 80/pg	1,600	$ 4,720
H.	SHIP COSTS (None)		
I.	COMPUTER COSTS:		
	1. Sigma 7 computer 10 hrs @ $155/hr	$ 1,550	
	2. VAX 11/780: 200 hrs @ $45/hr	9,000	$ 10,550
J.	MISCELLANEOUS:		
	1. Communications	$ 250	
	2. I.P.C. Programming 40 hrs @ $19.60	784	
	3. Lab. Overhead of 21% of C	6,184	
	4. GRA 3 months @ $1,155/month	3,465	
	5. 1/4 cost of leasing 176 megabyte disc drive for VAX computer	3,000	$ 13,683
K.	TOTAL DIRECT COSTS		$ 59,877
	Indirect costs @ 15% of TDC		8,982
L.	TOTAL COSTS		$ 68,859

SEISMOLOGY III

ROSE PROJECT*

G. M. Purdy, R. A. Stephen and J. I. Ewing

G. M. Purdy Tel: (617) 548-1400 Ext. 574
R. A. Stephen Ext. 575
J. I. Ewing Ext. 265

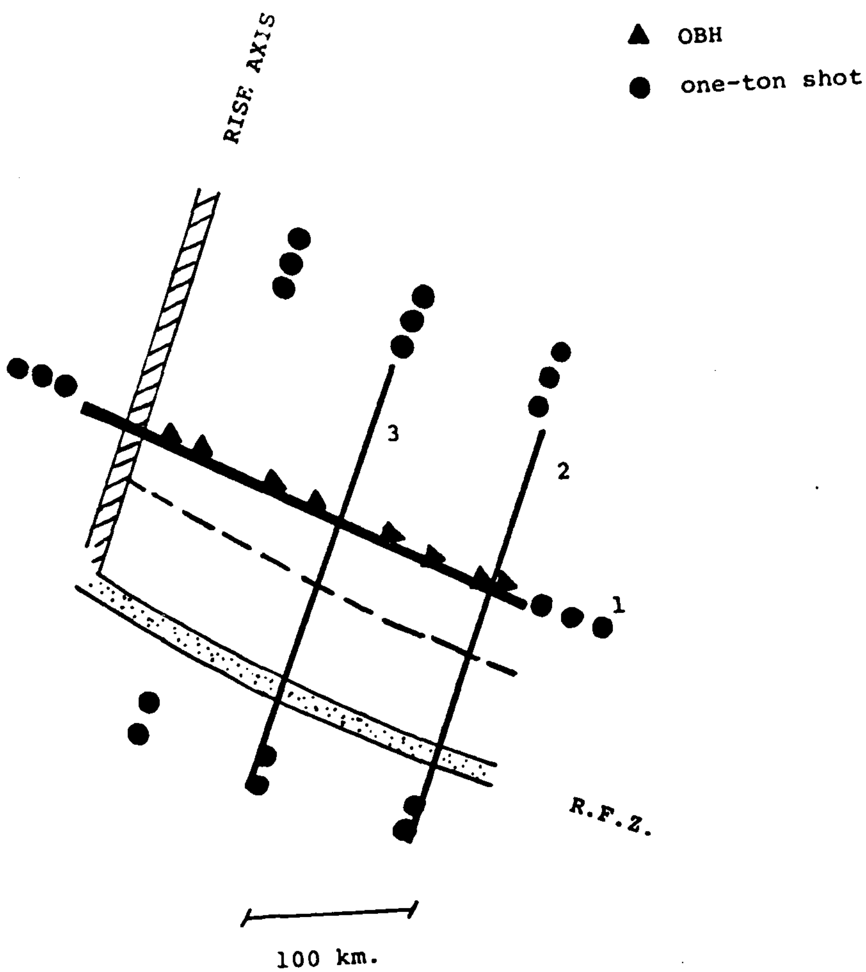
Summary

The following statement of our planned participation in the ROSE project is presented in three parts. The first describes our principal scientific objectives. These are well defined problems which, given a reasonably successful data collection phase, can be well solved by the planned experiments. In addition, the proper solutions to these problems are particularly dependent upon the data collected by our own instruments. We then describe our secondary objectives: we do not consider these to be of secondary importance but rather they are problems that can be less well defined before the data is available for inspection and thus are subject to modification as the project progresses into its second and third year. These problems are highly dependent upon data collected by other institutions and specifically require close co-operative interpretation efforts with our colleagues. The third part of this proposal describes precisely what we hope to achieve during the year 1979. This is necessarily weighted (as is our budget) towards the data collection and data reduction phases of the project.

We hope to devote a major proportion of our efforts to project ROSE and consider that it deserves a minimum of 50% of our time for a minimum of 3 years.

We plan four deployments of eight ocean bottom hydrophone instruments (two during the explosive phase and two during the passive phase) as part of the data collection effort for the Rivera Ocean Seismic Experiment (ROSE). Our data analysis interests are wide and varied, but we describe here specific objectives upon which our work will be concentrated during the next two or three years. Fig. 1 shows the location of our instruments and the shooting lines during the explosive phase to provide a view of the data immediately available to us for interpretation. Although the objectives described here are mostly related to the use of data recorded by our own instruments, it is clear that as data becomes available from other institutions in the second and third years of data analysis, it will play a vital role in the full realization of our objectives.

* See Appendix for abstract of ROSE overview proposal.



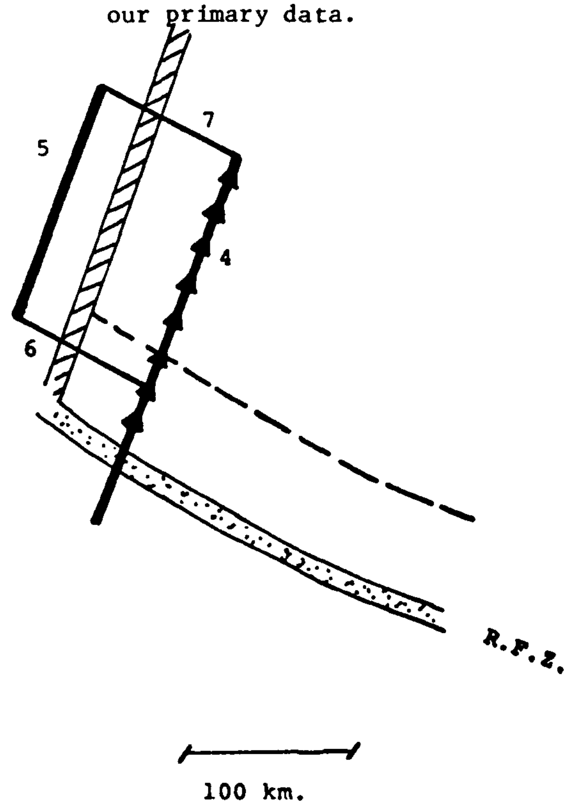


Fig. 1 Location of WHOI OBH instruments for their first and second deployments during the explosive phase of project ROSE. The bold shooting lines are those which will provide our primary data.

Our principal objectives are:

a) accurate determination of systematic variations in the seismic structure of the crust and upper mantle with age.

b) a study of the degree of lateral homogeneity of vertical velocity gradients within the curst.

c) a unified interpretation of all travel-time data from all instruments located off the ridge and fracture zone using a two-dimensional adaptation of the delay-time function method.

1. Principal Scientific Objectives

(a) Variations of Crustal Structure with Age
Evidence from seismic studies carried out during the past five years shows that there exist systematic changes with age of the crust and upper mantle (e.g. Orcutt et al., 1976; Houtz and Ewing, 1976; Lewis and Snydsman, 1977). More precise determination of these variations is important to our understanding of the formation and evolution of oceanic crust.

Clearly, the receivers located along lines 2, 3 and 4 will provide good control on the crustal and upper mantle structure at three ages between 0 and 7 m. y. We consider it important to increase the resolution of this study by locating our eight instruments along line 1 (Fig. 1) to provide many more sampling points and the opportunity to follow systematic variations from receiver to receiver.

Reliable solutions to these data will only be possible if adequate knowledge is obtained of the shallow structure beneath the shot positions. By restricting the interpretations to wave paths within the linear array and by maintaining receiver separations to $\sim$ 25 km, any major lateral inhomogeneities within the upper crust can be detected. The fir-·, and relatively straight forward step with our data from Line 1 will be to calculate delay time surfaces which best fit the Layer 3 and MOHO travel times. This will provide a quick overall view of the degree of homogeneity, help with estimating corrections for basement topography and reveal any major systematic changes in seismic structure. These results together with a study of all eight record sections in an attempt to recognize patters of amplitude-distance relations will then be used to decide which data deserve more careful analysis. Modelling of the amplitudes using synthetic seismogram techniques (requiring assumptions of lateral homogeneity) will most probably have to be restricted to short range shots in order to be meaningful.

Thus, our primary information will be concerning the shallow crustal structure, and our eight receiver positions (eleven including receivers from other institutions) should be sufficient to define well any systematic changes in vertical velocity structure along the line.

The fourteen receivers located along line 4 north of the Rivera Fracture Zone (8 from WHOI and 6 from MIT and LDGO) will determine well the structure of the young crust of the flanks of the East Pacific Rise and thus will provide one of the fundamental structural controls for the project. The high density of data from this 200 km long line will produce an exceptionally well controlled interpretation, the resolution of which will be limited not by the available data, but by the fundamental restrictions of the seismic refraction technique and by the available interpretation methods. We plan to work closely with our colleagues at LDGO and MIT in combining our datasets to produce a unified solution to the data collected along this line.

(b) Lateral Homogeneity of the Crust and Upper Mantle
Most refraction data from the deep oceans have been interpreted in terms of layers of varying thicknesses (using basic slope intercept techniques or delay time methods) or laterally uniform vertical velocity gradients (using τ-p inversions or synthetic seismogram techniques). Studies of lateral changes in the velocity depth structure of the crust and upper mantle have, with few exceptions, been made only on a regional scale. We propose to use the data set collected during ROSE to carry out a detailed investigation of the magnitude and pattern of inhomogeneities (i.e. lateral changes in vertical velocity gradients) within the crust and upper mantle. As the amplitude of refracted waves are highly dependent upon vertical velocity gradients, it follows that this investigation will be centered on a study of amplitude-range relationships and their dependence upon receiver location and shot azimuths.

There are a number of important questions which we believe this study will answer. What variations in amplitude-range relationships (and in the velocity-depth functions necessary to adequately model the waveform characteristics) are observed in receiver-shot combinations which result in overlapping wave paths? What is the degree of this 'overlap' when significant differences are observed? A study of the amplitude-range relationships at receivers separated by a few kilometers to determine what separations result in significant differences in waveform characteristics will tell us the nature and scale of the lateral changes. Sufficient data will be available to determine if systematic variations in the magnitude of these lateral changes exist. Does the crust become more homogeneous with age? Are observed lateral changes dependent upon shot azimuth in any systematic way: Are more inhomogeneities observed perpendicular or parallel to the isochron trend?

Assuming that the data collection techniques can produce true relative amplitude seismic sections the amplitudes on a section are primarily affected by:

a) vertical velocity structure
b) horizontal changes in velocity structure
c) basement topography near the source and the receiver

The effect of vertical velocity structure on amplitudes can be modelled using wave theory methods (Fuchs and Müller, 1971) or ray theory methods (Červený and Ravindra, 1971, Helmberger, 1968, Wiggins and Madrid, 1974) which represent the structure by flat, homogeneous layers. Experience shows, however, that amplitude anomalies can occur which cannot be modelled by these methods. The effects of horizontal velocity changes or basement topography are possible explanations but the extent to which each factor affects amplitudes is not clear. The following procedure is suggested for looking at these effects.

Consider a "region" in which the vertical velocity structure is considered to be constant. The minimum size of this region would be on the order of the length of a refraction line. At least two lines should be shot in the region. Only features which appear common on all the lines should be modelled using the flat, homogeneous layer approximation. When a satisfactory model has been constructed, amplitudes or energy of particular arrivals can be compared between the real data and the synthetics to look for systematic effects which could be caused by topography or local structure near the sources or receivers.

For example, in the first deployment of the WHOI OBH's (Fig. 1) the four pairs of OBH's can be considered to define four "regions" with 4 lines (2 split profiles) in each region. Four models can be constructed to fit the common features in each set of lines. (Changes between the four models may be a function of age). Plots of real and synthetic amplitudes (e.g. Fig. 2) for each line can be constructed and deviations of the real amplitudes from the synthetic amplitudes compared. If the same shot or group of shots cause the same deviation for both receivers, then the deviation is likely caused by topography or lateral inhomogeneity in the source region. If for a particular receiver, the deviations are constant for arrivals which are incident at the same angle, then the deviation is likely caused by topography or

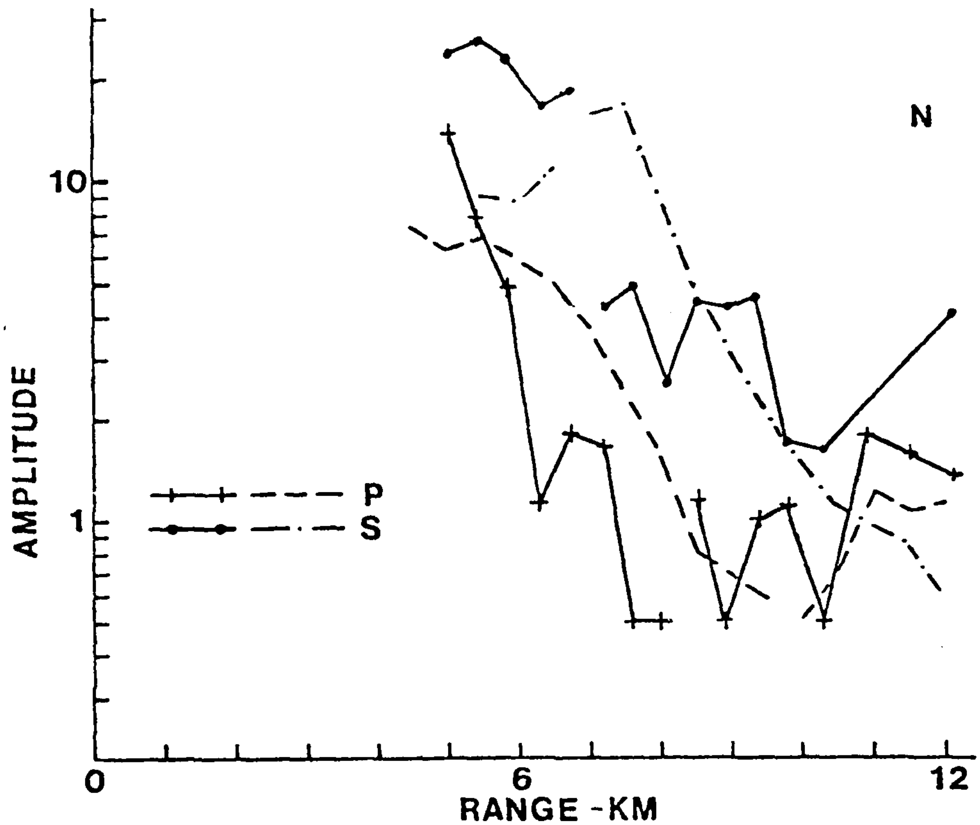


Figure 2: Example of an amplitude-distance plot which compares real data to synthetic (model) data. The real data is from the three-component borehole geophone used in the Oblique Seismic Experiment on DSDP Leg 52. Amplitudes are the root-mean-square peak-to-peak amplitudes of all three components (two components for the synthetics). Solid lines are curves for the observed data and the dashed lines are curves for the synthetic seismogram which was considered to fit the data best. (There were 6 lines of data shot at 2 geophone depths.) The left hand P-wave segment corresponds to refracted P-wave arrivals from Layer 3 and the right hand P-wave segment corresponds to interference arrivals. The left hand S-wave segment corresponds to direct S-wave energy and the right hand segment to refracted energy from Layer 3. The discrepancies between the dashed and solid lines could be caused by topographic irregularities in the source or receiver regions or by lateral inhomogeneities in Layer 2 and 3.

lateral inhomogeneity in the receiver region. Deviations in amplitude that do not satisfy either of these patterns are likely caused by lateral inhomogeneities between the source and receiver. This analysis can be performed for both lines 1 and 4 (Fig. 1) to see if the behavior of the various amplitude anomalies changes between lines across isochrons and lines along an isochron.

(c) Unified Interpretation of Travel Time Data

The primary thrust of this proposal is towards better determinations of the seismic structure of the crust and upper mantle (rather than either lithosphere structure, or the structure of the spreading center or transform fault). A variety of differing interpretation techniques will without doubt, be applied by the different investigators to this aspect of our project. This is a necessary and potentially rewarding situation. We propose to carry out a single interpretation of all travel times recorded away from the ridge and fracture zone using the delay time function method of Morris (1972). Such a large data set lends itself to this type of statistical treatment. Our results will not represent the 'definitive' solution as the technique depends upon certain limiting assumptions (particularly that the crust consists of a set of layers) and only takes account of travel time data. Nevertheless, it does provide a single unified interpretation which may reveal structural trends not obvious from a comparison of the results of many different interpretation techniques. Any such trends could then be more carefully investigated using more rigorous methods of analysis.

In particular, delay time techniques are ideally suited to the determination of anisotropy (e.g. Raitt et al., 1969). Sufficient data will be collected to permit the determination of changes in the degree of anisotropy of the upper mantle with age and to investigate whether or not the lower crust is anisotropic.

2. Secondary Scientific Objectives

In the explosive phase lines 1 and 4 (Fig. 1) will provide two discrete data sets which will be interpreted in detail using travel time and amplitude techniques as part of our interest in changes in structure with age. The structure beneath these two lines will then be known sufficiently well to remove the travel time effects of structural changes beneath the receivers. These receivers will then be well located to study the long range wave propagation across the ridge and fracture zone and enable us to separate the effects of changes in structure around the receiver from those caused by propagation across the heterogeneous structures at different azimuths and depths. The most powerful

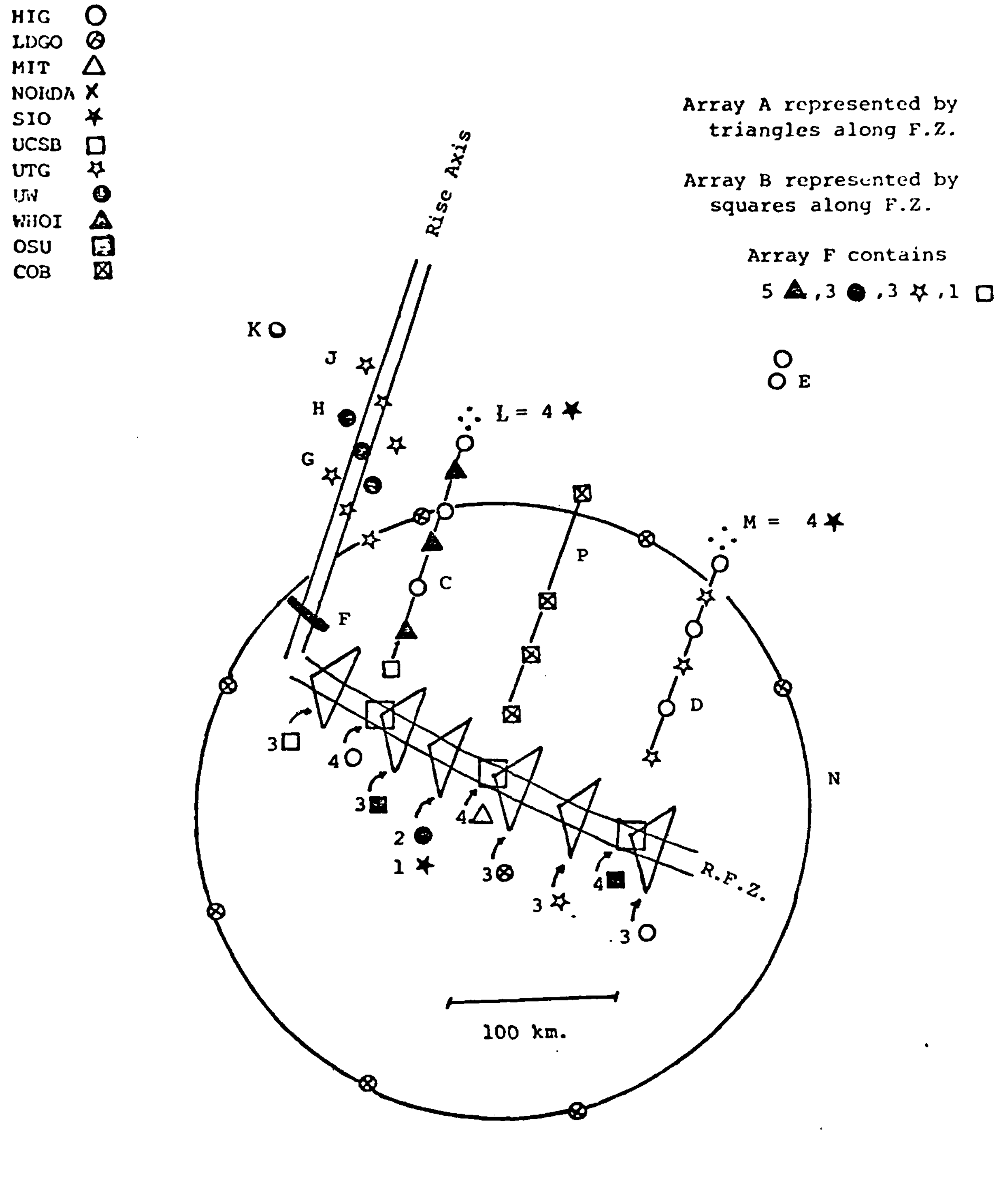


Fig. 3
Instrument layout for earthquake phase

data sets upon which such a study could be concentrated are the one ton shots at the western end of line 1 to the receivers on line 1, (and the comparison of travel time and amplitude distributions with the recordings by these same receivers of the one ton shots at the eastern end of line 1); the one ton shots south of the fracture zone to the receivers on line 1; and the shots on line 5 to the receivers on line 4. In this latter case, the data will be powerful in determining the longitudanal continuity of the low velocity zone beneath the ridge (Reid et al. 1977).

The location of our instruments during the passive phase is shown in Fig. 3. The majority of our instruments are located within the array F which straddles the ridge axis near its intersection with the Rivera Fracture Zone. Three of our instruments are positioned along line 4 in the same locations that they occupied during the second deployment of the explosive phase (Fig. 1). At this time, our plans for interpretation of selected portions of the arthquake data are not well defined. We have a particular interest in carrying out accurate relocations of selected ridge and fracture zone shocks using the velocity structures determined from the refraction experiments. Routine earthquake location programs assume flat layered models of velocity structure. In regions with pronounced lateral heterogeneities, this can produce considerable bias in epicenter location (Aki and Lee, 1976; Engdahl and Lee, 1976). This is especially true in a fracture zone environment because of the assymmetry of the structure. Refinements of the method which compensate for structure by varying the velocity structure beneath the stations and by introducing individually tailored station corrections have been successful in removing some of the bias. The artificial nature of these corrections which are determined somewhat arbitrarily renders this method unsatisfactory when trying to recognize subtle changes in seismicity distributions. The incorporation of recently developed techniques for three dimensional fixed end point ray tracing through heterogeneous velocity models (Julian and Gubbins 1977) into an epicenter relocation scheme will overcome these difficulties by using the velocity structures determined by refraction to refine the epicenter locations.

3. Proposed Work Year 1

Our first major task is preparation for the cruise: this is made difficult by this being our first OBH refraction operation using a non-WHOI vessel (probably R/V CONRAD). As we wish to conserve our fast turn-around capability despite the lack of laboratory and deck space (as the Lamont multichannel, Lamont OBS and MIT OBS system will also probably be on board the CONRAD), we need to devise and implement ways of breaking down, storing and assembling the OBH frames in the minimum of space. To achieve this, the final mechanical and electronic configuration of the instrument will not be changed in any way. We also plan to install our shot instant data logger and acoustic homing system both of which, of course, will be available for use by our colleagues from Lamont and MIT. We will unfortunately be unable to use our digitization system at sea as that depends upon the WHOI shipboard computer system; a minimum analog replay system will be on board to permit fast post-recovery assessments of data quality. Following completion of the field work in late March, a concentrated data reduction effort will begin, directed, at first, towards the explosive data. The single most time consuming step in this procedure will be the digitization of the data. This will be followed by the calculation of horizontal ranges, the application of standard travel time corrections and the construction of amplitude corrected record sections. At this point, the data will be ready for conversion to the standard ROSE format and can be deposited with the data centre.

Our continuous recordings during the earthquake phase will be searched for shocks and these too, will be digitized and distributed. By the end of 1979, the majority of our data reduction tasks will be completed, preliminary travel time analyses of lines 1 and 4 using the data from our own instruments will have been carried out and a start made on more careful amplitude analyses on selected portions of our data.

Equipment

The Woods Hole OBH is designed primarily for multiple deployments as a fixed ocean bottom receiver for seismic refraction work. It is designed to float 3m above the seafloor at depths of up to 6100 meters for periods of up to 10 days and continuously records the output of a single hydrophone on a four channel 1/40 i.p.s. analog magnetic tape recorder. The four channels are time code, two data channels separated in gain by 20 dB, and a rectified high frequency channel to allow clear identification of the water wave arrivals. A standard AMF acoustic transponder and release system is used. All 21 deployments so far carried out have yielded good data.

Our shipboard system installed in the main lab of the research vessel consists of the following: a master chronometer with a crystal accurate to 1 part in 10^9 used to synchronize the OBH clocks; test panel for the formalized pre-launch and post-recovery check-out procedures on the OBH instruments; a shot data logger linked to the shot instant hydrophone which automatically records on paper tape shot instant time (absolute), bubble pulse period (for shot depth determination), fuse burn time and ship's course and speed. Shot size is input manually. Shot instants are also recorded on an analog chart recorder as a backup. A four channel tape recorder and ultra-violet oscillograph recorder are used for fast replay of sections of each OBH tape for quality control immediately upon recovery. A simple acoustic homing system consisting of two hydrophone arrays streamed port and starboard from 30 foot long outriggers, linked to a storage oscilloscope and a graphic recorder, allow the ship to be conned over the top of each OBH in turn during the shooting run (the travel times of the transponder signal on the OBH to each of the two hydrophone arrays are maintained equal by changing the ship's course).

Budget Justification

We request salary support for the principal investigators Ewing, Purdy and Stephen, two of whom will go to sea (Ewing and Purdy) to supervise data collection. Koelsch and Witzell are engineers who will take responsibility for the preparation, testing and shipping of equipment and its refurbishment after the cruise. Koelsch will supervise primarily the electronics preparation and Witzell the mechanical hardware. They will be assisted by Grant and Handy respectively. The four months support for Grant is justified by the slow, tedious task of preparing and refurbishing the necessary nine AMF acoustic release transponders, the making up of the necessary 64 OBH battery packs and all the routine preparation of the OBH instrument and replay electronics. Koelsch and Grant will go to sea. Four months support each is requested for a research assistant (C. Dean) and a programmer. We consider this a realistic minimum in order to carry out the huge data reduction tasks, convert our data into ROSE standard format and begin preparation of standard programs to process ROSE format data received from other institutions. The four months support for a Summer Student Employee is to assist in this, especially in the straightforward, routine, but slow digitization process.

We request no permanent equipment. The majority of the items of expendable supplies are self explanatory and are the standard necessities to carry out four deployments of eight ocean bottom hydrophones. Some of these items, however, are needed specifically for ROSE e.g. we request $400 to modify the 8 OBH battery frames to accept lithium cell batteries. In this way we can extend the life of the OBH chronometer to >15 days so that if a logistic problem should prevent recovery of any of our instruments before the 10 day limit at which the tape is expended, the clock would still continue running so they could be checked and accurate drift corrections be applied upon their recovery. Recent experience has indicated that the 9-10 kHz acoustic transponders give significantly greater operating range than do the 13-13.5 kHz versions, and we request funds to convert four of these units. All 8 of our OBH's can then have this range advantage. On a WHOI vessel, the AMF transducer is built into the hull: as we will be operating from a non-WHOI ship, we request $400 to build a towfish to allow overside towing of this vital transducer. As there will be insufficient deck space to store our OBH frames intact between deployments, we need to change the way the glass balls are attached to the instrument packages to allow them to be disassembled quickly for storage. For this, we request $400. In addition, we request $100 to build a staging rack to speed up this tedious assembly and disassembly process.

The travel funds are to allow Ewing, Purdy, Koelsch and Grant to participate in the cruise. The 80 hrs. of Graphic Arts is for drafting of our preliminary results.

We request 160 hrs. of H-P computer time for digitization of the OBH tapes, and 135 hrs. of VAX computer time for data reduction, conversion to ROSE format and preliminary interpretation efforts. The editing of the data and its sorting and conversion to ROSE format will be speeded up significantly by the use of large amounts of disc storage on the VAX computer. Thus, we request 1/4 cost of leasing a 176 megabyte disc drive. The 182 hrs. shop services is for the conversion of the OBH frames, construction of shipping crates and packing the ~6 tons of equipment preparatory to shipment to the West Coast. No funds are requested for the actual shipping costs.

We request 12 months support for a GRA, Anne Tréhu, who is a graduate student entering her third year and will be working full time on the ROSE data as her Ph.D. thesis project.

APPENDIX: ABSTRACT FROM ROSE OVERVIEW PROPOSAL

The principal objective of this project is to understand how new material emplaced at an accreting plate boundary evolves into the "typical" structure postulated for the outer 100 km of the earth's surface. A variety of observations indicate that at almost all depths in the crust and upper mantle there are detectable changes that relate to age. We believe that a large step toward understanding the driving mechanism of plate tectonics can be made if we acquire a sufficient set of quantitative, high-resolution seismological data on and near a substantial segment of a spreading ridge axis. Toward this end, we propose to use ocean bottom seismographs (OBS) and other instrumentation for a two-month period of recording both earthquake and explosive events on and near the Rivera Fracture Zone. We plan to deploy between 60 and 80 OBS and OBH units in patterns which will vary according to the purpose of the various experiments. The first deployments are designed primarily for explosion seismology and will be in operation 2-3 weeks. The pattern will utilize several lines of explosions of various sizes for studying specific problems associated with features of the Rivera plate, velocity versus depth and attenuation of the sea bottom, crust, and upper mantle; and vertical and lateral geometry of significant boundaries in the upper lithosphere. At the East Pacific Rise objectives are the detection and delineation of low velocity zones and the definition of the Moho. Closely spaced detectors and shots along and perpendicular to the rise crest will furnish required ray-paths. Extended linear patterns of OBS across the Rivera Plate are intended to study the geometry and nature of velocity gradient boundaries as a function of depth and age of the crust. Large explosions detonated along lines east and west of the East Pacific Rise and along isochrons will be recorded by array elements. The propagation parameters obtained from these recordings should permit us to make a comprehensive analysis of the travel times and energy partitioning along paths through lithosphere at various distances from the accretion axis, as well as along paths through different levels of the accretion zone and fracture zone. Structural models determined by various inversion techniques can be tested and refined by comparing measured travel times and wave forms with synthetic seismograms derived from the models, additional experiments are planned using an orthogonal OBS array with a vertical hydrophone array to measure bottom impedance, reflectivity, and mode attenuation coefficients.

The second deployment is designed primarily for earthquake recording. The receiving array is designed to pursue two primary objectives: (1) to measure earthquake source parameters along the western portion of the Rivera Fracture Zone and study their variation as a function of position along the transform fault; and (2) to measure body and surface waves generated by earthquakes located on the fracture zone and rise crest, as well as by teleseismic events.

In addition to the spatial and temporal patterns of seismicity, which is of fundamental interest for the study of crustal spreading and transform faulting, source characterization of the earthquakes will be possible to a unique degree because of the large number and variety of near-source sensors simultaneously in operation. Of particular interest are the depths of earthquake foci and their variation along the transform fault with decreasing age contrast across the fault. The purpose is to obtain a quantitative measure of the change in the depth to a brittle-ductile transition in the crust and to infer crustal stresses from measurements of focal mechanisms well-constrained in location and depth with essential azimuth control. The wide variety of instruments will permit measurement of stress-drop, source-dimension, and seismic moment and evaluation of rise time and rupture velocity and the source.

Present observations of increasing seismic velocity with the age of the crust will be tested using earthquakes as seismic sources. Of particular value are shear waves and surface waves which are poorly generated by explosions. The seismic arrays are designed to detect waves traveling in the direction of increasing age and along isochrons. Thus, with earthquake-produced shear, Love, and Rayleigh waves it will be possible to obtain S-wave velocity structure as a function of depth and of age of the crust. These detectors will simplify the determination of pure-path measurements and provide short period high resolution estimates of the S-wave structure for 0 to about 7 m.y. old lithosphere. In addition to measurements of possible anisotropy, arrays over spreading centers and fracture zones would permit mapping of the seismic structure under an array where lateral inhomogeneity exists. With earthquakes of sufficient size, it will be possible to examine the asthenosphere to depths of tens of kilometers beneath the rise crest.

SEISMOLOGY III
PROJECT ROSE
WOODS HOLE BUDGET
1 January - 31 December 79

A.	SALARIES AND WAGES	ONR M/M		
	Professional:			
	J. I. Ewing, Senior Scientist	4.0		
	G. M. Purdy, Assistant Scientist	7.0		
	R. A. Stephen, Assistant Scientist	4.0		
	D. E. Koelsch, Res. Specialist	4.0		
	W. E. Witzell, Res. Specialist	1.5		
	Support:			
	C. Grant, Sr. Res. Assistant	6.0		
	R. Handy, Res. Assistant	1.0		
	C. Dean, Res. Assistant	4.0		
	Programmer (TBA)	4.0		
	Summer Student Employee	4.0		
1.	Gross regular salaries, includes allowance for vacations, holidays and sick pay of $ 7530 which is accounted for as employee benefits		$ 66,420	
2.	Cruise Leave, Sea Duty Vacation and overtime including premium pay of $1017		10,824	$ 77,244
B.	OTHER EMPLOYEE BENEFITS			21,750
C.	TOTAL SALARIES AND BENEFITS			$ 98,994
E.	EXPENDABLE SUPPLIES AND BENEFITS (see detail) Assuming 32 OBH deployments			$ 18,495
F.	TRAVEL (Domestic) 4 R/T West Coast (12 days expenses) A/F - $1,840 T/E - $600, Cars-$ 240			$ 2,680
G.	PUBLICATION COSTS: 1. Graphic Arts - 80 hrs @ $13			$ 1,040
H.	SHIP COSTS (None)			
I.	COMPUTER AND PERIPHERAL COSTS			
	1. 160 hrs H-P computer @ $25	$ 4,000		
	2. 135 hrs VAX 11 @ $45	6,075		$ 10,075
J.	OTHER MISCELLANEOUS COSTS			
	1. Communications	$ 500		
	2. Programming: 40 hrs @ $19.60	784		
	3. Shop Services: 182 hrs @ $13	2,366		
	4. Laboratory overhead of 21% of C, exclusive of premium pay	20,575		
	5. GRA: 5 mos @ $1070, 7 @ $1,155	13,435		
	6. 1/4 cost of leasing 176 megabyte disc drive for VAX computer	3,000		$ 40,660
K.	TOTAL DIRECT COSTS			$ 171,944
	Indirect costs @ 15% of TDC			25,792
L.	TOTAL COSTS			$ 197,736

BUDGET DETAIL - PROJECT ROSE

E. EXPENDABLE SUPPLIES AND EQUIPMENT (assuming 32 OBH deployments)

1.	Magnetic tape (32 reels 1/4" tape for OBH, 64 reels 1" tape for transcribing, 64 2400' reels of 9T digital tape)	$ 3,080	
2.	Batteries for OBH and AMF acoustic release/ transponders	4,000	
3.	Hardware, anchors, line, misc. rigging	3,000	
4.	Recorder paper (20 rolls for H-P recorder, and 70 rolls @ $37/roll for UV recorder)	2,990	
5.	Electronic spares (for OBH, AMF acoustic releases, shipboard test gear and lab replay system)	1,000	
6.	Plotter paper and mylar, files, envelopes, teletype paper	500	
7.	Boxes and packing materials for shipping	665	
8.	4 boards to convert existing AMF releases to 9-10 kHz band	1,760	
9.	Construction of towfish for AMF transducer and towing cable	400	
10.	Modification of OBH frames to allow fast removal of glass balls	400	
11.	Shipping racks for shipboard electronics	400	
12.	Outriggers and rigging for towing homing system hydrophones	200	
13.	Hanging rack for staging single OBH	100	
	TOTAL EXPENDABLE SUPPLIES AND EQUIPMENT		$ 18,495

SEISMOLOGY IV

OBH System Hardware: Basic Support and Maintenance

G.M. Purdy

(617) 548-1400 Ext. 574

Long-Range Objectives

This program supports, maintains and develops all the hardware components of our refraction system with the objective of providing a routine, but constantly improving, capability for carrying out precise seismic refraction measurements in the deep ocean.

Current Status Report

Our efforts during 1978 centered on the re-design and re-building of the digitization controller and associated hardware, and the maintenance of the replay system. The primary function of the digitization controller is to condition and multiply the OBH time code signal frequency (25 Hz) for use as a digitizer time base (thus removing the effects of tape wow), and convert the time code into a computer readable form. We found that our original controller was too sensitive to the small changes in amplitude of the time code and the variations in amplitude and tape speed between the different OBH instruments. The timing errors thus produced could only be detected by a slow and tedious checking scheme in software. The new controller can handle all four channels of OBH data simultaneously, and has reduced the number of timing errors by a factor of about ten. Most importantly, when a dropout of the phase lock loop occurs (the most common cause of a timing error), a flag is set in the computer so the header record of that particular shot can be marked as containing an error. Thus, considerable time is saved by only having to check the shots which are flagged in this way.

The advantages of continuous analog recording, as opposed to digital recording, are many and have been discussed in previous proposals. The major disadvantage is that of amplitude fidelity, this being limited by small changes in tape speed with time. We have been continually trying to improve this: the 10 Hz calibration pulse put into the tape every hour provides good control on the long-term changes, but short-term changes are difficult to detect reliably. By testing in the laboratory and making small changes to the tape recorder design, we have been attempting to improve the amplitude fidelity of our recording, though we doubt we can ever attain results comparable with those possible with a digital system. We have not yet found that these problems limit the accuracy with which we can interpret our data, but it remains a possible limitation of our instrument in the future.

Proposed Programs

The continued development and careful maintenance of our electronics systems is vital to the continued success of our programs. The small amount of support we request in this proposal has proven to be of considerable value. These funds ensure that the reliability of our instruments will continue at their present high level, and that our replaying, digitizing and calibration procedures are not continually delayed by trivial hardware failures.

We are constantly investigating ways of reducing the cost of our OBH operations. One of the most expensive parts of our system (spares and batteries, and salaries required for maintenance) are the AMF acoustic release transponders. They are also large and heavy, difficult to handle on deck, and expensive to ship. However, they clearly have an incomparable reliability record, which we do not wish to lose under any circumstances. We request funds in this proposal to purchase one Sonatech acoustic transponder release for testing and evaluation. These units cost approximately half that of AMF, have the same capabilities, are small and light, and use all digital electronics, which require the minimum of maintenance. Their reliability is not well proven at this time, so we do not wish to make the big step of converting all our instruments. However, should the Sonatech release prove to be as reliable as AMF, then considerable savings in money, time, and effort would be possible in the future. The release encoder is required to make our shipboard AMF command transmitter/receiver compatible with the Sonatech units. This request for funding is indicative of our wish to maintain a continually improving hardware capability so we will be able to progress to better data acquisition methods smoothly without the need for major redesign efforts.

We also request funds to increase our spares inventory by building two spare sets of cards for the OBH instruments, and two spare Benthos glass balls. There is a clear and continuing need for synchronizing our master chronometer with WWV time signals: the available receivers have proven unreliable and inadequate for this, so we request funds to purchase a new receiver.

BUDGET

SEISMOLOGY IV

(General OBH Hardware Support)

		Man/Months	
Professional Personnel			
	D. Koelsch, Research Specialist	1.5	
Support Personnel			
	C. Grant, Senior Research Assistant	1.5	
A.	Gross regular salaries (includes allowance for vacations, holidays, sick pay of $648, which is accounted for as employee benefits)	$ 5,397	
B.	Other Employee Benefits	1,347	
C.	Total Salaries and Benefits		6,744
D.	Permanent Equipment		
	1. Sonatech AMF compatible		
	a. Release Encoder	850	
	b. Sonatech release/transponder	4,300	
	2. Digital multimeter: Fluke Model 8030A-01	275	
	3. Spare OBH cards (two sets)	835	
	4. Two Benthos 17" glass balls @$274/ea.	548	
	5. WWV Receiver: Yaesu FRC7000	655	
			7,463
E.	Expendable Supplies and Equipment		
	1. Misc. electronic components (transistors, etc.)	250	
	2. UV Oscillograph - 10 rolls @$3.70	370	
	3. 3 sets of OBH batteries @$85	255	
	4. 2 reels - 7200', 1" Sangamo tape @$67	134	
	5. Mechanical & electronic spares for AMF acoustic transponder release system	500	
	6. Misc. electronics spares for replay system	200	
			1,709
F.	Miscellaneous Costs		
	1. Shipping and Communications	200	
	2. Shop Services - 40 hrs. @$13	520	
	3. Lab costs of 21% of C, exclusive of prem. pay	1,416	
			2,136
G.	Total Direct Costs		18,052
H.	Indirect Costs @ 15%		2,708
I.	Total Costs		20,760

SEISMOLOGY V

DEEP IMPLOSIVE SOURCE

J. I. Ewing and G. M. Purdy

J. I. Ewing Tel: (617) 548-1400 Ext. 265
G. M. Purdy Ext. 574

This task is directed toward learning the design parameters of a seismic source that will permit us, eventually, to carry out high resolution seismological studies by putting both source and receiver on or near the sea floor.

At the time of this writing, we have only a small amount of progress to report. This is in no way an indication of lack of interest on our part, but rather a matter of scheduling and other commitments.

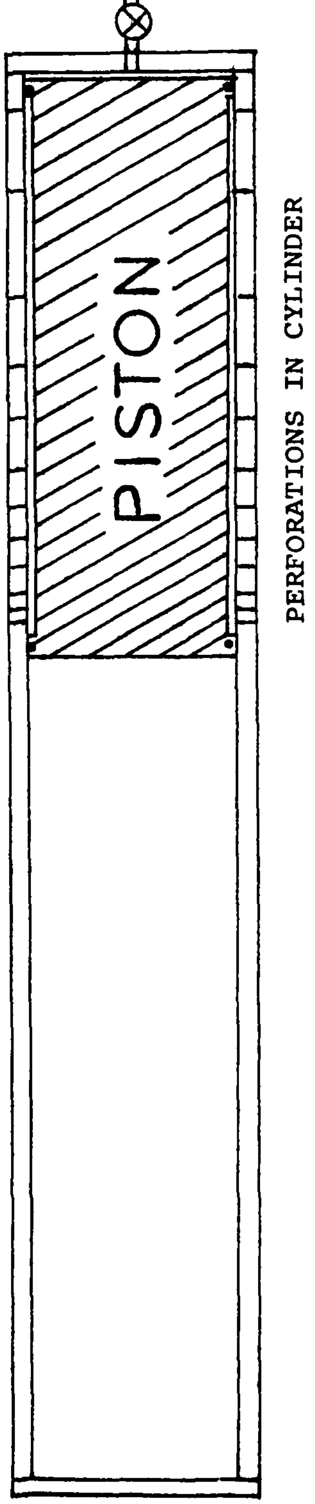
A prototype cylinder .5 meters in length and 12 cm inside diameter has been fabricated along with three separate end caps with orifices of 4, 8, and 12 cm. Investigation into various materials have led us away from our original plan to use glass discs as the imploding element. This decision was based both on cost and delivery schedules. Cast iron and cast aluminum discs have been cut from plate stock and tested with the prototype cylinder in a pressure tank and appear to rupture cleanly and with good repeatability. Thus we feel that our original plan to test various configurations of implosion sources, designed to operate by a rupture of the end cap of a cylinder, is still a valid one. Our present plans are to conduct field tests to measure levels and wave forms of sources with a variety of volume and orifice configurations and at a range of depths (pressures) in October/November of this year.

Discussions with colleagues inside and outside the Institution have led us to believe that a modification of the rupture disc design should also be considered. In the rupture disc design, the rate of filling of the cylinder probably reaches a maximum a very short time after the disc ruptures. As the acoustic energy is produced during the acceleration period, d^2v/dt^2, an improvement in the performance at the low frequency end of the spectrum should be achieved by a design that extends the time of acceleration of filling. A relatively simple method that may provide the desired effect is illustrated in Figure 1. In this design, the orifice area is increased with time after initiation of the infilling until the top of the piston has cleared the lowest of the orifices.

Funds allocated for the current year are sufficient to enable us to carry out these tests. Although we are optimistic about the results expected, we are obviously not in a position to ask for additional funding at this time. We hope the results will justify further funding and, if so, we will request it as an acceleration at an appropriate date.

FIGURE 1

Implosion is initiated by opening the valve at the top of the cylinder. As the piston moves downward, the rate of infilling is increased and the piston continues accelerating until the piston has passed all of the orifices.



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MARINE MAGNETIC ANOMALIES

Hans Schouten and Charles R. Denham

Hans Schouten Tel: (617) 548 1400 Ext. 574
Charles R. Denham Ext. 465

Long Range Objectives

1. The detailed understanding of the statistical relationships between magnetics, bathymetry and gravity in the oceans.

2. The use of enhancement techniques to improve the recognition and correlation of magnetic anomalies and to better determine the structure and evolution of fracture zones.

3. The quantitative study of marine magnetic anomalies to investigate the evolution of the source characteristics as a function of time and space.

Present Status and Progress in 1978

Numerical Models of the Sea Floor Spreading Magnetic Anomaly Source Layer:

We have completed our statistical studies on the variability of oceanic crustal accretion and its impact on marine magnetic anomalies and the occurrence of polarity reversals in basement drill cores. Our modeling has focused on a spreading system having Gaussian stretching and Gaussian spatial lava accumulation with Poisson temporal volcanic activity. The results have shown that the small-scale magnetic anomalies (the so-called tiny wiggles) are easily explained by the random accumulation of 5-10 overlapping lava units per kilometer spreading, both in slow and in fast spreading systems. Thus, while it is possible that some tiny wiggles are the result of actual geomagnetic activity, it appears likely that most are due to the accretion process and hence cannot be depended upon either for correlation or for refining the magnetic polarity time-scale. The paper was recently presented at the Second Ewing Symposium, and the manuscript for the Symposium volume is completed (Schouten and Denham, 1978 in press).

Magnetic Bacteria:

We have devoted some of our attention to a new interdisciplinary study with biologists A. Kalmijn (WHOI) and R. Blakemore (New Hampshire) on the magnetic properties of magnetotactic bacteria. Our motivation derives from the possibility that the bacteria are a significant source of small-grained, stably magnetized particles for deep sea sedimentary paleomagnetism. Through experiments with anhysteretic remanent magnetization in freeze-dried cells, we have observed median coercive forces exceeding 300 oe, which would be very adequate for preserving the geomagnetic signature in sediments. The bacteria may provide assurance that the paleomagnetism is permanently recorded even if the magnetic properties of other detritus are not themselves adequate for the purpose. Our data have also helped to explain the behavior of living cells exposed to strong magnetic fields. The median coercive force of freeze dried material and the median repolarization field of living cells are similar. Overall, the body of data being accumulated by all of us, including R. Flankel at the MIT National Magnetic Laboratory, is consistent with strings of single-domain pure magnetic crystals as being responsible for the magnetotactic effect. The findings are biologically and geologically important, and we plan to continue this particular phase of our work during the coming year, using our paleomagnetism laboratory and Kalmijn's controlled magnetic field facility at Fenno House.

Cretaceous Quiet Zone in the Central North Atlantic

The first half of this year, we have devoted part of our effort to the prediction of the major structural trends related to the sea floor spreading origin of the Cretaceous Quiet Zone (CQZ).

The approximately 400 nm wide CQZ's in the western and eastern North Atlantic are devoid of sea floor spreading magnetic lineations and are bounded by lineations MO (108 m.y.b.p.) and 34 (80 m.y.b.p.). We have compiled all available crossings of anomalies MO and 34 in the central North Atlantic. The abundance of MO locations in both the western and eastern North Atlantic provide a fit of an estimated accuracy of ± 10 nm. In establishing the fit of the less abundant anomalies 34 on both sides of the central North Atlantic, we rely heavily on the assumption that the Kane Fracture Zone, traced by Purdy et al. (1978) between anomalies 34, is indeed one and the same fracture zone, and not an unfortunate composite of closely parallel topographic expressions.

We have analyzed all available magnetic anomaly information near the Kane Fracture Zone and found that a unique system of offsets in anomalies 34 (and younger) on both sides of the central North Atlantic will support the topographic correlations made by Purdy et al. (1978).

The Kane Fracture Zone trace provides the most detailed picture of the central North Atlantic relative plate motions during the past 80 m.y. and, consequently, is an important baseline for the analysis of topographic and structural trends in the 0-80 m.y. part of the central North Atlantic between the Barracuda - 15°20'N Fracture Zone and the Pico-Gloria Fracture Zone near the Azores.

An accurate finite difference pole of relative central North Atlantic plate motions during the Cretaceous Quiet Zone (80-108 m.y.b.p.) has now been determined by superposition of anomalies MO and 34 on both sides of the central North Atlantic. This finite difference predicts the mean trend of the major topographic and structural discontinuities of sea floor spreading origin in the western and eastern North Atlantic CQZ's. It is the only hard fact that can be used in the evaluation of topographic, magnetic, and gravity correlation between adjacent ship tracks.

Since the finite difference pole predicts only the average motion between 108 m.y.b.p. and 80 m.y.b.p., we rely heavily on very detailed analysis of the available fracture zone data to obtain the actual relative central North Atlantic plate motions during the CQZ to the same degree of accuracy as the 0-80 m.y.b.p. Kane Fracture Zone survey and the 108-155 m.y.b.p. relative motions which Schouten and Klitgord (in prep.) derived from the western North Atlantic Mesozoic magnetic anomaly lineation pattern between the Bahama Escarpment and the Newfoundland Fracture Zone and its mirror image off West Africa.

The available bathymetry and Continuous Seismic Profiling (CSP) information in both CQZ's is in itself insufficient to establish the detailed traces of fracture zones. The bathymetry maps of the western North Atlantic CQZ display a predominant trend that agrees well with our prediction. However, in absence of polarity reversals during the CQZ interval, there are no correlatable sea floor spreading lineations that, by their offsets, identify the major fracture zones and, by their separation, identify changes in rate and direction of spreading. The available bathymetry and CSP information along tracks is, as yet, inconclusive by the nature of its wide and erratic distribution and the pronounced overall topography in the CQZ of the western North Atlantic. In the eastern North Atlantic, the bathymetry and CSP information is even more widely spaced and the thick sedimentary cover eliminates bathymetry as a tracer of fracture zones.

We have collaborated with Dr. B.J. Collette of the Vening Meinesz Laboratory, The Netherlands, in the scientific preparation of this eastern North Atlantic CQZ Kane survey o/b SS. Tyro (June 1978). Kristin Rohr, a WHOI-MIT joint program graduate student participated in the cruise. The preliminary results of this important survey confirm the continuity of the Kane Fracture Zone in the CQZ along the predicted mean trend. We continue our collaboration with the Vening Meinesz Laboratory in the final analysis of the

CSP, magnetics and gravity data to detail the actual trace of the Kane Fracture Zone between 80 and 108 m.y.b.p., which will provide the baseline for our detailed structural analysis of the central North Atlantic CQZ.

The second half of this year we will devote our attention to the one-dimensional numerical analysis of magnetic anomaly tracks in the western CQZ, primarily in order to locate the positions of the major magnetization contrasts which generate the anomalies. Cross-spectral estimates of CQZ magnetics, bathymetry and gravity have shown that the basement topography is not the main source of the CQZ magnetic anomalies. The available tracks are widely and erratically distributed, but correlation of the major magnetic discontinuity locations with the predicted continuation of the well known Mesozoic fracture zones (Schouten and Klitgord, 1977) will allow identification of fracture zone anomalies and analysis of their source characteristics. The results of this study will further predict the structural grain of the central North Atlantic CQZ and its relationship to the magnetic anomalies.

Structural Interpretation of the Residual Contours from Project Magnet Surveys, Charts 0806-2 and 0706-3:

Through Code 3521, Magnetics Division of the Naval Oceanographic Office, we obtained the residual magnetic contours SW of Bermuda (Figure 1a) based on W-E aeromagnetic lines flown at 6 n.m. spacing. The control of the contour maps and the quality of the magnetic data surpasses by far the shipboard information used by Schouten and Klitgord (1977) to identify the Mesozoic lineations and fracture zones in the western North Atlantic (Figure 2). Our interpretation of the contour maps (aided by the actual aeromagnetic residual anomalies plotted along track) is shown in Figure 1b. It establishes an extremely consistent pattern of Mesozoic sea floor spreading lineations (M25: 155 m.y.b.p., MO: 108 m.y.b.p.) and fracture zones. It confirms the changes in trend that coincide with the major changes in spreading rates that occured at anomaly M21 and between anomalies M11 and M4, when a world-wide reorganization of plate motions took place that included the breakup of South America and Africa (Schouten and Klitgord, in prep.). The trend in the Jurassic Quiet Zone (Blake Spur Anomaly - M25) is apparent even at the coarse (50 gamma) contour interval, the M11-MO trend can be continued into the Cretaceous Quiet Zone (east of MO) and conforms to the finite difference pole of CQZ relative plate motions that we discussed above.

These magnetic data, to date available only in the biased format of 50 gamma contour maps, establish the structural grain

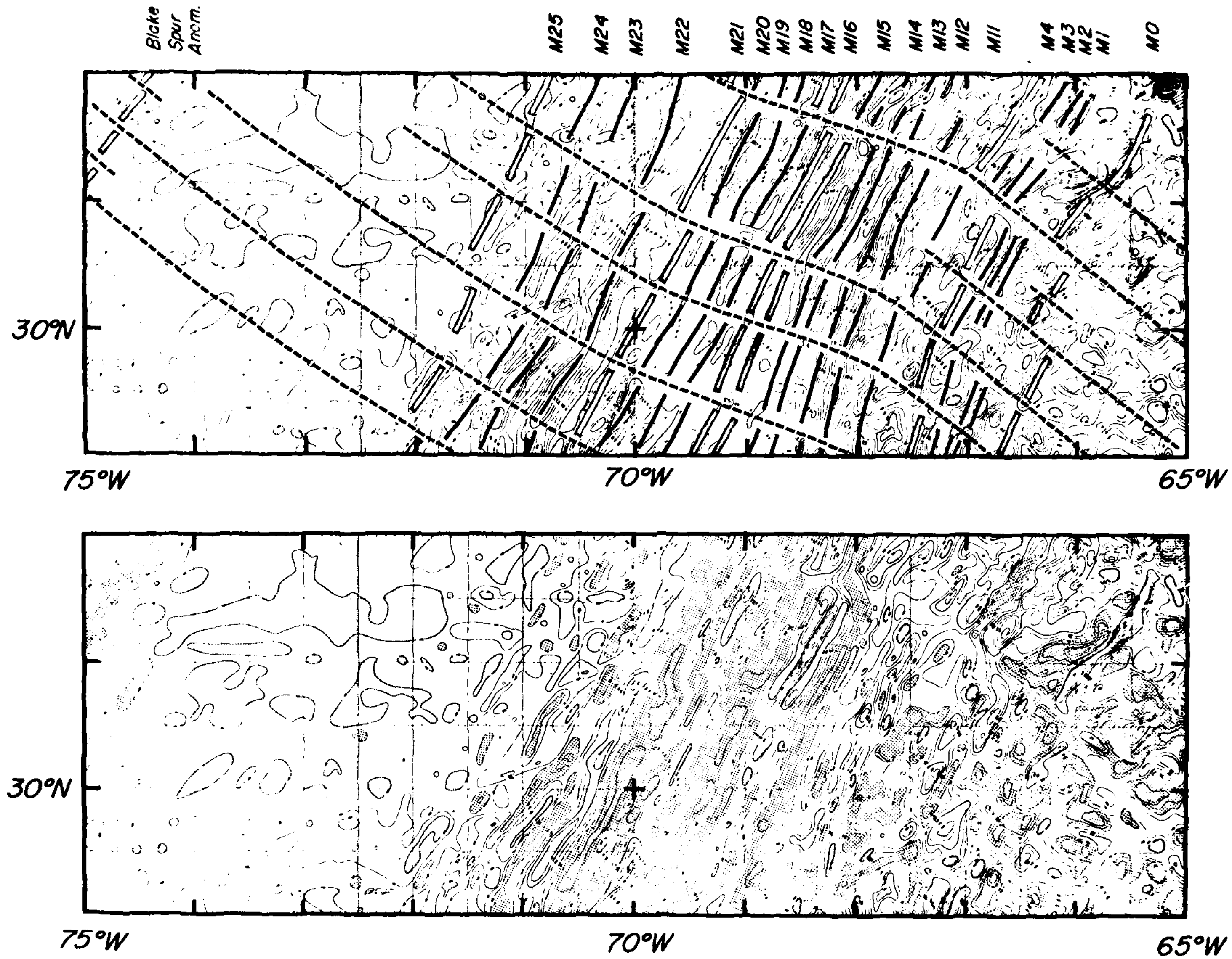

Figure 1. Interpretation of the Residual Contours from Project Magnet Surveys, Charts 0806-2 and 0706-3.

a) Lower. Magnetic anomaly map. The contour interval is 50 gammas, with stippling on regions more positive than -100 gammas. The map is based on east-west aeromagnetic lines at 6 n.m. spacing.
b) Upper. Interpretation of sea floor spreading anomalies M0-M25 and the Blake Spur Anomaly. The Cretaceous Quiet Zone lies to the southeast of M0, and the Jurassic Quiet Zone is between M25 and the Blake Spur Anomaly. The inferred fracture zone traces are shown by dashed lines.

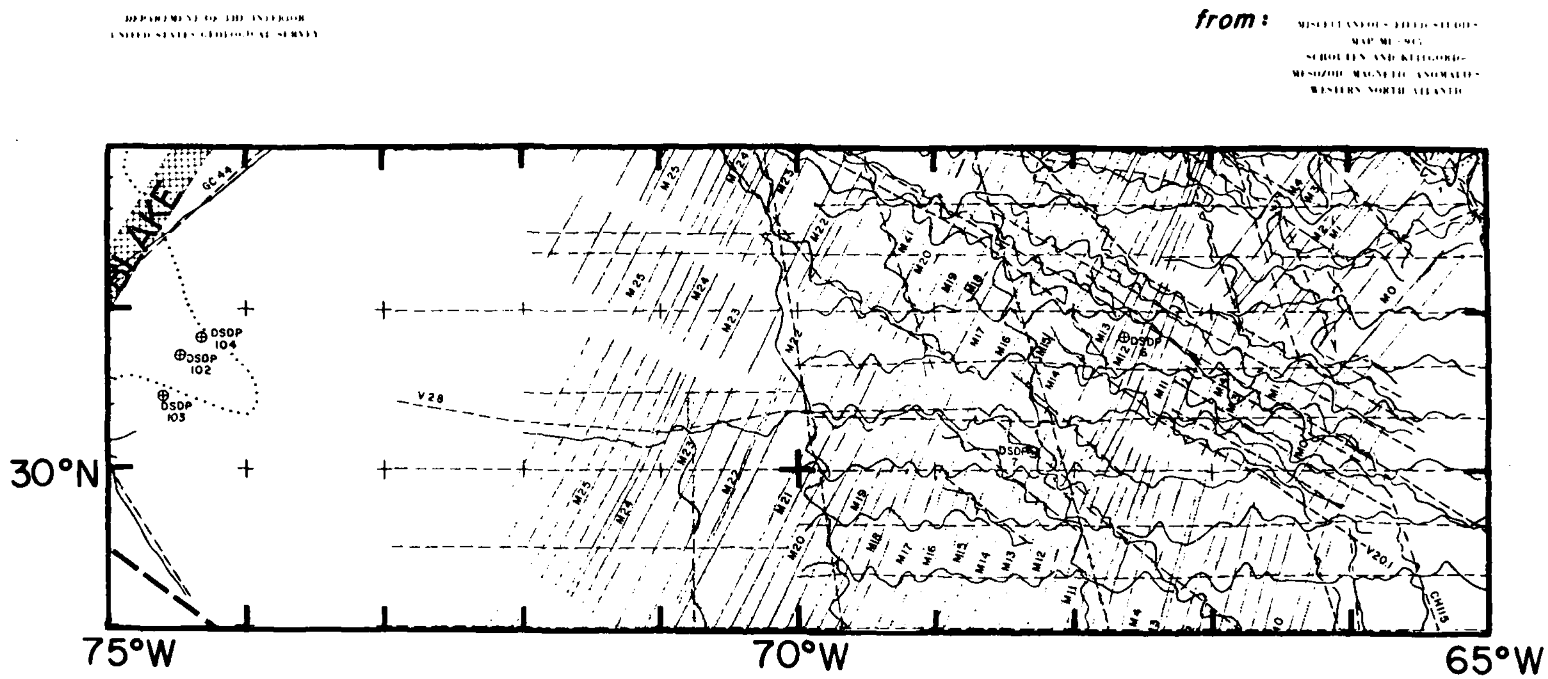

Figure 2. Interpretation of lineated marine magnetic anomalies in the same area as Figure 1, based exclusively on other data. The anomalies are shown as solid lines along the dashed ship's tracks. From USGS Map MF-915 by Schouten and Klitgord (1977).

of the western North Atlantic to a very high degree of accuracy and will be of great importance to those in the scientific community that are concentrating their efforts on the structure and evolution of the oceanic crust and continental margin off the U.S. East Coast.

Proposed Program for 1979

The uniform density of high quality aeromagnetic data collected off the U.S. East Coast by the magnetics division of the Naval Oceanographic Office is of great value to further our understanding of the structure and evolution of the early western North Atlantic sea floor. The understanding of the earliest evolution of the present North Atlantic Ocean will have a significant bearing on the study of the structure and evolution of the U.S. East Coast continental margin which has become a major target of the U.S. marine geological and geophysical efforts.

For 1979, we request support to interpret the western North Atlantic Project Magnet data and, particularly, to perform two-dimensional numerical analysis on the digital aeromagnetic data, in collaboration with Code 3521, Magnetics Division. In mid-August, Denham, Klitgord and Schouten will visit the Magnetics Division in Bay St. Louis to discuss our analysis of magnetic anomalies and the early sea floor spreading history of the central North Atlantic in relation to the Project Magnet survey and its analysis.

Of the numerical methods available to quantify and enhance trends in a two-dimensional distribution of data points, we consider directional filtering one which is very appropriate for the analysis of the digital Project Magnet data.

Two-dimensional directional filtering (Cote et al., 1960; Syberg, 1972) can be used to enhance the distinction between sea floor spreading anomalies and the orthogonal fracture zone signatures seen in magnetic measurements along closely-spaced parallel tracks such as the recent Project Magnet survey. Our objectives in applying directional filters to the magnetic data will be to detect the positions, orientations, and continuity of the fracture zones accurately both within the region of lineated sea floor spreading anomalies and in the adjacent Cretaceous and Jurassic Quiet Zones. The Quiet Zones represent long periods of time for which few details on the spreading history are known. Subtle fracture zone signatures can be seen there in the coarse 50 gamma contour charts which we hope will be enhanced in the directionally filtered digital data and its corresponding analytical function representation. (Nabighian, 1972) Another important type of directional filtering which we will use is the three-dimensional reduction to the pole (LeMouel, 1972), to standardize the magnetic anomalies.

The quality and uniform density of aeromagnetic information over an area of regionally well-studied sea floor as the Jurassic Quiet Zone, Mesozoic lineations and Cretaceous Quiet Zone, enables us to use two-dimensional numerical methods to enhance the detail of the structural grain of the underlying sea floor and to analyze the characteristics of the magnetic anomaly source.

To date, the U.S. Navy Project Magnet aeromagnetics survey covers the western North Atlantic west of 60°W and between 29°N and 42.5°N and the area between 50°W,60°W,35°N and 37.5°N. The U.S.N.S. Keathly shipboard magnetics continue this coverage south to latitude 23°N. The release by the U.S. Navy of this data in a digital format will be a major contribution to the scientific and economic endeavours off the U.S. East Coast continental margin. We urgently request ONR's intermediation in encouraging the release of this valuable data set.

So far this year, we have in press five papers prepared under full or partial ONR support, as follows:

Bowin, C., R. S. Lu, C. S. Lee, and H. Schouten, 1978. Plate convergence and accretion in the Taiwan-Luzon region. Amer. Assoc. Petrol Geol. Bull., September issue.

Purdy, G. M., P. P. Rabinowitz, and H. Schouten, 1978 in press. The Mid-Atlantic Ridge at 23°N: bathymetry and magnetics. In: Initial Reports of the Deep Sea Drilling Project, Volume XXXXV (Gov't Printing Office, Washington, D.C.).

Purdy, G. M., H. Schouten and seven others et al., 1978 in press. IPOD Site 6: a site survey. Ibid.

Schouten, H. and C. R. Denham, 1978 in press. Numerical models of the sea floor spreading magnetic anomaly source layer. In: Implications of Deep Drilling Results in the Atlantic Ocean, The Second Maurice Ewing Memorial Symposium, ed. M. Talwani.

Denham, C. R.,1978 in press. Statistical sedimentation and magnetic polarity stratigraphy. In: Symposium on the New Uniformitarianism, ed. W. B. Berggren and J. Van Couvering, Princeton Press.

Pertinent References

Cote, L.J. and eight others, 1960. The directional spectrum of a wind generated sea as determined from data obtained by the Stereo Wave Observation Project. Meterol. Papers, N.Y.U., Coll. of Eng., 2, 88 pp.

LeMouel, J.L., A. Galdeano and X. LePichon, 1972. Geophys. J.R. astr. Soc., 30, 353-371.

Nabighian, M.N., 1972. The analytic signal of two-dimensional magnetic bodies with polygonal cross-section: its properties and use for automated anomaly interpretation. Geophysics, 37, 507-517.

Purdy, G.M., P.D. Rabinowitz and J.A. Velterop, 1978 in press. The Kane Fracture Zone in the Central Atlantic Ocean. Earth Planet. Sci. Lett.

Schouten, Hans and Kim D. Klitgord, 1977. Mesozoic magnetic anomalies in the western North Atlantic. U.S.G.S. Misc. Field Studies Map MF-915, scale 1:2,000,000.

Schouten, Hans and Kim D. Klitgord, 1978 in preparation. Mesozoic magnetic anomalies in the western North Atlantic: a pattern of early plate motions.

Syberg, F.J.R., 1972. A Fourier method for the regional-residual problem of potential fields. Geophysical Prospecting, 20, 47-75.

MAGNETICS
1 January - 31 December, 1979

A.	SALARIES AND WAGES		ONR Man/Mths	Actual
	Professional:			
	H. Schouten, Associate Scientist		6.0	6.0
	C. Denham, Associate Scientist		3.0	3.0
	Support:			
	E. Young, Research Associate		1.0	1.0
	C. Dean, Research Assistant		6.0	6.0
	D. Allison, Secretary		1.0	1.0
	Gross Regular Salaries (includes allowance for vacations, holidays and sick pay of $ 3262 which is accounted for as employee benefits)			$ 27,185
B.	OTHER EMPLOYEE BENEFITS			6,786
	TOTAL SALARIES AND BENEFITS			$ 33,971
C.	PERMANENT EQUIPMENT (None)			
D.	EXPENDABLE SUPPLIES AND EQUIPMENT			
	1. General lab supplies (chart paper, mylar etc.)			$ 250
E.	TRAVEL (Domestic)			
	1. 2 R/T WH-Washington (AGU)(10 days exp.) A/F - $240, T/E $ 610, Cars - $160	$	1,010	
	2. 2 R/T WH-Bay St. Louis, (8 days exp.) A/F - $548, T/E - $400, Cars - $140		1,088	$ 2,098
F.	PUBLICATION COSTS			
	1. Page charges: 20 @ $50/page	$	1,000	
	2. Graphic Arts (100 hrs @ $13/hr)		1,300	$ 2,300
H.	COMPUTER & PERIPHERAL COSTS			
	1. 25 hours Sigma 7 @ $155	$	3,875	
	2. 75 hours VAX 11 @ $45/hr		3,375	$ 7,250
I.	MISCELLANEOUS COSTS			
	1. Shipping and communication	$	1,000	
	2. Laboratory overhead of 21% of Salaries + Benefits		7,134	
	3. Graduate Research Assistant (TBA) 3 months @ $1155		3,465	$ 11,599
J.	TOTAL DIRECT COSTS			$ 57,468
	INDIRECT COSTS @ 15% of TDC			8,620
K.	TOTAL COSTS			$ 66,088

GRAVITY FIELD

Carl Bowin

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Abstract

Utilizing geiod data from the GEOS-III radar altimeter and gravity data in our digital gravity data library we propose to examine lithospheric mass variations in plate convergence zones, marginal basins and beneath several intermediate sized (200 to 1000 km) regions having anomolous gravity-topographic relations. The anomolous regions are of two types. One has anomolously shallow or deep topography with apparently normal gravity values, and the other has anomolous gravity values over apparently normal topography.

We plan also to continue analysis of the airborne gravity test results of 30 June 1977. Analysis to date indicates that the vertical environmental accelerations of the aircraft can be adequately measured with a 2-nonosecond radar altimeter over water regions.

Long Range Status And Progress Over The Past Year

The principal long-range scientific objective of our program is to define and understand the tectonic processes that are responsible for the major structural features of the Earth's surface. Our main contribution toward the fulfillment of this objective has been the measurement and interpretation of the gravity field over the Earth and a comparison of the Earth's field with that of other planetary bodies.

Our investigation of the density structure of the Earth's crust and upper mantle and the processes by which they arise have been primarily directed at examining the differing relations between the gravity field and topography. Such relations provide information on the thickness of the lithosphere, its flexural rigidity, its variation of physical properties with depth, its crustal structure, presence of active tectonism, and isostatic compensation. These studies are principally conducted by utilizing analytical methods for defining and analyzing the transfer function between topography and gravity anomalies of various crustal features. Studies of sites of seafloor spreading, fracture zones, subduction zones, sites of collision between arcs and continental margins and passive continental margins are being conducted.

This contract year, the efforts of the Principal Investigator have been handicapped by an appendectomy in January and a bout with mycoplasmal pneumonia in July. Perhaps our most significant contribution so far this year is the demonstration that the thin elastic plate approximation for the lithosphere is not valid. Using elastic flexure deflection equations to model the deflection shown in the bathymetric profiles at the Timor and Seram troughs in the Banda Sea region, we find that neither applied moments nor compression forces match the observed profiles because of the absence of an outer high opposite the downwarped Australian shelf. Using thin plate equations, only tensional forces yield theoretical profiles that match observed profiles. However, the tensional forces required are excessive: equivalent to stresses of about 0.1 to 0.4 x 10^{12} dynes cm^{-2} (100 to 400 Kbar), which with an assumed value for Young's modulus of 1.0 x 10^{12} dyne cm^{-2} call for strains of 0.1 to 0.4! These values are obviously not reasonable. Thus, the lack of an outer rise at the Banda arc provides strong additional evidence that a thin elastic plate is not an adequate lithosphere model at a convergent boundary. The calculated large fiber stresses result from the assumption of a thin plate. Since such high fiber stresses as required in the Banda arc are clearly impossible, a thicker plate with physical properties that vary with depth would seem more reasonable and realistic.

The gravity anomalies in the Banda arc indicate four important results. 1) A Bouguer anomaly minimum around the tightly curved Banda arc shows that there is continuity of gross structure around the arc. 2) The Bouguer and free-air anomalies, however, reveal that a presumably recent segmentation to the arc is occurring. 3) That the subduction plate boundary terminates near northeastern Buru, not at the abrupt west end of island of Buru. And, 4) that large slabs of continental crust have not been subducted to more than a few kilometers depth beneath the Banda outer arc. Interpretation of geologic information indicates that a portion of Australian crust isolated from the present Australian platform has been incorporated into the Banda arc and has beoome increasingly fragmented from Buru around the arc towards Timor. Our tentative conclusion is that the arc has been deformed to its presently tight curvature, and that the structure of the Aru trough may be a clue to one mechanism by which this deformation occurs.

An analysis of the accretionary wedge along the Timor trough has led to recognition that differential slip between the deformed accretionary wedge and the underthrust Australian shelf sediments near DSDP hole 262 has essentially ceased, that the plan view of the accretionary wedge from the Java trench to the Timor trough shows the same evolutionary sequence as that reconstructed at DSDP site 262, and that the Banda arc at Timor began to encounter Australian continental margin sediments about 2.5 million years ago.

Our progress in admittance studies of spreading ridges has been greatly handicapped by the existing Sigma 7 computer system because of limited availability of core memory, particularly during day hours, and limited disk storage. Both these problems will be remedied very satisfactorily by the new VAX 11/780 computer system scheduled to be installed at WHOI in early November. We have lobbied very hard this year to improve the computing situation here and it is very satisfying that the Director has taken action.

In preparation for the installation of the VAX 11/780 computer system, we have acquired two terminals that will greatly aid our interaction with this computer system from our laboratory. One terminal is a Texas Instrument Silent 765 terminal with bubble memory. This memory is proving to be very useful in the creation of computer programs and in the transferring of programs and data files between remote computers. The second terminal is a used Tektronix 4012 graphic terminal with selectable band rate obtained with funds from this contract. A graphic terminal is proving to be exceedingly useful in the admittance and deflection studies conducted this year in that we can now see graphically power spectra, admittance, data files and computational results of varying input parameters to analytic equations in essentially an interactive mode.

The contouring of the free-air gravity anomaly atlas for the world is complete for the first edition. We anticipate that the drafting will be done by the end of the year. The task of preparing this atlas proved to be far greater than first anticipated several years ago when this effort commenced. Success in this endeavor is in large part due to the contributions of Waris Warsi and Julie Milligan. This atlas will continue to be important for guiding our analysis efforts, selecting features for detailed investigation and in providing a global view of gravity anomalies.

As we mentioned in last year's proposal, we conducted our first tests of a gravity meter mounted in an airplane on June 30, 1977. The gravity meter worked well from take off to landing without losing phase-lock. A loose printed circuit card caused the ART-57 platform to tumble once. In October, we were dismayed to find an error in the data recording such that some values were lost every 2 minutes so we set the data aside. We have just recently tried to salvage the recorded results, and these efforts have been highly successful. We are now in the process of reducing the data set and find excellent agreement between the VSA output and the second derivative of the elevation data from the 2 nanosecond radar altimeter. This test was conducted over water, and ground tracking data is also available although not yet received. This analysis effort will go on for some time, but the main objective was met of confirming that the largest imposed environmental accelerations are discernable in the VSA output, and they can be satisfactorily removed. Still to be removed are the Eotvos correction for speed, heading and height; the effects of yaw and speed surges on the Eotvos correction; lever arm effects from yaw, pitching and roll motions; and the elevation deviations from the flight path. Data recording for this first test was not adequate for all these corrections but is adequate to investigate some of them. We have submitted a proposal to NASA to conduct two flight tests during 1979 in order to further develop an airborne gravity meter system. Other flight tests are also possible.

All gravity data collected prior to the Knorr Pacific Ocean cruise has been reduced. On a few legs of the Knorr Pacific cruise, marine gravity data was obtained without gravity people aboard by the IPC computer technician. Special effort was made to obtain good results on the leg from Callao, Peru to Honolulu during Von Herzens cruise leg. This leg provided gravity data for a crossing of the East Pacific Rise near Latitude 2°S where anomolously shallow topography occurs on the east side of the rise. Data was also obtained on the approach to the Hawaiian hot spot from the southeast. This approach direction provides information on the regional topography and gravity variations in front of the Hawaiian hot spot trend. If the Hawaiian swell is due to a thinning of the lithosphere from conductive heating, then there should be a rise in the topography in front of the island of Hawaii almost as great as the dimensions of the swell on the sides of the leading edge. Existing limited data indicates that the frontal edge of the swell is too abrupt, suggesting a thermal discontinuity at depth or a different mechanism is responsible for the swell. The gravity data collected on this approach to the Hawaiian islands will help indicate if there is a gravity effect broader than the topographic front, and, in any event, will help constrain the nature of the mass distribution associated with the swell. This data has not yet been reduced at the time of this writing.

Program for 1979

As in past years, we propose to examine the structure, tectonics and isostatic condition of the lithosphere on a global scale. Our gravity library will be a principal component of this study, but other pertinent information will be incorporated. These data include seismicity, seismic refraction, seismic reflection, seismic surface and body waves, magnetic field, heat flow, active volcanism and surface geology.

Specifically, we propose to study the geoid and gravity field over plate convergence zones. We have received magnetic tapes containing DMA processed GEOS-III radar altimeter data. Because of cost and disk storage considerations, we have not yet been able to interact with the GEOS-III magnetic tape data, but we plan to extensively with the VAX 11/780 system. We plan to start with the Tonga-Kermadec-North Island convergence zone. A seismic zone dips beneath Tonga at about 45° and extends to nearly 700 km. Beneath Kermadec it dips more steeply, at about 60° and the depth of the deepest earthquakes shoals southwards. The change in dip between the Tonga and Kermadec segments is abrupt implying that the lithosphere is torn. The tear occurs where the Louisville Ridge (probably an old hot-spot trace and possibly a fracture zone) intersects the trench. A relation is easy to suggest but hard to prove. The length of the seismic zone correlates well with the subduction rate: the faster the subduction the deeper the earthquakes and the longer the seismic zone. There is a dramatic change in surficial morphology at the southern end of this convergence zone. From water depths of over 8 km in the Kermadec trench, east of North Island the maximum depths are only slightly in excess of 3 km. Seismicity, on the other hand, suggests gross continuity of tectonic activity between the two areas. In the Kermadec region, negative isostatic gravity anomalies occur over the deep trench, but they occur over mountainous topography in eastern North Island. This setting offers an extraordinary opportunity to investigate the nature of the transition from one extreme structural and crustal regime to the other. The geoid pattern shown by the GEOS-III data demonstrates a marked contrast between the Tonga-Kermadec segment and the North Island region. We propose to model possible mass distributions for subducted lithosphere that account for the observed geoidal variations, to relate these mass distributions to the distribution of hypocenters, topographic features, and variations of volcanic eruptive compositions. We also plan to explore the relation of the geoid anomalies to surface gravity data as available.

A geoidal high occurs inside the Tonga and Kermadec arcs and presumably is related to a density excess in the downgoing slab. This prominent high disappears at the south end of the Kermadec arc and is not present at North Island. We will attempt to develop an explanation for the evolution of this convergent zone. We have computer programs for the calculation of geoidal anomalies from three-dimensional structures that include the effect of spherical curvature.

We will compare the Tonga-Kermadec arc geoidal anomalies with those of the Banda arc where a negative geoidal anomaly occurs on the concave side of the arc rather than a positive geoidal anomaly as seen in the Tonga-Kermadec system. We plan to continue this comparison to other plate convergent zones in the western Pacific and Caribbean where we have conducted gravity and geologic studies previously. Some analyses will be made of the South American Andes and of the Persian Gulf-Iran convergence zones for comparison with the Tonga-Kermadec, Lesser Antillean, and western Pacific ocean-ocean convergence zones.

We plan to complete our study in progress of the admittance of spreading ridges. These investigations include an interpretation of the origin of the anomolous negative anomaly at the crest of ridges with rift valleys, and the development of a physical model that can explain the magnitude and spacial characteristics of the broad positive regional free-air anomaly (and geoid anomaly) over the width of the entire spreading ridge. Existing models yield gravity anomalies that are too peaked at the ridge crest.

We anticipate that the new VAX 11/780 computer system, its considerably lower cost, the large amount of dedicated disk storage available for gravity-geoid studies, and the availability of graphic and teletype terminals in our laboratory space will significantly increase our ability to process, analyze and interpret data. The budget items for purchase of a Calcomp plotter interface, VAX 11/780 computer time and lease costs of a dedicated disk storage drive are important for these efforts.

We would like to pursue further examination of the distribution and origin of the intermediate wavelength (200-1000 km) sized features with anomolous gravity-topographic relations observed in the North Atlantic and South Pacific. The width and gravity amplitude of some of these features are commonly much like those for features having commensurate topographic expression. Others have unusually deep or shallow topography with apparently normal gravity values. Do the anomolous features have similar or different geoidal anomaly expression than those with normal topographic and gravity expression? The anomolous features exist, and we will hardly understand the lithosphere until they are explained.

In conjunction with the previously mentioned investigations, we also plan to examine the regional variations in gravity and geoidal anomalies associated with the marginal basins of the western Pacific.

Further, we plan to continue analysis of the airborne gravity test results of 30 June 1977. Airborne and submarine gravity measurements have many similarities in the problems that must be overcome, and we are finding that the solution to one helps with the accomplishment of the other. Our admittance analysis efforts have aided our investigations of proper filtering and processing of the airborne gravity test data, and our discussions regarding digital signal processing of the airborne data help provide us with better insight into possible data analysis and interpretation techniques. All these efforts have so far proved to be mutually supportive.

GRAVITY FIELD
1 January - 31 December 79

A. SALARIES AND WAGES		ONR Man/Months	
Professional:			
C. O. Bowin, Associate Scientist		5.0	
Support:			
R. Goldsborough, Res. Associate		5.0	
L. Gove, Res. Assistant		6.0	
J. Milligan, Res. Assistant		8.0	
E. Scheer, Res. Assistant		5.0	
Secretary		2.0	
Gross Regular Salaries, includes an allowance for vacations, holidays and sick pay of $ 5,076 which is accounted for as employee benefits			$ 42,292
B. OTHER EMPLOYEE BENEFITS			10,555
C. TOTAL SALARIES AND BENEFITS			$ 52,847
D. PERMANENT EQUIPMENT			
1. Oscilloscope	$ 3,500		
2. Calcomp interface for VAX11/780	4,100		$ 7,600
E. EXPENDABLE SUPPLIES AND EQUIPMENT			
1. General laboratory supplies for inc. equipment maintenance			$ 2,000
F. TRAVEL (FOREIGN)			
1. 1 R/T WH - Canberra with 14 days travel expenses A/F $ 2,882, T/E - $ 898, Car - $80			$ 3,860
G. PUBLICATION COSTS			
1. Graphic Arts: 100 hrs @ $13	$ 1,300		
2. Page charges: 10 pages @ $80	800		$ 2,100
I. COMPUTER COSTS: VAX11/780			$ 16,000
J. OTHER MISCELLANEOUS COSTS:			
1. Shop Services: 100 hrs @ $13	$ 1,300		
2. Shipping and communications	600		
3. GEOREF Services	300		
4. 1/2 yearly lease cost of disk drive for VAX11/780	6,000		
5. Laboratory overhead of 21% of Salaries + Benefits	11,098		$ 19,298
K. TOTAL DIRECT COSTS			$ 103,705
Indirect Costs @ 15% of TDC			15,556
L. TOTAL COSTS			$ 119,261

DEVELOPMENT OF A SMALL PORTABLE GRAVITY METER

Carl Bowin

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Abstract

This proposal is for the continued development of a portable VSA gravity meter system. This system will be easily transportable for installation on various vehicles: surface ships, airplanes and submarines. Its physical dimensions will allow the whole system, including the gyro stabilized platform, to fit through the hatch of a US or British submarine, thus greatly expanding the areas where good gravity data may be taken.

The design effort has been in cooperation with engineers from Draper Labs, who have helped to define the control loops for a two axis gyro stabilized platform. Construction of the platform is currently under way at WHOI. A new gravity meter readout is also currently under construction at WHOI. It is an outgrowth of development work of the last several years. Its large dynamic range and various modes of operation will allow the use of this instrument in all the various vehicles anticipated. This unit will replace the older existing readouts presently in use.

Long Range Status and Progress Over the Past Year

Since commencement of this program in the fall of 1977, our efforts have been directed towards the development of a portable gravity meter system suitable for installation and operation aboard Class 637 submarines. We have made a personal inspection of SSN 676 (Billfish) to learn of possible locations where the gravity meter might be installed and to begin learning how navigation and depth information might be automatically recorded for the gravity data processing. For the Class 637 submarines, the weapons room offers the only practical location for the gravity meter system. Certain deficiencies in the data normally recorded from the SINS system were identified during that inspection visit. In February, we were able to make contact with personnel at NADC who are intimately familiar with the computer program in the SINS system. It was learned that it would be exceedingly difficult to have these deficiencies remedied by software changes in the SINS computer program. Our present strategy is to tie into synchro outputs available for velocity north and east, and install Mark 3 Mod 6, or Mark 3 Mod 4, interface cards in the SINS system to output latitude and longitude information to the gravity system computer for logging on a magnetic tape recorder. How to best handle depth beneath the surface, and depth of water below the submarine still needs to be resolved.

Another group at NADC conducted a gravity meter test aboard a different class of submarine in 1977. The test was successful, and their experience is very helpful to this program. They have provided us with listings of their computer software, and several subroutines are most useful.

A subcontract to Draper Laboratories has been established for consulting assistance in the development of the small accurate stable platform suitable for gravity meter stabilization and easy installation in the submarine. Inertial grade instruments were located and have been transferred GFE to the Woods Hole Oceanographic Institution. A group at the NUSC have offered their advice and experiences in helping us construct a mounting plate for use in the weapons room for mounting the gravity meter system. They previously have mounted test equipment aboard Class 637 submarines for SEAFARER experiments.

Program for 1979

We propose to construct a second platform based on the design effort and experience gained during the year of 1978. It is anticipated that the improvements incorporated into the second unit will greatly enhance its usefulness. The major change will be the replacement of the comparatively large minicomputer in the platform control feedback loop with a small microprocessor. The computer is used to continuously calculate the torquing rates to be applied to the gyros. We are now using a Hewlett-Packard 2114 minicomputer, which is twice the size and weight of the platform electronics. A microprocessor which is just several printed circuit cards in size will be included in the same package with the other platform electronics. This microprocessor will be dedicated solely to platform control. Through the software of the microprocessor, we will be able to tune the platform for optimum response for each particular vehicle. There will be a significant savings in both size and weight which is important for airplane and submarine work. We have obtained GFE the required inertial components to continue this development program.

We also propose to further develop the data aquisition system for the gravity meter. The budget contains funds for a tape drive to be used for data recording. Airplane and submarine work require relatively high data rates of ten values per second, too fast for the paper tape system now in use. Other necessary data will be sampled and recorded such as velocity, heading, pitch and roll, and position. Software will be developed to run on a Hewlett-Packard 2114 minicomputer with the digital recording on magnetic tape. This tape will be used in the post cruise processing programs currently being developed at WHOI. The data aquisition system will also sample data from the gyro stabilized platform to properly analyze vehicle motion for a further refinement of the gravity data.

Data processing programs are currently being developed. We are using data obtained during an airplane flight test at Wallops Island NASA Flight Center last summer. Methods of digital signal processing, digital filtering and data correlation are being investigated. Results of this work and the experience gained in digital signal processing will be used to develop programs for the reduction of the gravity data. These programs will be developed to run on the VAX 11/780 computer soon to be delivered to WHOI.

To compliment the portable gravity meter system, we plan to rebuild a VSA and oven gravity sensor. This will provide a sensor dedicated to this system. Up to this point, it has been necessary to borrow a VSA from one of the shipboard systems. The oven package will be tailored to fit the platform in size and weight. This will afford an improved weight distribution and static balance on the platform.

DEVELOPMENT OF A PORTABLE GRAVIMETER
1 January - 31 December 1979

A. SALARIES AND WAGES	ONR Man/Months		
Professional:			
C. O. Bowin, Associate Scientist	1.0		
A. T. Spencer, Res. Specialist	2.0		
Support:			
R. Goldsborough, Res. Associate	7.0		
E. Scheer, Res. Assistant	7.0		
L. Gove, Res. Assistant	6.0		
Gross Regular Salaries, including an allowance for vacations, holidays and sick pay of $ 3,380 which is accounted for as employee benefits		$	31,659
B. OTHER EMPLOYEE BENEFITS			8,497
C. TOTAL SALARIES AND BENEFITS		$	40,156
D. PERMANENT EQUIPMENT			
1. Platform electronics	$ 6,000		
2. Oven components	1,500		
3. Magnetic tape drive	8,500	$	16,000
E. EXPENDABLE SUPPLIES AND EQUIPMENT			
1. General lab. supplies		$	1,500
F. TRAVEL (DOMESTIC)			
1. 2 R/T Naval Air Development Center, Johnsville, with 6 days travel expenses A/F $ 200, T/E - $ 300		$	500
I. COMPUTER COSTS;		$	2,250
J. OTHER MISCELLANEOUS COSTS			
1. Shipping and communications	$ 500		
2. Laboratory overhead of 21% of C,	8,433	$	8,933
K. TOTAL DIRECT COSTS		$	69,339
Indirect Costs @ 15%			10,401
L. TOTAL COSTS		$	79,740

CARBONATES AND RELATED TOPICS

John D. Milliman

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Abstract

Studies in 1978 centered around field programs concerning high-latitude carbonate sedimentation particle flux in the deep sea, and the morphology and late Quaternary history of the upper slope and outer shelf off western Florida. Work for 1979 will include continued analysis of high-latitude carbonate samples collected on the RRS SHACKLETON, and also recovery of sediment traps and current meters emplaced this year in the eastern Mediterrean Sea. A short cruise on a Norwegian oceanographic/fisheries ship to the Spitzbergen shelf is possible, but will not be completely defined until the late autumn of this year; however, a relatively long cruise/program for the Spitzbergen shelf is being planned for 1980.

Long-term Goals

My ONR-research interests involve delineating sources, transport and depositional history of marine sediments, as well as morphological features that may affect or result from these processes. For the first several years of ONR support, my work concerned deep-sea carbonates, their dissolution and lithification. During the past year, however, my efforts have expanded into neretic areas (high-latitude carbonates) and into non-carbonate,deep-sea processes (i.e. the flux of particulate matter through the water column). Also, this year marked my first dives on NR-1, which has proved an excellent tool for studying the morphology and sediment history of the outer shelf and upper slope.

I hope to continue these types of studies in forthcoming years, changing the sites of specific investigation, but maintaining the same general conceptual interests. To a considerable extent, the high-latitude carbonate studies can be complimented by NR-1 dives. At the same time, sediment flux measurements will augment my interest in deep-sea biogenic sediments. Some years (such as this one) will be mainly field-oriented, while others (such as next year) should be devoted largely to analyzing and integrating the 1978 field data, as well as planning for 1980 field work.

Accomplishments in 1978

Work this year revolved around organizing and participating in three field programs within the expanded ONR program. By the end of 1978, I will have spent nearly three months at sea (and at ONR-related meetings). Still, by the end of the year, I should have submitted two papers for publication and have another four in various stages of completion (Table 1).

1) High-latitude Carbonates - A relatively long-term program has begun to study the distribution, rate of production/accumulation and diagenesis of carbonate sediments in high-latitude neretic environments. To acquaint geologists and oceanographers with the fairly wide distribution of carbonate-rich sediments on high-latitude shelves (and upper slopes), we (Milliman, Alexandersson and Scoffin) are preparing a review paper of the present status of knowledge concerning high-latitude carbonate sedimentation. Among the points discussed in this paper, a preliminary (and conservative) calculation shows that production of carbonate on the shallow shelf (water depths less than 80 m) off northern Scotland (59-60°N) is at least half that on the Bahama Banks - a surprisingly high rate of production considering the depth and lack of green algae, hermatypic corals and benthonic foraminifera as prime contributors. Strong currents in the Orkney and Hebrides Islands can transport this material considerable distances, eventually building large sand waves (up to 60 m in amplitude) composed largely of shell debris.

Increased interest (mainly amongst Europeans) in high-latitude carbonate sedimentation appears to merit convening a workshop to discuss both theory and fact. Tentatively, we are planning such a workshop to be held in Scotland in 1980.

The main field program for this year was the extensive sampling of a high-latitude shelf in order to document the distribution and accumulation of carbonates. This was accomplished on a cruise aboard the RRS SHACKLETON from June 16 to July 6, with more than 100 stations occupied on the Hebrides Shelf (56-57°N) and Rockall Bank (56-58°N). The bank is covered with a blanket of carbonate sand, the composition of which depends upon water depth and nature of the substrate. Net production appears to be far greater on hard substrate than in mud or sand bottom; moreover, a far wider variety of carbonate debris is produced by epibenthonic than endobenthonic organisms. Generally, sediments in water depths shallower than 100 m on the bank contain prominent concentrations of bryozoans; between 100 and 190 m, mollusks dominate, with barnacles locally abundant in the proximity of rock outcrops. Deeper waters are characterized by increasing percentages of planktonic foraminifera. Underwater TV observations indicate that the carbonate cover is generally less than 1 m thick (as evidenced by

TABLE 1. ONR-RELATED ACCOMPLISHMENTS DURING 1978

Program	Field Work During 1978	Resultant Papers	Tentative date of ms completion
High-latitude carbonates	R.R.S. SHACKLETON cruise off western Scotland, Rockall Bank (June-July)	1. High-latitude carbonates - knowns and unknowns	Fall, 1978
		2. Carbonate Sediments on Rockall Bank (tentative title)	Fall, 1978
		3. Suspended particulate matter on Rockall Bank, late June, 1978	Fall, 1978
Particle flux in the deep sea	Deployment of 2 trap/current meter arrays in the eastern Mediterranean from F/S METEOR (October)		
NR-1	Three-week cruise off western Florida (April)	1. Side-looking sonar targets on the west Florida outer shelf and upper slope: result of biological excavation	Fall, 1978
		2. Ridge/Trough system on the upper continental slope, SW Florida	Winter, 1978-79
		3. Late Quaternary history of the outer shelf off west Florida	Winter, 1978-79
Carbonate Dissolution	Placement of dissolution samples in the "Peterson Site", Central western Pacific Ocean	1. Dissolution of calcium carbonate in the deep sea	Mid-1979

the abundance of rock outcrops). Assuming this carbonate cover is entirely Holocene in age, rates of accumulation must be less than 7 cm/1000 years. Because few data are available from other deep shelves, we do not know how these rates compare on a global scale. A preliminary report on the results of the Rockall cruise should be completed for publication by late autumn of this year.

One additional note of interest was the finding of large quantities of ahermatypic coral (*Lophelia*) surrounding Rockall Bank in water depths between 200 and 300 m. Dredging,plus underwater TV observations, indicate that the coral is sporadically distributed, occurring generally in banks, 5 to 50 m in diameter. Relief appears to be less than 1 m; although further observations may increase this estimate, it is doubtful that the banks would reach the size seen in the 20-40 m lithoherms in Florida Strait (Neumann et al., 1977).

Finally, during the cruise, I took suspended matter samples from 16 stations on Rockall Bank. The samples are being analysed for total concentration, combustible/non-combustible fractions, and non-combustible constituents (as determined by petrographic and SEM study). The results will be presented in a forthcoming publication, tentatively scheduled for submission in the late atutumn.

2) Particle flux in the Deep Sea - To measure the flux of particles in the eastern Mediterranean we have constructed six sediment traps for deployment on two moorings east and south of Malta during the October cruise of the FS METEOR. The traps, which are designed after the Gardner/Rowe model, have been modified to hold a rosette of eight rotating containers, each collecting material for a set interval of time; in this way we can collect a time-series of samples. In order to measure the horizontal advective regime in the area, we also are mounting two current meters on each mooring. At the time of array deployment, we shall take suspended matter samples (using 180 1 bottles), as well as nephelometer/CTD profiles, not only at the two mooring sites, but also continuing throughout the rest of the cruise to Alexandria. These data should provide us with a detailed picture of the suspended particulate regime within the southeastern Mediterranean.

3) NR-1 - Together with Michael Rawson (LDGO), I made a three-week cruise off western Florida aboard the NR-1 in April of this year. More than 600 miles were steamed with standard remote sensing equipment (side-scan sonar, sub-bottom echo sounding), and 40 dives were made; 60 rolls of 35 mm pictures and 250 feet of movie film taken, and 5 rock samples collected. In addition, 45 XBT profiles were taken from the surface support ship (SUNBIRD) and some 600 miles of continuous-seismic profiling taken. The transcribed tapes, together with representative slides,have been combined into a 300+ page ms sent to various ONR offices. We expect to submit three manuscripts

of the cruise for publication within the next six to eight months. One deals with the biologic origin of depressions (seen by both front- and side-looking sonar) on the outer shelf and upper slope (Milliman and Rawson). Another concerns the structure and origin of the ridge and trough topography on the upper slope west of Key West (Milliman, Rawson, Chayes and Ellis). The final paper deals with the microtopography and late Quaternary history of the upper continental margin off southwestern Florida (Milliman, Pyle and Rawson).

4) Carbonate Dissolution - The results of the dissolution experiments to date were presented at the eighth Liverpool carbonate symposium in early January of this year. As stated last year, one final dissolution experiment was planned for this year: prepared samples were placed on a mooring by Susumu Honjo during August, 1978, near the site at which Peterson and Berger made their now classic measurements of carbonate dissolution. My samples were placed in the same permeable cloths/sample containers that were used on previous experiments. Honjo's more sophisticated dissolution pumps were placed on the same mooring so that the rates determined from the two methods could be compared directly. We expect not only to intercalibrate our measurements, but also will use this experiment to provide the final data for a cooperative paper between Honjo and myself on dissolution of calcium carbonate in the deep sea.

<u>Proposed Research for 1979</u>

Two of the four research programs funded in 1978 will not be discussed further in this proposal. The carbonate dissolution program has been essentially completed. Hopefully, NR-1 work will continue next year, but funding will come from acceleration funding, and thus need not be discussed further here.

1. <u>High-latitude Carbonates</u> - Part of 1979 will be spent completing analyses of sediment samples collected during the SHACKLETON cruise this year. Although a preliminary report should be completed before the end of the year, several points need to be investigated further:

a) <u>Diagenesis of the Carbonates</u> - Because of the relatively high latitude (i.e. cold waters) and slow rate of accumulation, one would expect high rates of degradation and dissolution. Visual inspection of the samples does not support this contention: many shells appear almost polished and some sediments have lithified, possibly with dolomitic cement. This aspect will be investigated further by myself (optical petrography and mineralogy) and by E.T. Alexandersson (Uppsala University) using scanning electron microscopy (SEM).

b) <u>Deep-water Coral Banks</u> - The role (and importance) of ahermatypic coral banks in high-latitude carbonate sedimentation is poorly understood. Since Teichert's excellent review of the problem in 1958, few new data have been collected. This status quo has changed recently with new work by the Norwegians (J. Thiede, formerly of OSU, being the primary driving force) and our SHACKLETON cruise.

I propose to work with T. Scoffin (Edinburgh) closely on the distribution and (more important) the growth and diagenesis of ahermatypes collected on Rockall Bank. In order to understand more fully these factors, I propose obtaining samples of the same genus of coral *(Lophelia)* sampled at lower latitudes. The coral lithoherms in Florida Straits (Neumann et al., 1977) are an obvious example. Impregnation and thin-section analysis of ahermatypic coral skeletons show that they accrete periodically, with resultant formation of growth bands. What triggers mineralization or non-mineralization is not known, nor do we know the interval between events, nor the rate of mineralization. During the SHACKLETON cruise, we obtained sufficiently large pieces of coral (up to 40 cm long) to permit C-14 age determinations. Hopefully, these age determinations will be done by the end of the year, but interpretation of data, plus integrating with data collected by the Norwegians and other workers, still must be done. The diagnetic aspects will be studied with Alexandersson (see above).

At the same time, Alexandersson, Scoffin and I are planning a second high-latitude cruise, this one to take place in the arctic - Spitsbergen shelf. Recent work (Bjørlykke, K., et al., 1978) shows that sediment on this shelf contains high concentrations of carbonate, primarily barnacle and molluscan debris. However, sample coverage is sparse and analyses too preliminary to allow us to define the conditions governing deposition and diagenesis. We hope to obtain splits of available samples and subsequent petrographic and mineralogic analyses which might help designate areas for further sampling. We would hope that such forthcoming field studies would include vibracoring and side-looking sonar, as well as sub-bottom echo sounding in order to delineate proximity to outcrops and the sediment thickness.

2. <u>Particle Flux in the Deep Sea</u> - The sediment traps and current meters deployed in October of this year will be recovered during the late spring of 1979. Aliquots of the material collected in the traps will be analysed by S.W. Fowler (IAEA, Monaco) for trace elements and organic compounds, as well as transuranics. My analyses will include total material collected (used to calculate flux), combustible/non-combustible determination, and SEM study of the individual particles; an EDEX analyzer will allow delineation of minor elements within individual particles. These data, together with the "standing stock" data collected during the METEOR cruise will be presented in a paper in 1979.

The current meter records will be reduced and interpreted. Although it is expected that the currents will prove to be weak, long-term records may prove sufficiently interesting to warrant separate publication of the data.

New work for 1979 will include continuing participation in both HEBBLE (High-Energy Benthic Boundary Layer Experiment) and LEBBLE (Low-Energy Benthic Boundary Layer Experiment). At present, HEBBLE will probably continue to remain in formulation and preliminary experimental stages, thus requiring little of my direct participation. However, a preliminary LEBBLE cruise, in the Panama Basin, will include an inter-calibration experiment of various sediment traps; the traps used in the Mediterranean will be included for calibration. In addition, I am planning to study the silica flux within the water column and sediment in the LEBBLE area. Although it is assumed that less than 1 percent of the silica produced in surface waters actually survives preliminary burial in the upper sediment (Hurd, 1973), few data actually exist, and most of those are for lake sediments (e.g. Conway, H.L., et al., 1977), not the deep sea. Suspended matter samples, plus trap material, sediment collected in box cores and in interstitial water samples (collected and analyses by F.L. Sayles) should provide sufficient data to allow for this calculation.

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CARBONATES AND RELATED TOPICS

1 January - 31 December 1979

A. SALARIES AND WAGES

Professional:	ONR Man/Months	Actual
J. D. Milliman, Associate Scientist	5.0 (1 at sea)	5.0
Support:		
J. Ellis, Research Associate	4.0	4.0
C. Grant, Sr. Research Assistant	1.0 (1 at sea)	1.0
D. Keith, Res. Assistant	3.0	3.0
A. Sousa, Secretary	1.0	1.0

1.	Gross Regular Salaries (includes allowance for holidays, sick pay and vacation of $ 2603 which is accounted for as employee benefits)		$ 22,443
2.	Cruise Leave, Sea Duty Vacation and Overtime including premium pay of $ 817		3,923
	TOTAL SALARIES AND WAGES		$ 26,366
B.	OTHER EMPLOYEE BENEFITS		7,377
	TOTAL SALARIES, WAGES AND BENEFITS		$ 33,743
C.	PERMANENT EQUIPMENT (none)		
D.	EXPENDABLE SUPPLIES AND EQUIPMENT		
	1. Miscellaneous laboratory supplies		$ 1,500
E.	TRAVEL (Foreign)		
	1. 2 R/T WH-Monaco, 7 days expenses A/F - $1,916 T/E $ 700, Car $90	$ 2,706	
	2. 1 R/T WH-Uppsala, Sweden (20 days) A/F - $ 972, T/E - $ 1,680	2,652	$ 5,358
F.	PUBLICATION COSTS:		
	1. Page charges: 20 @ $60/page	$ 1,200	
	2. Graphic Arts: 80 @ $13/hr	1,040	$ 2,240
I.	OTHER MISCELLANEOUS COSTS:		
	1. Shipping and communications	$ 1,850	
	2. Reduction of current meter data	3,000	
	3. Laboratory overhead of 21% of Salaries + Benefits, exclusive of premium pay	6,914	$ 11,764
J.	TOTAL DIRECT COSTS		$ 54,605
K.	INDIRECT COSTS @ 15% of TDC		8,191
L.	TOTAL COSTS		$ 62,796

STRUCTURE AND TECTONICS AT TRANSFORM FAULT-RIDGE CREST INTERSECTIONS

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K. Crane Tel. (617) 548-1400 Ext. 586

Long Range Objectives

The objectives of this study are to synthesize the tectonic and structural framework of transform intersections from data gathered over a wide range of sources. The mechanics of plate decoupling along transform faults are complex involving changing plate boundaries, leaky fracture zones, crustal welding, bending and en echelon fracturing. Prior to 1973, detailed near-bottom structural investigations had been carried out at transforms in the FAMOUS region (Detrick et al., 1973; Arcyana, 1975). These short transforms all belong to the class associated with "slow spreading" ridges.

In 1974 the principal investigator began studies at the Siqueiros Transform-East Pacific Rise intersections using the Scripps MPL Deep-Tow instrumentation. This was the first detailed near bottom survey at a transform-fast-spreading ridge junction.

Continuing phases of transform study in which the principal investigator has participated are as follows:

1974 Siqueiros Transform Fault Fast Spreading
DEEP-TOW ONR, NSF

1975 Charlie-Gibbs Transform Fault Slow Spreading
DEEP-TOW ONR, NSF

1976 Quebrada Transform Fault Fast Spreading
DEEP-TOW NSF

1977 Tamayo Transform Fault Medium Spreading
DEEP-TOW NSF

1978 Tamayo Transform Fault Medium Spreading
Surface Ship Reflection IPOD

Each of these core programs have dealt with the tectonic and petrologic framework at the individual transform intersections.

Future transform programs in 1979 involving the WHOI ANGUS system will be in the following locations:

1979 Oceanographer Transform Fault Slow Spreading
ANGUS program NSF

Proposed Program in 1979

In addition to the above mentioned programs, a wealth of data exists either in map or record form. These data bases include:

1) USN MULTIBEAM SURVEYS — FAMOUS region; Galapagos Spreading Center

2) GLORIA Remote side-scan — Kurchatov Transform Fault; Charlie-Gibbs Transform; FAMOUS area

3) DEEP-TOW near bottom side-lookers and narrow beam echo-sounders

4) ANGUS, ALVIN photography and mapping near and on the bottom

The objectives of merging and synthesizing these data bases are:

1) to determine the relative zones of decoupling from ridge to ridge,

2) to analyze the morphological transition from the transform to the center of spreading,

3) to determine which stresses are dominant within the intersection (shear, tensional or compressional),

and

4) to determine if there is any correlation between spreading rates and igneous activity along the transform fault.

Thus the wide variety of data (structural and morphological) should allow us to formulate several ideas concerning the evolution of the seismically active transform features.

Budget Justification

Other personnel working with K. Crane will be C. Wooding, who will process and merge much of the structural data, and the secretary, S. Tonge. In addition, funds are requested for mapping supplies, graphic arts and publication costs. The travel is limited to a trip to GSA for K. Crane to present a paper on the comparison of the structural features at the respective intersections and to Washington, D.C. to enhance some of the near bottom photographs and side scan imagery with National Geographic.

STRUCTURE AND TECTONICS AT TRANSFORM FAULT-RIDGE CREST INTERSECTIONS
1 January - 31 December 1979

A. SALARIES AND WAGES	ONR Man/months		
Professional:			
R. Ballard, Assoc. Scientist	N/C		
K. Crane, Postdoctoral Investigator	4.0		
Support:			
C. Wooding, Res. Assistant (comp.proc.)	1.0		
S. Tonge, Secretary	1.0		

Gross Regular Salaries, including an allowance for vacations, holidays and sick pay of $ 1,005 which is accounted for as employee benefits

	$ 8,374	
B. OTHER EMPLOYEE BENEFITS	2,090	
C. TOTAL SALARIES AND BENEFITS		$ 10,464
E. EXPENDABLE EQUIPMENT AND SUPPLIES		
1. Volcanic, structural and tectonic maps		$ 500
F. TRAVEL (DOMESTIC)		
1. 1 R/T WH-GSA meeting with 4 days travel expenses A/F - $ 472, T/E - $ 200, Car - $ 80	$ 752	
2. 1 R/T WH-Washington, with 4 days travel expenses A/F - $ 120, T/E - $ 200, Car - $80	400	
Total Travel		$ 1,152
G. PUBLICATION COSTS		
1. Page charges: 50 @ $20	$ 1,000	
2. Graphic Arts: 40 hrs @ $13	520	$ 1,520
H. COMPUTER AND PERIPHERAL COSTS: 15hrs H-P @ $25		$ 375
I. OTHER MISCELLANEOUS COSTS		
1. Shipping and communications	$ 250	
2. Laboratory overhead of 21% of C	2,197	$ 2,447
J. TOTAL DIRECT COSTS		$ 16,458
Indirect Costs @ 15% of TDC		2,469
K. TOTAL COSTS		$ 18,927

SEDIMENT DYNAMICS

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PART I: High Energy Benthic Boundary Layer Experiment (HEBBLE) Program; Laboratory Investigations

ABSTRACT

Within the last few years a new suite of active bedforms have been discovered in cohesive abyssal sediment beneath regions swept by bottom currents of 5-15 cm/sec. This results in the initiation of a project called the High Energy Benthic Boundary Layer Experiment program which is designed to co-ordinate a multidisciplinary (physics, geology, biology) and interinstitutional attack on the subject of benthic boundary layer dynamics in the deep sea.

Emphasis for the first HEBBLE year, proposed here, is on site selection activity and deployment of existing bottom boundary layer sensors in current-swept areas. In 1979 we propose to write up the data obtained with Deep-tow on MELVILLE in August/September 1978 and to effect a major Scotian Rise site survey cruise for the HEBBLE program on the ATLANTIS II in May/June 1979. Both cruises include HEBBLE principal investigators from the other major oceanographic institutions.

A. LONG RANGE OBJECTIVES, PRESENT STATUS AND PROGRESS IN 1978

The HEBBLE program objective is to determine the temporal and spatial patterns of high energy bottom current "events" that cause a visible modification of the modern sea floor, i.e. produce bedforms ranging in size from centimeters to kilometers. It is our belief that the current produced bedforms of the cm scale are in equilibrium with [illegible]n high energy events, e.g. "eddy bursts"; that the large scale [illegible]km[illegible] [illegible]edforms result from vector averaging of these high energy even[illegible] [illegible] [illegible]riods of tens to thousands of years and that the massive (100's km) sediment drifts reflect averaging depositional processes of the 10^6 year time scale. We also hypothesize that erosional bedforms (furrows and drag and tail) result from the interaction of sediment starved high energy currents on cohesive substrate and that the depositional bedforms (mud waves and ripples) result from preferential accumulation in a net depositional environment. It is the testing of these hypotheses that comprises the overall scientific objectives of the geological aspects of this program. Other aspects on the physics and dynamics of fluid flow and biological bed interactions can be found in the HEBBLE proposals submitted to ONR through the University of Washington, Oregon State University, University of Rhode Island, Lamont-Doherty Geological Observatory, Scripps Institution of Oceanography, Massachusetts Institute of Technology, and Florida State University (Tallahassee).

We are in the process of consolidating our ONR effort into one single well defined program, i.e. the High Energy Benthic Boundary Layer Program (HEBBLE). The status of this effort is documented in a HEBBLE report resulting from deliberations of an interdisciplinary group of scientists that met in Keystone, Colorado in March, 1978. (This report is available to those interested at the ONR site visit.) This effort has occupied Drs. McCave and Hollister during the first half of 1978; remaining ONR support was (is being) used to organize, participate and begin data analysis from the NATOW II (INDOMED, Leg XI) cruise of R/V MELVILLE. The overall objective of this cruise is to locate and survey spatial patterns of active current-produced bedforms that will provide the beginnings of the site selection/site suitability determinations for future work within the HEBBLE program.

The status report of the MELVILLE cruise will not be presented at this site review because it is still ongoing, however we suggest a December cruise review for Code 483 in Washington, DC.

Dr. I. N. (Nick) McCave joined us in January 1978 under the auspices of ONR and he has been involved in activities mostly related to HEBBLE since he arrived. He did much of the scientific organization of the Keystone meeting and acted as principal editor of the HEBBLE Report which resulted from that meeting. He prepared articles for the Oceanus issue on the Deep Sea and for the WHOI annual report. He has acted as advisor to M. J. Richardson on aspects of suspended sediment interpretation and analysis of Coulter counter data. Also he has advised S. Briggs whose work is on sand waves in Vineyard Sound. Also in this research area he has completed a paper on intertidal sand waves in the Wash embayment of eastern England.

For the remainder of the year his activities will be dominated by the INDOMED Leg XI/NATOW II deep-tow cruise to examine bedforms in the N.E. and N.W. Atlantic in August/September and subsequently by beginning analysis of data. Some feasibility tests for settling velocity determination of oceanic particulate have been run and more laboratory work on this will be undertaken.

We have had a major office/laboratory relocation during 1978 and the status is as follows: the sediment laboratories of Hollister and Milliman have been combined in the Hollister lab area on Clark 4.

Students and assistants working with Hollister have new office space on Clark 1. McCave and Hollister are sharing an office on Clark 2 and Jeff Ellis has moved into the Hollister Clark 4 lab to manage the combined sediment laboratories. We feel that this combination will result in one single and exceptionally well outfitted and efficient laboratory which will serve as a focus for both shallow (Milliman) and deep water (Hollister) portions of the HEBBLE and continental margin program. This laboratory's principal strength lies in the ability to do detailed chemical and textural analysis of fine grained cohesive material.

We anticipate the full scale operation of this facility to begin in early summer of 1978 and be in full swing when samples are returned from the present HEBBLE (MELVILLE) cruise in the fall of 1978. Our 1979 effort will rely on this facility for completing the sediment analysis for this and for the proposed ATLANTIS II cruise to the HEBBLE site in the Scotian Rise (see below). As we (and ONR) continually stress in our annual report/proposal renewals, progress and accomplishments over the past program year, i.e. since the last site visit, has to be reflected in published scientific and technical papers. The abstracts or summaries of each publication written since last site visit are in chronologic order below:

B. PAPERS SUBMITTED IN 1978 USING ONR SUPPORT

1. Dow, W. and C. D. Hollister, Comparison of high-resolution normal-incidence 3.5 kHz and 12 kHz reflection with geotechnical properties of Giant Piston cores, WHOI Technical Report 78-47, June 1978, 20 p.

2. Flood, R.D. and C.D. Hollister, Active bedforms on the Blake-Bahama Outer Ridge, Submitted to Science.

3. Hollister, C., M. Glenn and P.F. Lonsdale, Morphology of seamounts in the western Pacific and Philippine Basin from multi-beam sonar data, Accepted by Earth & Planet. Sci. Lett. upon revision.

4. Glover, L., W. Gardner, C. Hollister, Sediment dynamics and geomorphology of the Northwest Coast of Puerto Rico and the Mona Submarine Canyon, To be submitted to Marine Geology, finished in-house review and now in review by ONR (NR-1).

5. Marshall, N. and C. Hollister, Visual observations in submarine canyons off the island of Molokai, Hawaiian Islands, Accepted by Marine Geology with revisions to be made to text.

6. Hollister, C., R. Flood and I.N. McCave, 1978. Plastering and decorating in the North Atlantic, Oceanus 21:5-13.

7. McCave, I.N., 1978. Sediments in the abyssal boundary layer, Oceanus 21:27-33.

8. McCave, I.N., C.D. Hollister and T.E. Pyle, 1978. The HEBBLE Report (Report of a Workshop on High Energy Benthic Boundary Layer Experiment), WHOI Technical Report 78-48, 80 p.

In addition this principal investigator has advised four Ph.D. students who received their degree during the past contract year:

Edward P. Laine, Geologic effects of the Gulf Stream System in the North American Basin, MIT/WHOI Joint Program in Oceanography, 164 p.

Wilford D. Gardner, Fluxes, dynamics, and chemistry of particulates in the ocean, MIT/WHOI Joint Program in Oceanography, 289 p.

Roger D. Flood, Studies of deep-sea sedimentary microtopography in the North Atlantic Ocean, MIT/WHOI Joint Porgram in Oceanography, 395 p.

David A. Deese, Sub-seabed disposal of radioactive waste: Prevention or management?, Fletcher School of Law and Diplomacy, 424 p.

C. SYNOPSIS OF SCIENTIFIC ACCOMPLISHMENTS MADE IN 1978

1. Comparison of high-resolution normal-incidence 3.5 kHz and 12 kHz reflection with geotechnical properties of giant piston cores.

A deep operating self-contained high-frequency echo sounder known as Deep Probe was recently developed at WHOI for the purpose of resolving fine details of bottom and sub-bottom sediment layering in the deep ocean. In August 1975 this system was mounted on R/V KNORR for a coring expedition (KNORR #51) to the Rockall Trough area east of the United Kingdom under the direction of Dr. Charles Hollister.

The purpose of this exercise was to determine the correlation between the high frequency acoustic sounding records and the stratification of several Giant Piston Cores (GPC) taken in the same area.

Three of these cores, GPC-13, 17 and 19, have been analyzed and compared graphically with the acoustic survey of each core location, using Deep Probe, near-bottom, both as a 12 kHz echo-sounder, and as a deep receiver for detecting returns from a 3.5 kHz pinger mounted on the surface vessel. The acoustic traces for both frequencies were then compared for detail and depth of penetration with respect to the cores.

Good to excellent correlation with core stratigraphy is indicated at 12 kHz. Resolution ranged from fair to poor at 3.5 kHz although transmission losses through the core were lower at this frequency.

The general conclusion is that deep echo-sounding at 12 kHz is an excellent technique for delineation of shallow bottom and sub-bottom sediments in high detail, and that deep sounders having characteristics similar to Deep Probe could therefore prove valuable for detailed surveys of small areas preliminary to coring, or in deep-towed fish form, for general seismic profiling of shallow sediments over longer tracts in the deep ocean.

2. Active bedforms on the Blake-Bahama Outer Ridge.

Bedforms in cohesive sediments have been observed and sampled by submersible on the Blake-Bahama Outer Ridge. These features, ranging from ripples to furrows, have developed as a result of deep current activity. Furrows have been depositional for at least the last 11,000 years in one area investigated and are erosional in the other. Morphological variation may reflect variations of sediment supply.

3. Morphology of seamounts in the western Pacific and Philippine Basin from multi-beam sonar data.

New multi-beam bathymetric data from the Philippine Sea and Northwest Pacific Basin reveal linear chains of small (less than 40 km^3) volcanic shields (Philippine) and cones (Pacific) rising 100 to 1000 m above the 6 km deep ocean floor. Some have well developed collapse calderas and spines. Their morphology suggests recent formation in supposedly stable mid-plate regions and their occurrence in linear chains approximately parallel to plate motion suggests an origin through "mini-hot spots".

4. Sediment dynamics and geomorphology of the Northwest Coast of Puerto Rico and the Mona Submarine Canyon.

The Nuclear Research Submarine (NR-1) was used to study morphology, sediment distribution and transport, and bottom current activity off the northwest coast of Puerto Rico. Detailed bathymetry from the surface-support ship, USS PORTLAND, shows several submarine canyons in the area. The north coast canyons, Arecibo, Tiberones and Quebradillas, are evidently erosional although no recent turbidity-current evidence is seen. The canyons are presently filling with fine river-transported sediments.

High-resolution seismic reflection profiles from the PORTLAND show a pattern of faults that suggest tectonic control of Mona Canyon. Turbidity current evidence is clear in the deep axis, but the head of Mona Caryon is also filling with fine river alluvium.

A sediment province map shows the effects of submarine canyons, turbidity currents, and bottom currents on surface sediment distribution. Locations of observed ripples and dunes illustrate bottom current activity. Current measurements from NR-1 show oscillating currents with tidal frequency in the head of Mona Canyon. A large field of poorly-sorted sediment in this area (sand-silt-clay) was evidently formed by mixing of different sediment types in the oscillating current regime.

5. Visual observations in submarine canyons off the island of Molokai, Hawaiian Islands.

Pelekunu Submarine Canyon on the north side of Molokai appears to have formed by subaerial erosion and subsequently subsided about 2,000 meters below sea level. Amikopala Canyon on the south side of Molokai contains a thin sediment fill and large blocks that appears to be lateral infill float. No evidence of significant downcanyon sediment movement was observed in either canyon.

The existence of a former sea cliff between 1,000-2,000 m and of a submerged terrace below 2,000 m off Molokai is suggested. These correlations and the lack of submarine canyons on the Maui platform indicate that the period of subsidence occurred around 1.25-1.50 million years ago.

6. Plastering and decorating in the North Atlantic.

Vast areas of the deep-sea floor are decorated with distinctive sediment bedforms that have been produced by strong, near-bottom currents. These forms and currents are important because, on a practical level, our understanding of their construction and routes can have a direct bearing on the selection of sites for the disposal of toxic wastes in the deep sea, and may also be applied to exploration for minerals, oil, and gas. On a theoretical level, the features provide a long-term geological record of seabed current activity, a record that would be impossible to obtain through conventional measurement techniques, such as current-meter moorings.

In all oceans, strong bottom current activity is concentrated on the western side of basins. This is exactly where we find the most dramatic and most abundant current-produced abyssal bedforms; this is where the most turbid bottom water exists.

The activity of bottom currents in the North Atlantic is recorded in large sediment drifts and their bedforms. These are listed and examined in order from north to south, the Feni Drift, Hatton Drift, Katla Ridges and Gardar Drift, Charlie-Gibbs Fracture Zone, Erik Ridge, the Labrador Rise and S.E. Newfoundland Ridge. The continental rise of the eastern

USA including the Blake-Bahama Outer Ridge, and the Caicos and Antilles Drifts. Mud waves furrows, ripples and other bedforms decorate the surface of these drifts indicating current strengths and patterns in ways we have not yet completely deciphered.

7. Sediments in the abyssal boundary layer.

The region of increased suspended material near the seabed--the nepheloid (cloudy) layer--was first detected optically through light-scattering measurements taken by K. Kalle in 1938 and N. G. Jerlov in the late 1940s. There is both a theoretical and empirical justification for these light-scattering measurements being related to suspended sediment content. There is a good relationship between concentration measured gravimetrically and the exposure parameter from photographic nephelometers. Presently, reliable gravimetric data are obtained by filtering about 10 liters of water through Nuclepore filters with a pore size of 0.4 microns. This yields values in the range 10-200 μg/l for nepheloid layers. Most of the sediment in the nepheloid layer can be found in a strip along the western side of the ocean. Comparing this with a map showing a model of the deep-water circulation of the oceans supports a picture of strong western boundary bottom currents with weaker flows elsewhere.

Increases in sediment load in places along the transport paths on the western side of the Atlantic suggest some input to the layer, probably due to erosion of the seabed by bottom currents. We can bracket the erosion condition between friction velocity values [u_* ($=\sqrt{\tau_0/\rho}$)] of 0.5 and 1.5 cm/sec, corresponding to flow speeds of 12 to 40 cms/sec, the precise value depending on the roughness and cohesion of the bed. At the lowest erosion rate, with the shear stress only fractionally over critical, it would not take long to strip off an amount equal to the highest nephel load of 0.003 grams per square centimeter. So even in those areas where there is erosion, it is not likely to occur very often or over a large area at any one time.

Although material may be eroded quickly, deposition involving the entire nepheloid layer is a slow process and the half life of particles in suspension appears to be nine months or more

8. The HEBBLE Report.

A workshop was held March 13-17, 1978, on a High Energy Benthic Boundary Layer Experiment. The meeting followed recognition of the importance of high speed currents at the deep ocean bed in eroding, transporting and depositing sediments and in producing bedforms. The importance of the turbulence and turbulent mixing processes in these regions was also emphasized. The workshop proposed an experiment with three main phases, detailed survey and site selection, short (3-day), and long (6-month) experimental deployment of instrument packages designed to recover current, turbulence, optical, acoustic and photographic data. The site survey phase would involve not only hydrographic, echosounding and deep-tow survey but also recovery of undisturbed bottom samples and investigation of their properties in laboratory flumes. The short experiments would run at a high rate of data acquisition and get data on short term fluctuations of the floor and bed. The long experiments would have slower rates of data acquisition and employ in-situ processing and compaction of information from sensors. A cyclosonde profiling the lowermost 300 m of the water column with CTD, velocity and optical probes would be an essential feature. This and other aspects of the proposed program would require considerable engineering work in development of seabed instrument arrays. (NASA/JPL and ONR initiated a joint HEBBLE program in June 1978; see The HEBBLE Program below for details.)

D. PROGRAM FOR 1979

1. MELVILLE--Deep-tow Data Analysis.

Following the recommendations of our ONR program manager in last year's critique we are confining the data analysis phase of the MELVILLE cruise to the calendar year 1979 and this will be one effort of this P.I. and his group for the 1979 period. The principal investigators participating in this cruise, (Tucholke, Embley, Wimbush, Lonsdale, McCave, Flood, Johnson, Laine) have agreed that Deep-tow data will be archived, reduced and analyzed at Scripps with flow film copies made of analogue records at WHOI. Rather than distribute different types of data from different areas to different P.I.'s as we have in the past we will bring all (or most at any one time) of the P.I.'s together to analyze all of the data at one institution where the computer system is compatible with data formats. Lonsdale has agreed to serve as data coordinator and to host the analysis workshops which we plan to hold at Scripps between January and April 1979.

McCave will return from the U.K. for three months in the summer of 1979 to continue working up the Deep-tow data and advising thesis problems for M. J. Richardson and C. Paola as well as help work up the data from the proposed ATLANTIS II cruise and conduct settling experiments. We plan to have most, if not all, of the data in manuscript draft form by the end of 1979, with most of the actual data reduction (i.e. put into final illustrations for publication) by the time of the next ONR site visit.

2. NR-1 Data Wrap up.

We would also like to continue the very successful NR-1 data[1] "wrap up" program that was started last year by adding Linda Glover to our 1979 budget for three months effort. Her next project would be to organize and help write the NR-1 data obtained (1973) on the Blake Plateau (with Hollister, Cacchione and Flood).

3. Settling Distribution of Particles in Nepheloid Layer.

McCave also plans to tackle the problem of settling velocity distribution of particles in the nepheloid layer. The settling velocity of fine-grained sediment appears in equations for the distribution of suspended material in boundary layers, for the rate of deposition of sediment and for its vertical flux in the interior. It has never been measured in the deep sea. The advent of precision weighing techniques with Nuclepore filters has raised the possibility of successful application of the bottom-withdrawal tube method to low-concentration suspensions. It has already been successfully used in the laboratory and in estuaries. It is estimated that determinations of settling velocity distribution can be made on suspensions with a concentration as low as 30 μg/l.

A 30-liter water bottle of about 1.5 m length with no internal springs and having conical end caps containing taps will be constructed. This will act as the sedimentation column. In deep water the transit time of the bottle to the surface would allow significant accumulation of sediment in the bottom and therefore a system for rotating the bottle during ascent will be necessary. The suspension will be homogenized on deck by inverting the bottle 20 to 30 times on a rotating bottle holder. The bottle will also be insulated in styrofoam jackets to prevent convection developing inside. Samples are withdrawn from the bottom, filtered, weighed and a sedimentation/time curve is constructed from which the settling velocity distribution is obtained.

Budget costs for the settling bottle include materials, shop time and two weeks of salary for C. Winget in Ocean Engineering for design of hinges, release mechanisms, bottle rotation system and insulated bottle holder. Two days of OCEANUS time are requested to deploy the system in the well-developed nepheloid layer on the lower continental rise south of New England.

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[1]See NR-1 manuscript which is now in review and available at the site visit.

4. The HEBBLE Program

We have, in direct consultation with Pyle (ONR) and Martin (JPL), decided to set up the management structure seen in figure 1. We have also had a meeting of the Executive Committee (with the exception of Peter Lonsdale who is on the MELVILLE) at Woods Hole on July 5 which resulted in an operational task diagram (see in figure 2) out to 1984. This P.I. will serve as project director for this phase of HEBBLE with Rick Chandler and Mary Berry serving as operating staff. This central director's office (with staff) was suggested independently both by ONR and JPL management and it seems we will use this for starters as we see it develop and progress. The Executive Committee has also been named: physical oceanography representative is Mark Wimbush (URI); sediment dynamics representative is Nick McCave (WHOI-East Anglia); site selection functions will be handled by Peter Lonsdale (SIO); and ocean engineering by Sandy Williams (WHOI) with Sandy being the principal coordinator of the joint engineering efforts between JPL and the principal investigators. There will be a rotating chairmanship for this Executive Committee and that chairman will be responsible for keeping the project director's office informed of all scientific input and of any major engineering or systems design changes. In turn the project director's office will be responsible to the lead agency program manager, Tom Pyle, ONR Code 483. The scientific investigators that we have identified from the Keystone, Colorado HEBBLE Workshop are the following:

Physical Oceanography-Turbulence--M. Wimbush (Chairman)

G. Weatherly, S. Williams, G. Gust, L. Armi

Nephels and Sediment Flux--R. Zaneveld (Chairman)

N. McCave, P. Biscaye, M. Orr, W. Gardner

Biological and Sediment Interaction--P. Jumars (Chairman)

J. D. Smith, J. Yingst, E. Laine, A. Silva

Laboratory Experiments and Sea Flume--J. Southard (Chairman)

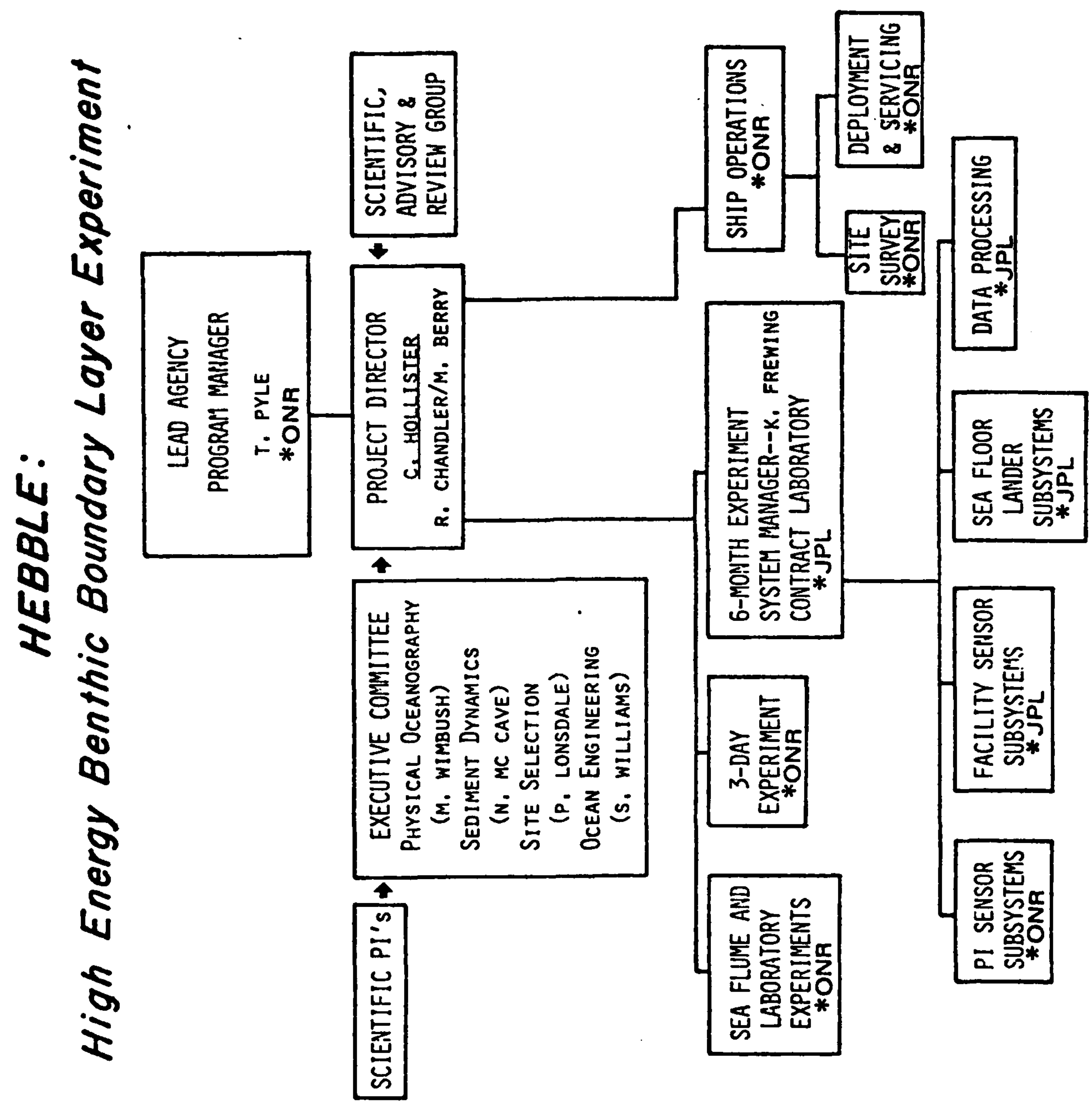
A. Silva, N. McCave, G. Gust, R. Gularte (URI)

Site Criteria and Survey--P. Lonsdale (Chairman)

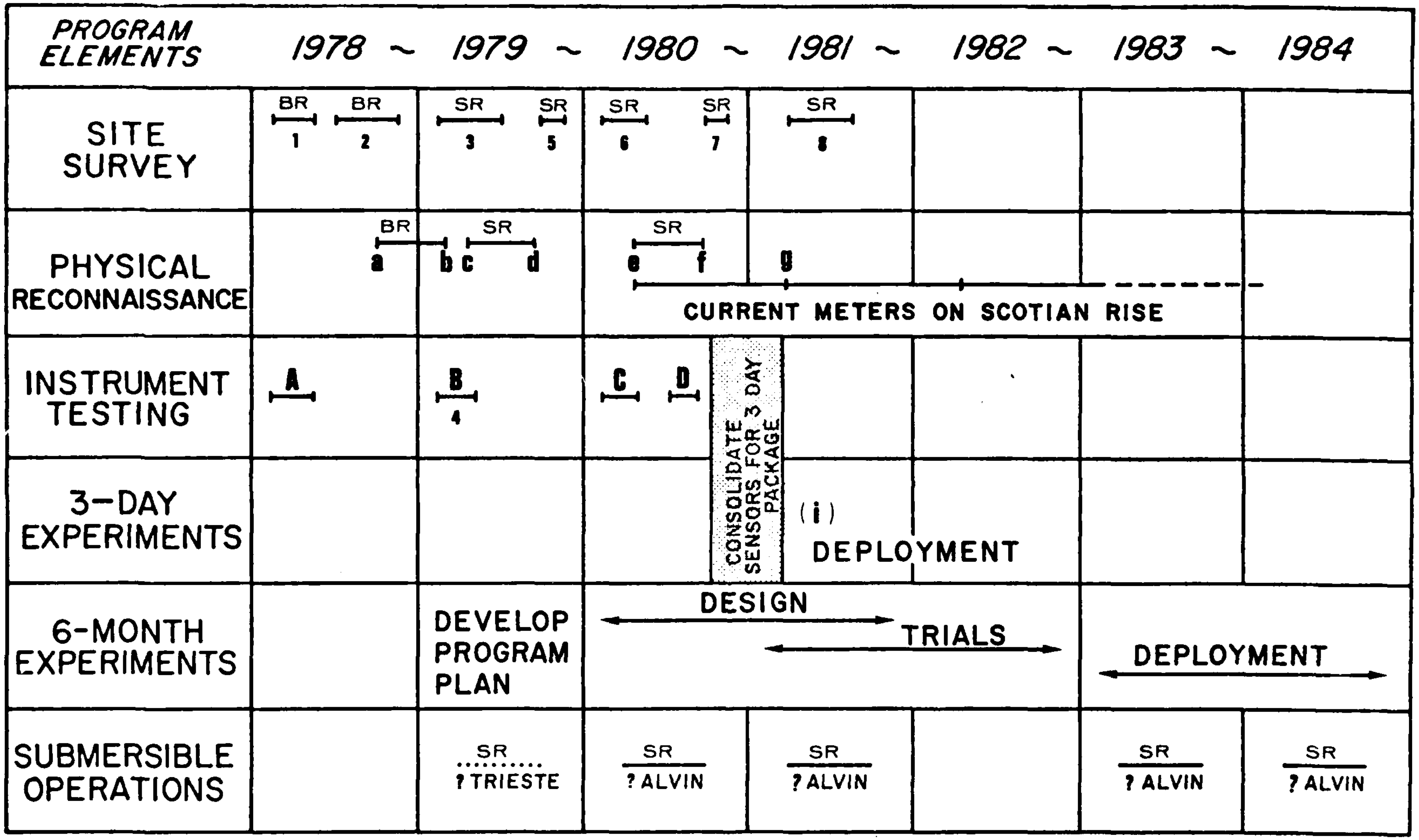
B. Tucholke, E. Laine, P. Jumars, C. Hollister

We are in the process of setting up a scientific advisory and review group.

FIGURE 1



HEBBLE:
High Energy Benthic Boundary Layer Experiment
LEAD AGENCY
PROGRAM MANAGER
T. PYLE
*ONR
PROJECT DIRECTOR
C. HOLLISTER
R. CHANDLER/M. BERRY
SCIENTIFIC, ADVISORY & REVIEW GROUP
EXECUTIVE COMMITTEE
PHYSICAL OCEANOGRAPHY
(M. WIMBUSH)
SEDIMENT DYNAMICS
(N. MC CAVE)
SITE SELECTION
(P. LONSDALE)
OCEAN ENGINEERING
(S. WILLIAMS)
SCIENTIFIC PI's
SHIP OPERATIONS
*ONR
DEPLOYMENT & SERVICING
*ONR
SITE SURVEY
*ONR
6-MONTH EXPERIMENT
SYSTEM MANAGER--K. FREWING
CONTRACT LABORATORY
*JPL
3-DAY EXPERIMENT
*ONR
SEA FLUME AND LABORATORY EXPERIMENTS
*ONR
DATA PROCESSING
*JPL
SEA FLOOR LANDER SUBSYSTEMS
*JPL
FACILITY SENSOR SUBSYSTEMS
*JPL
PI SENSOR SUBSYSTEMS
*ONR



BR = BERMUDA RISE SR = SCOTIAN RISE

1, a, A, (i) ETC. REFER TO NOTES ON FOLLOWING PAGE

FIGURE 2

Our immediate concern is with survey work to identify sites for deployment of experiments. There is a long lead time in this as surveys at successively decreasing scales are necessary. There is already reasonable information on a Blake-Bahama Outer Ridge site and this summer's MELVILLE cruise will examine some of the northeastern Bermuda Rise with Deep-tow. The Scotian Rise is a potential HEBBLE continental rise site but as yet only the most fragmentary data exist apart from 12 kHz bathymetry. This will need hydrographic survey, more detailed photography, closely spaced 3.5 kHz lines, and deep-tow survey. Plans are getting underway (see Part II of this proposal) for the Nova Scotian Rise site survey in spring '79 and it is anticipated that the following will be on board:

C. Hollister (Chief Scientist)	W. Gardner
A. Silva	M. Wimbush
E. Laine	S. Williams
R. Zaneveld	P. Lonsdale?
P. Biscaye	B. Tucholke?

5. HEBBLE Program Plan: Notes for Figure 2

Cruise #	Site Survey
1	Cruise on R/V ENDEAVOR to N.E. Bermuda Rise, hydrography, 3.5, 12 kHz, bottom photos, current meters, trial of BASS.
2	Cruise on R/V MELVILLE in August/September with the Deep-tow vehicle to survey areas on the N.E. (and S.W.?) Bermuda Rise. A Wimbush current meter and time lapse camera will be set at this time.
3.	32 day cruise on R/V ATLANTIS II in May to conduct hydrographic (CTD, transmissometer, nephelometer, radon), 3.5 kHz and 12 kHz, and photographic large scale survey of the Scotian Rise and Western Boundary Undercurrent over it, and to set a Wimbush camera/current meter system.
4	10 day instrument testing cruise on OCEANUS, Marshall Orr, Chief Scientist.
5	10 day cruise on R/V CONRAD in the fall to do work that could not be accomplished on the A-II in May, probably more underway geophysics and camera lowerings, and to pick up the Wimbush system.

Cruise #	Site Survey
6	20 day cruise (April/May on A-II?) to do surveys with close line spacing on a few specific areas of the Scotian Rise, some bottom photography with the WHOI Troika (towed camera sled), set transponders and a Wimbush system/BASS/ABYSS array (ABYSS is Marshall Orr's Acoustic Backscattering Sensor). Set current meters to monitor the WBUC, test Seaflume and hot film probes.
7	10 day cruise (September/October) with similar survey objectives as the previous one (#6), pick up Wimbush/BASS/ABYSS array and second test of Seaflume.
8	30 day cruise on R/V KNORR with Deep-tow to do detailed site survey of a few selected areas on the Scotian Rise, pick up and set current meter arrays and deploy a 3-day experiment package.

Physical Reconnaissance

a August/September set Wimbush camera/current meter system on N.E. Bermuda Rise from MELVILLE (Cruise #2).

b Pick up Wimbush I in May from OCEANUS (P.O. Cruise, Schmitz, Chief Scientist).

c Deploy Wimbush II in May on Scotian Rise from the A-II (Cruise #3).

d Pick up Wimbush II in the fall (September/October) on CONRAD (Cruise #5).

e Set Wimbush system/BASS/ABYSS array to run for 6 months on Scotian Rise, and set minimum 4 strings with two current meters on each across WBUC (Cruise #6).

f Pick up Wimbush/BASS/ABYSS (Cruise #7).

g Pickup and set new current meter moorings (Cruise #8).

Instrument Testing

A First deep water test of BASS on N.E. Bermuda Rise (Cruise #1 on ENDEAVOR).

B Testing of ABYSS, BASS, a Wimbush system and Gust's hot film turbulence probes in the vicinity of Hudson Canyon (Cruise #4, OCEANUS, July, Orr, Chief Scientist).

C Test of new deep water Seaflume and possibly Gust's hot film probes on Scotian Rise (Cruise #6).

D Second test of Seaflume on Scotian Rise (Cruise #7).

Testing of instruments and systems constructed as part of the 6-month experiment effort will be scheduled in the 1981-82 period.

3-Day Experiments

(i) Deployment of a 3-day experiment (turbulence, probes, BASS, ABYSS, stereo cameras, transmissometer, current meters) from KNORR on the Scotian Rise (Cruise #8).

Further deployments of the 3-day experiment package are envisaged on the Scotian Rise and possibly the N.E. Bermuda Rise in the period 1981/82.

6-Month Experiment

This will be designed and constructed by the JPL. As the development of the program plan comes along in 1979 the shiptime requirements for testing and deployment post-1981 will become more clear. It is at present envisaged that 1983 and 1984 will be the years for deployment of the 6-month experiment sea bed lander.

Submersible Operations

The possibility of these is uncertain because the most suitable and maneuverable vehicle is ALVIN with a 4000 m depth limitation and we are not certain how deep the core of the WBUC is on the Scotian Rise. Clearly a maneuverable DSRV with a greater depth range would be highly desirable. The possibility of TRIESTE being available in 1979 would allow us to take an early look at the sea bed on the Scotian Rise and make a direct assessment of current strength. In 1980 and 1981 ALVIN (if possible) would be involved in the deployment of sea flume and monitoring of the 3-day experiment. In 1983 and/or 1984 we anticipate use of a 20,000 ft. submersible in final survey of deployment sites for the sea bed lander.

Summary Table of Proposed HEBBLE Principal Investigators

Survey

C. D. Hollister (site selection)
P. F. Lonsdale (deep-tow)
B. E. Tucholke (sub-bottom stratigraphy, troika)
E. P. Laine (box cores, surficial acoustic characteristics)

P.O.

M. Wimbush (velocity, heat, time-lapse photography)
G. Weatherly (velocity structure, modelling)
G. Gust (turbulence)
A. J. Williams (BASS, instruments)
L. Armi (T/S structure, mixing)

Sediment Dynamics and Nephels

I. N. McCave (nephels)
J.R.V. Zaneveld (optical nephels)
M. Orr (acoustic nephels)
P. E. Biscaye (nephels and radon)
J. B. Southard (seaflume)
A. J. Silva (lab experiments, geotechnics)
P. Jumars]
J. D. Smith] (organism-sediment interaction)

P.I.'s will designate the other participating members of their laboratories as "associate investigators" and supply the project director with their names and programs in 1979.

SEDIMENT DYNAMICS
HIGH ENERGY BENTHIC BOUNDARY LAYER EXPERIMENT PROGRAM
LABORATORY INVESTIGATIONS
1 January - 31 December 1979

			ONR Man/Months	Actual
A.	SALARIES AND WAGES			
	Professional:	C. D. Hollister, Assoc. Sci.	5	5
		I. N. McCave, Visiting Inv.	3	3
		L. Glover, Visiting Inv.	2	2
		Assoc. Scientist, TBA	N/C	N/C
		Postdoctoral Investigator, TBA	6	6
		C. Winget, Res. Specialist	0.5	0.5
	Support:	J. Ellis, Res. Assoc.	1	1
		B. Von Herzen, Summer student empl.	3	3
		R. Chandler, Res. Asst.	10	10
		P. Hindley, Res. Asst.	4	4
		M. Berry, Secretary	6	6

Gross Regular Salaries (includes an allowance for vacations, holidays and sick pay of $5,599 which is accounted for as employee benefits)			$49,508
B.	OTHER EMPLOYEE BENEFITS		12,843
C.	TOTAL SALARIES AND BENEFITS		62,351
E.	EXPENDABLE SUPPLIES AND EQUIPMENT		
	1. Photographic reproduction of Deep-tow data	$1,500	
	2. Photographic files for Deep-tow photographs	450	
	3. Expendable supplies for settling velocity distribution experiment	740	2,690
F.	TRAVEL*		
	1. Domestic	13,396	
	2. Foreign	8,654	22,050
G.	PUBLICATION COSTS		
	1. Graphic Arts: 230 hrs @ $13	2,990	
	2. Page charges: 30 x $80/pg.	2,400	5,390
H.	SHIP COSTS		
	2 days R/V OCEANUS @ $3,433 (SVD experiment)		6,866
I.	COMPUTER AND PERIPHERAL COSTS		
	Sigma 7: 10 hrs @ $155/hr.		1,550
J.	OTHER MISCELLANEOUS COSTS		
	1. Shop services: 220 hrs @ $13/hr.	2,860	
	2. Shipping and communications	3,000	
	3. Laboratory overhead of 21% of C	13,094	
	4. GRA: 5 months @ $1070, 5 @ $1155	11,125	30,079
K.	TOTAL DIRECT COSTS		130,976
	Indirect Costs @ 15% of TDC		19,646
L.	TOTAL REQUESTED		$150,622

*See following page for detailed travel.

HIGH ENERGY BENTHIC BOUNDARY LAYER EXPERIMENT PROGRAM
LABORATORY INVESTIGATIONS
1 January - 31 December 1979

F. TRAVEL

1. Domestic		
10 R/T Woods Hole-La Jolla (95 days travel expenses A/F-$4,720; T/E-$4,750; cars-$800	10,270	
2 R/T Woods Hole-Lamont (5 days expenses) A/F-$150; T/E-$250; cars-$160	560	
3 R/T Woods Hole-Washington, DC (6 days travel expenses A/F-$360; T/E-$300; cars-$240	900	
3 R/T Woods Hole-URI (3 days travel expenses Mileage-$112; T/E-$150	262	
2 R/T Woods Hole-Pasadena (6 days travel expenses A/F-$944; T/E-$300; cars-$160	1,404	
		$13,396
2. Foreign		
1 R/T Norwich, U.K.-Woods Hole (10 days travel expenses A/F-$804; T/E-$600; cars-$80	1,484	
2 R/T Norwich, U.K.-La Jolla (95 days travel expenses A/F-$2,220; T/E-$4,750; cars-$200	7,170	
		8,654
TOTAL TRAVEL		$22,050

SEDIMENT DYNAMICS

Charles D. Hollister (617) 548-1400 Ext. 472

PART II: HEBBLE Cruise on ATLANTIS II to Scotian Rise

ABSTRACT

In the HEBBLE Report[1] it is stated that one of the high priority objectives of the HEBBLE Program is to do detailed site surveys and to deploy existing sensors in HEBBLE candidate sites as soon as possible in order to make a reconnaissance of the temporal and spatial variability of high energy "events" and the resulting bedforms. This is the overall objective of this proposed cruise (in May 1979) on ATLANTIS II to the Scotian Rise, potentially a prime HEBBLE candidate site. On this cruise, current and water mass related variables of the benthic boundary layer will be measured to determine the position of the "axis of maximum activity" of the Western Boundary Undercurrent.

A. LONG RANGE OBJECTIVE, STATUS AND PROGRESS IN 1978

See Part I of this proposal.

B. PROGRAM FOR 1979

Prejudices concerning the site selection criteria for HEBBLE have developed over the past 15 years in the minds of a small number of investigators who have been studying microphysiography of the abyssal sea floor and trying to relate observed features to hydrographic data and sparse data from current meters placed far from the bottom. It has only been in the last few years that enough data, of the right kind, has been obtained showing that some of the bed features are actually being formed and modified, now, by active processes associated with near bottom ocean circulation.

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[1]McCave, I.N., C.D. Hollister, and T.E. Pyle, 1978. The HEBBLE Report (Report of a Workshop on High Energy Benthic Boundary Layer Experiment), WHOI Technical Report 78-48, 80 p.

Although very little is known about both bedforms and low frequency (>2 days) variability in bottom flow, geological studies of sediment dynamics have been based on this morphologic and hydrographic information together with observations of sediment provenance and current produced structures, textures and grain sizes in cores. Parallel to this effort has been the development of theoretical ideas concerning boundary layer flow, deep mixed layers as seen by nephelometers and the recently developed CTD, and the realization that near-bottom current speeds of ocean flow are often unexpectedly high. Taking this into account the majority of participants in the HEBBLE Workshop at Keystone, Colorado accepted the following site selection criteria:

1. Regional (100's to 1000's of kms^2) description of sea floor

   (a) topographically uncomplicated on a meso-scale (100's to 1000's of meters)

   (b) covered with cohesive (clay to clayey silt) sediment that displays

   (c) well developed current produced bedforms of the scale (λ) of 10's of cms to 10's of meters (i.e. from small crag and tail, through mud ripples possibly to small abyssal furrows).

2. Water column characteristics

   (a) an area of known or suspected high flow speeds, ideally in areas of strong mean flow and weaker low frequency variability; not downstream of large eddy-shedding topographic elements

   (b) modern continental input of terrigenous debris should be as low as possible (ideally zero)

   (c) a region of characteristic water-mass parameters that can be identified and traced.

A more formal way of guiding the selection of a site is through use of the conservation equation (e.g. for suspended sediment) to provide a framework:

$$\frac{DC}{DT} + \lambda C + \bar{\nabla}\cdot\bar{F} = 0$$

C is the concentration
λ is the settling rate, a function of particle size
$\bar{F}$ is the flux of C, often parameterized in the water column as
$\bar{F} = -D\nabla C$ where D = dispersion coefficient
and D/DT = total derivative = $\partial/\partial t + \vec{u}\cdot\nabla$

Within this framework we are searching for a region at which the substantive derivative DC/Dt can be approximated by $DC/Dt \simeq \bar{u} \cdot c$. In other words, the importance of temporal variability is small relative to other aspects. This is a site selection criterion for the large scale and should not be taken to imply that temporal variability is considered unimportant, particularly at smaller scales.

We are also searching for sites at which either none or hopefully only one of the remaining terms is varying. As a group, two possible sites are favored, the Blake-Bahama Outer Ridge and Scotian Rise. More preliminary survey work is required before a definitive site can be proposed, and that survey work is proposed herein.

The methods of identifying and surveying such areas will vary considerably depending on the scale and location being examined. However they can be broken down conveniently into the following three phases:

Phase 1 The collection and synthesis of all presently available data, identifying areas warranting further study (done by 1 January 1979).

Phase 2 Field operations in these areas using rapid surface vessel survey techniques (e.g. 12 and 3.5 kHz) with station time for CTD, radon, bottom camera and nephelometry (proposed for 1979)

Phase 3 Detailed near-bottom microphysiographic studies using deeply-towed echosounder, side scan sonar and stereo cameras with ancillary moored short term current meters. Determination of site variables such as bed shear strength and erodibility would be carried out using an instrumented sea bed flume. Box cores of the bed would be obtained for laboratory determinations. Subsequently there would be two experimental programs:

Program 1: deployment of near bottom, short term (e.g. 3-day) experiments including time-lapse cameras, Reynolds stress sensors, stacked current meter arrays, recording transmissometers.

Program 2: deployment of long term (6 month) HEBBLE with cyclosonde and full scale bottom monitoring array with microprocessor control.

We think it feasible to do it in the following time sequence:[1]

1978: Do Phase 1 (a continuing activity) and some areas of Phase 2.

1979: Do Phase 2 on A-II (this proposal and Biscaye proposal of LDGO) and CONRAD (see Tucholke, LDGO, ONR Omnibus proposal).

1980/81: Concentrate on specific site surveying (Phase 3) and 3-day HEBBLE trials while designing the equipment for the experimental 6 month HEBBLE.

1982: Begin shallow water field tests of some 6 month HEBBLE systems while continuing use of 3-day HEBBLEs.

1983/84: Conduct 6 month HEBBLEs.

This proposed cruise is the first one to the Scotian Rise to be mounted under the new HEBBLE program. This is focussed on HEBBLE site selection and physical reconnaisance activities on the Scotian Rise. We plan to deploy (on A-II) the Wimbush time lapse camera/VACM system on the Scotian Rise to begin determination of frequency of occurrence of sediment movement, computations of the critical shear stress necessary for bedform migration, comparison of the sediment flux to stress or current speed. The exact site(s), station locations and cruise tracks will be developed in the fall of 1978 and early 1979 after consultation with our colleagues at Bedford and NAVOCEANO.

We will probably concentrate our effort in the region roughly midway between the Gully Submarine Canyon of Nova Scotia and the New England Seamounts. This region just north of the Seamounts has the smoothest regional bathymetry of any continental rise region off the North American continent and is also in a region where the Western Boundary Undercurrent is known to be vigorous (Zimmerman, 1971) and is producing bedforms in cohesive sediment (see pp. 394-396 in Heezen and Hollister, The Face of the Deep). We will extend these observations by occupying across slope station transects using the techniques/investigators listed below:

(1) time lapse photography/transmissometry/Reynolds stress sensors/VACM on bottom mounted system = Wimbush, Williams

(2) profile of nephels plus light transmission through the water column plus deep-tow CTD and 30-liter Niskin bottles = Zaneveld, Biscaye, Gardner

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[1]See Figure 2, Part I, this proposal for schedule of events.

(3) near-bottom (10's cm), oblique photography of bedforms on standard Lamont nephelometer current meter system = Biscaye, Hollister

(4) box cores for organism content, bioturbation, geotechnical properties, surface bed roughness estimations = Silva, Laine, Gularte

(5) underway 12 and 3.5 kHz and reflection seismic profiling with small airguns for outcrops and large bedforms pinching?? and other current-produced structure and stratigraphy = Hollister, Laine, Tucholke

(6) excess radon determinations for indication of turbulent mixing = Biscaye

(7) We may decide to deploy transponder benchmarkers with the two to five year passive HEBBLE arrays being developed by Sandy Williams at WHOI.

We plan to occupy 7 sections across the continental rise at approximately 50 km apart, each section consisting of 10 stations approximately 15 km apart. The resulting total of roughly 70 deep water stations is an optimistic objective for a one month cruise. However, because of the short steaming distance between stations it may not be possible to measure every parameter at every station and the chief scientist (C. Hollister) and the other HEBBLE principal investigators may, of necessity, change plans in reaction to the results coming from the cruise and to the time constraints imposed by the distance involved.

We expect to concentrate very heavily on station work and filling in with underway geophysical work during the time required to analyze the data and prepare for the next set of stations. This cruise will require a full shipboard complement, a large number of whom will come from sister institutions of URI, LDGO and OSU. The LDGO program of radon, particulate filtration and nephelometry and bottom photography which will be carried out around the clock will require a six-man shipboard contingent working 16 hours on/8 off watches (see Biscaye, LDGO ONR Omnibus proposal for details). A direct requirement for this ambitious multi-institutional program is a well organized, tightly run, cruise with extensive preparation and co-ordination, and to this end E.T. Bunce has accepted the offer of being the cruise coordinator. She, with this P.I. will be responsible for putting the cruise together and making sure all the shipboard pieces of equipment (and investigators) are in good working order.

HIGH ENERGY BENTHIC BOUNDARY LAYER EXPERIMENT PROGRAM - SCOTIAN RISE
1 January -31 December 1979

A. SALARIES AND WAGES

		ONR Man/Months
Professional:	C. D. Hollister, Assoc. Sci.	1.5
	E. T. Bunce, Senior Scientist	2.0
	Assoc. Scientist, TBA	1.5
	Postdoc. Investigator, TBA	2.0
Support:	P. Hindley, Res. Assistant	3.0
	R. Handy, Res. Assistant	1.0
	J. Connell, Res. Assistant	2.0

Other Personnel:	M. Wimbush, Assoc. Prof. (URI)	
(No Cost)	R. Zaneveld, Assoc. Prof. (OSC)	
	P. Biscaye, Sr. Res. Associate	(LDGO)
	W. Gardner, Postdoctoral	(LDGO)
	L. Sullivan, Technician	(LDGO)
	A. Silva, Assoc. Prof.	(URI)
	E. Laine, Res. Assoc.	(URI)

Gross Regular Salaries (includes an allowance for vacations, holidays and sick pay of $ 2,488 which is accounted for as employee benefits)		$ 22,909
Cruise Leave, Dea Duty Vacation and overtime, including premium pay of $ 3,018		14,039
TOTAL SALARIES AND WAGES		$ 36,948
B. OTHER EMPLOYEE BENEFITS		11,985
C. TOTAL SALARIES AND BENEFITS		$ 48,933
E. EXPENDABLE SUPPLIES AND EQUIPMENT		
1. General shipboard supplies	$ 500	
2. Film for 50 camera stations	1,500	
3, Processing chemicals	200	
4. Paper for prints	150	
5. Underway geophysics measurements:		
a. Echo-sounding, 3.5 and 12kHz	1,190	
b. Continuous seismic profiling w/airguns, hydrophone arrays, etc.	5,066	$ 8,606
H. SHIP COSTS: 30 days RV ATLANTIS II @ $4856		$ 145,680
J. OTHER MISCELLANEOUS COSTS:		
1. Shop services: 200 hrs @ $13	$ 2,600	
2. Shipping and communications	2,000	
3. Laboratory overhead of 21% of C, exclusive of premium pay	9,642	
4. GRA: 5 mos @ $1,070, 5 @ $1,155	11,125	
5. Contingency funding for loss of cable, array or major breakdown	4,000	$ 29,367
K. TOTAL DIRECT COSTS		$ 232,586
Indirect Costs @ 15% of TDC		34,888
L. TOTAL COSTS		$ 267,474

DATA PROCESSING AND MANAGEMENT

Charles R. Denham and Robert C. Groman

Charles R. Denham Tel: (617) 548-1400 Ext. 465
Robert C. Groman Tel: (617) 548-1400 Ext. 469

Long Range Objectives

The main responsibilities of our group are the processing and management of digital underway geophysical data. Since 1970 we have written and continually improved computer programs for merging and graphical display of the department's geomagnetics, bathymetric, and gravity measurements while at sea, as well as for dealing ashore with data received from other organizations. The digital data are managed using the Digital Data Library System (DDLS) [Groman, 1974], providing our researchers with access to a magnetic tape library of Institution data collected since 1963. The processed digital data routinely are sent to the National Geophysical and Solar-Terrestrial Data Center at Boulder, Colorado for use by others.

Present Status and Progress in 1978

Our library of underway geophysical measurements now contains more than 275,000 records, representing an increase of about 20% since this time last year. NGSDC has received all of our reprocessed and newly released data. The latter were collected in late 1977 (ATLANTIS II cruise 96) and early 1978 (ATLANTIS II cruise 97).

Since there have been fewer geophysical cruises during 1978 than in 1977 (three legs versus nine), we have spent more time ashore than usual working directly with our department's scientists and others, helping them to take advantage of our computer programs and data library. Table 1 shows a summary of specific tasks which we performed for our department during the first six months of 1978.

We participated heavily in the systems analysis of a new shore-based computer for the Institution, which is scheduled to arrive late this year. We were also actively involved in a survey of word processing equipment. We continue to provide programming assistance to departmental researchers and students on request.

TABLE 1

Summary of Specific Departmental Tasks
January - June 1978

DATE	REQUESTED BY	FUNDING	BRIEF DESCRIPTION
3 January	D.A. Johnson	ONR	Graphical display; AII 93-7
23 January	H. Hoskins	OIP	Data processing; AII 93-18 seismic navigation
24 February	L. Whiteley/ D.A. Johnson	ONR	Change core and dredge data retrieval program
28 February	H. Hoskins	OIP	Data processing; AII 95 seismic navigation
1 March	H. Hoskins	OIP	Data processing and graphical display; AII 93-18
1 March	E. Bunce	NSF/ONR	Cruise report; AII 93-7
10 March	C. Hollister	ERDA	Graphical display; summary charts
1 April	S. Briggs	ERDA	Data processing and programming ASTERIAS
20 April	D. Ross	NSF	Graphical display; AII 93-18
16 May	H. Hoskins	OIP	Data processing; finalize AII 97-1
24 May	H. Hoskins	OIP	Graphical display; AII 93-2
31 May	G. Purdy	ONR	Data processing and graphical display; AII 96-3
1 June	H. Hoskins/G. Purdy	OIP/ERDA	Data processing and graphical display; LYNCH and AII 97-2
14 June	C. Hollister	ERDA	Graphical display; summary charts
19 June	E. Uchupi	OIP	Graphical display; AII 93-2
22 June	G. Purdy	USGS	Graphical display; LORAN C
30 June	D. Ross	NSF	Graphical display; AII 93-19

During the latter part of 1978 we will be working on the database of Institution computer programs. We are also preparing a comprehensive report of the data processing and display programs which we use at sea. The report will contain program documentation and listings.

Relevant Accomplishments over Total Program Period

The Office of Naval Research has funded the data processing and management group in geophysics for nearly eight years. During this time we have organized data management procedures and a library of underway data on computer tape; created data processing procedures and computer programs in order to fully process geomagnetic, depth and gravity data while still at sea; published a summary atlas of the data; forwarded all processed data to NGSDC for national archiving; and written cruise data and computer program reports.

Proposed Programs for 1979

At present, we are scheduled to support two cruise legs during 1979 with our data processing personnel and software. We will convert our graphical display programs to the new computer system during 1979 to take advantage of the superior graphics equipment, reduced costs, and of course the new library described below. In addition, the NGSDC MGD-77 data exchange format we helped design will be implemented. Since nearly all the processing is accomplished at sea, there will be little need for converting the shore-based data processing programs to the new shore-based computer system.

Our major task ashore during 1979 will center on redesigning our tape-based data library to a disk-based library. This effort is stimulated by the Institution's acquisition of a new computer with improved disk storage and graphical display features. Important elements of the library's design are: 1) sequential retrieval of underway geophysical data by cruise leg; 2) retrieval by geographical bounds; 3) non-uniform data block sizes; 4) affordable updating and maintenance costs; 5) binary data storage; and 6) merged-merged data storage format. These features will be implemented using the sublist data structure illustrated in Figure 1. We plan to have the pointers refer to file names (rather than track and sector addresses) in order to take advantage of the intrinsic file handling capabilities of the computer's operating system. This will allow us to resort to tape storage for infrequently

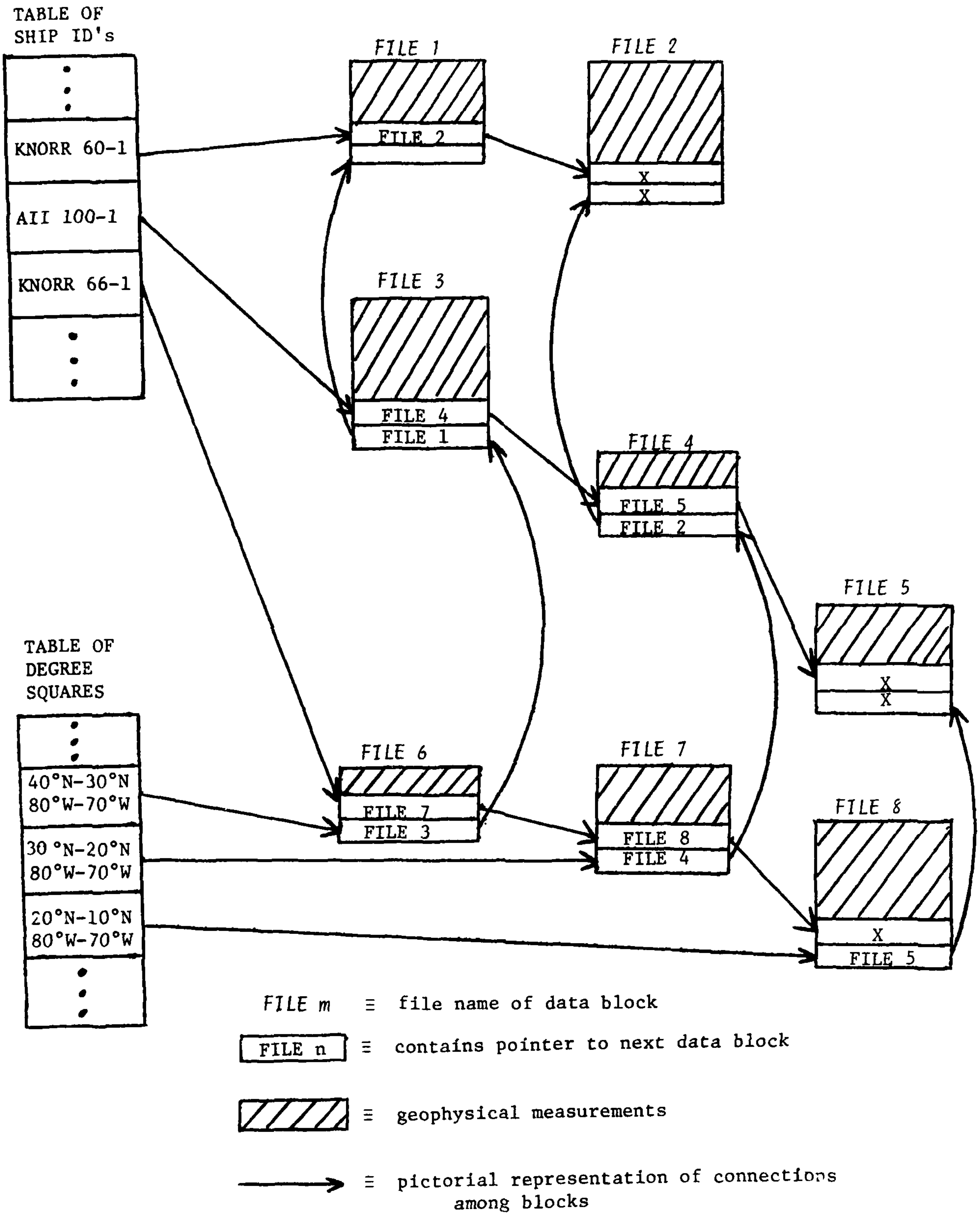

FIGURE 1: Scheme for data retrieval by cruise leg or geophysical area.

accessed data in order to reduce (if necessary) the requirements for on-line disk space. The storage and retrieval software will be written during 1979, and the existing data will be converted to the new scheme in 1980. For the 1980 work we will have to acquire sufficient dedicated disk storage for the library.

Relevant Publications

Dunworth, J.A., 1978. Index of digital underway geophysical data at W.H.O.I. through 11 May 1978. Woods Hole Oceanographic Institution Technical Memorandum WHOI-2-78.

Gegg, S.R. Programs for charting data in Lambert conic conformal projection on a minicomputer. In preparation.

Groman, R.C., 1974. The digital data library system: library storage and retrieval of digital geophysical data. Woods Hole Oceanographic Institution Technical Report WHOI-74-68, unpublished manuscript.

Groman, R.C. and J.A. Dunworth, 1978. Cruise data report R/V ATLANTIS II 93, Leg 7. Woods Hole Oceanographic Institution Technical Report WHOI-78-34, unpublished manuscript.

Groman, R.C. and H. Hoskins, 1977. A complete navigation and total geomagnetic field processing package using the Hewlett-Packard 9830 calculator. Woods Hole Oceanographic Institution Technical Report WHOI-77-23, unpublished manuscript.

MGD77 Task Group, 1977. The marine geophysical data exchange format 'MGD 77'. National Geophysical and Solar-Terrestrial Data Center, No. 10, September 1977.

DATA PROCESSING & MANAGEMENT

1 January - 31 December 1979

		ONR Man/Months	Actual	
A.	SALARIES AND WAGES:			
	Professional:			
	C. Denham, Associate Scientist	N/C	2.0	
	R. Groman, Res. Associate	4.0	10.0	
	Support:			
	C. Wooding, Res. Assistant	1.0		
	J. Dunworth, Res. Assistant	4.0		
	S. Gegg, Res. Assistant	4.0		
	S. Tonge, Secretary	1.0		
	Gross Regular Salaries (includes allowance for vacations, holidays, and sick pay of $ 1,574 which is accounted for as employee benefits)	$ 15,160		
B.	OTHER EMPLOYEE BENEFITS	4,132		
C.	TOTAL SALARIES AND BENEFITS			$ 19,292
D.	PERMANENT EQUIPMENT (None)			
E.	EXPENDABLE EQUIPMENT AND SUPPLIES			
	1. Photo supplies			70
F.	TRAVEL (Domestic)			
	1. 1 R/T WH-New York with 4 days expenses A/F - $75, T/E inc. reg.$ 300, car - $80	$ 455		
	2. 1 R/T WH-Rochester, NY with 4 days expenses A/F - $115, T/E $200, mileage $35	350		$ 805
G.	PUBLICATION COSTS			
	1. Graphic Arts: (24 hrs. @ $13.00)			$ 312
H.	SHIP COSTS (None)			
I.	COMPUTER COSTS:			
	1. Sigma 7: 13 hrs. @ $155/hr	$ 2,015		
	2. VAX 11: 45 hrs. @ $45/hr	2,025		
	3. Hewlett-Packard: 15 hrs. @ $ 25/hr	375		$ 4,415
J.	OTHER MISCELLANEOUS COSTS:			
	1. Shipping and communications	$ 225		
	2. Laboratory overhead of 21% of C	4,051		$ 4,276
K.	TOTAL DIRECT COSTS			$ 29,170
	Indirect costs @ 15%			4,376
L.	TOTAL COSTS			$ 33,546

SEA FLOOR SAMPLES LABORATORY

D. A. Johnson

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Abstract

This proposal is a renewal request to the Office of Naval Research to continue support for the operation of the W.H.O.I. Sea Floor Samples Laboratory during 1979. The central purpose of the project is to insure that the minimal, essential level of shore-based support is available for our ongoing geological sampling programs at sea. These programs include both conventional techniques (coring and dredging) as well as specialized capabilities (submersible sampling, giant coring). Our experience over several years has shown that effective utilization of ocean floor samples requires the continuing application of effective procedures for sample archiving and description, and that these shore-based procedures should be supported separately from the costs of shipboard sample acquisition. We have provided this service since 1973, under support from O.N.R. and N.S.F. on a 50/50 basis. We request continuation of this support from O.N.R. during 1979, at a level of one full-time technician and one-third time for secretarial services.

Long-Range Status and Progress during 1978

Since the initiation of this task in January of 1973, we have developed and implemented a set of procedures for shipboard and shore-based sample archiving and description, in close cooperation with representatives of approximately 15 major data centers and core laboratories throughout the U.S. These procedures have been described in numerous technical reports (see LIST OF CORE LAB REPORTS) and have been applied to the backlog of core, dredge, and submersible samples.

The users of our collections have included representatives from virtually all of the 130 organizations which are on our distribution list for receiving sample descriptions. These organizations include government laboratories, universities, industry, and private research institutions, both in the U.S. and overseas, which are engaged in marine-related research activities. Less than one-fourth of our sample requests are from Woods Hole users; the large majority of the requests come from individuals not directly associated with the original cruise during which the samples were obtained. Consequently our principal impact has been to extend the availability of samples to individuals who might not otherwise be aware of their existence and their applicability in their own research.

Within the past 3 years, we have published the first five volumes of visual descriptions and smear slide analyses (Johnson and Driscoll, 1975; 1977), and have distributed these to approximately 130 institutions, libraries, and data centers. These volumes represent all cores obtained prior to January 1977. In addition to descriptive information, these volumes include maps which show the cruise track for each expedition, a computer print-out listing the cores taken on each expedition and a separate listing of all cores in the W.H.O.I. collection arranged geographically according to Marsden square numbers. Subsequent volumes of descriptions for newly acquired cores will be printed and distributed periodically, depending upon the rate of sample acquisition.

During 1978 we have formulated and have begun to carry out a systematic set of procedures for the cataloging and description of all rock samples in the W.H.O.I. collection. We have found that the rock collection is now in a condition comparable to that of the core collection in 1973 when we began work on systematic core descriptions: some of the collection is thoroughly documented and described, but the vast majority has major gaps in the documentation, labeling, and other record-keeping procedures. Consequently we have devoted a considerable proportion of our effort in the past year toward a thorough re-examination of the entire collection to update and complete the remaining documentation. This task is now completed. We propose to continue a major effort directed toward the compilation and distribution of a descriptive catalog of the entire rock sample collection.

Particular attention during 1978 has been devoted toward a thorough review of the logistical and operational aspects of all U.S. core lab facilities, and this review is already leading to significant improvements in our operations. While each institution will continue to exercise individual preferences in some matters (for example: types of sampling devices used; sediment classification schemes; sample storage facilities), we are now beginning to convert the essential logistical and descriptive information to a common format so as to allow rapid retrieval of sample data in a single step, rather than on an institution-by-institution basis. The Environmental Data Service of NOAA is now acting as a central data repository, and their staff personnel are working closely with us, as curatorial representatives, to convert our data into appropriate formats for submission to this central facility.

A major step has been taken during 1978 (under the leadership of A. Driscoll) to standardize the shipboard coring equipment used by each of the major oceanographic institutions. Such a step will enable us to have our operations interchangeable between various ships, and will allow us to save considerably in the purchase of new core barrels, weight stands, fittings, and other major equipment items.

Proposed Programs for 1979

During 1979 the following tasks will form the basis of our continuing program:

(1) Preparation and distribution of core descriptions for current core and dredge material. A considerable volume of material has been received from recent cruises in the Indian Ocean, Cayman Trough, Galapagos Spreading Center, Iceland Basin, and Reykjanes Ridge. Additional material is expected during 1979 from the western Indian Ocean, northeastern Atlantic, Bermuda Rise, and Kane Fracture Zone. We will give highest priority to the preparation of these current materials and making them available to potential users.

(2) Cataloging and description of backlog of dredge samples. With the increasing scientific efforts which are being directed toward crustal dynamics and petrogenesis, critical collections of oceanic rocks must be readily accessible to qualified investigators. The oceanic crustal samples in the Woods Hole collection (obtained principally by dredging, submersible sampling, and drillings) comprise one of the most extensive collections in the world. To meet the increasing demands of our own petrologists, their colleagues at other institutions, and other potential users, we have formulated a comprehensive set of procedures for rock sample archiving and initial description. These procedures have resulted from frequent consultation with our own petrology staff and students, and meet 3 basic tests:

Practicality. We have considered the logistical aspects of sample acquisition and processing at sea, and have proposed a set of procedures for sampling handling and record-keeping which will ensure the retention of all critical information, yet will not be unnecessarily time-consuming.

Scientific usefulness. We have suggested the types of information to be recorded on the various data sheets and record books which will be of greatest use to petrologists who will subsequently utilize the collection. The principal aim is to provide enough initial information for a petrologist to determine immediately whether or not a particular rock sample is of potential scientific value for his particular type of investigation.

Cost-effectiveness. The descriptive information which is being cataloged on a routine basis is not intended to be comprehensive; more detailed petrological and petrographic analyses are the responsibility of the scientists to whom the funds for sample collection were given. We intend to place the curatorial costs in a reasonable proportion to the costs of initial sample acquisition.

We have distributed copies of our current procedures for rock description to our colleagues at other institutions. We fully expect that significant modifications may be incorporated on the basis of comments from these individuals, plus our own experience during the initial stages of sample description.

In order to be able to continue our comprehensive program of systematic rock description, as well as keeping up with the continuing acquisition of new cores and dredges, we will require 16 man-months of salary support from ONR in 1979. An equal amount is being requested from N.S.F. (continuation of grant OCE76-81488). This level of effort (32 man-months total) is considerably less than that which we received during the early stages of this project (1973 and 1974). Cost in 1979 is higher due to merit salary increases over the past several years. Our experience has shown that this level of effort is essential if we are to be able to go beyond the immediate demands of keeping up with incoming materials and sample requests and do an adequate job on the backlog of rock samples, the demand for which is continuing to increase.

(3) Submission of digital sample data to NGSDC. As a result of recent discussions by representatives of marine data centers, we have agreed to submit basic logistic and descriptive data for all samples to a national data center in a common format. Coding forms have been prepared by NGSDC and distributed to us; we will complete the task of coding all sample data during 1979.

LIST OF CORE LAB REPORTS

Johnson, D.A. and A.H. Driscoll, 1972. The curating of W.H.O.I.'s geological collections. WHOI Technical Memorandum, WHOI 2-72, 80 pp.

Driscoll, A.H., 1973. Digitization of geological sample data at sea for use with MUDDIE program. WHOI Technical Report, WHOI-73-54, 15 pp.

Gilman, J.A., 1973. Procedure for photographing W.H.O.I. sediment cores. WHOI Technical Memorandum, WHOI-1-73, 11 pp.

Mountain, G.S., 1973. Procedures for description of W.H.O.I. geological samples data file, volume I, 1957 to 1973. WHOI Technical Report, WHOI-75-37, 278 pp.

Johnson, D.A. and A.H. Driscoll, 1975. Descriptions of W.H.O.I. sediment cores. WHOI Technical Report No. 75-8, volumes I-IV, 2940 pp.

Johnson, D.A. and A.H. Driscoll, 1977. Descriptions of W.H.O.I. sediment cores, volume 5, WHOI Technical Report No. 77-26, 796 pp.

BUDGET

SEA FLOOR SAMPLES LABORATORY
1 January 1979 - 31 December 1979

		ONR Man-Months	ACTUAL Man-Months
A.	SALARIES AND WAGES		
	Professional:		
	D.A. Johnson, Assoc. Scientist	N/C	N/C
	C.R. Denham, Assoc. Scientist	N/C	N/C
	Support:		
	J.E. Broda, Res. Assistant	6.0	12.0
	H.G. Farmer, Res. Asst.	6.0	12.0
	D. Allison, Secretary	4.0	8.0
	Gross Regular Salaries (including allowances for holidays, vacation, and sick pay of $1,994 which is accounted for as employees benefits)	$16,616	
B.	OTHER EMPLOYEE BENEFITS	4,147	
	TOTAL SALARIES AND BENEFITS		$20,763
C.	PERMANENT EQUIPMENT (none)		-0-
D.	EXPENDABLE SUPPLIES AND EQUIPMENT		
	1. Microscope slide preparation supplies	250	
	2. Core photography & printing	200	
	3. Drawers for rock storage	300	
	Total Expendables		750
E.	TRAVEL (none)		-0-
F.	PUBLICATION COSTS		
	Graphic Arts: 35 hrs @ $13/hr.		455
G.	SHIP COSTS (none)		-0-
H.	COMPUTER COSTS		
	Sigma-7, 5 hrs @ $155/hr		775
I.	MISCELLANEOUS COSTS		
	1. Shipping & communications	450	
	2. Xeroxing	200	
	3. Laboratory Overhead at 21% of A + B exclusive of premium pay.	4,360	
	Total Miscellaneous Costs		5,010
	TOTAL DIRECT COSTS		$27,753
J.	INDIRECT COSTS @ 15%		4,163
	TOTAL COSTS		$31,916

MARGINAL SEAS

David A. Ross

PII Redacted [redacted] Telephone No.
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Abstract

The principle objective of this project is the understanding of the geological and geophysical characteristics of marginal seas. During the past year papers on the hydrography of the Red Sea, structure of the western Gulf of Oman, structure of the Persian Gulf and shallow structure of the eastern Mediterranean have been essentially completed. In addition six other ONR-sponsored papers were published during this past year. For the coming year I principally wish to begin writing a synthesis of the marine geology and geophysics of the marginal seas of the Arabian Plate region.

Long-Range Objectives

The long-term objectives of this project are to understand and determine the origin, evolution and present-day geological and geophysical characteristics of marginal seas. Marginal seas are those marine basins partially separated from the main oceans by topographic barriers. The degree of separation can range from high (i.e., Black Sea) to low (i.e., East China Sea). Marginal seas are especially important since they may, in some instances, represent beginning phases (i.e., Red Sea) or later evolutionary stages (i.e., Mediterranean Sea) in the development of ocean basins. The strategic location of many marginal seas and their high petroleum potential also makes them important areas for study.

Background

Our studies have emphasized the shallow structure, bathymetry, sediments (including their acoustical properties), and recent history of marginal seas. The techniques used have been of two principal types. First, during recent years (1975-1978) I have made a series of oceanographic expeditions (generally NSF-funded) to selected marginal seas (Red Sea, Black Sea, eastern Mediterranean, Persian Gulf, Gulf of Oman, Gulf of Aqaba) and collected basic, often previously unknown, geological and geophysical information such as bathymetry, magnetics and gravity data, continuous seismic reflection profiles (in some instances using our multi-channel system), and by using sonobuoys, refraction data. We have also obtained a large collection of sediment cores from these areas and have, in some instances, taken bottom photographs and made suspended sediment matter observations. For some of our studies our results have been presented as symposium volumes (Degens and Ross, 1969, 1974) as well as in numerous individual scientific papers.

Our studies are often done with scientists from the adjacent foreign country as well as with colleagues at other U.S. and foreign institutions. The cooperation has generally been very successful and has helped us in our approach to develop multi-discipline investigations of individual regions. Cooperation with foreign scientists and officials has also helped us obtain the necessary permissions and logistic support for our work. Although the expanding jurisdiction resulting from the Law of the Sea Conference could make such future efforts harder to negotiate, the contacts and techniques we have developed over the past years should be of considerable value to us in later efforts. In most of my past efforts the cooperating foreign country has also contributed to the cost of the expedition.

The second technique I have used in my studies has been to examine the existing knowledge within the literature of the certain marginal seas to produce syntheses of specific areas. Examples are a recent paper about the Red Sea summarizing its general circulation (Ross, in press a) and one on the Sea of Azov (Ross, 1977).

Progress over the Past Year

Past ONR support for the Marginal Sea project has permitted me to continue and expand on many of my studies of individual marginal seas and to participate in other expeditions such as aboard GLOMAR CHALLENGER which would be difficult without such funding. For the past year I had proposed studies on the hydrography of the Red Sea, one on the western Gulf of Oman and a third on the structure of the Persian Gulf (the latter two are also NSF-supported). These papers are completed (respectively, Ross, in press a; White and Ross, in press; and Ross and Uchupi, in press a). In addition, a paper on the shallow structure and acoustic properties of the sediments of the eastern Mediterranean has been completed (Ross and Uchupi, in press b). Finally, a summary paper on sedimentary processes on the continental slope (based on a past ONR-funded project) has been completed (MacIlvaine and Ross, in press).

In addition, during the past year the following ONR-supported papers have been published: Ross, 1977; Ross, 1978a; Ross, 1978b, Neprochnov and Ross, 1978; Ross, et al, 1978 and Muratov, et al, 1978.

Proposed 1979 Work

It now appears that sufficient information (collected both by us and other institutions) now exists concerning the marginal seas of the Middle East (Red Sea, Persian Gulf, Gulf of Oman, Gulf of Aqaba, Gulf of Aden and Dead Sea) to produce a detailed synthesis of the area. Several of the works produced during the past year (Ross and Uchupi, in press a and White and Ross, in press), help complete the necessary background for this work. I would like to spend my time during the coming year summarizing this material and begin the writing of a synthesis of marine geology and geophysics of the marginal seas of the Arabian Plate region.

In addition to the synthesis I wish to continue my field work and develop plans for other areas. Among the areas where new studies should be valuable are the marginal seas along the Chinese coast, in particular the Yellow Sea, East China Sea and South China Sea. The timing for such a program is appropriate and I have indicated my interest (and submitted a small proposal) in such an effort to members of the U.S. oceanographic delegation going to China.

Finally, my research in the marginal seas regions of the Middle East has been done, as previously mentioned, in close association with appropriate foreign organizations. Since these countries are just developing their marine science programs, they have used our work in some instances as a starting point and have requested that I (and my colleagues) assist them in further development of their oceanographic programs. In the past year I was a consultant (with the Office of the Oceanographer of the Navy) to the Imperial Iranian Navy for a visit and preparation of a report on the development of an Iranian National Oceanographic Program. I have been asked to assist them in the implementation of their plan. During the past year I also completed field work in the Gulf of Aqaba (Elat) that was part of an earlier program I had helped the Israelis develop. Lastly, I will, in this coming year, work with the Saudi Arabians in presenting a scientific symposium on the Persian Gulf region. The support I receive from ONR greatly helps my involvement in such programs which, although their value may not be immediately obvious, certainly will improve the climate for U.S. marine science in this region of the world.

References

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MARGINAL SEAS

BUDGET

1 January 1979 - 31 December 1979

		ONR Man/Months	Actual
Senior Personnel:			
D. A. Ross		3.0	3.0
Support Personnel:			
E. Gately		2.0	2.0
A. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay of $938 which is accounted for as employee benefits)		$9,488	
B. Other Employee Benefits		$2,653	
TOTAL SALARIES AND BENEFITS		$12,141	
F. Publication Costs: 15 pages @ $50		$ 750	
I. Other Miscellaneous Costs:			
Shipping and Communications	$ 200		
Xeroxing	$ 200		
Lab overhead of 21% of A+B	$2,550	$ 2,950	
TOTAL DIRECT COSTS		$15,841	
J. Indirect Costs @ 15% of $15,841		$ 2,376	
TOTAL COSTS		$18,217	

MARGINAL SEAS

1 January - 31 December 1979

		ONR Man/Months	Actual
A.	SALARIES AND WAGES		
	Professional:		
	David A. Ross, Associate Scientist	3.0	3.0
	Support:		
	Ellen Gateley, Staff Assistant	2.0	2.0
	Gross Regular Salaries including an allowance for vacations, holidays and sick pay of $ 938 which is accounted for as employee benefits		$ 9,488
B.	OTHER EMPLOYEE BENEFITS		2,653
C.	TOTAL SALARIES AND BENEFITS		$ 12,141
G.	PUBLICATION COSTS:		
	1. 15 pages @ $50		$ 750
J.	OTHER MISCELLANEOUS COSTS:		
	1. Shipping and communications	$ 200	
	2. Xeroxing	200	
	3. Laboratory overhead of 21% of C	2,550	$ 2,950
K.	TOTAL DIRECT COSTS		$ 15,841
	Indirect Costs @ 15% of TDC		2,376
L.	TOTAL REQUESTED		$ 18,217

SOFAR Sediment Trap Experiment

S. Honjo, D. Spencer, and D. Webb

Due to the ingenuity and dedication of Doug Webb, the full scale prototype (Mark II) experiment of the floating sediment trap was highly successful. A Mark II trap was moored with a Woods Hole-URI SOFAR free floating, neutral buoyancy buoy. The experiment was conducted aboard the R/V Endeavor on the 17th of May, 1978, in the west of Bermuda area. We repeated the deployment/recovery cycle of the buoy and then let it go at 600 m until July 1978. The recovery is planned for July 25.

The "opening" of the Mark II trap was 3.1 m^2 (2 m diameter) and 6.5 m high. The collecting cone is made of a flexible (polyethylene) film with an extremely smooth surface which was supported upwardly by a sealed aluminum ring-float. The sample chamber closing mechanism was commanded by an acoustic signal from the ship. The Mark II trap has a bacteriacide diffuser which is designed to last for three months in sea water. We expect to gain the first scientific data from this prototype experiment.

During July 1978, five Mark II (semi prototype) models will be deployed for four months again for further evaluation. Then, a number of Mark IIIs, the production model, will be deployed for 9 months during late 1978.

SYNTHESIS - ATLANTIC OCEAN

Kenneth O. Emery
(617) 548-1400 Ext. 579

Elazar Uchupi
(617) 548-1400 Ext. 579

Progress Report

During 1978, E. Uchupi continued the examination of seismic reflection profiles to determine the nature of oceanic basement, the depth below sea level of this horizon, the thickness of the sediment blanket above both continental and oceanic basement, the thickness of the Neogene and pre-Neogene sedimentary sequences, and the nature and depth of the acoustic horizon (Horizon A) separating these two sedimentary units. It is expected that this phase of the synthesis will be completed by the end of this year. In addition, E. Uchupi, with the aid of Helen Hays, completely revised the bathymetric charts of the Atlantic Ocean, incorporating all available data recorded since the last revision about four years ago.

While E. Uchupi was involved in the interpretation of the seismic reflection data, K.O. Emery's main concern during this year was the writing of the sea-floor morphology section of the synthesis. To date, during 1978, he has been able to add the following to the previously completed text and figures:

<u>Continental Shelves</u>

- Definitions
- Dimensions
- Detailed Morphology
  - General
  - Glacial, Diapir, Fault, Slump Topographies
  - Subaerial Topography
  - Submerged Shore Topography
  - Youthful Marine Topography

(18 pages text plus 5 new figures)

Synthesis - Atlantic Ocean
Progress Report (continued)
K.O. Emery and Elazar Uchupi

Sea Level History

General

The Past 36,000 Years

The Past 6,000 Years

The Past 100 Years

(14 pages text plus 6 new figures)

Continental Slopes

Definitions and Dimensions

General Topography

Carbonate Platforms and Escarpments

Salt and Mud Diapirs

Submarine Canyons

Landslide Scars

(31 pages text plus 5 new figures)

Large Deltas and Deep-Ocean Cones

(3 pages text plus 2 new figures)

Continental Rises

Deep-Ocean Channels

Lower Continental Rise Hills

Sediment Drift Accumulations

Landslides

(20 pages text plus 2 new figures)

IV. OCEAN ENGINEERING

OCEAN ENGINEERING

TABLE OF CONTENTS

OCEAN ENGINEERING DEPARTMENT

The research program proposed by the Ocean Engineering Department for 1978 reflects the continuing interests of its members in subjects that are important to the Navy. Acoustics is the main theme in two of the individual proposals, and plays an important role in three of the others, while still another studies a phenomenon that has an influence on acoustic propagation at high frequencies. Mid-ocean topography and deep structures also affect low frequency long range propagation and are studied in two other proposals.

Robert Spindel has been carrying out some work in long range acoustic propagation which has promise of telling us a great deal about the oceans, and the limits of the ocean as a communication link. The fluctuations of acoustic propagation in amplitude and phase along various multipaths is being measured. This can be related to spatial and temporal coherence expected in arrays, and thus helps define the size of arrays and signal processing systems to be used. Inversely, the fluctuations occur because of spatial and temporal changes in the ocean, and mathematical techniques can be applied to the acoustic data to obtain information about the ocean. Spindel proposes to continue analysis of present data from several experiments and a field test in 1979. This work will be conducted jointly with Scripps (IGPP), Miami and MIT.

Robert Ballard is joining the Ocean Engineering Department in 1978. He was a member of the Department from 1970 to 1974, then was in the Geology and Geophysics Department from 1974 to 1978. His work has become so involved with ALVIN, ANGUS, and Deep Sea Technology that the return to Ocean Engineering is appropriate. Ballard's proposed undertakings for 1979 have been separated into two programs for convenience. The first is concerned primarily with field work and the second with data analysis and synthesis of the results of several years.

The field work consists of a detailed investigation of the inner rift valley of the Galapagos Rift at 86°W using deep towed ANGUS and ALVIN.

The synthesis program will be conducted at Stanford University with Jerry Van Andel and will integrate the results of the Galapagos Rift program with Mid-Atlantic Ridge at 36°N, Mid-Cayman Rise, and East Pacific Rise at 21°N studies. The purpose is to understand the origins of mid-ocean rift valleys.

Marshall Orr proposes a program that uses high frequency acoustics to observe the temporal and spatial distributions of particulates associated with the high energy benthic boundary layer. Techniques to observe these distributions have been a vexing problem in material transport studies and the acoustic method shows promise. In addition laboratory measurements will be made on the magnitude of backscattered acoustic signals from small scale temperature and velocity fluctuations. The results of these measurements could have several practical applications in Naval problems.

Douglas Webb proposes a continuation of a program to measure surface currents from a ship while underway. This is a joint project with Institute of Oceanographic Sciences, Wormley and is currently reaching the stages of the first ocean test. The continued improvement in precise navigational systems, and the means to measure velocity relative to the water makes this technique an attractive method for obtaining surface current data.

Albert Williams has developed a system named BASS (Benthic Acoustic Stress Sensor) that measures the three dimensional vector average of current over a 15 cm volume at four heights from 25 cm to 200 cm every 750 milliseconds. He proposes to use this system in a study of high energy regimes of the Benthic Boundary Layer in cooperation with several other investigators using other techniques. A large coordinated program is being discussed for the early eighties and Williams proposes some field tests and analysis in preparation for this major effort named HEBBLE, (High Energy Benthic Boundary Layer Experiment).

Albert Williams is the originator of an instrument named SCIMP (Self Contained Imaging Micro Profiler) that he has used to demonstrate the existence of salt fingers in the ocean with some definition of the condition under which they exist. The vertical mixing processes and their relative importance in the ocean is not well understood. Williams proposes to carry out some experimental observations in the BOMEX staircase region to study the role of salt finger type double diffusion convection in mixing North Atlantic Central Water into the Subtropical Underwater.

Ocean Engineering
Departmental Budget Summary

12 Month Period
1 January 1979 - 31 December 1979

A.	SALARIES		$323,274
B.	OTHER EMPLOYEE BENEFITS		92,076
	TOTAL SALARIES & BENEFITS		$415,350
C.	PERMANENT EQUIPMENT		126,971
D.	EXPENDABLE SUPPLIES & EQUIPMENT		89,829
E.	TRAVEL		
	1. Domestic	$12,828	
	2. International	15,568	
			28,396
F.	PUBLICATION COSTS		
	1. Graphic Services	$ 7,637	
	2. Page Charges	2,000	
	3. Reprint Charges	200	
			9,835
G.	SHIP COSTS		
	1. R/V OCEANUS	$130,454	
	2. Shipboard Computer	25,092	
			155,546
H.	COMPUTER COSTS		
	1. Sigma 7	$14,880	
	2. HP shore system	2,925	
	3. Programming	9,408	
			27,213
I.	MISCELLANEOUS COSTS		
	1. Shop Services	$18,330	
	2. Shipping & Communications	9,289	
	3. Xerox Charges	1,380	
	4. Moving & Living Expenses	1,500	
	5. Laboratory Overhead	85,479	
			115,978
J.	TOTAL DIRECT COSTS		$969,120
	INDIRECT COSTS @ 15%		145,367
TOTAL COSTS			$1,114,487

Variability of Sound Transmission Through the Ocean Interior

Dr. Robert C. Spindel
(617) 548-1400, Ext. 283

Abstract

This will be the third year of this program. During the first two years it was conducted jointly with the Institute of Geophysics and Planetary Physics (IGPP) of the Scripps Institution of Oceanography and proposals were submitted jointly by both Institutions. For this contract year we are shifting the emphasis in our association, but are formulating our respective proposals so that together they continue to reflect complimentary and closely aligned efforts. The goal of the overall program is to achieve sufficient understanding of fluctuations in acoustic signals transmitted to long ranges in the ocean in order to implement techniques for monitoring the ocean acoustically. Beginning with this contract year the major part of the experimental program, its planning and execution, will take place at Woods Hole. IGPP will contribute to the experimental program at a lower level, to system planning, to theoretical acoustic studies and to data analysis. We have broadened the base of the program to include the Department of Earth and Planetary Sciences at MIT, through its representative Dr. C. Wunsch. The primary responsibility of this new associate will be the development of mathematical models for inverting acoustic data in order to yield oceanographic information. An ancillary program in which we will cooperate is being conducted by the University of Miami. Its primary objective is to study the regions of validity of theoretical predictions, a key issue in the development of monitoring systems.

Scientific Objective

The objectives of the program are basically identical to those set forth in the initial proposal in this series. In the 1977 proposal we stated, "we will study, by observation and theory, the role of ocean processes (internal wave induced temperature fluctuations and currents, intrusions and associated fine structure, mesoscale eddies, etc.) in determining the variability of sound transmission through the ocean's interior. The goals are (i) to contribute to our understanding of the fundamental limits on signal coherence (space and time) in the ocean environment, and (ii) to work towards the inverse problem of monitoring the oceans by acoustic means." While our ultimate goals are unchanged, the program now concentrates heavily on acoustic monitoring. Our ideas concerning possible methods of implementing practical monitoring schemes have advanced significantly. The attributes of acoustic signals and the various equipments involved can now be specified. Testing these ideas is the next logical step in the program, and this is reflected in our proposal for 1979. We expect to be able to demonstrate a working three dimensional monitoring system on a scale of about 1000 km within the next two to three years.

Present Status and Progress Over the Past Year

During March-April 1978 Woods Hole and IGPP cooperated in the execution of a joint experiment in the Pacific. The experiment was designed to utilize the low frequency, moored, acoustic range system developed at Woods Hole and a high frequency, reciprocal acoustic transmission system being developed at IGPP. Deployment of the equipment at various ranges enabled the study of a variety of acoustic forward scattering regimes. Woods Hole 220 Hz transmissions covered long range (25 to 1000 km) forward scattering geometrics while IGPP 2250 Hz transmissions were to cover a short range (25 km) reciprocal path. A complete environmental measuring program was a part of this experiment. Included in the acoustic portion of the experiment was an initial test of a Woods Hole self-contained 220 Hz wideband source transmitting a phase encoded signal, and self-contained microprocessor controlled receivers for reception, processing and recording of this signal. In addition, high stability rubidium clocks were incorporated into the Woods Hole Doppler tracking system in order to provide mooring motion information to an accuracy of 15 cm in 30 days with a resolution of about 3 cm.

A plot of the moorings deployed during the experiment is shown in Figure 1, with a side view shown in Figure 2. The function of each individual mooring is indicated in the figures. Not shown is a receiver at 1000 km and the IGPP 2250 kHz transceivers which were located on moorings 10 and 50.

Analysis of the data is still underway at the time of this writing. Because of malfunctions in the IGPP 2250 Hz transceivers, no reciprocal acoustic transmissions were recorded. The 220 Hz wideband transmissions were received at ranges of 25, 125 and 1000 km at various depths. Matched filter processing of these data indicated that a bandwidth of approximately 10 Hz had been achieved. This corresponds to a pulse resolution of about 0.1 second. An example of data using various receivers is shown in Figure 3. In large measure the experiment constituted an engineering test of these remote, self-contained instruments. Figure 4 shows mooring motion data for a six day period using the rubidium clock tracking system. The results of these tests will be reported at the IEEE Oceans 78 Conference and at the November meeting of the Acoustical Society of America.

<u>September Experiment</u>

A second experiment designed to monitor acoustic travel time changes of a low frequency signal (220 Hz) upon passage through a mesoscale eddy was to have taken place in July 1978. This experiment was to have been funded principally by ONR Code 500 using equipment developed under both Code 500 and ONR Code 480 funding. Due to delays in commencement of the joint WHOI-IGPP cruise (it was originally scheduled for early January 1978, but didn't actually take place until mid-March mid-April 1978) this experiment was postponed. At the time of this writing it is definitely scheduled for September 1978, and in addition, has been somewhat modified in format. Modifications are based on the results of the March tests and on our current views regarding ocean monitoring schemes. This experiment will still be funded almost entirely by Code 500, but since it is a part of a continuing series of tests to perfect a monitoring scheme we outline it here.

The 220 Hz source is to be improved by the addition of two resonator tubes to achieve a bandwidth near 20 Hz and thus a pulse resolution of 50 msec. The coded sequence is to be modified to provide a 4 sec rather than a 6 second sweep which will be repeated 16 times for a total transmission time of 64 seconds. This 64 second transmission will be repeated once every 10 minutes for 60 days. The DIBOS microprocessor receiving buoys

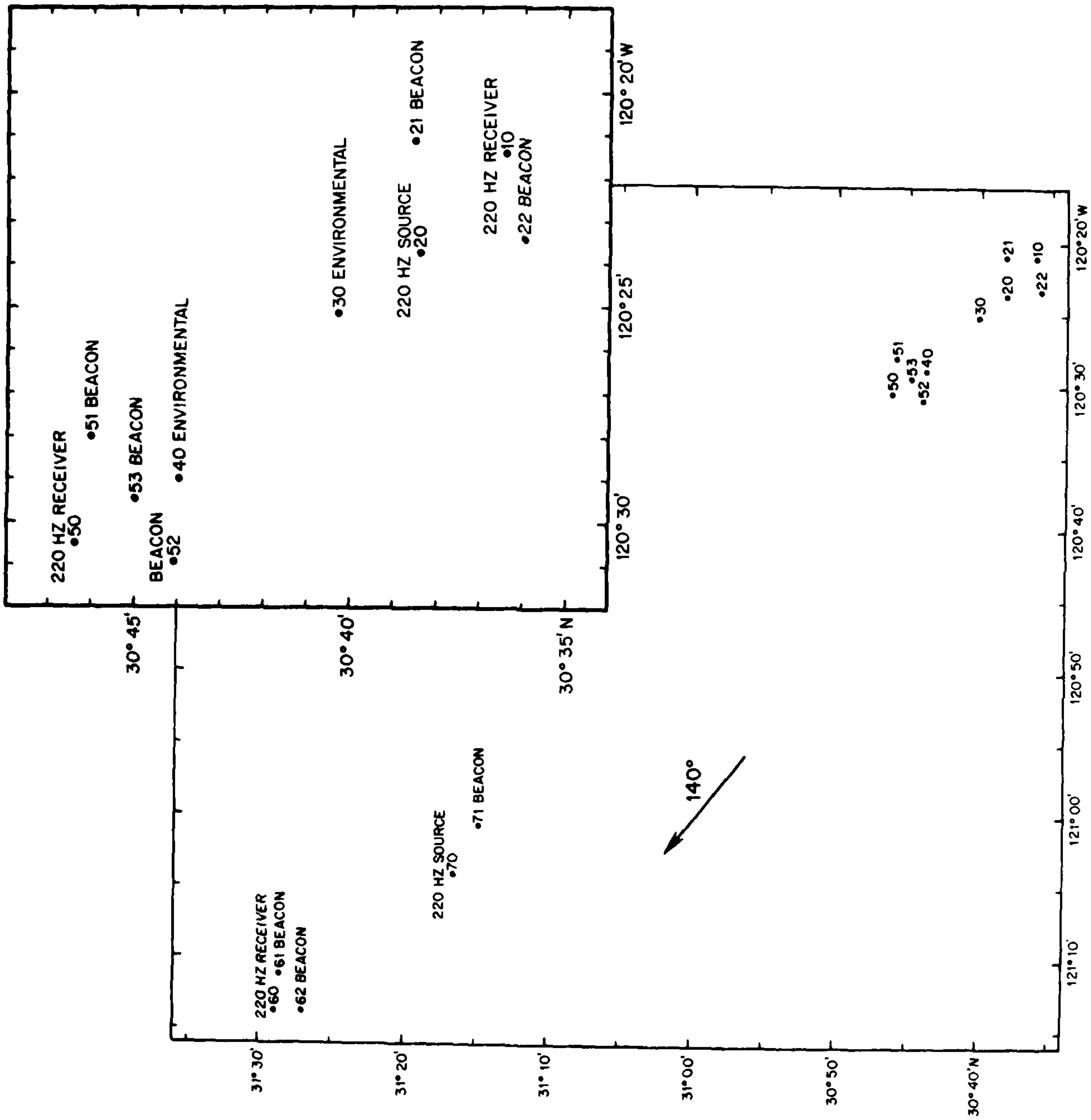

Figure 1 Mooring deployments during March-April 1978 in the WHOI-IGPP joint experiment.

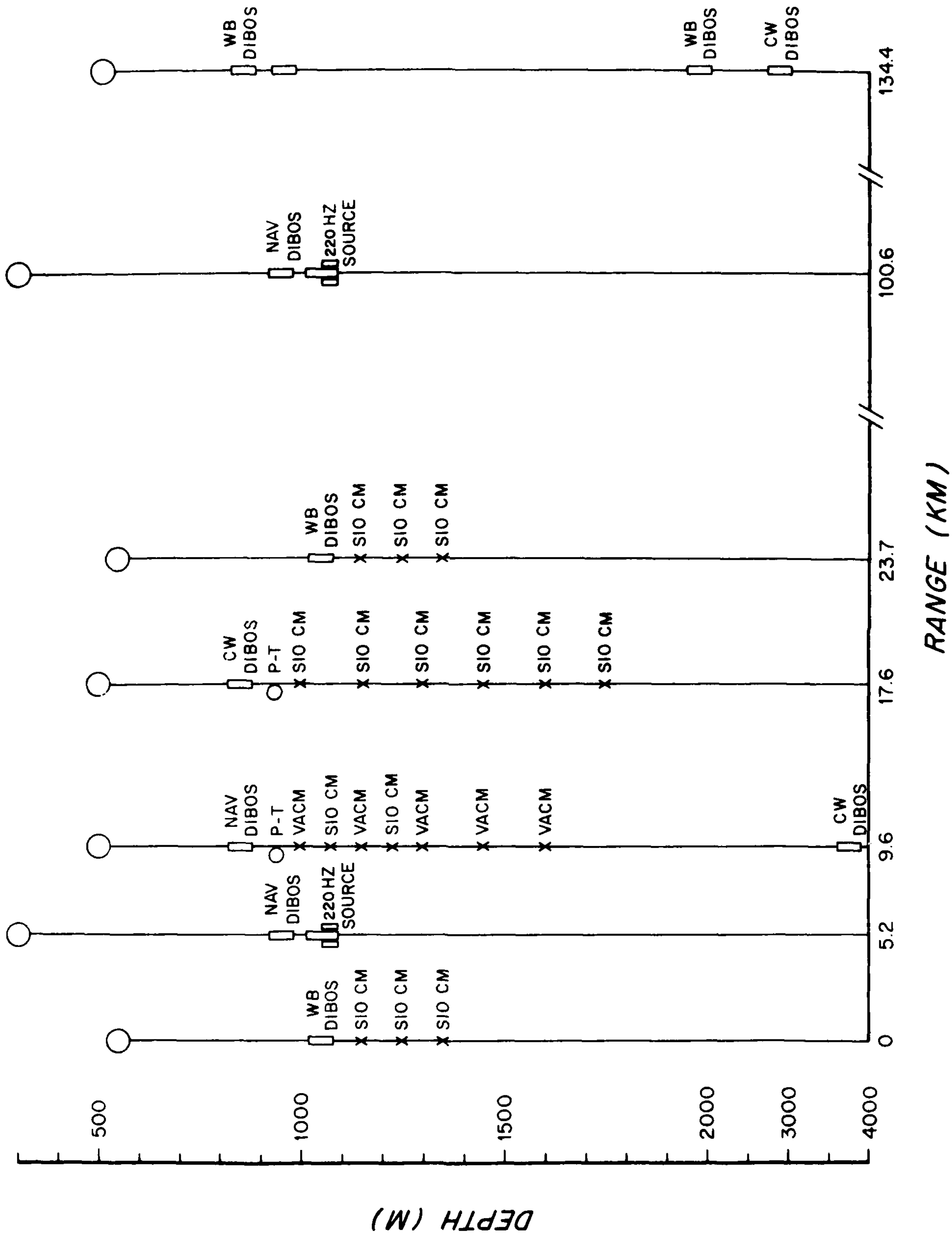

Figure 2 Side view of WHOI-IGPP moorings.

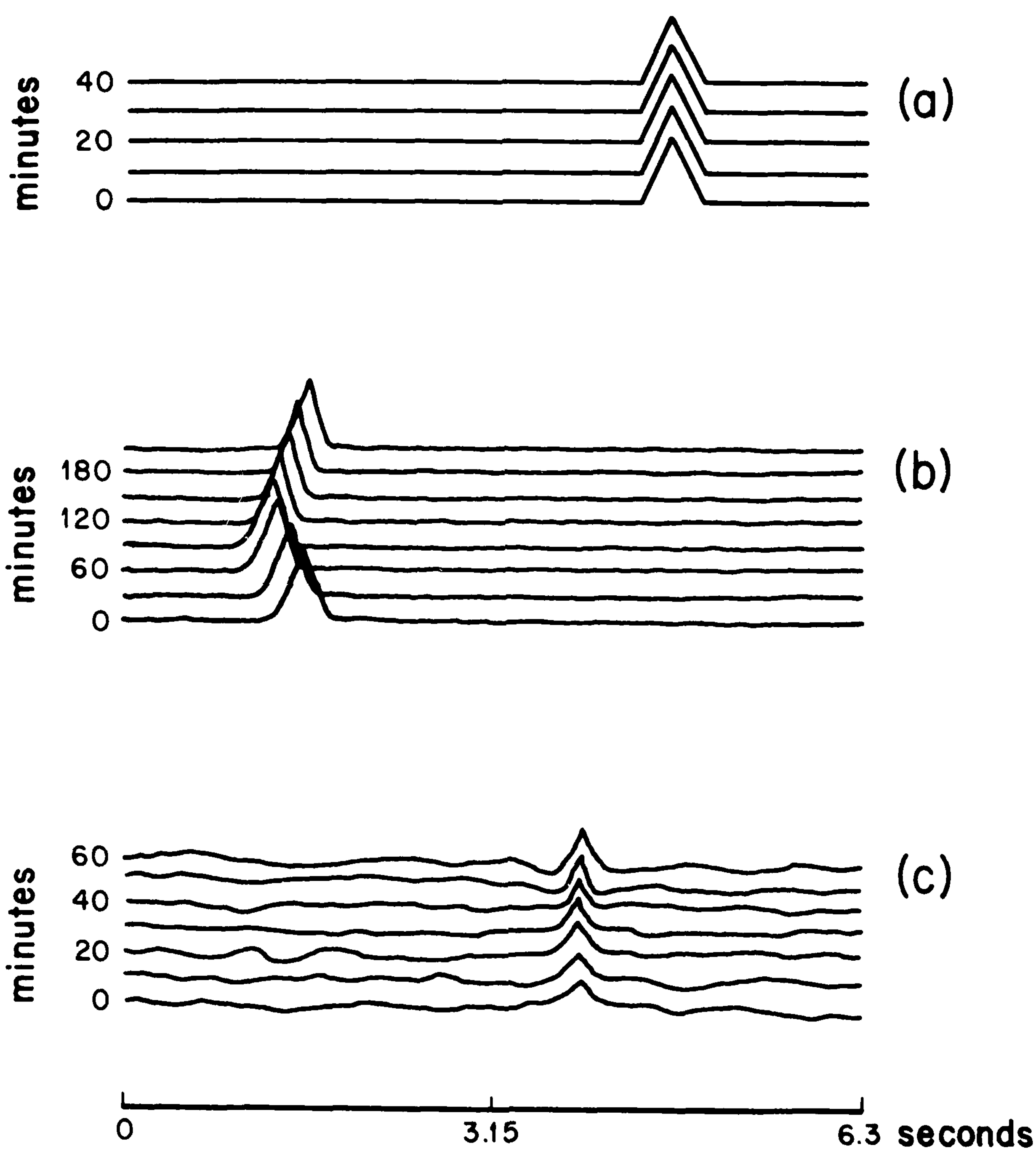

Figure 3 Example of recompressed pulse from wideband acoustic source. (a) Test Data, (b) Data with drifting hydrophone, (c) Data at 100 km.

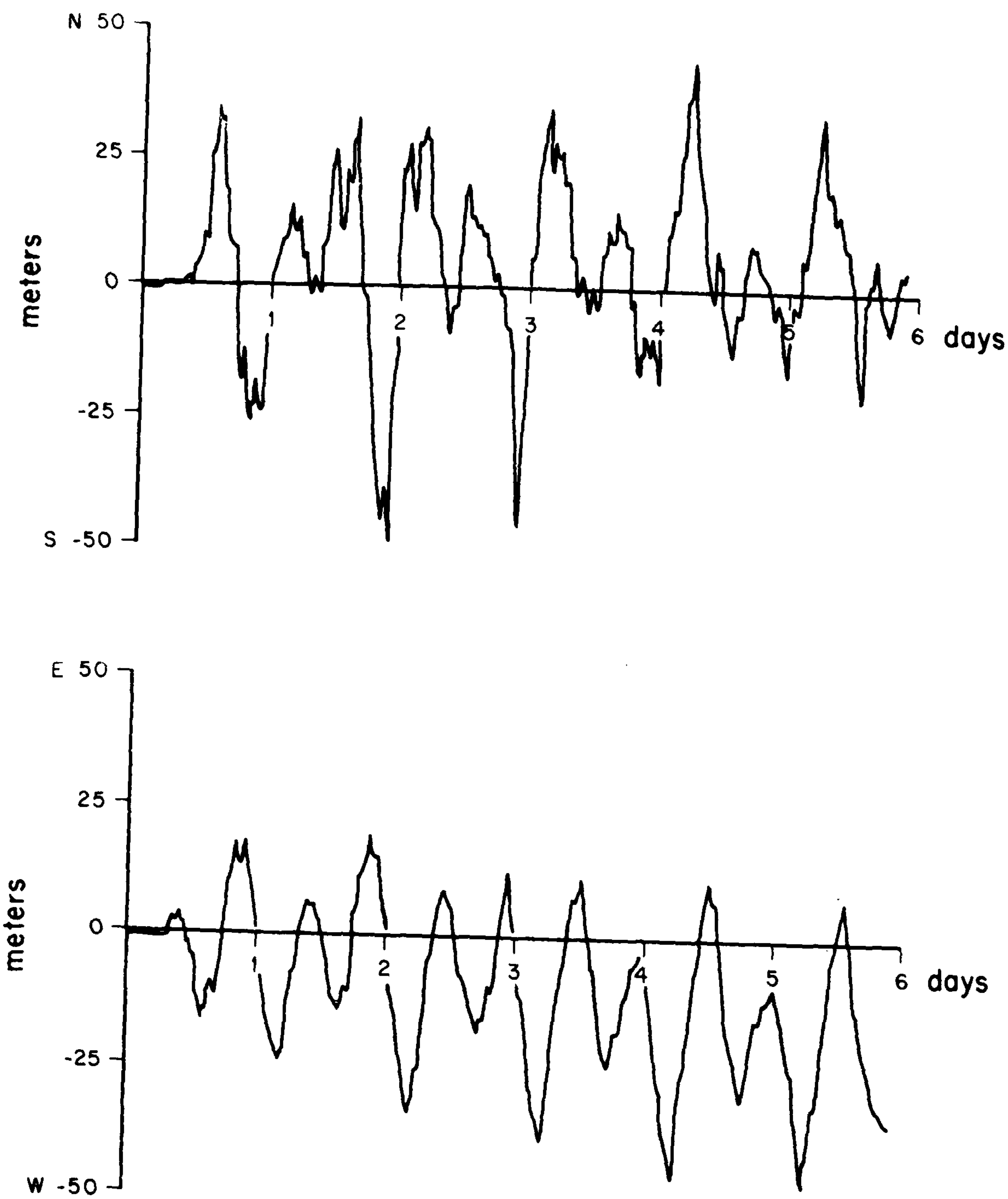

Figure 4 Example of mooring motion measured with Rb clock controlled acoustic Doppler system.

will be altered to receive this new sequence. A source mooring will be deployed to the East of the POLYMODE Local Dynamics area, with a receiver mooring about 500 km to the West. Transmission will take place through the POLYMODE Local Dynamics array, through a mesoscale eddy, and will be received at 500 km by the DIBOS and at 780 km by the mid-station hydrophone. Reception at this location is to be obtained through the cooperation of the Institute for Acoustical Research, Miami with IGPP performing the required programming and actual data collection.

An interesting facet of the experiment is the addition of a vertical hydrophone array to the DIBOS system. The 500 km mooring will have a steered vertical array at a depth of 2000 m and a non-steered half-wave-length array at 3000 m. The steered array will allow separation of upward and downward incoming paths as well as improving signal-to-noise ratio. The deeper array is intended to provide signal gain only.

The objects of the experiment are to:

(a) determine if a group of arrivals can be traced by a receiver over extended periods,
(b) observe a travel time distortion due to a mesoscale eddy,
(c) perform a forward scattering experiment by leaving the source on continuously for a 3 day period,
(d) determine whether upgoing and downgoing rays can be easily separated by a simple array,
(e) to test a wider band source,
(f) take advantage of POLYMODE environmental data.

A means of recovering these two moorings has not yet been determined, however, several likely possibilities are under investigation.

<u>Summary of 1978</u>

A successful test of a source-receiver moored acoustic range employing phase encoded transmissions was conducted in March 1978. The coded signals were successfully received at ranges of 25, 125 and 1000 km, and recompressed to achieve an approximate 0.1 sec travel time resolution. High accuracy motion tracking was achieved using a rubidium oscillator time base with an acoustic Doppler tracking system.

A working group consisting of WHOI, IGPP and MIT staff members was established to plan and guide the progress of acoustic monitoring schemes. This group has set a schedule for work in this area over the next two to three years beginning with a 60 day experiment in September 1978, continuing with a joint experiment with the University of Miami in September 1979 (which will concentrate on the study of forward scattering regimes), a moored monitoring system deployment say 4 sources and 4 receivers, in 1980, a fixed system monitoring experiment in the Pacific in 1981 and, a full scale Atlantic deployment sometime thereafter.

The parameter specifications for ocean monitoring systems have become more definite as a result of theoretical expositions and the data obtained in March of this year. The system will initially focus on meso-scale features with spatial scales of 100 km and time scales of 30 days. This reduces sampling rates and eliminates the need for mooring motion tracking to the accuracy required for monitoring intrusive and current effects. Most motion is tidal and can be removed by simple averaging or filtering. It is clear that a source frequency below 50 Hz would be superior to the current 220 Hz system and Woods Hole (together with IGPP) is actively pursuing the development of a simple source near 30 Hz. However, it appears that much useful information can be obtained with the 220 Hz technology and that it might be quite possible to implement a monitoring system at this frequency. Most of the uncertainty regarding source frequency is due to insufficient knowledge regarding scattering regimes in range and frequency space. Hence cooperation with the University of Miami, where this issue is the central focus, is deemed to be extremely important.

Program for 1979-80

Our fundamental program for 1979-80 is composed of two basic parts. The first part calls for an experiment in the fall of the year to be conducted jointly with the University of Miami, followed in 1980 by a small scale, moored monitoring system development. The goal of the former experiment is to test the range of applicability of the so-called Dashen systematics, i.e. the range of validity of the theoretically derived Λ - Φ statistics. Previous comparisons of experimental observations with theoretical predictions have yielded conflicting results. Observations with CW sources are difficult to interpret due to the unknown number of refracted ray paths actually involved in source to receiver transmissions. Pulse type, or travel time observations have yielded less ambiguous results, but have not covered significantly varied regimes in Λ - Φ (or range and frequency) space. We plan to use a 500 Hz wideband, moored source being developed at the University of Miami, the Woods Hole 220 Hz wideband source and perhaps a 30 Hz wideband source being developed by D. Webb of Woods Hole, at a variety of ranges and depths. Listening is to be accomplished on MABS analog recording systems and the TVA and VHA vertical arrays at Bermuda. An environmental program is being planned so that we will have the necessary data for calculation of the local Λ - Φ parameters. Position keeping of moorings will be required, and will be provided by the Woods Hole Doppler tracking system.

In addition to delineating high and low scattering regions in Λ - Φ space we expect this experiment to provide initial testing of the 30 Hz acoustic source.

In 1980 we plan the deployment of a moored monitoring system using 220 Hz technology. At present we expect to deploy four sources and six receivers in an approximate 500 km square, almost certainly to the West of Bermuda. Four receivers will be single channel DIBOS units; the other two will be 2250 Hz transceivers modified to operate at 200 Hz. They will have several channel capabilities. Each of these will be equipped with a vertical receiving array in order to provide vertical beam steering for ray discrimination. When lower frequency sources are used a vertical array such as this can be used to test monitoring via modal decomposition techniques rather than travel time methods.

A schematic illustration of the system as deployed appears in Figure 5. The plan view shows sources and receivers on an approximate 100 km spacing covering an area of 16 x 10^4 km^2. The sixteen square areas, each 100 km^2, represent regions in which an inverse solution is expected.

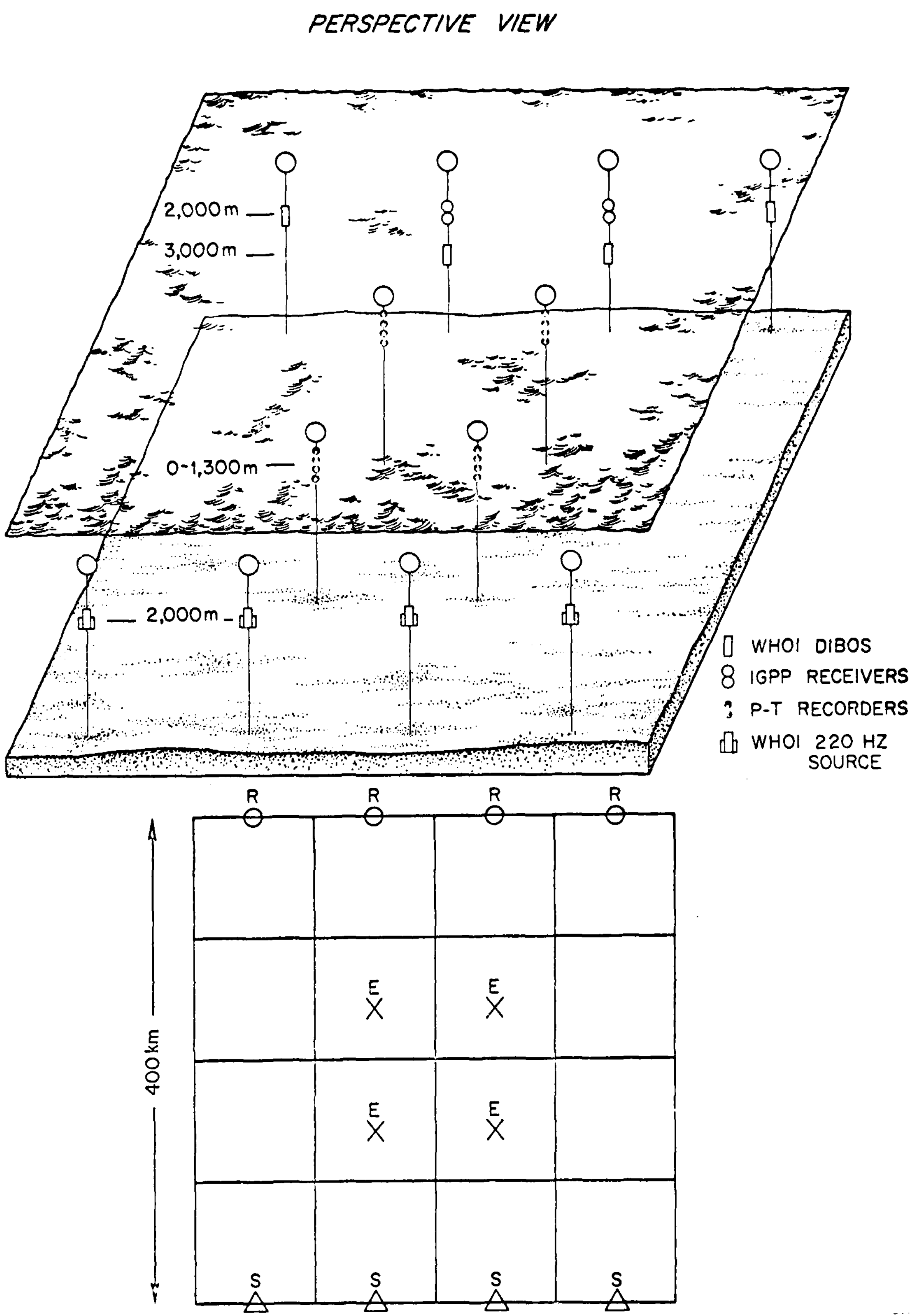

Figure 5 Schematic diagram of proposed 1980 monitoring system.

The size of these sub-areas is chosen to be approximately the same as the spatial scale of a mesoscale feature. Four environmental moorings each with four precision pressure-temperature recorders are deployed in the central region of the array. It is in this region that the inverse solution is most accurate and thus the data obtained by the P-T recorders can be used to check the acoustic result against actual oceanic conditions prevailing at the time of the experiment. Our tentative plans call for the deployment of the array for a six month period. Thus two separate ship periods will be required, one for deployment and one for recovery. While the acoustic moorings, sources and receivers, are to be engineered at Woods Hole, we have not yet finalized our plans regarding the environmental moorings. Possibilities include Woods Hole, Draper Laboratories and MIT, or the Woods Hole Buoy Group.

At this time we can only be precise about the general structure of our 1979 and 1980 programs. It is impossible to offer a definitive statement concerning specific experimental details since much of our planning is undergoing constant change and revision due to the rapid advancement of the field. Moreover a large part of our planning depends upon the timely development of equipment that is, at present, in the research stage. For example, we are pursuing the development of a low frequency, wideband source (near 30 Hz) using several novel and unique ideas. The advent of such a source would certainly change the details of our planned experiment, although the general configuration of the experiment would remain basically as outlined herein.

The budget for 1979 includes items for the 1979 experiment and some preparation on long lead time units for 1980. We are in an active recruitment mode and expect to hire an Assistant Scientist before January 1 of this year. Half of his time will be devoted to this project. In addition, we plan to hire an Associate Scientist who will also spend approximately half time on this program. His salary is not included in the budget at this time; upon hiring we hope to be able to discuss this matter with ONR.

Permanent and expendable equipment items in the budget are straightforward. Four sources are to be constructed for the 1980 220 Hz small scale monitoring experiment and four DIBOS (Digital Buoy System) receivers are to be completed. Several laboratory equipment items include a frequency synthesizer and oscilloscope with curve tracer module (5CT1N). It should be noted that these are the first such items to appear in a Code 480 contract and represent the only new additions to our laboratory in about five years. The synthesizer is essential for constructing and testing the DIBOS instruments. Our present synthesizer has been repaired many times and it is feared that it is nearing the end of its useful life.

Battery sets for AMF releases are needed as well as batteries for the DIBOS instruments (Lithium cells). Mooring lines, anchors and hardware are needed for the 1979 as well as the 1980 experiments.

Variability of Sound Transmission Through the Ocean Interior

12 Month Period
1 January 1979 - 31 December 1979

	ONR MM		Actual MM	
Professionals:				
R. Spindel	8		8	
Assistant Scientist (TBA)	6		6	
K. Peal	2		2	
D. Koelsch	2		2	
M. Jones	4		4	
G. Glass	3		3	
P. Boutin	8		8	
S. Bergstrom	2		2	
Support Personnel:				
F. Schuler	8		8	
S. Cressy	8		8	
J. Kemp	8		8	
S. Rosenblad	4		4	
C. Grant	1		1	
P. Pettigrew	1		1	
C. Weeks	7		7	
C. Muzzey	2		2	
	74		74	
A. 1. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay, etc. of $11,556 which is accounted for as employee benefits)		$101,014		
3. Cruise Leave, Sea Duty Vacation and Overtime (including premium pay of $3,378)		16,837		
TOTAL				$117,851
B. OTHER EMPLOYEE BENEFITS				33,088
C. TOTAL SALARIES AND BENEFITS				$150,939
D. PERMANENT EQUIPMENT (See attached list)				82,195
E. EXPENDABLE SUPPLIES AND EQUIPMENT (See attached list)				39,852
F. TRAVEL (See attached list)				3,799
G. PUBLICATION COSTS				
1. Graphic Services - 20 hrs @ $13/hr		$ 260		
2. Page Charges - 20 pages JASA @ $60/pg		1,200		
3. Reprint Charges		200		1,660
H. COMPUTER COSTS				
1. Sigma 7 - 30 hrs. @ $155/hr				4,650
I. SHIP COSTS - 21 days R/V OCEANUS @ $3,433/day				72,093
J. MISCELLANEOUS				
1. Shop Services - 700 hrs @ $13/hr		$ 9,100		
2. Shipping and Communications		1,000		
3. Xerox Charges		300		
4. Laboratory Overhead (21% of C, exclusive of Premium Pay)		30,988		41,388
K. TOTAL DIRECT COSTS				$396,576
L. INDIRECT COSTS @ 15%				59,486
M. TOTAL COSTS				$456,062

D. PERMANENT EQUIPMENT

1.	4 Acoustic Sources @ $14,430	$57,720	
2.	2 OAR Radio & Flashers @ $500	1,000	
3.	Modifications to 4 Wideband Acoustic Receivers @ 4K	16,000	
4.	1 General Radio Microvolter	350	
5.	1 Rockland 5100-01 Frequency Synthesizer	3,800	
6.	1 Tektronix 5440 Oscilloscope with plug in units 5A48, 5B42, 5CT1N	3,325	
			$82,195

E. EXPENDABLE SUPPLIES AND EQUIPMENT

1.	4 Acoustic Source Batteries @ $1,650	$6,600	
2.	6 AMF Battery Sets @ $308	1,848	
3.	200 Power Conversion Lithium Cells @ $18.30	3,660	
4.	Mooring Equipment -		
	a. Anchors - 15,600 lbs @ $0.19/lb	2,964	
	b. 3000 meters jacketed wire rope @ $2.54/m	7,620	
	c. 8000 meters ½" VLS Dacron Polyester @ $3.58/lb-1 meter = 0.25 lbs	7,160	
	d. Hardware - shackles, slip links, etc.	2,000	
5.	Preparation of (2) Draper Lab P-T Recorders	4,000	
6.	Preparation of (2) AMF VACM Current Meter	4,000	
			$39,852

F. TRAVEL

1. Domestic:	a.	2 RT San Diego	$1,012	
		3 Car Rentals @ $70	210	
		5 Days travel expense @ $40/day	200	
	b.	2 RT Bay St. Louis, Miss.	607	
		2 Car Rentals @ $70	140	
		4 Days travel expense @ $44/day	176	
	c.	2 RT Washington, D.C.	264	
		2 Car Rentals @ $70	140	
		2 Days travel expense @ $50/day	100	
	d.	2 RT Miami, Florida	568	
		3 Car Rentals @ $70	210	
		4 Days travel expense @ $43/day	172	
				$ 3,799

VOLCANIC AND TECTONIC PROCESSES IN RIFT VALLEYS OF THE MID-OCEAN RIDGES

Robert D. Ballard (617) 548-1400, Ext. 288

Abstract:

Detailed investigations of the central zone of extrusive activity within the inner rift valley of the mid-ocean ridge system has resulted in a better understanding of the volcanic and tectonic processes which form and subsequently transport the upper layers of the oceanic crust. From these studies has come a detailed model of the interrelationship of these two crustal processes which suggests that volcanic activity is of an episodic nature while rifting occurs more continuously. Two major forms of lava extrusives, pillow flows and sheet flows, are associated with the volcanic cycle, particularly those having a faster opening rate, with the latter form containing a complex series of flow types and collapse structures. The volcanic cycle results in the construction of discreet individual volcanoes running down the central valley axis. This new volcanic terrain then undergoes extensive rifting with the formation of numerous open fissures. This initial rifting permits seawater to penetrate into the hot crust, resulting in the formation of hydrothermal vents which eventually stop with continued rifting. As the new crust undergoes extension to make room for the next period of volcanic activity, vertical displacement occurs along many of the fissures already formed in the young volcanic material as the volcanic hills collapse above the depleted magma chamber. Instead of splitting the volcanoes in half, the new zone of extension and subsequent extrusive activity shifts to either one side of the volcano or the other. These aging volcanic units can be found in the older marginal highs which flank the central extrusive zone, appearing as individual volcanoes which have undergone tectonic modification. Despite the details of this model, many of its aspects remain unclear and require further testing and clarification. What, for example, is the relationship between sheet flows and pillow flows, and what is the origin of the unusual collapse or drainback craters that have recently been found in the extensive sheet flows of faster accreting plate boundaries? Are hydrothermal vents directly tied to the onset of rifting in young volcanic terrain? What is the strike variation of volcanic, tectonic, and hydrothermal activity within the inner rift valley? In theory, a mapping program along the strike of the valley should lead from one center of recent activity to another and should reveal the genetic sequence that begins with the initial outpouring of sheet flows and is completed with the formation of a mature and highly fractured pillowed terrain. This proposal requests funds to (1) conduct a detailed investigation of the inner rift valley of the Galapagos Rift at 86°W using the deep-towed ANGUS and submersible ALVIN in an effort to answer the questions mentioned above, followed by (2) a comprehensive synthesis program to be conducted at Stanford University. This latter effort will integrate the results of the Galapagos Rift program into a world-wide investigation of the mid-ocean ridge rift valley aimed at understanding its origin.

Long-Range Research Objectives:

In 1972, the Principal Investigator embarked upon a long-range research program dealing with the investigation of active spreading centers through the combined use of manned and unmanned mapping techniques. To carry out this program, the P.I. participated in two parallel efforts; the first is technological in scope, and resulted in the development of new and advanced techniques for conducting detailed investigations in the deep-sea, while the second concentrates on using those techniques to study the origin of the rift valley within the world's mid-ocean ridge system.

The technological effort initially concentrated on the deep submersible ALVIN and its associated instrument systems (see Figure 1). This effort led, in 1972, to the initiation of Project FAMOUS; the first major submersible science program which used these new techniques to investigate the volcanic and tectonic processes associated with the rift valley of the Mid-Atlantic Ridge. This study resulted in several publications by the P.I. with the three most significant ones being: Ballard and van Andel (1977a), which describes the major technological aspects of the submersible program, Ballard and van Andel (1977b), which deals with the major scientific thrust of our volcanic and tectonic study, and Ballard and Moore (1977), which is a photographic atlas of the Mid-Atlantic Ridge rift valley.

Project FAMOUS was followed in quick succession by similar programs in the Mid-Cayman Rise (1976), Galapagos Rift (1977), and East Pacific Rise (1978). Beginning with the Cayman Trough, a major development effort began to improve the unmanned ANGUS sled to not only make it a valuable support system for the submersible ALVIN, but also to make it an independent research tool. This development effort dealt with all aspects of the system (see Figure 1); including a significant upgrading of its photographic capabilities (new cameras and lighting units, new at-sea color processing facilities, and new data loggers); computer system (new software, new displays, and new operating procedures); and sensor systems (addition of new vehicle monitoring parameters and new scientific instruments). In addition to these technical improvements, steps were recently taken to make ANGUS available to the entire scientific community by transferring its operational responsibilities to the Ocean Engineering Department.

In addition to ANGUS, continuing improvements have been made in the ALVIN (see Figure 1), as well as other systems used in our study program. Two years of effort, for example, was spent improving the U.S. Navy bathyscaph, TRIESTE II, which made it possible for that craft to conduct its science program in 1977. These improvements included the use of our transponder navigation unit, redesign of its photography system, including the use of our at-sea color film process-

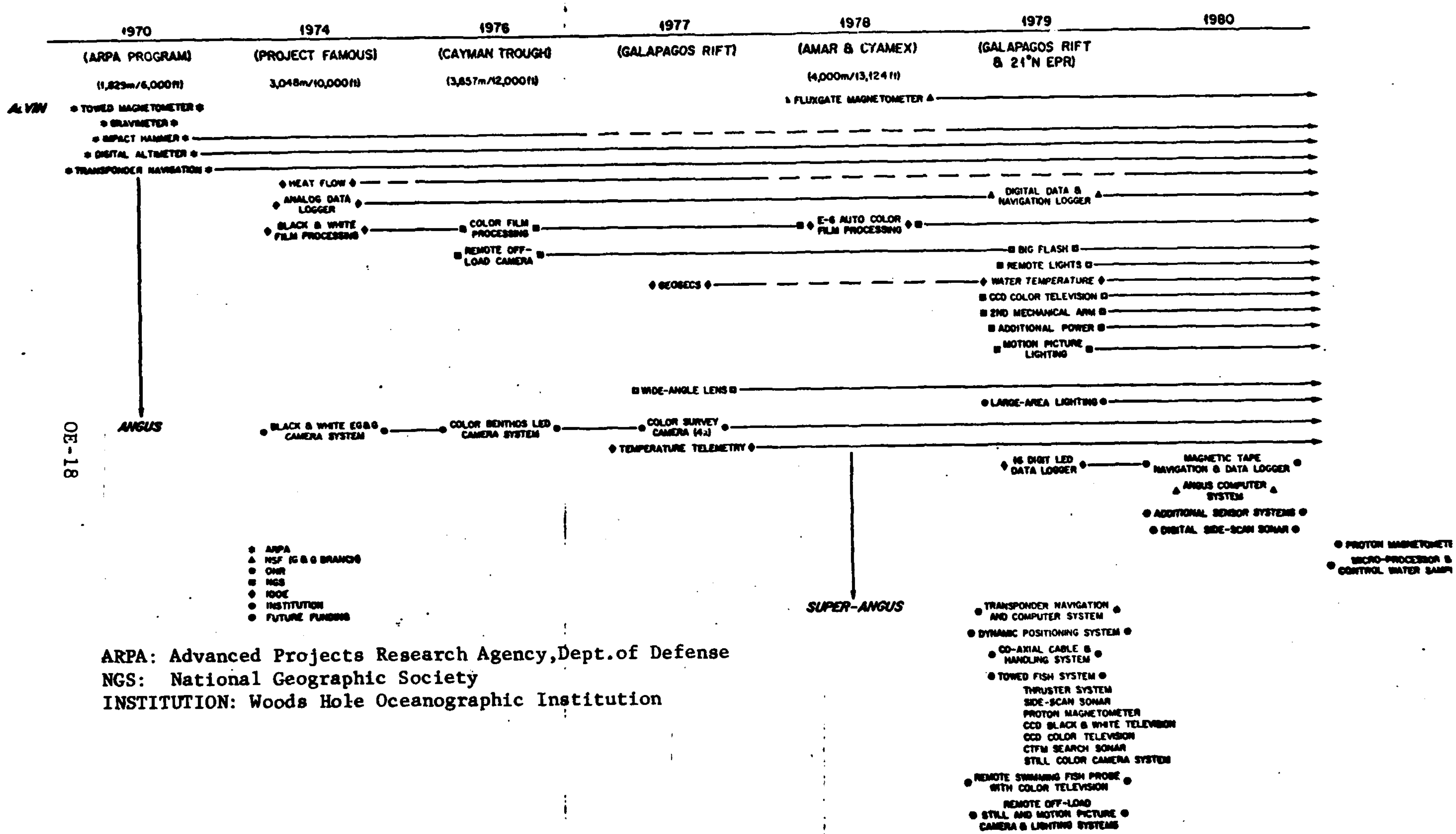

Figure 1. Technology program Principal Investigator has participated in since 1970.

ing facility, and the building of a new data logger.

The long-range scientific objectives of the P.I. have also greatly benefited from the field programs in the Mid-Cayman Rise, Galapagos Rift, and East Pacific Rise. The volcanic and structural model proposed by Ballard and van Andel (1977a) for the FAMOUS area has been applied to these spreading centers and been found to be valid even for those having a faster opening rate (van Andel and Ballard, in press). The ANGUS data obtained in both the Mid-Cayman Rise and Galapagos Rift revealed the presence of major submarine sheet flows containing impressive lava drainback structures not previously thought to occur in the deep sea. These features have been analyzed in detail, compared to known land forms, and an attempt has been made to explain their origin (Ballard, Holcomb, and van Andel, in press). More recently, similar collapse structures and extensive sheet flows have been found in the rift valley of the East Pacific Rise at 21°N, and the P.I. is participating in the collection and analysis of that data base (CYAMEX, in press). Work in both the Galapagos Rift and EPR at 21°N has led to the investigation of active hydrothermal vents within the rift valley along the central region of recent volcanic activity. This work has provided new insight into the origin of hydrothermal vents and their relationship to continuing volcanic processes (Crane and Ballard, in press).

Present Status and Progress Over the Past Year:

The P.I.'s long-term research program continued this year with his participation in the French CYANA diving program in the rift valley of the East Pacific Rise at 21°N. This work was carried out in March and April, followed by a two-week workshop at Scripps. Funding for this program came from I.D.O.E.

The second part of the year will involve a return program to the Mid-Atlantic Ridge rift valley in July and August. This program is funded by N.S.F. With the results of the FAMOUS project now published in two volumes of the G.S.A. Bulletin, a synthesis of that data has raised several questions which this summer's program will attempt to address. Dives, for example, will be made on the first series of terraces flanking the inner rift valley with the express purpose of testing the model proposed by Ballard and van Andel (1977a). A major portion of the study, however, will concentrate on an ALVIN/ANGUS program in a segment of the rift valley which was never investigated by these techniques and, in essence, represents an entirely new spreading center study.

Program in 1979:

1979 is the final year of the P.I.'s long-term program in active spreading centers, and represents a major transition in his research effort. The first half of the year will be spent participating in two field programs; the first in the Galapagos Rift (this proposal), and the second in the East Pacific Rise (I.D.O.E. program). This lengthy field effort will be followed by the initiation of a major synthesis program, which will be conducted at Stanford University working with Dr. van Andel. Since 1979 is a transition year consisting of two different efforts, they are being presented separately in this proposal with two separate budgets.

VOLCANIC AND TECTONIC PROCESSES OF THE GALAPAGOS RIFT

(Field Program)

Last year, the P.I. was Co-chief Scientist of an expedition to the Galapagos Rift at 86°W (Figure 2), which resulted in (1) the delineation of an extremely young zone of recent volcanic activity, characterized by extensive sheet flows and associated collapse structures not previously known to exist in the deep sea, and (2) the location and investigation of a series of active hydrothermal springs. Since that time, a comprehensive analysis program has been conducted which has provided new insight into the volcanic and tectonic processes which are operating within the rift valley and helped us understand how these processes are associated with hydrothermal activity. Based upon the success of this program, plans have been made to conduct a second and even larger expedition to revisit the Galapagos Rift in 1979. Prior to the writing of this proposal, preliminary discussions were held with O.N.R. and N.S.F. regarding their potential sponsorship of this effort. Based upon these discussions and subsequent submission of proposals to the ALVIN UNOLS Committee, a preliminary decision was made to conduct this expedition. The expedition will be divided into four Legs, with the first three taking place in January and February, and the final Leg occurring in November. A submersible diving program and a surface ship program will be conducted on each of these four Legs. The diving effort on Legs 1 and 4 will be carried out by biologists working under the sponsorship of N.S.F., while geochemists will participate in Leg 3, under the sponsorship of O.N.R. The purpose of this proposal is to discuss the work the P.I. will be doing on the surface ship during Legs 1 and 2, and the submersible during Leg 2.

<u>ANGUS Science and Technology Program on Legs 1 and 2</u>

The entire research effort for the Galapagos program is dependent upon the scientists in ALVIN being able to locate and investigate the hydrothermal vents discovered in 1977, as well as any new vents found during the field work in 1979. ALVIN, however, can only cover a small area during each dive, and is therefore a very expensive and inefficient system for locating these vents. It will, therefore, be the responsibility of the ANGUS system to carry out this task. Using satellite navigation, the rift valley previously visited in 1977 will be relocated.

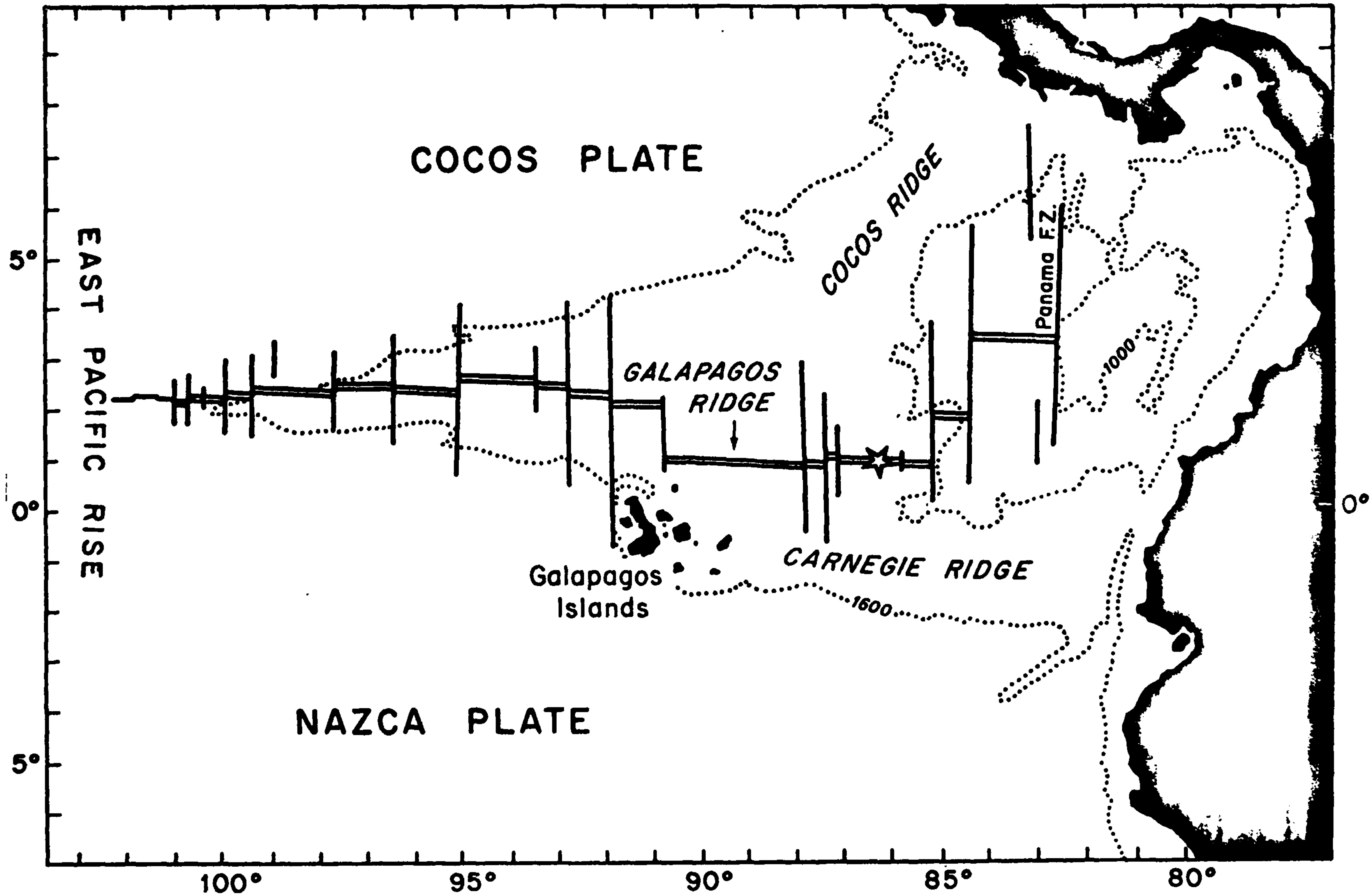

Figure 2. Segment of Galapagos Rift (star) in which 1977 study program was conducted.

Once a network of acoustic transponders have been installed and surveyed, ANGUS will be used to search for and locate the hydrothermal vents. To insure the success of this search program, funds are being requested to build a new high-energy strobe system for ANGUS which will increase its search area by a factor of four, and greatly reduce the chance of damage or loss. This system will be discussed later. Once the vents have been located, using this large-area photography system assisted by a temperature anomaly monitoring unit mounted in ANGUS, the biology program with ALVIN will begin. While that effort is going on, the P.I. will use ANGUS to conduct a science program in the rift valley regions to the east and west. The thrust of that science program will be:

(1) To understand why the hydrothermal vents are located where they are, and what relationship they have with the volcanic cycle. Crane and Ballard (in press) suggest that the hydrothermal vents within the Galapagos Rift are short-lived phenomena and take place soon after a new cycle of volcanic activity has ended. They suggest that the initial fissuring of young pillow flows provide an opportunity for entrapped heated water to escape, initiating a hydrothermal cycle. If this model is correct, additional vents should be located along the trend of the vents presently known. Also, additional vents should be found to the west of the study area, where initial fissuring of the young volcanic cover must also be taking place. The ANGUS system will be used to conduct this mapping program to test the predictions of this model.

(2) Extensive sheet flows were discovered in the Galapagos rift valley, as well as more recently in the East Pacific Rise at 21°N (Figure 3). Prior to these discoveries, numerous scientists believed the dominant, and almost exclusive, form of magma extrusion occurred as pillowed flows. This belief significantly affected their concepts and models that they proposed for the origin of the upper extrusive layers of the oceanic crust. If, however, sheet flows prove to be as, or more important than pillow flows, particularly in faster spreading centers, significant changes must be made in our present concepts and models for the volcanic processes of active spreading centers. It is, therefore, important that the nature of sheet flow activity be further examined through the mapping of additional segments of the rift valley to the east and west of 86°W, where the earlier study of 1977 was conducted. Fortunately, the young zone of recent pillow and sheet flow activity is also where the active hydrothermal vents are found. As ANGUS conducts the work outlined in task (1), it will be possible to also investigate the relationship between pillow and sheet flows, as discussed here (task #2).

(3) Sheet flows have been found to contain a wide spectrum of collapse structures (Ballard, Holcomb, and van Andel, in press), varying in size from a few centimeters to as much as 200 meters in diameter

(Figure 4). The origin of these collapse structures is not understood, as they only recently have been found to exist. A series of saturation lowering by the ANGUS system over the known collapse structures of the Galapagos Rift at 86°W should greatly improve our understanding of those features. With such a thorough coverage, the exact size, shape, micro-topography, associated flow forms, and regional drainage pattern can be determined.

(4) Recent detailed studies in rift valleys (Ballard and van Andel, 1977; van Andel and Ballard, in press) have provided us with a model of crustal accretion which suggests that the central volcanic process results in the building of discreet and relatively uniform volcanic hills, which are subsequently faulted and transported laterally as intact crustal units (Figure 5). These studies have also shown that the central zone of volcanism, itself, is narrow with shifts in its location through time being of a minor amount; approximately 500 meters to a kilometer. Our knowledge of the tectonic alteration of this new volcanic terrain as a function of time has progressively improved. Our knowledge of the variation of these processes along strike, however, is poorly known, since all of the detailed studies conducted in active spreading centers thus far have attempted to locate the central zone of volcanism and immediately extend those observations across isocrons, perpendicular to the strike of the valley. Of critical importance now is the extension of these observations along the strike of the valley to determine the total area affected by one cycle of central volcanic activity. In other words, how far down the valley must one go before one travels from one locus of recent volcanism to another. Such observations are needed before we can understand the overall volcanic pattern and the configuration of its subsurface magma chambers.

ALVIN Science Program on Leg 2

The diving program on Leg 2 will be shared with the National Geographic Society which has requested a series of dives on that Leg for the purpose of making a television special on the subject of Plate Tectonics. Since the National Geographic Society's interests are similar to those of our science program, the P.I. will probably participate in some of the Geographic dives, as a science observer. To support this program, National Geographic has just awarded him a $52,000 grant to build and install a highly advanced digital Charge Coupled Device (CCD) color television system on ALVIN, increase the submersible's power, and greatly improve its lighting capability (Figure 6). All of the equipment that they will be purchasing for this effort will become a part of ALVIN's permanent scientific equipment once their program is over. National Geographic is also developing a remote lighting and photography system to take large pictures of the vent areas, using high-energy light sources. These experiments will be discussed at the site review, and should enhance our underwater photography capability in future science programs.

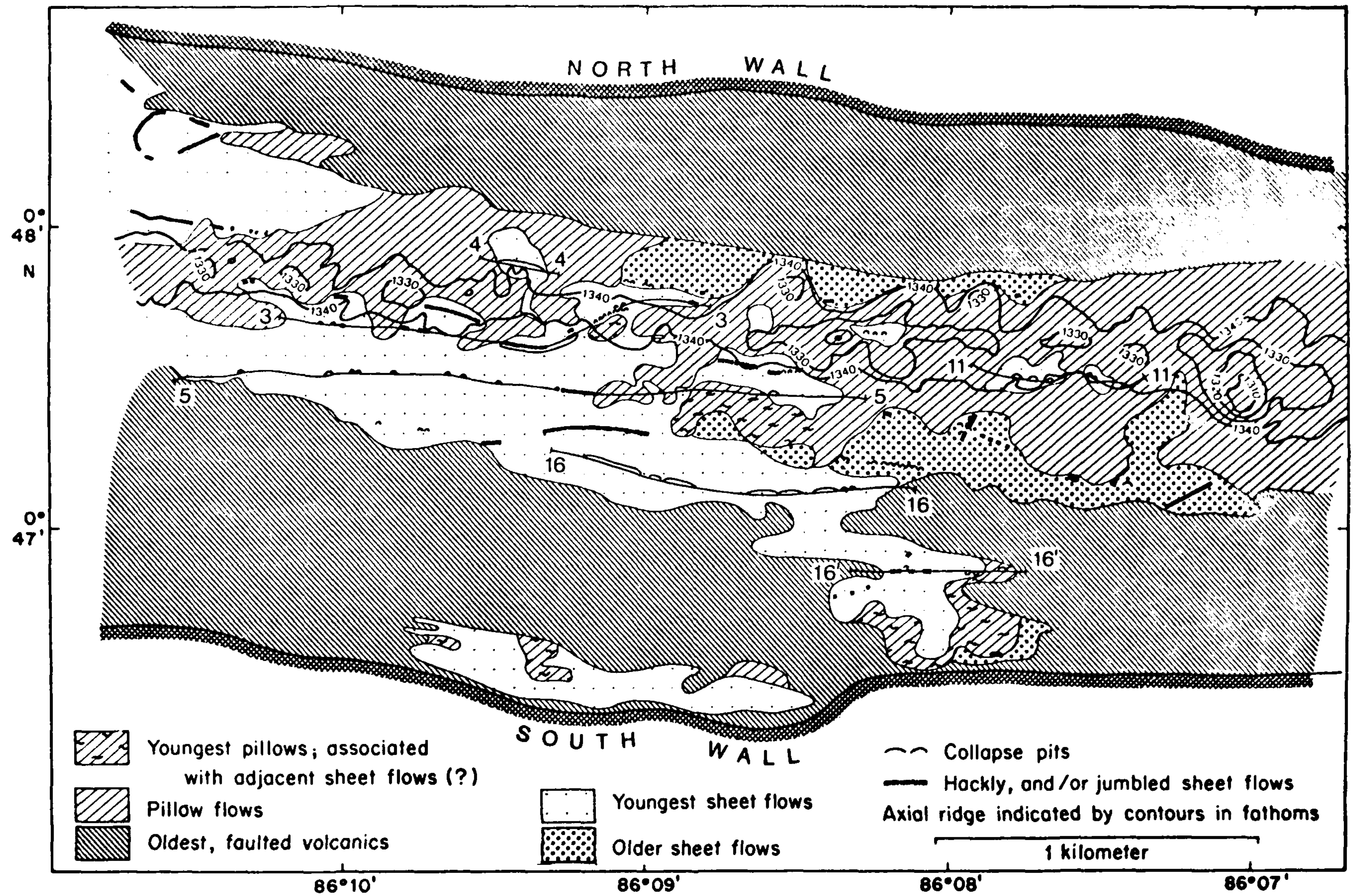

Figure 3. Simplified geologic map of Galapagos Rift study area (from van Andel and Ballard, in press).

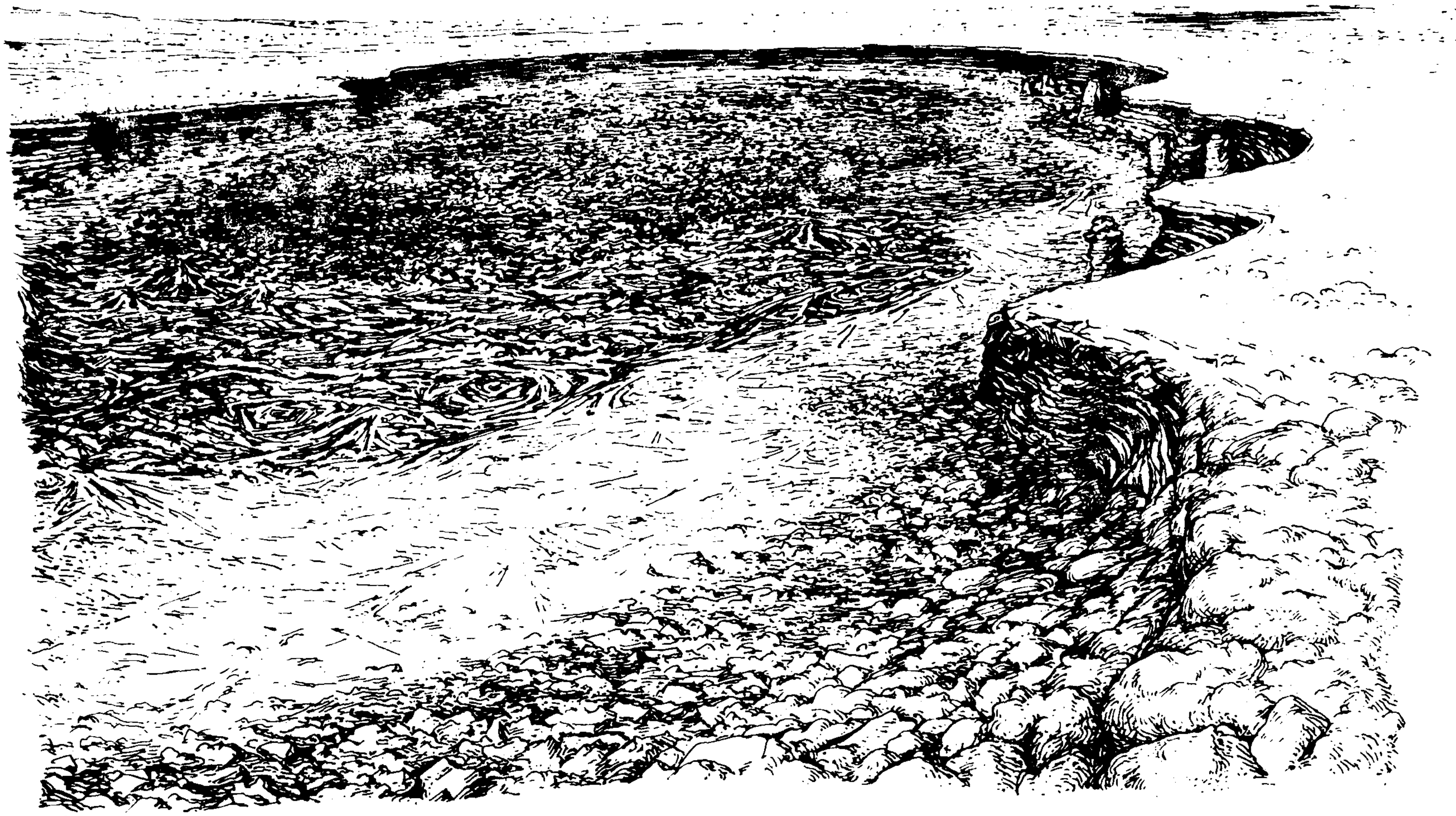

Figure 4. Artist's concept of a large collapse pit or lava lake commonly found in the young sheet flows within the Galapagos Rift. These features are about 200-300 meters across and contain a wide variety of lava forms.

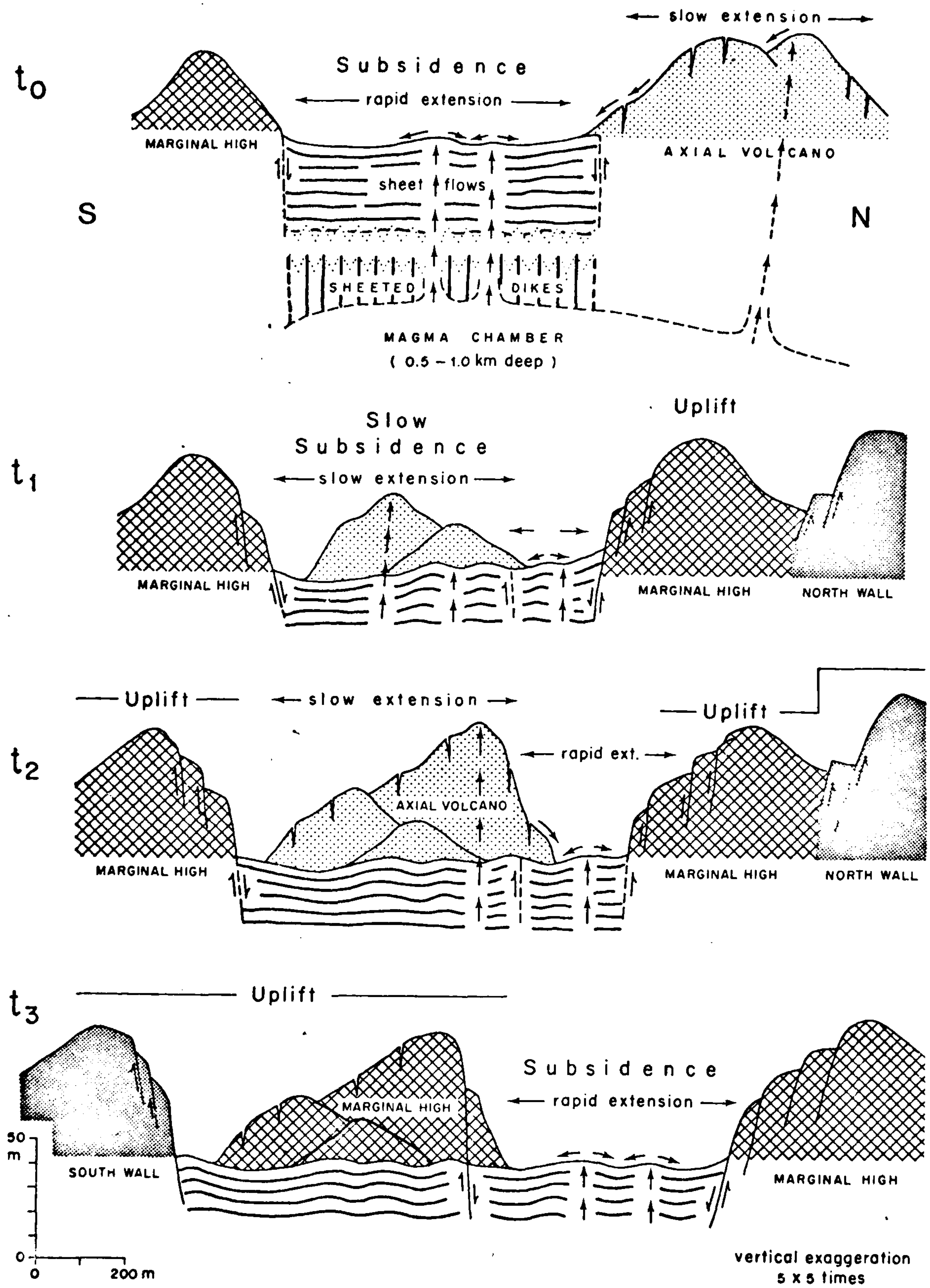

Figure 5. Model for the formation of central volcanic hills along the axis of the rift valley. (After van Andel and Ballard, in press).

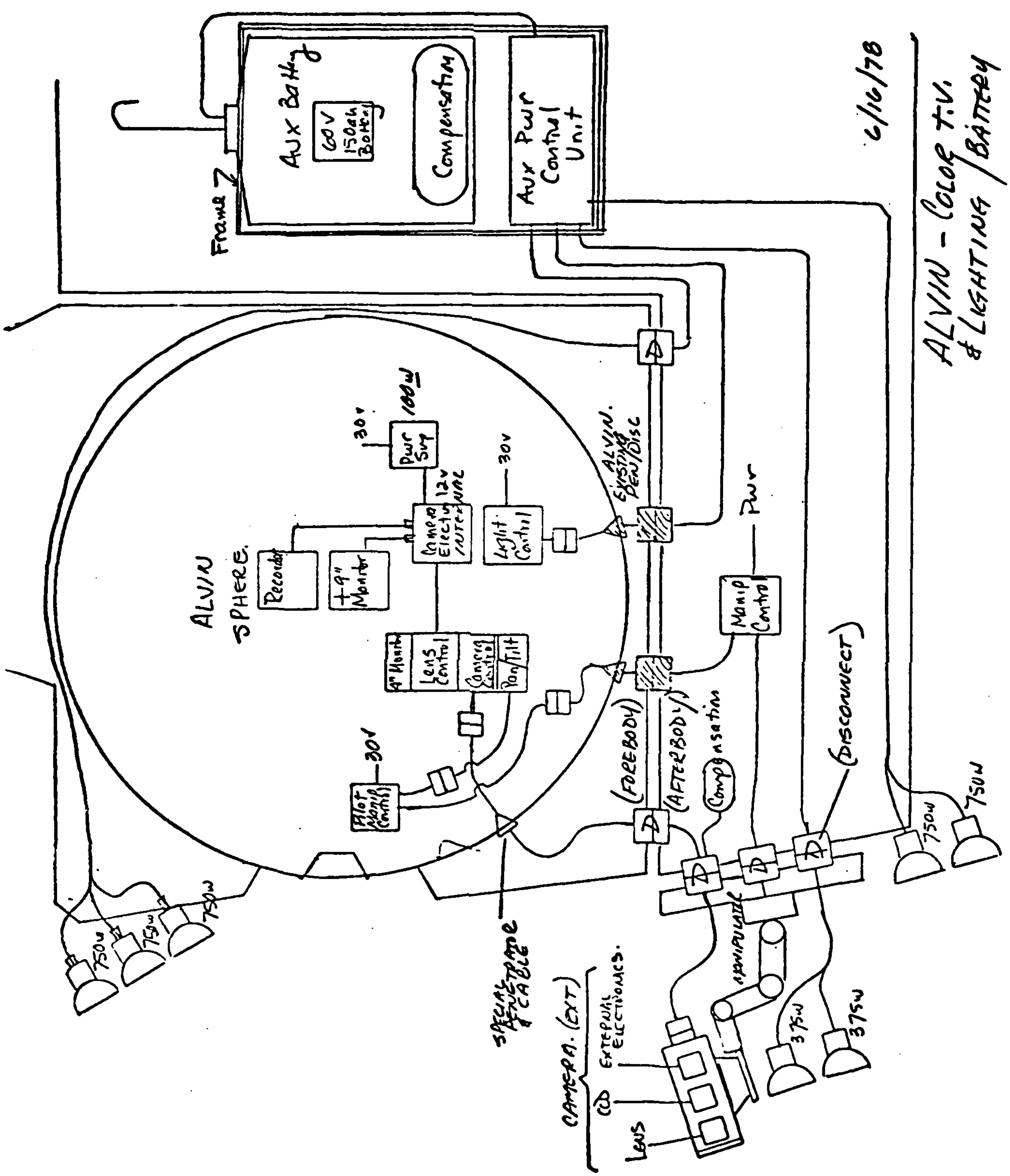

Figure 6. Diagram of new CCD color television system which P.I. will be placing aboard ALVIN under grant from the National Geographic Society. Grant will also include additional lights and power for the submersible.

The science program that the P.I. will conduct using ALVIN will concentrate on the following points:

(1) New vent areas discovered by the ANGUS system will be investigated by the submersible to determine their geologic and tectonic setting in an attempt to relate the hydrothermal activity to the volcanic processes within the rift valley.

(2) The submersible will be used to conduct detailed observations of the extensive sheet flows within the valley to learn more about their mode of occurrence. Specific flow units will be examined in an effort to locate their source areas and understand the relationship of sheet flows to pillow flows.

(3) The collapse structures known to exist within the sheet flows will be of particular interest to the submersible program. The unusual pillars (Figure 7), which are found on the outer perimeter of large collapse pits, will be studied in detail and attempts will be made to recover samples of these pillars to (a) determine if they are hollow structures formed by the upward migration of entrapped superheated water and (b) to determine the origin of the thin, laminated sheets which coated the walls of the pits to better understand the eruptive history of these lava lakes and, in particular, their subsurface drainage system.

(4) The ANGUS work conducted thus far in the rift valley has revealed the presence of several forms of hydrothermal activity. These include (1) open warm-water vents on the central pillow ridge, (2) hydrothermal staining around the base of lava forms in fresh flow units, (3) bright-colored (particularly yellow) deposits of material in young sheet flows, and (4) mounds comprised of hydrothermal deposits located in the heavily sedimented terrain that flanks the central volcanic ridge to the north and south. The ANGUS data revealing the nature and location of these deposits have been shown to a number of geochemists who are greatly interested in recovering samples of this material. For that reason, an ancillary sampling program will be carried out by ALVIN, while it is doing the work outlined in tasks 1 - 3. These samples will then be given to this group of interested geochemists headed by Dr. Dickenson of Stanford University.

BUDGET JUSTIFICATION:

Since the Galapagos Rift expedition will be conducted in the months of January and February of 1979, it is impossible for us to carry out this effort without the commitment of funds by O.N.R. prior to the normal yearly starting period of January 1979. For that reason, our budget proposal to support this effort has been divided into two sub-budgets. The first is for long-lead work or equipment and supplies, which must be purchased prior to January 1979, while the second deals with funds needed for the program's operations in early 1979.

(LONG-LEAD CRUISE PREPARATIONS)

The funds requested in this budget deal with three categories: ANGUS/ACNAV, ALVIN/ALNAV, and the transponders jointly used by these two systems. From an operational point of view, the engineers providing the transponder navigation support for this program are treating the Galapagos Rift (N.S.F. and O.N.R.) and East Pacific Rise (I.D.O.E.) efforts as a single cruise in an attempt to minimize duplication and make the overall effort more cost-effective. Each user is then being charged a percentage of the costs associated with providing the transponder navigation service based upon his particular tracking needs. Our effort involves the use of the transponder pool for a portion of Legs 1 and 2 on GILLISS, and Leg 2 on ALVIN. A portion of the salaries in this budget and Items 1, 2, and 3 of Expendables are for this service. Items 4 and 5 in Expendables are the standard operating costs for the supplies to run the ANGUS/ACNAV and ALVIN/ALNAV systems, which must be purchased before the cruise begins. The only piece of Permanent Equipment (Items 1 - 4) requested for this program deals with the installation of a high-energy strobe unit on the ANGUS sled. The previous ANGUS system has used a 200 watt-sec strobe light to take color pictures of the sea floor (Figure 8). This system, however, must be flown at an altitude of 4-5 meters, resulting in numerous collisions with the sea floor. When working in the Galapagos Rift in 1977, the sled hung-up on the rough volcanic terrain on several occasions, nearly resulting in its loss. Since that time, we have been researching a new lighting system, which would make it possible to fly the sled at three times the altitude, and therefore significantly reduce the number of collisions, as well as increasing the area photographed by a factor of four. As a part of our engineering evaluation, we borrowed the LIBEC lighting system from the Naval Research Laboratory, and conducted a series of tests. Working with the National Geographic Society and Benthos, Inc., we have subsequently designed a high-energy light strobe system which can be operated on a standard trawl wire ANGUS configuration, but which has a strobe energy of 1,500 watt-sec, and which will operate for the duration of our high-capacity camera (2,900 frames) without requiring recharging (Figure 8). The strobe units, power

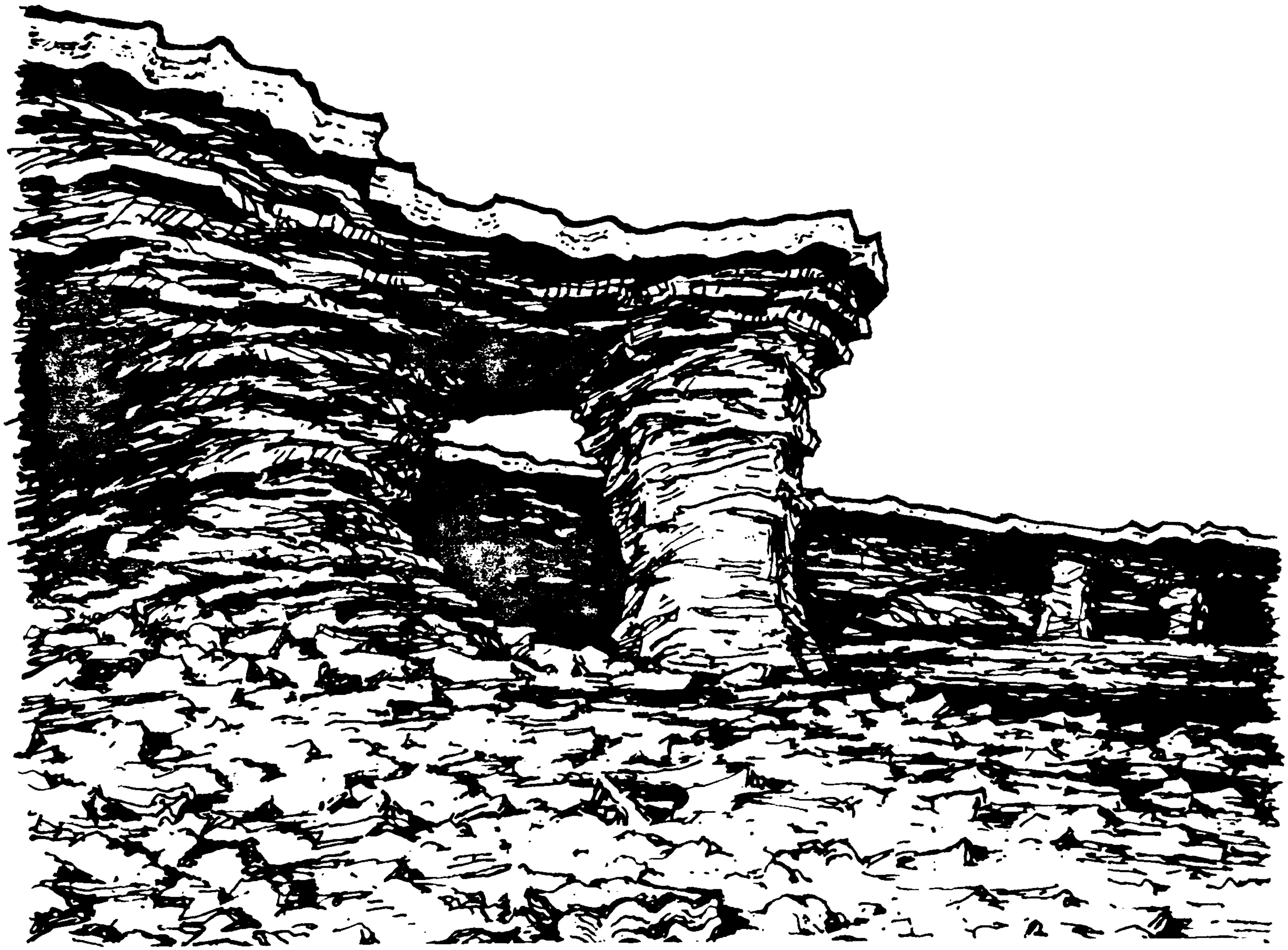

Figure 7. Artist's concept of pillar structures found in collapse structures within the Galapagos Rift. These structures appear to be related to the upward migration of water through young sheet flows advancing across the recently fissured sea floor.

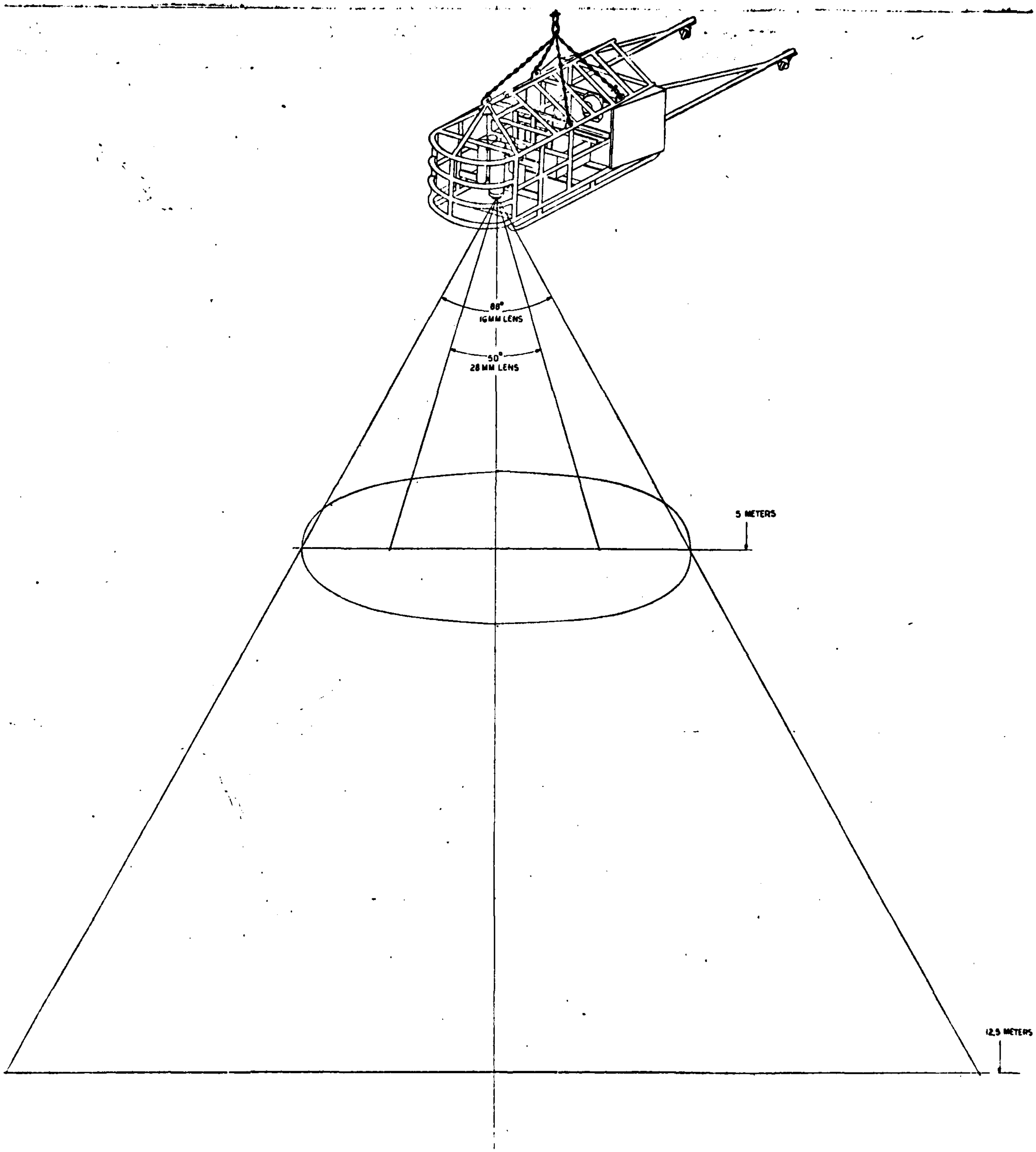

Figure 8. Diagram of ANGUS sled showing its two different lens configurations. Ellipse shows area presently photographed at an altitude of 5 meters using 200 watt-sec strobe unit. Lower line shows the greatly enlarged area that will be photographed using new 1500 watt-sec strobe when flown at higher altitude of 12-13 meters.

packs, and recharger for this system appear as Items 1 - 4 under Permanent Equipment, while the costs of modifying the sled to mount this system is shown in Item 6 of Expendables. Also needed are the associated salaries for the personnel, welding, and machine shop expenses. A detailed discussion of this new light system will be given at the Site Review. It should be pointed out that the larger area seen by the camera and strobe light system will greatly assist in the search for new hydrothermal vents, as well as make the overall mapping program easier. The only other major item in this budget is travel expenses for four of our technical staff to load the major instrument systems aboard the R/V GILLISS, which is based in Miami.

(OPERATIONS BUDGET)

The funds requested in this budget are also subdivided into three categories: ANGUS/ACNAV; ALVIN/ALNAV, and transponders. The major costs shown in the ANGUS/ACNAV budget deal with (1) the salary expenses of the ANGUS team to operate the system during the cruise and conduct post-cruise data reduction (this latter effort will produce detailed topographic maps, x-y plots of each camera lowering at the desired scales, and geologic profiles), (2) spares for the various systems, (3) travel expenses for the ANGUS field team, and (4) the cost of operating the shipboard computer system which supports the ANGUS and ACNAV systems. The major funds requested in the ALVIN/ALNAV budget are to support the navigation team aboard LULU, which will track ALVIN during Leg 2. The salary for the P.I. is also included in this budget, as well as the ANGUS budget for his at-sea time during this program. A major savings to these two budgets will occur as a result of National Geographic providing all the color film, chemicals, and shipboard film processing technicians to run the color laboratory for the ANGUS and ALVIN efforts. The final budget is for a small amount of support for post-cruise handling of the transponders used during the expedition. Not included in any of these budgets are shipping costs of all the equipment needed for this expedition. A Government Bill of Lading will be sought to transport this equipment to Miami to be loaded on board the GILLISS, and funds have been requested from I.D.O.E. to ship the equipment back to Woods Hole from Scripps after the East Pacific Rise program.

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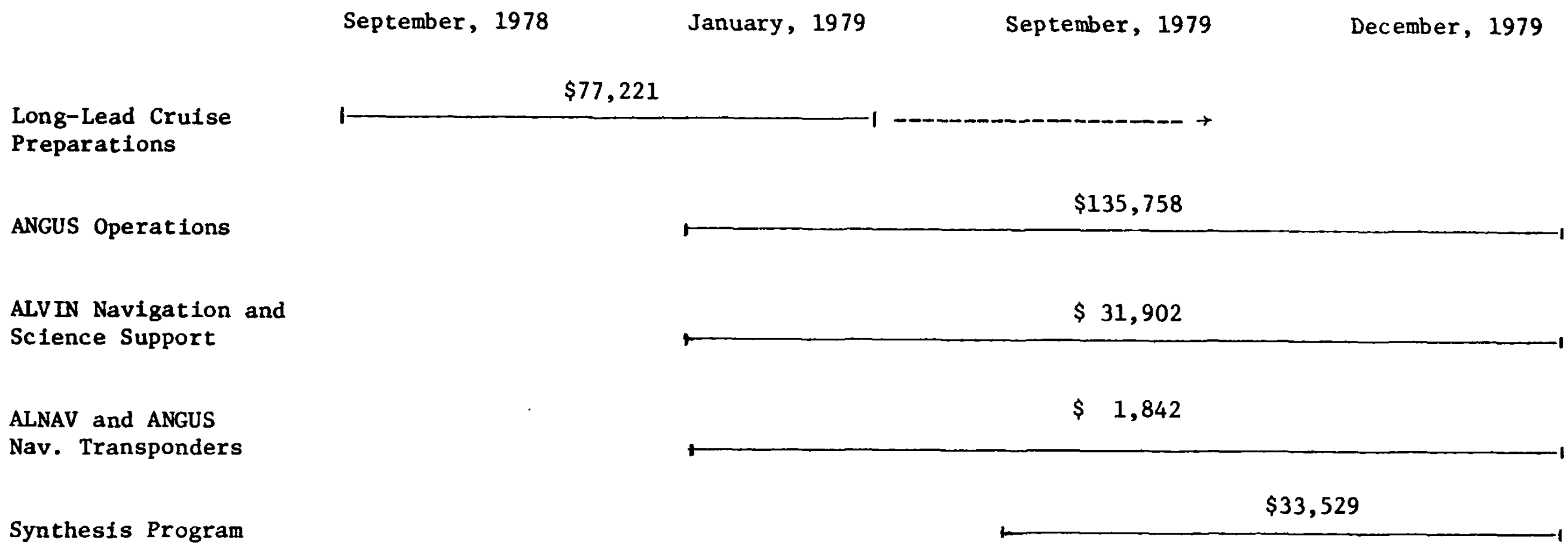
BUDGET SCHEDULE



Long Lead Cruise Preparations

12 months period
15 September 1978 - 14 September 1979

	Man Months				
Professionals:	Transponders	ANGUS	ALVIN	ALNAV	TOTAL
R. Ballard		1			1
W. Marquet		1		1	2
Support Personnel:					
E. Young		2			2
D. Parrott	1.5				1.5
J. Porteous		1			1
G. Meier			1	1	2
V. Wilson		2			2
					11.5

A. 1. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay, etc. of $1,902 which is accounted for as employee benefits)	$19,195	
2. Graduate Research Assistants Salaries	-0-	
3. Cruise Leave, Sea Duty Vacation and Overtime (including premium pay of $ -0-.)	-0-	
TOTAL		$19,195
B. OTHER EMPLOYEE BENEFITS		5,361
C. TOTAL SALARIES AND BENEFITS		24,556
D. PERMANENT EQUIPMENT (See Attached)		20,200
E. EXPENDABLE SUPPLIES AND EQUIPMENT (See Attached)		13,220
F. TRAVEL -Domestic		
1. 4 RT WHOI-Miami, plus 4 days living expenses per man		2,176
G. OTHER DIRECT COSTS (See Attached)		6,997
H. TOTAL DIRECT COSTS		67,149
I. INDIRECT COSTS @ 15% of H (Total Direct Costs)		10,072
J. TOTAL COSTS		$77,221

Long Lead Cruise Preparations

D.	PERMANENT EQUIPMENT		
1.	Benthos 1500 watt second strobe with two remote heads	$10,700	
2.	Two deep sea lead acid battery packs @ $2,500 each	5,000	
3.	Battery charger for lead acid batteries	800	
4.	Benthos Model 391 nicad battery pack	3,700	
	TOTAL		$20,200
E.	EXPENDABLE SUPPLIES AND EQUIPMENT		
1.	Supplies and services to modify, refurbish and service (w/o batteries) 3 each transponders at an average cost of $1,100 each	3,300	
2.	Supplies to build 12 each expendable transponder anchor assemblies @ $75 each	900	
3.	Transponder batteries, 7 sets @ $350 each	2,450	
4.	ALVIN Navigation (ALNAV) supplies on RV LULU, 12 days @ $50 per day plus spare parts @ $1,000	1,600	
5.	ANGUS Navigation (ACNAV) supplies on the escort ship, 26 days @ $95 per day plus spare parts @ $1,500	3,970	
6.	Material to modify ANGUS fish to fit the super flash and lead acid battery pack	1,000	
	TOTAL		$13,220
G.	OTHER DIRECT COSTS		
1.	Shipping & Communications	700	
2.	Welding Shop, 40 hrs @ $13/hr	520	
3.	Machine Shop, 20 hrs @ $13/hr	260	
4.	Drafting, 20 hrs @ $13/hr	260	
5.	Xerox Charges	100	
6.	Laboratory Overhead (21% of C)	5,157	
	TOTAL		$6,997

ANGUS Operations

12 months period
1 January 1979 - 31 December 1979

	Man Months				
Professionals:	Pre-Cruise	At Sea	Post Cruise	Data Reduction	Total
R. Ballard		1			1
W. Marquet	.5		.5	1	2
Support Personnel:					
C. Crane		1			1
E. Young		1	1		2
V. Wilson		2	1		3
C. Scheer		2			2
D. Parrott		2	.5		2.5
C. Wooding	.5	1		3	4.5
S. Gegg		1		3	4
D. Welch		1			1
D. Hosom	.5			3	3.5
					26.5

A.	1. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay, etc. of $4,596 which is accounted for as employee benefits)	$39,271	
	2. Graduate Research Assistants Salaries	-0-	
	3. Cruise Leave, Sea Duty Vacation and Overtime (including premium pay of $2,784)	11,875	
	TOTAL		$51,146
B.	OTHER EMPLOYEE BENEFITS		14,955
C.	TOTAL SALARIES AND WAGES		$66,101
D.	PERMANENT EQUIPMENT (See Attached)		175
E.	EXPENDABLE SUPPLIES AND EQUIPMENT (See Attached)		3,480
F.	TRAVEL (See Attached)		10,775
G.	COMPUTER COSTS		
	1. 60 hrs of HP shore computer @ $25/hr		1,500
H.	SHIP COSTS		
	1. Shipboard Computer Technician 41 days @ $492/day		20,172
I.	OTHER DIRECT COSTS (See Attached)		15,847
J.	TOTAL DIRECT COSTS		$118,050
K.	INDIRECT COSTS @ 15% of I. (Total Direct Costs)		17,708
L.	TOTAL COSTS		$135,758

ANGUS Operations

D.	PERMANENT EQUIPMENT		
	1. Hand calculator for surface navigator		$ 175
E.	EXPENDABLE SUPPLIES AND EQUIPMENT		
	1. Spare parts for 1500 ws strobe	1,250	
	2. Photo van spares, including processor	500	
	3. Acoustic navigation system spares	600	
	4. Spare parts kit for Model 391 battery	730	
	5. Misc. supplies	400	
	TOTAL		$ 3,480
F.	TRAVEL		
	1. Domestic (none)		
	2. Foreign		
	a. Six one-way WHOI-Panama, plus 12 days living expenses	3,060	
	b. Five one-way WHOI-Galapagos, plus 15 days living expenses	3,130	
	c. Seven one-way WHOI-Manta, plus 28 days living expenses Note: unload ship in Manta at end of cruise, therefore more perdiem	4,585	
	TOTAL		$10,775
I.	OTHER DIRECT COSTS		
	1. Machine Shop, 40 hrs @ $13/hr	520	
	2. Graphic Arts, 60 hrs @ $13/hr	780	
	3. Shipping & Communications	1,100	
	4. Xerox Charges	150	
	5. Laboratory Overhead (21% of C)	13,297	
	TOTAL		$15,847

WHOI Proposal #1224

ALVIN Navigation and Science Support

12 months period
1 January 1979 - 31 December 1979

	Man Months				
Professionals:	Pre-Cruise	At Sea	Post Cruise	Data Reduction	Total
R. Ballard		1			1
D. Hosom		1		1	2
Support Personnel:					
E. Smith	1	1	1		3
					6

A. 1. Gross Regular Salaries (includes allowance for vacation, holidays, sick pay, etc. of $721 which is accounted for as employee benefits)	$ 9,570	
2. Graduate Research Assistants Salaries	-0-	
3. Cruise Leave, Sea Duty Vacation and Overtime (including premium pay of $534)	3,788	
TOTAL		$13,358
B. OTHER EMPLOYEE BENEFITS		4,587
C. TOTAL SALARIES AND WAGES		$17,945
D. PERMANENT EQUIPMENT (See Attached)		450
E. EXPENDABLE SUPPLIES AND EQUIPMENT		2,100
F. TRAVEL (See Attached)		2,220
G. COMPUTER COSTS		
1. 9 hrs of HP shore computer @ $25/hr		225
H. OTHER DIRECT COSTS (See Attached)		4,801
I. TOTAL DIRECT COSTS		$27,741
J. INDIRECT COSTS @ 15% of I (Total Direct Costs)		4,161
K. TOTAL COSTS		$31,902

ALVIN Navigation and Science Support

D.	PERMANENT EQUIPMENT		
	1. Volt ohm-meter		$ 450
E.	EXPENDABLE SUPPLIES AND EQUIPMENT		
	1. Replacement ALVIN Navigation (ALNAV) spares	850	
	2. Color T.V. Recorder Tape, 10 days @ $60/day	600	
	3. Data Logger supplies, 10 days @ $20/day	200	
	4. Supplies to build rock sampling tools and rock storage boxes	450	
	TOTAL		$ 2,100
F.	TRAVEL		
	1. Domestic (none)		
	2. Foreign		
	a. Two RT WHOI-Manta, plus 8 man days living expenses		$ 2,220
H.	OTHER DIRECT COSTS		
	1. Machine Shop, 20 hrs @ $13/hr	260	
	2. Graphic Arts, 20 hrs @ $13/hr	260	
	3. Shipping & Communications	600	
	4. Xerox Charges	25	
	5. Laboratory Overhead (21% of C)	3,656	
	TOTAL		$ 4,801

WHOI Proposal #1224

ALNAV and ANGUS Navigation Transponders

12 months period
1 January 1979 - 31 December 1979

Personnel:	Man Months: Pre-Cruise	At Sea	Post Cruise	Total
D. Parrott			.5	.5
				.5

A. 1. Gross Regular Salaries (includes allowance for vacation, holidays, sick pay, etc. of $75 which is accounted for as employee benefits)	$ 629	
2. Graduate Research Assistants Salaries	-0-	
3. Cruise Leave, Sea Duty Vacation and Overtime (including premium pay of $ -0-.)	-0-	
TOTAL		$ 629
B. OTHER EMPLOYEE BENEFITS		158
C. TOTAL SALARIES AND WAGES		$ 787
D. PERMANENT EQUIPMENT (none)		
E. EXPENDABLE SUPPLIES AND EQUIPMENT		
1. Replacement transponder spare parts		500
F. TRAVEL (none)		
G. OTHER DIRECT COSTS		
1. Shop Services, 10 hrs @ $13/hr	130	
2. Communications	15	
3. Xerox Charges	5	
4. Laboratory Overhead (21% of C)	165	
TOTAL		$ 315
H. TOTAL DIRECT COSTS		$ 1,602
I. INDIRECT COSTS @ 15% of H (Total Direct Costs)		240
J. TOTAL COSTS		$ 1,842

VOLCANIC AND TECTONIC PROCESSES OF ACTIVE SPREADING CENTERS

(Synthesis Program at Stanford University)

Robert D. Ballard **(617) 548-1400, Ext. 224**

Introduction

A major aspect of the marine earth science program in the 1970's has centered around the detailed investigation of the mid-ocean ridge system. Understanding the structural evolution of this ridge system is critical to our overall understanding of the processes of plate tectonics which affect the structure of the entire earth. The importance of the mid-ocean ridge system to earth scientists was evidenced in January of 1972, when the National Academy of Sciences conducted a workshop at Princeton University to determine how a detailed geological and geophysical program might best be planned and organized to investigate this important geologic system. A recommendation of that workshop was to follow the present regional study programs with more detailed investigations,using deep-towed survey systems and deep submersibles. Although initial work had already begun in this direction and was providing valuable new insight into the volcanic and tectonic processes of the mid-ocean ridges, a more comprehensive effort was needed.

This comprehensive effort began in 1972 with the initiation of a joint French-American program (Project FAMOUS) to investigate, in detail, the rift valley of the Mid-Atlantic Ridge at 36°N. With the successful completion of that program in 1974, new programs of a similar fashion were carried out in the Cayman Trough, Galapagos Rift, and East Pacific Rise, as well as a revisit to the Mid-Atlantic Ridge.

By the summer of 1979, six comprehensive submersible programs will have been conducted in rift valleys of mid-ocean ridges having opening rates of slow to intermediate speed. Before beginning any new program, the Principal Investigator (who has participated in all six of these programs) believes a great deal of new insight can be gained by conducting a comprehensive synthesis of this unique data base. This proposal requests funds to partially support that synthesis effort, which will be carried out at Stanford University from September of 1979 to June of 1980. Stanford was selected for two reasons; first Dr. Tj. van Andel is on the staff, and it is with him that the Principal Investigator has been working closely since the beginning on this comprehensive study and, secondly, Stanford provides an ideal atmosphere, far from the sea-going efforts of Woods Hole, to conduct such a synthesis.

Proposed Program

The six field programs mentioned above have all taken place between June of 1974 and March of 1978, and have all been staged out of Woods Hole.

As a result, the analysis of the data collected to date has concentrated more on the unique characteristics of each rift valley setting than on a more comprehensive synthesis of the entire data base. For that reason, the Principal Investigator and Dr. van Andel have joined together to conduct such a comprehensive synthesis.

Inventory of Data Available To Date:

The principle data upon which this study will be based includes the following:

Primary Study Areas: Mid-Atlantic Ridge at 36°N, Mid-Cayman Rise, Galapagos Rift at 86°W, East Pacific Rise at 21°N.

1. Detailed bathymetric maps at an average scale of 1:8000 and 2-meter contour intervals based upon either Deep-Tow or multi-narrow beam surveys.

2. Extensive photographic coverage collected primarily by ALVIN and ANGUS, but also including photographs taken by CYANA, ARCHIMEDE, Deep-Tow, and LIBEC. Estimated total number of photographs is in excess of 250,000.

3. Dive observations obtained from ALVIN, CYANA, TRIESTE II, and ARCHIMEDE on bottom lithology and structure.

4. Structural and topographic data collected by the Deep-Tow side-scan sonar.

Secondary Study areas include:

1. Mid-Atlantic Ridge crest at 23°N investigated by van Andel and others.

2. Detailed investigation conducted by Canadians at 45°N on MAR.

3. NOAA's program in the TAGS area (26°N, MAR).

4. Bathymetric surveys of the East Pacific Rise at 9-12°S and 7-8°S on the Mid-Atlantic Ridge.

5. Deep-Tow surveys of the East Pacific Rise at 9°N.

Summary of Data Inventory from Planned Operations Prior to September 1979:

1. AMAR - Multi-narrow beam, ANGUS, and ALVIN data from the rift valley at 35°N on the Mid-Atlantic Ridge.

2. Galapagos: Multi-narrow beam, ANGUS, and ALVIN data from the rift valley east and west of earlier study at 86°W.

3. 21°N EPR: Sea Beam topographic data collected by CHARCHOT, and CYANA, ALVIN, ANGUS and Deep-Tow observations.

4. 9°N EPR: Deep-Tow data.

Analysis Program:

When the synthesis program begins at Stanford in September of 1979, the initial period of time will be spent completing the basic data analysis associated with the 1979 programs in the Galapagos Rift and East Pacific Rise. A request has been made to I.D.O.E. to cover the EPR data analysis, while funds in this proposal are requested to complete the Galapagos Rift analysis.

In addition to the data inventory listed above, requests are being made to the Ocean Survey Division of the Naval Oceanographic Office for a series of selected multi-narrow beam swath maps across the mid-ocean ridge system, where declassification is possible.

Once the final inventory of data has been accumulated, the synthesis will begin. The line of attack that will be followed is similar to that already taken by Ballard and van Andel in their earlier analysis of the Mid-Atlantic Ridge and Galapagos Rift programs (Ballard and van Andel, 1977; van Andel and Ballard, in press, Ballard, Holcomb, and van Andel, in press).

1. A topographic analysis and detailed models will be made of all the study areas at comparable scales, projections, and contour intervals. The analysis will be done at three scales ranging from kilometers to tens of meters.

2. Photographic and visual observations will then be transferred to the different topographic charts from which structural and volcanic models will be developed.

3. Emphasis of the small scale modeling will be to identify the relationship between the fundamentally different forms of underwater volcanic activity (pillow and sheet flows) and their relationship to variation in opening rates. The model proposed by Ballard and van Andel, 1977 will be tested and applied to other rift valley settings having a faster spreading rate. From this should come a better understanding of the eruptive history of the rift valley, which creates the upper layers of the oceanic crust, which are then acted upon by tectonic processes which fracture the crust and transport it up and out of the rift valley.

4. The emphasis of the large scale modeling will be on the structural evolution of the rift valley. Several models have already been proposed for the gradual increase in faulting and uplift based upon isostatic principals. A focus of our study will be to test these models and modify them according to our detailed observations.

The work we have conducted to date suggest that a genetic sequence of volcanic and tectonic events can be defined for all spreading centers which begin with volcanic processes that form oceanic crust along a narrow central zone within the rift valley and ends with their tectonic uplift to form the fault blocks bounding the valley, itself. Given such a genetic sequence, scientists working in other rift valleys can quickly determine the stages in which they are in without having to conduct as an exhaustive a survey as those that went into the construction of this model. It is also our hope that from this synthesis a better understanding can be reached as to what directions future spreading center programs should take. Finally, the book that will be published as a result of this study will bring together the data collected by the most comprehensive effort ever undertaken by deep submersibles for scientific purposes and will permit an appraisal to be made about their role and relationship to other deep-sea surveying techniques.

BUDGET JUSTIFICATION:

The P.I. will be at Stanford for a nine-month period beginning in September, 1979 and ending in June, 1980. The funds requested in this budget are for the period of time he will be there during calendar year 1979 (four months). The P.I. has also prepared a budget for 1980, which he will present at the site review. The major items in the 1979 budget deal with his salary, travel expenses, and moving expenses for this synthesis program. Other costs include the shipping of a great deal of material between Woods Hole and Stanford and graphic art services leading to the publication of the results. The trip from San Francisco to New Orleans is to visit the Ocean Survey Division of the Naval Oceanographic Office to prepare maps based upon multi-narrow beam data already collected in various study areas.

12 Month Period
1 January 1979 - 31 December 1979

	ONR Man Months
Professionals:	
R. D. Ballard	3.5
Support Personnel:	
C. Scheer	2.0
S. Smith	1.0
	6.5

A.	1. Gross Regular Salaries(includes allowance for vacations, holidays, sick pay, etc. of $908 which is accounted for as employee benefits)	$10,103	
B.	OTHER EMPLOYEE BENEFITS	2,954	
C.	TOTAL SALARIES AND BENEFITS		$13,057
D.	PERMANENT EQUIPMENT		
	1. Drafting machine	$200	
	2. Projector	450	650
E.	EXPENDABLE SUPPLIES & EQUIPMENT		
	1. Mapping Supplies	$250	
	2. Modeling Supplies	200	
	3. Film Processing	600	
			1,050
F.	TRAVEL		
	1. Domestic: a. 2 RT San Francisco	$1,048	
	4 Car rentals @ $70	280	
	4 days travel expense @ $45/day	180	
	b. 2 RT San Francisco to New Orleans	508	
	2 Car rentals @ $70	140	
	2 days travel expense @ $44/day	88	
			2,244
G.	PUBLICATION COSTS		-0-
H.	COMPUTER COST: 1. Sigma 7 - 11 hrs. @ $155/hr.		1,705
I.	SHIP COSTS		-0-
J.	MISCELLANEOUS COSTS		
	1. Moving & Living Expenses @ Stanford Univ.	$1,500	
	2. Shipping & Communications	1,200	
	3. Graphic Services - 115 hrs. @ $13/hr	1,495	
	4. Reproduction Charges	400	
	5. Laboratory Overhead (21% of C)	2,742	
			7,337
K.	TOTAL DIRECT COSTS		$26,043
L.	INDIRECT COSTS @ 15%		3,906
M.	TOTAL COSTS		$29,949

REMOTE ACOUSTIC SENSING OF NATURALLY OCCURRING
SUSPENDED PARTICLE DISTRIBUTIONS

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ABSTRACT

A moored upward/downward two-frequency acoustic backscattering system (ABSS) and associated laboratory calibration facilities are presently being fabricated to study the temporal and spatial distribution of the particulates associated with the High-Energy Benthic Boundary Layer Experiment(HEBBLE). The 1979 fiscal year research program proposes to proceed with the calibration of the acoustic systems with the laboratory test facilities and to perform engineering field tests in conjunction with two other HEBBLE equipment suites on a common tripod (BASS, Williams, WHOI, and stereoscopic camera and current instrumentation, Wimbush, URI). The engineering field test will consist of two one-day tests in the vicinity of the head of the Hudson Canyon and one three-day deployment in the Western Boundary Undercurrent. Towed acoustic systems will be used during the Hudson Canyon experiment to determine if internal waves focused at the head of the canyon are causing resuspension of particulates.

LONG RANGE SCIENTIFIC OBJECTIVES

A moored upward/downward two-frequency acoustic backscattering system (ABSS) and associated laboratory test tank facilities are being constructed with support from the Office of Naval Research and the United States Geological Survey. The scientific objectives of the research program are two-fold:

(1) to monitor with ABSS the variability of the suspended particulate burden associated with a high-energy benthic boundary layer (e.g. the Western Boundary Undercurrent (ONR) and the Eastern Continental Shelf (USGS)), and

(2) to use the laboratory test facility:

(a) to calibrate ABSS. The calibration will attempt to determine the relationship of the signal level of the backscattered acoustic signal to the suspended particle concentration and size distribution, and

(b) to measure the magnitude of backscattered acoustic signals from small scale temperature and velocity fluctuations. The measurements are to determine if the backscattered signal levels associated with these physical processes are of sufficient magnitude to limit the sensitivity of the acoustic signals to low-level particulate concentrations.

PRESENT STATUS AND PROGRESS OVER THE PAST YEAR

The acoustic program is in its first year, having received delayed approval and release of funds from both ONR and USGS during the April-May 1978 time frame. The following tasks have been, or are in the process of being, completed.

Test Tank

(1) The test tank and integral components (pumps, filters and temperature controls) have been or are being acquired.

(2) The anechoic wedge design and fabrication techniques have been worked out.

(3) The design of the acoustic system to be used with the test tank is in progress.

(4) The modification of facilities to hold the test tank and associated apparatus is nearly complete.

Moored Acoustic System

(1) The electronic design is in progress.

(2) The acquisition of components is in progress.

Due to the late start in the project, it is anticipated that the test tank will be ready for shake-down experiments in October 1978 and that the initial dockside test of the moored acoustic backscattering system will occur in January or February 1979.

PROPOSED RESEARCH PROGRAM FOR 1979

The 1979 research program is to be divided between the laboratory test tank experiments and field studies.

The test tank facility will be used to determine the frequency dependence and the amplitude of the backscattered acoustic signal which results from the introduction of varying concentration and size distribution of suspended particulates. This work will determine the sensitivity of the acoustic systems to suspended particulates of varying composition, concentration and size. The magnitude of the backscattered acoustic signals formed from temperature gradients and/or velocity fluctuations will also be measured to determine their effects in limiting the lower limit of the particle detection capabilities of the acoustic systems. The magnitude of the measured acoustic signal levels will be intercompared with theoretical predictions.

The field work will be carried out aboard the R/V OCEANUS during a ten-day cruise presently scheduled from July 8-18, 1979. The cruise will have two objectives:

(1) to perform an integrated field test with the upward/downward looking moored acoustic system (ABSS), a bottom acoustic stress measuring system (BASS, Albert J. Williams 3rd, WHOI), and a stereoscopic camera and current meter system (Mark Wimbush, URI), and

(2) to acquire data with towed multi-frequency acoustic backscattering systems (Orr and Hess, WHOI), the moored benthic boundary layer systems, XBT's, and in situ water sampling to determine if internal waves focused at the head of the Hudson Canyon are causing resuspension or erosion of sediments.

The integrated field test of the benthic boundary layer monitoring systems will consist of three deployments on a common tripod mooring. Two shallow deployments of one-day duration will be placed at the head of the Hudson Canyon and will provide an evaluation of the compatibility of the three benthic boundary layer monitoring systems. This experiment will be the first field test of ABSS. The third integrated deployment of the benthic boundary layer instruments will be in the Western Boundary Undercurrent to the northeast of the Hudson Canyon. This deployment will be to test the ABSS system at a depth and in an environment similar to that expected during the HEBBLE experiments to be performed in subsequent years. The experiment will obtain baseline data on the variability of the suspended particle burden and the inter-relationship of this variability with changes in the local bedform and Reynolds stresses.

In conjunction with the shallow moored benthic boundary layer system deployments, a shipboard experiment using towed high-frequency acoustic backscattering systems (Orr and Hess, WHOI) is planned. The purpose of the experiment is to survey the water column in the vicinity of the head of the Hudson Canyon to determine if the high suspended matter distributions which have been observed in this area (Biscaye and Olsen, 1975) are the result of erosion or resuspension of particulates caused by the focusing of internal waves at the canyon head (Wunsch,Hotchkiss, and Millard, 1978).

During July 1977, the towed high-frequency acoustic systems were used over an eight-hour period in the area of reported high concentrations of particulates. Regions of heavy acoustic backscattering were detected on the northeast bank of the canyon (Figure 1, Arrow 1). The scatterers appeared to be either settling into, or being resuspended from, the eastern sides of the canyon (Figure 2, Arrow 1). Backscattering levels were considerably lower on the western side, suggesting the canyon is either acting as a giant sediment trap, or currents are preventing the exchange of water and particulates across the canyon. The temporal duration of the July 1977 experiment was not sufficient to determine if the heavy particulate load was the result of resuspension by internal waves in the immediate vicinity of the canyon head or advection of material which had been suspended to the north of the canyon head.

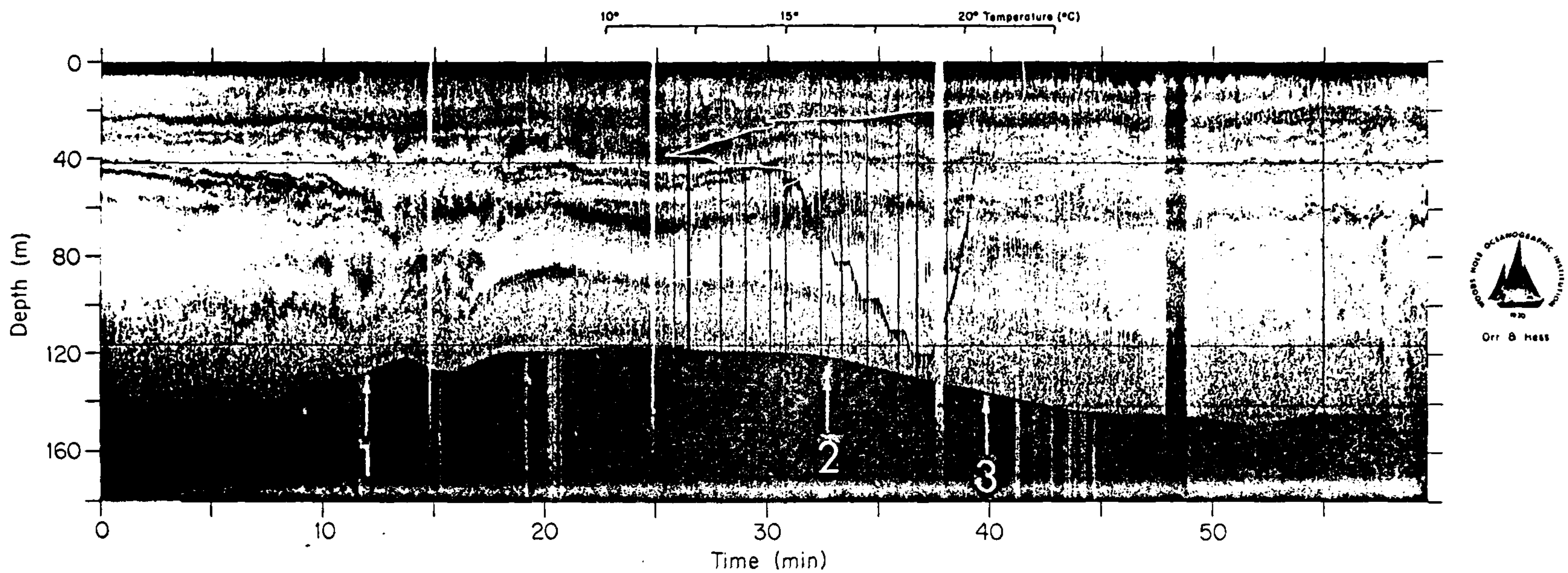

Figure 1 Two hundred kHz acoustic backscattering data obtained at the head of the Hudson Canyon in the area of heavy particle concentrations previously identified by Biscaye and Olsen. Regions of heavy acoustic backscattering or particulate concentrations are noted (Arrows 1, 2 and 3). The nepheloid layer observed near the bottom ($\approx$ 120 m depth) has particle concentrations of 380 μg/l as compared to particle concentrations of 60 μg/l at a depth of 96 m. The stepped diagonal line was caused by acoustic backscattering from the instrument housing of an STD. The temperature profile taken by the STD has been plotted on the acoustic record in white. Layers of heavy acoustic backscattering (dark areas on the record) are correlated with sharp temperature gradients in the water column. The three vertical white lines on the acoustic record are a result of turning the transmitter off so that gray scale levels caused by the time varying gain in the receiver could be contrasted to actual signal levels from the particle distribution near the bottom.

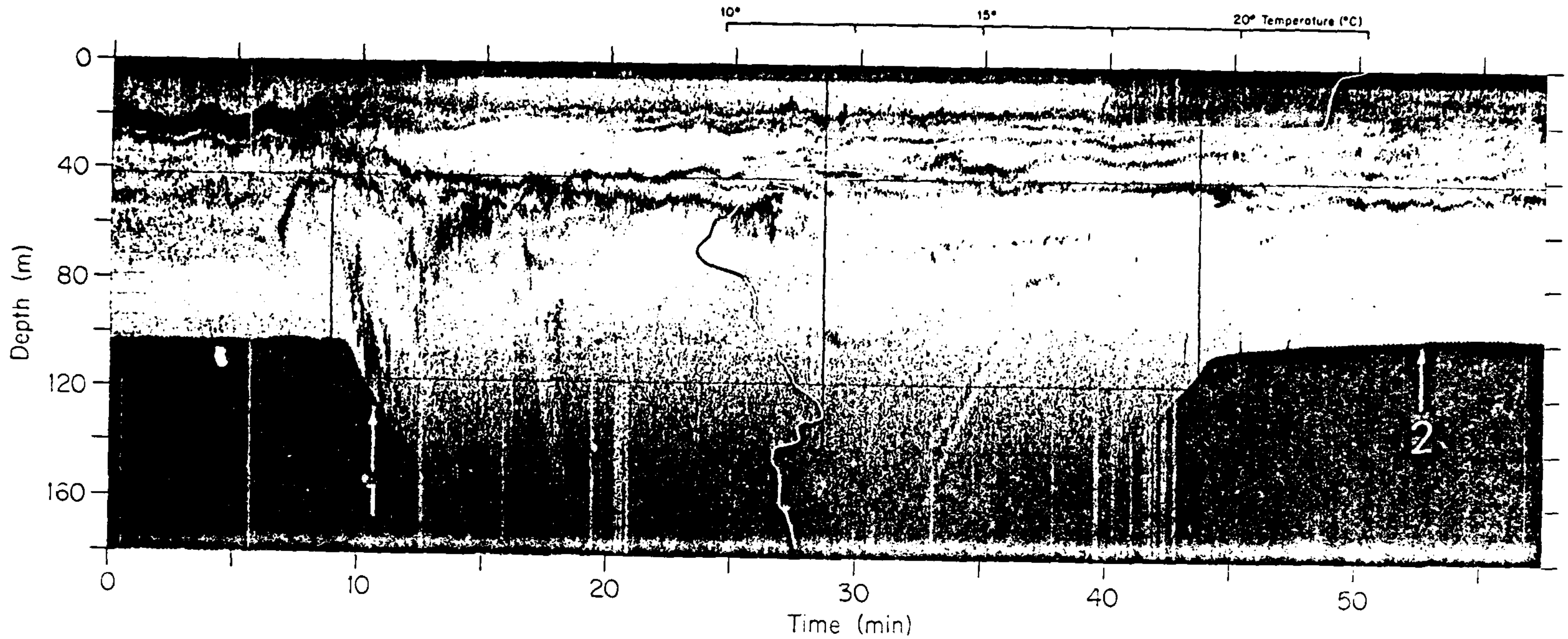

Figure 2 Two hundred kHz acoustic backscattering data obtained at the head of the Hudson Canyon. The northeastern (Arrow 1) and southwestern (Arrow 2) sides of the continental shelf as well as the canyon are shown. Heavy particle concentrations were detected near the northeastern wall (Arrow 1) and also over the northeastern shelf near the wall (Figure 1). There is a strong assymetry between the acoustic backscattering levels (hence particle concentrations) observed over the northeastern and southwestern sections of the shelf. The particle concentration over the southwestern shelf appears to be considerably lower than that over the northeastern shelf. Interleaving water masses cause the multiple scattering layers detected in the water column. The temperature trace obtained when an XBT was dropped at about 28 min into the record (vertical dark line) has been drawn over the acoustic record (white and black line). The areas of heavy layered acoustic scattering are related to the sharp gradients in the temperature structure. The reader must be sure to slide (in his mind) the temperature record to the vicinity of the XBT drop. Otherwise, due to the spatial variability in depth of the temperature structure, a strong correlation of temperature gradient to acoustic scattering layer does not exist.

The towed acoustic systems will be used while the benthic boundary layer experiments are in the water during the two shallow water deployments at the head of the canyon. Correlation of bottom current measurements, Reynolds stress measurements, ABSS measurements and the towed acoustic system measurements should provide data which may allow the identification of the mechanism which creates the high particulate concentrations that have been observed in the vicinity of the northeastern canyon wall. During the three-day deployment of the benthic boundary layer instrumentation in the Western Boundary Undercurrent, the OCEANUS will return to the vicinity of the Hudson Canyon to continue the towed high-frequency acoustic backscattering work. In conjunction with the towed high-frequency acoustic system work, an XBT survey of the area and water sampling using both Niskin sampling and a multiport water sampling device will be carried out to support the interpretation of the acoustic records. The water samples will be filtered on the ship using 0.45 nucleopore filters. The filters will be analyzed for total mass content.

JUSTIFICATION OF PERSONNEL

During a cruise, the use of the moored acoustic backscattering system, the towed acoustic backscattering system, the multiport water sampling system and associated filtration systems requires five people. The water sampling system requires an operator who will also be involved with the water filtration. The towed acoustic backscattering systems are used on a round-the-clock basis and require three experienced watchstanders. The moored acoustic backscattering system will be cycled for redeployment by the designer, F. Hess, who will also assist in the acquisition of the towed acoustic data. M. Orr is presently slated to serve as chief scientist on the cruise and will be heavily involved with the acoustic, navigation and water sampling operations. In addition to the proposed field experiments, tank tests will be carried out during the year, data reduction procedures will be developed, and the cruise data will be reduced for publication.

REFERENCES

Biscaye, P.E. and Olsen, C.R., "Suspended particulate concentrations and compositions in the New York Bight", Proceedings of Symposium, American Museum of Natural History, Nov. 1975.

Wunch, C., Hotchkiss, F.S. and Millard, R.C., "Dynamics of deep water canyons", 1978, unpublished manuscript, Massachusetts Institute of Technology.

Remote Acoustic Sensing of Naturally Occurring
Suspended Particle Distributions

12 Month Period
1 January 1979 - 31 December 1979

	Total MM	Actual MM
Professionals:		
M. Orr	4	4
F. Hess	4	4
L. Baxter II	3	3
S. Bergstrom	2	2
M. Jones	5	5
Support Personnel:		
D. Crowell	4	4
W. Kucharski	2	2
S. Rosenblad	1	1
B. Deslauriers	2	2
P. Pettigrew	1.5	1.5
S. Smith	2	2

A. 1. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay, etc. of $4,429 which is accounted for as employee benefits)	$42,473	
3. Cruise Leave, Sea Duty Vacation and Overtime (including premium pay of $597)	3,185	
TOTAL		$45,658
B. OTHER EMPLOYEE BENEFITS		12,887
C. TOTAL SALARIES AND BENEFITS		$58,545
D. PERMANENT EQUIPMENT		
1. Temperature Sensor	$ 856	
2. Electric Tugger/Capstan	3,000	
3. Hallikanen Temperature Control for Test Tank	1,000	
		4,856
E. EXPENDABLE SUPPLIES AND EQUIPMENT See appended list		16,256
F. TRAVEL		
1. Domestic: a, 1 RT San Francisco	$524	
2 Car rentals	105	
6 Days travel expense @ $45/day	270	
b. 1 RT Washington, D.C.	132	
2 Car rentals	105	
3 Days travel expense @ $50/day	150	
		1,286
G. PUBLICATION COSTS		
1. Graphic Services - 160 hrs. @ $13/hr	$2,080	
2. Page charges - 10 pgs @ $80/pg	800	
		2,880
H. COMPUTER COSTS		
1. Sigma 7 - 5 hrs @ $155/hr		775
I. SHIP COSTS 5 days R/V OCEANUS @ $3,433/day	$17,165	
2. Shipboard Computer Techs, 5 days @ $492/day	2,460	19,625
J. MISCELLANEOUS		
1. Shop Services - 320 hrs @ $13/hr	$4,160	
2. Shipping & Communications - Communications	520	
3. Xerox Charges	200	
4. Laboratory Overhead (21% of C)exclusive of premium pay	12,169	
		17,049
K. TOTAL DIRECT COSTS		$121,272
L. INDIRECT COSTS @ 15%		18,191
M. TOTAL COSTS		$139,463

E. EXPENDABLE SUPPLIES AND EQUIPMENT

1.	Lithium batteries, 31 @ $24/ea	$ 744
2.	Electronic Supplies & Spares	1,500
3.	Cassette Tapes, 18 @ $16/ea	288
4.	EPC Unit Support Kits, 3 @ $235/ea	705
5.	Mag Tape, 40 rolls @ $29/ea	1,160
6.	Transducer Repair Components	2,500
7.	Filtration Supplies -	
	a. Test Tank & Cruise	600
8.	Light Sensitive Fibre Optics Paper -	
	3 boxes @ $385/ea	1,155
9.	XBT - 120 200 m T-10 @ $14.92/ea	1,790
	120 750 m T-7 @ $30.85/ea	3,702
10.	Maintenance of EPC, Analog Tape Recorder	
	and Fibre Optics Recorder	2,000
11.	Surveillance Camera Film - 8 @ $14/ea	112

$16,256

MEASUREMENT OF OCEAN SURFACE CURRENT USING A TOWED LOG

Douglas C. Webb

PII Redacted (617) 548-1400, Ext. 425 [redacted]

ABSTRACT

This proposal is for a continued, vigorous effort to measure ocean surface currents from ships while underway. The development of a towed log system to do this was begun in August 1977 as a joint project between the Woods Hole Oceanographic Institution and the Institute of Oceanographic Sciences (IOS), Wormley, England. The system is presently in the final stages of construction at IOS and field tests will begin shortly.

During the period covered by this contract, we propose to build a second towed body so that one system can remain in Woods Hole, build deck handling equipment to simplify its use, provide a capability for real time display of surface currents and participate in at least two field experiments.

INTRODUCTION

This proposal is for a continued, vigorous effort to measure ocean surface currents from ships while underway. The technique used is one of the oldest known to navigators and scientists. The difference between the ship's true position as determined from a high precision reference navigation system and its dead reckoning position as determined from its speed and heading through the water is assumed to be due to surface currents.

This measurement is of very considerable importance to many oceanographers but is difficult to accomplish with a high degree of accuracy, and frequently has only been marginally useful. The objective of this investigation is to bring together into one integrated measurement system the best combination of dead reckoning sensors and position measurement systems, plus electronic data recording, reduction and display equipment.

It is possible that the system being developed will have an important role in two research areas: First, use aboard research ships to supplement other observations of the details of ocean currents, i.e., fronts, eddies, wind-driven currents, etc. The rapid reduction and display of data will assist in the tactical decision making of the investigator. Second, use aboard ships of opportunity will provide a substantial increase in our knowledge of the statistics of ocean currents over long tracks.

A number of approaches and investigations are being pursued currently, and it is not clear which approach will be the most generally useful. It is intended to make a substantial effort to use the WHOI system in tests and comparison with other systems wherever possible. It is also intended to upgrade the measurement system wherever new sensors become available. Specifically, 1979 will be the first year for use of the satellite Global Positioning System (GPS).

INSTRUMENT DESCRIPTION

The development of a system for the measurement of surface currents using a towed log was begun in August 1977 as a joint program between the Woods Hole Oceanographic Institution and the Institute of Oceanographic Sciences (IOS), Wormley, England. The resulting system consists of a towed body containing all the sensors, a tow cable, and a shipboard data logger. The contributions from each of the institutions were arranged to take advantage of their respective experience and capabilities with Woods Hole providing the basic electronics systems of both the fish and the data logger, and IOS providing the speed sensor and towed body.

The design of the towed body is based largely on the GLORIA MK II side scan sonar with which IOS has had a great deal of experience. The fish body is 1.55 meters long by 25 cm in diameter with a weight in air of about 60 kg (Figure 1) and is towed from the nose using a double armored, torque balanced cable. The fish and cable were designed for tow speeds in the range 2 to 20+ knots at a depth of approximately 20 meters.

Except for the tow point at the nose of the fish, it is constructed of completely non-metallic materials to avoid introducing errors in the magnetic compass. The sensor package is contained in the lower half of the body while the upper portion contains plasticell foam, providing buoyancy and righting moment. The electromagnetic speed sensor protrudes about 4 cm from the bottom of the fish near its nose in a field relatively free of flow disturbances.

A block diagram of the electronics system is shown in Figure 2 and a detailed summary of the measurements is contained in Table 1. The two axis speed sensor and associated electronics are of standard IOS design for shipboard use and have been used for several years on both R/V DISCOVERY and R/V SHACKLETON. The heading sensor consists of an electrically driven gyroscope slaved to a flux gate compass. The other sensors are pendulum potentiometer pitch and roll sensors, a thermistor temperature probe, and a strain gage pressure transducer.

Each of the eight sensor channels plus three internal calibration voltages are sampled once per second, digitized with a 12 bit analog-to-digital converter, converted to an FSK modulated, 600 baud serial ASCII code and then transmitted up the tow cable to the shipboard data logger.

The tow cable is 3/8" diameter, multicore double armored, and torque balanced with a rated breaking strength of 11,000 pounds which exceeds the expected cable loads for tow speeds to twenty knots.

An RCA CMOS microprocessor has been incorporated into the shipboard data logger to simplify the circuitry and to enable greater flexibility in modifying its functions. As the data comes up the cable, it is demodulated, demultiplexed and accumulated for ten seconds in the memory of the microprocessor. It is then edited, combined with time from an internal high precision clock and stored on a magnetic tape cartridge. Using the present sampling rates and number of measurements, the cartridge must be changed about once per day although it is likely that tests will show that these can be reduced with a corresponding extension of recording time.

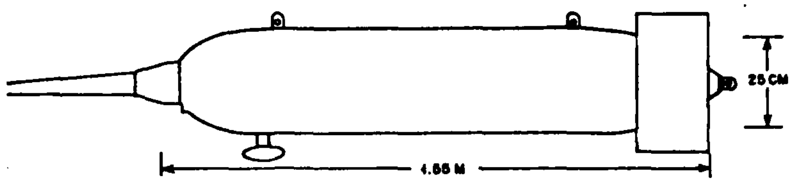

FIGURE 1: FISH BODY

TOW SPEED:	2-20+ KNOTS
TOW DEPTH;	20 METERS
WT. IN AIR	60 KG
WT. IN WATER	NEUTRAL
TOW CABLE	8 MM TORQUE BALANCED
RIGHTING MOMENT	15 NM/RAD

WHOI DWG LRM 78

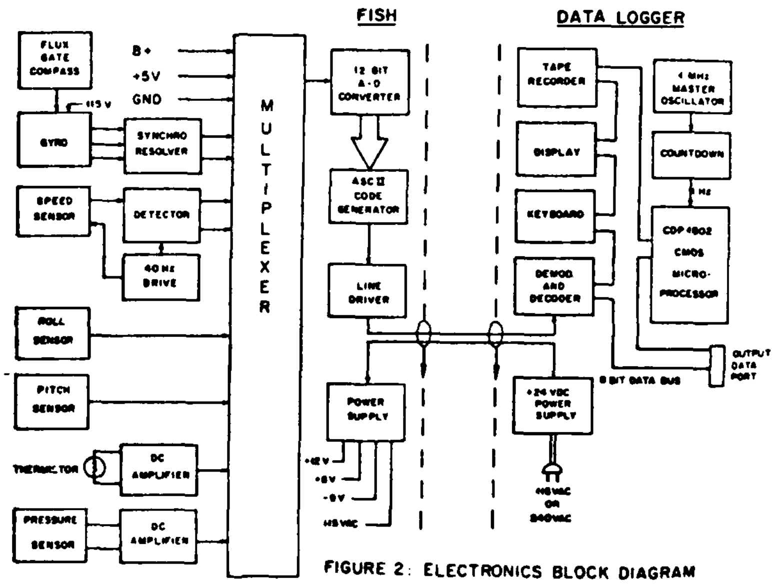

FIGURE 2: ELECTRONICS BLOCK DIAGRAM

MEASUREMENT	SENSOR TYPE	RANGE	ACCURACY	RESOLUTION	SAMPLING RATE
SPEED	2 AXIS ELECTROMAGNETIC 11 CM DIAMETER DISCUS HEAD SUPPLIED BY IOS	LONGITUDINAL -5 TO +15 M/SEC TRANSVERSE ±5 M/SEC	1% OF READING	.5CM/SEC	1 SEC
HEADING	SLAVED GYROSCOPE AIM MODEL 400 CEL	0-360°	±1°	.1°	1 SEC
ROLL & PITCH	PENDULUM POTENTIOMETER HUMPHREY MODEL CP-17	± 45°	±1°	.02°	1 SEC
PRESSURE	STRAIN GAGE PAINE INSTRUMENTS MODEL 211	0-300 PSI	±1.5 PSI	.1 PSI	1 SEC
TEMPERATURE	THERMISTOR YSI MODEL 44032	0-30°C	.01°C	.01°C	10 SEC

TABLE 1: TOWED LOG MEASUREMENT SUMMARY

WHOI-DWG-LRM-78

The data logger includes provisions for visual display of any data channel including the clock, automatic and manual tape recorder control, and an output port and playback capability for interfacing to a computer.

Initially data reduction will be accomplished ashore. The data cartridges will be played back using the data logger in playback mode to get the data into the computer where it will be combined with the satellite navigation positions from the ship's bridge log to calculate the ocean surface current.

PRESENT STATUS

Presently the system is in the final stages of fabrication at IOS and field trials are expected to begin in July 1978 aboard the R/V SHACKLETON. In addition to gaining experience in handling, deploying, towing and operating the system, meaningful calibration points can be obtained by comparing results with the hull mounted, two axis speed log on the ship. IOS has used this system frequently in the past and are familiar with its operating characteristics.

Following this initial trial, participation is planned in the August-September 1978 JASIN experiment with M. Briscoe aboard the ATLANTIS II. It is expected that T. Howard of Stanford University will be making surface current measurements using Bragg reflection of radar from the surface, providing an opportunity to intercompare results with another system.

Finally, during the return crossing to Woods Hole, there are minimal scientific commitments for the ship which will enable us to simulate ship of opportunity conditions. This will be a trial of uninterrupted, relatively high speed passage through a relatively energetic ocean area.

In conjuction with the hardware development, data reduction computer programs are being written. Presently, a "quick look" capability is available and more detailed programs will be developed.

FUTURE DEVELOPMENT WORK

To date there have been no field trials, and consequently, no evaluation of system performance can be made yet. However, it is obvious that there are several important complementary developments in progress which could greatly improve the chances of its success. Likewise, in surveying the operational requirements for ship of opportunity work, there are several areas which will have to be improved upon to enable the system to operate satisfactorily in this environment.

The prototype system incorporates an electromagnetic speed sensor to take advantage of its availability and the considerable operating experience at IOS. We believe it is perfectly adequate in this application and that we will be able to satisfactorily evaluate the performance of the towed system using it. However, the acoustic Doppler backscatter systems now under development can completely circumvent the problems of flow disturbances around the towed body. Although we feel we have incorporated the electromagnetic sensor optimally to minimize these disturbances, the measurement is made in and near the boundary layer surrounding the body. A speed measurement made in the undisturbed flow away from the body can only be an improvement, and consequently, the progress made in developing the acoustic sensors will be monitored closely for incorporation into the system, if possible.

A second critical parameter in measuring surface currents is the accuracy of the reference navigational positions. LORAN C gives very good coverage but only over limited areas of the world's oceans. The present satellite navigation systems give worldwide coverage with position accuracies of ±200 meters. However, the fixes are relatively infrequent and in some areas of the world so infrequent and unreliable as to be unusable with the system. Fortunately, the development of the towed log coincides with the implementation of the Global Positioning System (GPS) which is scheduled to begin limited operation in 1979. This system employs 24 satellites to give continuous, three-dimensional coverage with a target accuracy of ±10 meters.

In addition to the improved accuracy which directly affects the precision of the towed log measurements, the continuous coverage will permit more flexibility in its operation, i.e., instead of being able to calculate currents only at intervals determined by satellite passes, the intervals can be tailored to give finer or larger scale resolution as required.

In a recent survey of possible applications of the towed log to ship of opportunity operations, it was quite obvious that the navigational capabilities of many of these ships are very limited, and that a separate system may have to be supplied with the towed log. Here again, the GPS might make this possible as highly portable (manpack) receivers are being developed which can be easily transported and installed with the data logger.

The question of availability of the system must be addressed. Use of the system following its construction was discussed with IOS and no conflicts are expected during the period of this contract. However, assuming the system proves to yield scientifically useful data, we plan to include it in as many experiments as possible over the next several years. Therefore, it is important that we have a system available at Woods Hole. Experience in the construction of the first towed body at IOS has revealed many improvements and simplifications that can be incorporated to reduce costs, improve low speed performance, and make it more portable.

In many applications aboard research ships, the immediate display of surface current vectors will guide the tactical decisions of the investigator. Therefore, it is essential that some means of providing this capability be developed. The calculations required are relatively complex and need rather sophisticated computing power to solve, but a full scale computer, in addition to being expensive, greatly complicates the logistics associated with using the system. However, by using one of the intelligent data terminals such as the Tektronix 4051 or Hewlett Packard 9845, a relatively inexpensive, portable current vector calculation and display system can be constructed. In the future the system may also include automatic logging of meterological data, XBT's, and any other data of related interest.

PROPOSED PROGRAM

During the period covered by this contract, the main thrust of the program will be the continued development and refinement of the system to make it more useful to the scientific community, and to include it as an integral part of at least two field experiments. The specific points are as follows:

(1) Construct a second fish body in order that one complete system can remain in Woods Hole.

(2) Provide a capability for real time display of surface currents. This must be an interactive process due to the number of variables involved in each situation, i.e., change of fish position relative to the ship, magnetic field deviations due to geographical location, changing sampling and averaging periods, error correction, etc.

(3) Build deck handling gear to simplify shipping, deployment, and towing.

(4) Participate in at least two field tests during the summer and fall of 1979 and begin preparations for a third experiment during 1980.

(a) Dr. H. Stommel is conducting studies in the mid-Atlantic between Woods Hole and Las Palmas aboard R/V ATLANTIS II during May 1979, and we propose to participate.

(b) Dr. R. Watts, University of Rhode Island, and Dr. Richard Garvine, University of Delaware, are planning to study Gulf Stream dynamics near the U.S. East Coast during October 1979 and are very interested in using the system to map the stream position in conjunction with XBT surveys in the area. We propose to participate with one or both of the investigators.

(c) Preparations for a study of warm rings in the North Atlantic are presently under way, and it has been requested that we participate.

In addition, any other available opportunities for field use that do not conflict with these cruises or equipment repair and development will be considered. A chance to use the system with the new hull mounted doppler acoustic systems would be most welcome.

(5) If possible, borrow a NAVSTAR GPS navigation receiver for evaluation on the ATLANTIS II cruise discussed in (4a). Much of the work on this cruise will be in areas having weak current signals and the continuous coverage (at least over part of the day) and improved accuracy will greatly enhance the data.

WHOI Proposal #1224

MEASUREMENT OF OCEAN SURFACE CURRENT
USING A TOWED LOG

1 January 1979 - 31 December 1979

		ONR Man Mos.	Actual Man Mos.
Professionals:			
D.C. Webb, Principal Investigator		.5	.5
D.S. Bitterman, Research Associate		12.0	12.0
Support Personnel:			
G.C. Chaplin, Research Assistant		6.0	6.0
K.M. Pires, Secretary		1.0	1.0
A.	1. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay, etc. of $3,495, which is accounted for as employee benefits)	$30,509	
	2. Cruise Leave, Sea Duty Vacation and Overtime (including premium pay of $ -0-)	1,749	
	TOTAL		$32,258
B.	Other Employee Benefits		8,585
C.	TOTAL SALARIES AND BENEFITS		$40,843
D.	PERMANENT EQUIPMENT		
	1. Handling gear	$1,000	
	2. Fish body and cable	4,000	
	3. Tektronics 4051 graphic terminal with RS232 interface	7,945	
	4. Modifications to data logger	1,000	13,945
E.	EXPENDABLE SUPPLIES AND EQUIPMENT		
	1. Tapes (40 @ $20 ea)	800	
	2. Misc. electronics parts and spares	1,000	1,800
F.	TRAVEL		
	1. Domestic: 1 RT, W.H. - Newark, Del.	176	
	1 Rental Car	70	
	3 days travel expenses @ $40	120	
	2. International: One-way, Las Palmas - W.H.	449	
	1 Rental Car	35	
	2 days travel expenses @ $27	54	904
G.	PUBLICATION COSTS (38.46 hrs @ $13/hr)		500
H.	COMPUTER COSTS		
	1. Hewlett Packard (48 hrs @ $25)		1,200
I.	MISCELLANEOUS		
	1. Shop Services (100 hrs @ $13.00)	$1,300	
	2. Shipping		
	a. 1 RT, Newark, Del.	552	
	b. 1 Way, Las Palmas	722	
	3. Communications	200	
	4. Xerox charges	100	
	5. Laboratory Overhead (21% of C, exclusive of premium pay)	8,577	11,451
J.	TOTAL DIRECT COSTS		$70,643
K.	INDIRECT COSTS @ 15%		10,596
L.	TOTAL DIRECT AND INDIRECT COSTS		$81,239

Velocity Structure in the High Energy Benthic Boundary Layer

Albert J. Williams 3rd
PII Redacted (617) 548-1400, Ext. 456 [redacted]

ABSTRACT

The effect of deep sea boundary layer flows on sediment movement will be studied in an experimental program named HEBBLE. The study will focus on the high energy regime, probably the Western Boundary Undercurrent on the Nova Scotian Rise. Sediment properties, nepheloid layers, density stratification, bedforms, currents, and turbulence will be monitored and studied in the context of a carefully surveyed site. My interest is the structure of the flow field in the turbulent benthic boundary layer, and I have developed an instrument called BASS (Benthic Acoustic Stress Sensor) that measures the three dimensional vector average of the current over a 15 cm volume at 4 heights from 25 cm to 200 cm every 750 ms. This measurement permits the calculation of velocity fluctuation cross products which when averaged over periods longer than 5 minutes tend toward stationary values (in the conditions studied) proportional to Reynolds stress, the momentum transport normal to the wall in turbulent flows. Three 8-hour deep sea deployments have been made and longer term measurements are planned.

LONG RANGE OBJECTIVES

Turbulent boundary layer flows in the deep sea interact with the sea-floor to suspend and transport sediment; create bedforms such as craig and tail formations, ripples, and furrows; and move heat and dissolved materials as well as momentum to and from the bottom. The roughness of the sediment interface in turn affects the turbulent character of the flow. Very little is known yet about the flow within the logarithmic boundary layer of the deep sea, and even models and laboratory simulations of the benthic boundary layer are suspect because they don't extend to high enough Reynolds number and don't represent rough unbounded flows. It has long been thought that deep sea flows are incapable of eroding cohesive sediments and depositing them thousands of kilometers downstream, but there is increasing evidence that this does indeed occur; evidence from photographs of erosional features, near bottom turbidity, extended horizontal nephloid layers, and now high velocity currents measured in the logarithmic layer.

I have developed an interest in benthic boundary layer processes, particularly the effect of sediment bedforms on the turbulent velocity structure in the flow and the implied mixing of the boundary flow and the shear stresses it imposes on the sediment. This interest started with the development of instrumentation to measure these turbulent flows and extends to understanding the processes through a benthic boundary layer experimental program. I have long been interested in oceanic mixing driven by small scale processes, and I have a continuing interest in microstructure and mixing in the thermocline (see adjoining proposal), but the necessity to measure and describe velocity-shear induced mixing in the thermocline drew me into the benthic boundary layer problem where important processes of a relatively pure velocity-shear type occur. In the context of this proposal, my long range objective is to understand these processes in a high energy regime, that is, in a sufficiently strong current that bedforms are created and sediment is moved. I also have a strong interest in near bottom mixing where sediment is not moved, and I am a participant in the Low Energy Benthic Boundary Layer Experiment as well as in HEBBLE.

PRESENT STATUS AND PROGRESS IN 1978

I will report on the status of HEBBLE as well as my own part in the project. The High Energy Benthic Boundary Layer Experiment developed out of a series of conferences starting with the NATO conference on the Benthic Boundary Layer in Les Arcs, France, in 1975; continuing with an ONR meeting in Boston in 1976; an ONR sponsored meeting in Bay St. Louis in 1977; and finally an ONR sponsored conference in Keystone, Colorado, in March 1978. In Bay St. Louis, a distinction was drawn between the low energy regime in which chemistry and biology would dominate the dynamics and the high energy regime in which sediment movement would be more important. A weekly working seminar at WHOI, started in late 1976 by Robert Frosch, has explored the interdisciplinary interactions in the BBL in its most general case and provided an informed basis for some of the further discussions, particularly the division of the study into the simplified low energy and high energy regimes. From this position, the Keystone Conference was held early this year.

HEBBLE Conference 1978

Participants at the conference were selected nationally from those researchers studying various aspects of the benthic boundary layer who might contribute expertise in the design of a high energy BBL experiment, whether they were personally interested in the experiment or not. A report was produced treating the spatial and temporal aspects of high energy BBL processes; and outlining an experimental scenario for an experiment starting with site selection, proceeding through in situ experiments with recovered samples for laboratory flume work, to a three-day intensive in situ fluid study, and concluding with a six-month deployment of fixed and profiling arrays. Disciplinary sub-groups reported on our present understanding of currents and turbulence, nephelometry, bed morphology, and biological/bed interactions and recommended procedures for observing important processes in HEBBLE. Finally, discussion was directed toward engineering implementation of HEBBLE and management of that implementation. The original conference leaders, Hollister and McCave, now have been joined by Wimbush and me as an ad hoc HEBBLE committee to coordinate further activities and keep things moving.

In defining the engineering requirements of the six-month fixed and profiling arrays, it became clear that a level of complexity and interaction between individual experiments would be reached that is uncommon in oceanography, and we might lack experience and manpower in our own institutions to deal with these problems effectively. Accordingly, McCave, Hollister, and I have talked with people at the Jet Propulsion Laboratory about collaboration on a seafloor lander. Originally the expertise JPL has in image processing and data handling came to our attention, and this expertise has now been confirmed. In addition, we have become aware of their expertise in scientific system management and their interest in applying their skill at developing autonomous, "smart", landers for oceanic applications. This interest extends from Jim Edberg, Ocean Technology Manager; through Bruce Murray, Director of JPL; to Robert Frosch, Administrator of NASA. In the next year we will develop a plan for an efficiently managed project that could develop and produce instrumentation for and handle data from a HEBBLE. This plan development will be funded partly by JPL, and we wish to support our end of the interaction through ONR.

At the Keystone Conference it was discovered that site selection was in a more primitive state than we had thought. This year we have started a more vigorous site selection program. ENDEAVOR 23 studied the North Bermuda Rise and the Gulf Stream Outer Ridge with cores, hydrostation, camera, and BASS (my current meter array named Benthic Acoustic Stress Sensor). MELVILLE with Deep Tow will study the North Bermuda Rise in August. This will provide the detailed site survey of one location. In 1979, we intend to start surveying the Nova Scotian Rise. Topographically, this site appears simple, but detailed bathymetry and hydrography are unavailable. An AII cruise in May will survey 50,000 square miles, taking cores, hydrographic stations, bottom photographs, and deploying BASS for several 8-hour intervals, and Wimbush's camera current meter array for the summer. A mop-up operation of bathymetry, cores, hydrographic and camera stations is planned for the fall from CONRAD including recovery of the Wimbush lander. A more detailed survey of the Nova Scotian Rise is planned for 1980 in which 50 square miles will be surveyed with close tracks, and individual instruments will be placed on the bottom for testing and for spot measurements. One such spot measurement will be the erodibility of the sediment as measured by a lowered seaflume. At the conclusion of this phase of the survey, the North Bermuda Rise, the Blake Bahama Outer Ridge, and the Nova Scotian Rise will have been surveyed adequately enough to choose the HEBBLE site from among them. If the Nova Scotian Rise remains simple upon closer scrutiny and has a strong flow in the Western Boundary Undercurrent, it will be the site chosen.

Detailed site selection will follow a Deep Tow survey in 1981. On this cruise, a three-day fluids experiment will be deployed several times to test the instrumentation and hone the experiment. Samples of bottom will be recovered for laboratory flume studies and biological study as well. If the Nova Scotian Rise is rejected as a site, either the Blake Bahama Outer Ridge or the North Bermuda Rise will be the target of this last survey phase.

Our planning for HEBBLE has included development plans for the six-month profiling and fixed arrays. These arrays will monitor the bottom 300 meters of the water column, the bottom 2 meters of the water, and the top few centimeters of the sediment, respectively. It is principally the development of these arrays that we wish to get JPL to undertake. My own estimate is that these arrays could be ready for deployment in 1983 if we start planning our collaboration now. The arrays are described in the HEBBLE Report (WHOI-78-48). Briefly the profiler will be a CTD with nephelometer and camera. The fixed array will contain current meters, nephelometers, TV imaging equipment, stereo-cameras, upward and downward looking acoustic backscatter systems, and sediment property monitors. The arrays will process data *in situ* to compress them for long duration recording and will recognize events and change sample programs accordingly.

BASS 1978

Progress has been made in my own involvement in HEBBLE in the past year as well. A trial experiment with BASS in Vineyard Sound (Tochko Thesis, WHOI/MIT 1978, supported by NSF) validated the BASS instrumentation, showed the suitability of the data for calculation of Reynolds stress, and highlighted the value of multilevel stress measurements over natural bottoms. Local topography makes single level Reynolds stress measurements doubtful. A zero point uncertainty in this experiment which required an artifical correction (based on diver observations of BASS orientation) was corrected in a January experiment on sandwaves in Vineyard Sound (Briggs & Williams, AGU 1978). Plastic bags were placed over the sensors for the first 10 minutes of the deployment to provide an *in situ* zero. The bags were pulled off from the surface to start the measurement period. Again the multiple scale height of the flow in response to the rough bottom was observed.

A deep deployable and recoverable BASS was built in the winter using an acoustic current meter sensor tower that was free from disturbance from all directions for 2 meters above the bottom. An expendable support tripod was to be jettisoned to terminate the deployment after which the sensors and electronics would float to the surface, acoustically tracked. This was deployed three times in June on ENDEAVOR 23. The first deployment in 4700 meters in an erosional feature of the North Bermuda Rise showed a steady current of 60 cm/sec at 2 meters. The second in 4400 meters in a depositional region on top of the Rise showed only 12 cm/sec at 2 meters. A third deployment at 4900 meters on the Gulf Stream Outer Ridge in an erosional region showed 30 cm/sec at 2 meters. The Reynolds stresses will be computed in the next months from these digital records.

PROGRAM FOR 1979

BASS 1979

My own program involves observation and analysis of deep boundary layer flows and further development of the BASS instrumentation for longer duration measurements. The first sets of BASS data were analyzed on the HP 2100 computer. While the level of personal involvement that this required was reasonable during program development, we don't have enough manpower to continue this way for each successive deployment. An analysis package is now being prepared for our Sigma 7 computer. By the end of the year we will be able to print out 15-minute mean quantities such as magnitude and direction of the current at each sensor, Reynolds stress at each sensor, turbulent energy along each axis, and any covariance of interest over the 15-minute interval. Next year we would like to extend our analysis program to include display of instantaneous derived quantities such as the uw product. The point of such display capability is that boundary layer flows, like so many phenomena controlled by small scale processes, are event dominated. Although we hope and expect to be able to treat the flow statistically, we must also understand the events that produce the shear stresses and turbulent mixing. The flow is actually more structured than the statistical description would lead one to believe. Flow visualization points this out in a qualitative way, but it is also possible to recognize events in a time series and analyze their contributions individually.

I presently have three deep sea records awaiting detailed analysis. I propose obtaining more records from the Western Boundary Undercurrent off the Nova Scotian Rise in 1979 on the AII cruise in May. These will be spot measurements (6-hour deployment) and will be unsupported by topographic survey or even photographs of the bottom. However, they will show the flow field in the bottom two meters and will further test BASS.

These deep sea measurements are backed up by a modest test program in the flume/tow tank at WHOI and by shallow water tests with diver observation and manipulation. These tests are designed to verify sensor interchangeability sensitivity to fluctuations, and zero point drift and offset.

In preparation for further HEBBLE work, combinations of instruments must be assembled and tested. In 1979, it is proposed that Orr's moored acoustic backscatter system, Wimbush's time lapse movie camera, and my acoustic current meters be combined on my BASS tripod for shallow and deep water tests. The test will be on Orr's OCEANUS cruise July 8-18, 1979, in the vicinity of Hudson Canyon.

Two shallow tests on the shelf near the head of the canyon and a deep deployment on the rise in the Western Boundary Undercurrent northeast of the canyon are planned. On the shelf, internal tides are expected to suspend sediment by generating internal wave packets. These will provide a short term test for our instrument ensemble. Orr in his proposal has described surface measurements which will support the bottom observations. The deep deployment will be another measurement in the Western Boundary Undercurrent but will include bottom photographs and suspended sediment profiles from the same site. These measurements will be analyzed as BBL velocity profiles and Reynolds stress measurements as well as instrument tests.

BASS development to enable three-month or longer deployment times is desirable. The BASS system is presently limited in duration to 8 hours of recording. The principal limit is tape and the secondary limit is battery power. Extension of the measurement duration can be accomplished by in situ processing of the BASS measurements before recording. Experience now indicates the most effective compression involves bulk averages of 5 to 15 minute blocks. Means, Reynolds stresses, and turbulent kinetic energies for each block at each sensor become stationary for blocks longer than this. Thus a small suite of values each 10 minutes represents most of the information presently extracted from the record with a data compression factor of 1000. This alone would allow a recording interval of almost a year. However, power constraints prevent such long, continuous operation and a better compromise involves alternate periods of direct recording and spot bulk samples over a duration of up to two months. This extension is possible with microprocessor control and in 1979 such a system will be used in place of the present sequential sampling control board.

HEBBLE Conference 1979

The other activities for which I seek support in 1979 are related to the management of HEBBLE. In March we will have completed analysis of the North Bermuda Rise site survey including Deep Tow. These results should be discussed with the principal investigators of HEBBLE. Planning with JPL will have presumably progressed to the point where firmer specifications for instrumentation can be made. The P.I.'s concerned with instrumentation should discuss these specifications. In general, communication among the HEBBLE participants is to be fostered. Thus, we propose to hold a second Keystone Conference in March. We seek ONR sponsorship of this conference.

The conference shall serve three functions: First, it shall be the source of scientific direction by the participants of HEBBLE. The P.I.'s will share their observations in planning the experiment. Second, it shall provide a forum for technical decision-making by P.I.'s involved in the measurement program. Third, it shall be an opportunity for an advisory group of non-P.I.'s to review our progress and plans and provide advice.

Finally, I am requesting additional support of 1 month for myself and several trips to JPL in Pasadena for JPL/HEBBLE planning.

WHOI Proposal #1224

VELOCITY STRUCTURE
Budget
1 January 1979 - 31 December 1979

Professionals:		ONR Man Mos.	Actual Man Mos.
A.J. Williams 3rd, Principal Investigator		3	3
Support Personnel:			
W.E. Terry, Research Assistant		2	2
A.W. Morton, Sr. Research Assistant		2	2
K.M. Pires, Secretary		1	1
A. 1. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay, etc. of $1143 which is accounted for as employee benefits)			$12,709
2. Cruise Leave, Sea Duty Vacation and Overtime (including premium pay of $655)			2,083
TOTAL			$14,792
B. Other Employee Benefits			4,590
C. TOTAL SALARIES AND BENEFITS			$19,382
D. PERMANENT EQUIPMENT			
1. HP 1600A Logic Analyzer			4,500
E. EXPENDABLE SUPPLIES (see attached)			5,000
F. TRAVEL			
1. Domestic:	1 RT Bay St. Louis, MO	$249	
	1 car rental	70	
	3 days travel expenses @ $44/da	132	
	2 RT Pasadena, CA	$506	
	2 car rentals	140	
	4 days travel expenses @ $40/da	160	1,257
G. PUBLICATION COSTS			
1. Graphic Services, 77 hrs. @ $13/hr.			1,001
H. COMPUTER COSTS			
1. Sigma 7 (25 hrs @ $155/hr)			3,875
I. SHIP COSTS			
1. 5 days OCEANUS @ $3433/day		$17,165	
2. Shipboard computer tech		2,460	19,625
J. MISCELLANEOUS			
1. Shop Services (100 hrs @ $13/hr)		$1,300	
2. Programming (240 hr @ $19.60/hr)		4,704	
3. Communication		500	
4. Xerox charges		50	
5. Laboratory Overhead (21% of C exclusive of premium pay)		3,933	10,487
K. TOTAL DIRECT COSTS			$65,127
L. INDIRECT COSTS @ 15% G&A			9,769
M. TOTAL DIRECT AND INDIRECT COSTS			$74,896

VELOCITY STRUCTURE - Expendable Supplies

Misc. stockroom items	$330
Cassette case & box	22
Stepping motor	66
Stainless steel lengths	77
CMOS RAM & EPROMS (hardware)	2,651
Integrated circuits	220
RCA S2600D (hardware)	64
Piezoelectric crystals	1,100
PC boards	152
Nicad cells	103
Disc cartridges	215
TOTAL	$5,000

WHOI Proposal #1224

VELOCITY STRUCTURE

Supplementary Budget

1 January 1979 - 31 December 1979

Professionals:	ONR Man Mos.	Actual Man Mos.
A.J. Williams 3rd, Principal Investigator	1	1
Support Personnel:		
K.M. Pires, Secretary	1	1

A. 1. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay, etc. of $372 which is accounted for as employee benefits)		$3,095
B. Other Employee Benefits		772
C. TOTAL SALARIES AND BENEFITS		$3,867
D. TRAVEL		
1. Domestic: 1 RT Keystone, Colorado	$370	
1 Rental car	70	
2 RT Pasadena, CA	$560	
2 Rental cars	140	
14 days travel exp. @ $40/da	560	1,700
E. MISCELLANEOUS		
1. Laboratory Overhead (21% of C)		812
F. TOTAL DIRECT COSTS		$6,379
G. INDIRECT COSTS @ 15% G&A		957
H. TOTAL DIRECT AND INDIRECT COSTS		$7,336

Salt Fingers, Mixing, and Microstructure

Albert J. Williams 3rd

PII Redacted (617) 548-1400, Ext. 456 [redacted]

ABSTRACT

Mixing in the ocean interior occurs by stirring at finer and finer scales until molecular diffusion erases the temperature and salinity differences between the component fluids. The processes that allow mixing to occur may draw energy from the internal wave field through velocity shear instability or may depend on the gravitational potential of the vertical distribution of salt. The former leads to turbulent mixing producing isotropic microstructure while the latter leads to double diffusive convection producing vertically aligned microstructure. The role of salt-finger type double diffusive convection in mixing the North Atlantic Central Water into the Subtropical Underwater in the BOMEX staircase region will be studied with an XBT survey and SCIMP (Self-Contained Imaging Micro Profiler) profiles in 1979.

LONG RANGE OBJECTIVES

I wish to portray the small scale mixing processes in the ocean interior and describe the relative importance of each in various situations. My interest is less in knowing the total mixing rate in the thermocline than in knowing what microstructure is produced by the mixing process. I am particularly interested in the relative roles of double diffusion and velocity shear in various environments.

The central element in my observation program is an instrument that photographs optical inhomogenieties in the water while sinking slowly. It records the output of a CTD and a velocity shearmeter as well. The vehicle is ballasted to be slightly negative in buoyancy and this condition is maintained by acoustic commands from the surface which cause heavy or light fluid to be jettisoned. This instrument is called SCIMP for Self-Contained Imaging Micro Profiler.

The optical system is a horizontal shadowgraph of 2 cm, 5 cm, or 15 cm aperture and 180 cm path length in water. The weak inhomogenieties in the thermocline refract light only slightly and the optimum position of the viewing screen for such a shadowgraph system is 10 meters or more back from the object. This is accomplished by optical compression within the imaging system. The most suitable effective screen distance (focal length of the strongest microstructures) has been 20 meters. The screen is photographed to produce a time lapse movie of the profile. Although each frame represents a different position of the profiler, the more subtle features are made visible to the viewer by the movie display.

A summary of the observations made with SCIMP follows: Salt fingers were observed in the Mediterranean outflow on a large discontinuity in temperature and salinity, salt fingers and more chaotic structures were observed on each interface of a staircase in the Mediterranean outflow, very weak salt fingers were observed in the thick interfaces between the giant steps of the Tyrrhenian Sea thermohaline staircase, chaotic structures were observed near the surface in the Caribbean south of Puerto Rico, chaotic structures were observed at the slope front off the New England shelf, chaotic structures and convective structures were observed in the contact region between intrusions in the Gulf Stream front, chaotic structures and some salt fingering were observed in the outer region of both warm and cold core Gulf Stream rings.

The interpretation of these structures is sometimes clear and sometimes uncertain. Where warm, salty water overlies cooler, fresher water, there is the possibility of salt finger convection. Counter flowing columns of water exchange heat laterally while transporting heat and salt downward. These fingers grow rapidly and are inevitable (given temperature and salinity distributions in the temperate and tropic Atlantic thermocline) unless inhibited by velocity shear. Even with steady shear the fingers do not entirely disappear but rather orient into sheets aligned with the shear. Changes in shear associated with internal waves should not suppress salt fingers because they grow rapidly compared to the BV period in the regions of interest. Laboratory experiments and models provide a relatively clear picture of the salt finger interface. It is composed of tall narrow fingers or sheets which appear optically as vertical bands given correct alignment between the fingers and the optic axis.

The height of the fingers or sheets is limited by convective instability and a relatively thick layer, 10 to 100 meters thick, is mixed by the buoyancy fluxes at the boundary interfaces. A stack of layers and interfaces is termed a staircase. This seems to be the preferred arrangement away from fronts. The clearest staircases have been observed in the Mediterranean outflow, Tyrrhenian Sea, and the BOMEX area. My observations in the first two areas have shown the vertical bands expected of fingering interfaces where they should occur.

At interfaces associated with frontal intrusions the Richardson number is frequently less than 1 (and frequently less than 1/4 over 2 meter intervals). At such interfaces the images show chaotic structure and this result is also clear. When the shear exceeds a critical value determined by the gravitational stability of an interface ($R_i < 1/4$), the interface becomes unstable and turbulent mixing results. In the early stages of shear instability there may be coherent rolls which then break into jets and blobs of detached fluid. At this stage, gravitational forces are small compared to inertial and viscous forces, thus there is little or no gravitational orientation of the refractive structures. In the edge of Gulf Stream Rings, such images may occupy 1/4 of the water column in the top 200 meters.

When two fluids, differing in both temperature and salinity mix, double diffusion causes temperature difference to dissipate faster than salinity difference. Thus, where the temperature and salinity differences have the same sign, it is possible to generate fluid both more dense and less dense than either fluid was before mixing. This is the source of buoyancy flux in salt fingering and in the diffusive interfaces observed in the Arctic. It appears to occur as well in certain cases of turbulent mixing. The signature of such a process should be vertically aligned plumes of optically inhomogeneous fluid outside the active mixing region. Such vertical structure has been observed in the frontal intrusions of the Gulf Stream. The implication here is that shear induced mixing has progressed to the point where temperature differences have been attenuated but not so far that salinity differences have been reduced much. Then mixing has slowed so that the fluid can restratify whereupon the warm, fresh fluid moves upward while the cold, salty fluid sinks. This scenario is compatible with transient shear mixing. Since the diffusion of momentum is the fastest of the three - momentum, heat, and salt - the motion will slow before the salt has diffused.

PROGRAM FOR 1979

Ray Schmitt, a WHOI postdoctoral fellow, and I wish to observe the thermohaline staircase of the BOMEX area to assess the role of salt fingering in mixing of North Atlantic Central Water with Subtropical Underwater. A scientific and an applied result is expected from this research. The scientific result is the estimate of vertical mixing in the thermocline which can then be compared to frontal mixing and advection in the open ocean to balance the flux of heat into and water out of the surface. The measurements required for estimates of vertical mixing are temperature and salinity difference, thickness of layers and interfaces, aerial extent of staircase, dimensions of fingers or sheets, and shear across interfaces. These will be obtained with SCIMP profiles and an XBT survey. A five working-day cruise (two days' transit) in the BOMEX area is planned for the spring aboard OCEANUS or ENDEAVOR.

The applied result of the study of the BOMEX staircase will be an increased understanding of the role of salt flux in generating finestructure. With a fast vessel of the OCEANUS class, a nearly synoptic survey of the staircase (200-600 m) is possible over a 1° square. The operational plan will be: Day 1, steam from Barbados to 11°N, 56°W; Days 2-6, survey 1° square on 15 mile track spacing with SCIMP station every 12 hours and XBT every 1/2 hour; Day 7, steam back to Barbados. This will allow two complete surveys to be made of the 1° square, depicting horizontal extent, and horizontal gradient within layers of the staircase structures. The goal of this aspect of the study is the determination of conditions permitting or inhibiting staircase finestructure.

WHOI Proposal #1224

SALT FINGERS
Budget
1 January 1979 - 31 December 1979

Professionals:	ONR Man Mos.	Actual Man Mos.
A.J. Williams 3rd, Principal Investigator	3	3
Support Personnel:		
R. Schmitt, Postdoctoral	3	3
A. Morton, Sr. Research Asst.	2	2
K. Pires, Secretary	1	1

A. 1. Gross Regular Salaries (includes allowance for vacations, holidays, sick pay, etc. of $1,578 which is accounted for as employee benefits)		$14,034
2. Cruise Leave, Sea Duty Vacation and Overtime (including premium pay of $363)		1,155
TOTAL		$15,189
B. Other Employee Benefits		4,139
C. TOTAL SALARIES AND BENEFITS		$19,328
D. EXPENDABLE SUPPLIES AND EQUIPMENT		
1. 150 XBT's, Model T4 @ $30.47 ea	$4,571	
2. Miscellaneous supplies (see attached)	2,000	6,571
E. TRAVEL		
1. International: 3 RT Barbados	1,689	
1 car rental	70	
6 days travel expenses @ $46/day	276	2,035
F. PUBLICATION COSTS		
1. Graphic Services, 77 hrs. @ $13/hr		1,001
G. COMPUTER COSTS		
1. Sigma 7 (25 hrs @ $155/hr)		3,875
H. SHIP COSTS		
1. 7 days OCEANUS @ $3433/day		24,031
I. MISCELLANEOUS		
1. Shop Services (60 hrs @ $13/hr)	780	
2. Programming (240 hr @ $19.60/hr)	4,704	
3. Shipping & Communication		
a. Shipping (air ship one way Barbados, 3000 lb @ 56¢/lb)	1,680	
b. Communications	500	
4. Xerox charges	50	
5. Laboratory Overhead (21% of C, exclusive of premium pay)	3,983	11,697
J. TOTAL DIRECT COSTS		$68,538
K. INDIRECT COSTS @ 15% G&A		10,281
L. TOTAL DIRECT AND INDIRECT COSTS		$78,819

V. PHYSICAL OCEANOGRAPHY

PHYSICAL OCEANOGRAPHY

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PHYSICAL OCEANOGRAPHY

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INTRODUCTION

This year's proposal in physical oceanography demonstrates a trend in the department towards the study of the large-scale permanent ocean circulation. While this trend is probably a healthy one, we are glad to have the meso- and micro-scales so ably represented by Dr. Sanford.

Dr. McCartney's work will be directed to the northern North Atlantic. His studies suggest that the main feature of the general circulation in this region is a cyclonic gyre composed of a family of mixed layers that gradually deepen as they move northward past Ireland and Scotland, westward past Iceland, and southward past Greenland towards the Labrador Sea. During this passage the mixed layers cool from 13° to 3.5°C in response to the strong net negative heat flux. Dr. McCartney (with a student) is also conducting model studies of the deepening of the mixed layer south of the Gulf Stream and its effect on the depth of the main thermocline.

In 1979 Mr. Bruce has the opportunity to extend his work on the circulation off East Africa farther eastward toward the interior of the Indian Ocean. He proposes a cruise aboard U.S.N.S. Wilkes which will greatly amplify his studies of the Somali eddies that are stimulated each year by the southwest monsoon. By the nature of ship routing, his work with XBTs from oil tankers (which will continue) has been unable to define the eastern and northern limits of these eddies. He will also take XBT measurements from an Italian ship that will be traversing his area of interest as a part of FGGE. Mr. Bruce's work should make a substantial contribution to the FGGE experiment.

Dr. Sanford has perfected a unique new instrument, the expendable free-fall temperature and velocity profiler (XTVP). He has deployed one hundred of these profilers in the Local Dynamics Experiment of POLYMODE. His work in 1979 will focus on the analysis of these profile data and on the small-scale currents excited by a seamount during this experiment. He will also analyse current shear measurements taken during the Fine- and Microstructure Experiment (FAME).

Dr. Richardson will continue to study cyclonic Gulf Stream Rings using satellite imagery, free-drifting buoys and subsurface data from CTDs and XBTs. (His proposal will be found in a separate interdisciplinary section). He is also beginning to direct his efforts towards the general circulation of the western North Atlantic. He has arranged for the International Ice Patrol to launch free-drifting buoys in the Slope Water Current south of the Grand Banks, an area where there is little certain knowledge of the circulation.

Dr. Warren will continue his fundamental researches into the paths of the deep water flow in the Indian Ocean. He expects to publish the results of his section across that ocean at 18°S, and he will lead a cruise that should establish the sources of the deep water in the Central Indian Basin. Dr. Warren and his Canadian and English colleagues have written a paper that vigorously contests the "two-gyre" hypothesis of Mr. Worthington. In this paper it is concluded that the greater part of the Gulf Stream (about 60%) flows continuously around the southeast extension of the Grand Banks and returns southward in the central and eastern North Atlantic.

Mr. Worthington will attempt to respond to Dr. Warren and his colleagues in the matter of the Gulf Stream branching. Two long-term projects should be ready for publication in 1979. First, the energy exchanges for the Atlantic and Indian Oceans have been calculated, a work for which Mr. Bunker must take virtually all the credit. Second, the world water mass census (with C. G. Day and R. L. Barbour) has been completed. Mr. Worthington also proposes to initiate a field program to investigate changes in the Gulf Stream volume transport.

In addition to these proposals, there are two reports from investigators who are not seeking support for 1979. Dr. Voorhis has summarized his work on the very energetic oceanic fronts in the Subtropical Convergence region. He will be at the University of Delaware as a Visiting Professor from September 1978 through August 1979. He will propose new work when he returns to Woods Hole. Dr. Katz has described his work on the joint Woods Hole - Scripps acoustic experiment off San Diego. He has also submitted a comprehensive paper on his pioneering work with towed sensors.

Physical Oceanography
Departmental Budget Summary
12 months period
1 January - 31 December 1979

				Total
A.	SALARIES			$226,788
B.	OTHER EMPLOYEE BENEFITS			65,853
	TOTAL SALARIES AND BENEFITS			292,641
C.	PERMANENT EQUIPMENT			2,019
D.	EXPENDABLE SUPPLIES AND EQUIPMENT			46,253
E.	TRAVEL	1. Domestic	$ 7,028	
		2. Foreign	48,383	55,411
F.	PUBLICATION COSTS	1. Graphic Services	4,810	
		2. Page Charges	5,120	
		3. Reprint Charges	560	10,490
G.	SHIP COSTS	1. Medium	27,464	
		2. Computer Technician	3,936	31,400
H.	COMPUTER	1. Sigma 7	40,145	
		2. H.P.	2,000	42,145
I.	MISCELLANEOUS	1. Shop Services	3,055	
		2. Programming	2,548	
		3. Shipping, Communications, and Postage	37,940	
		4. Laboratory Overhead	60,657	
		5. Xerox Charges	700	
		6. Other	30,055	134,955
J.	TOTAL DIRECT COSTS			615,314
K.	INDIRECT COSTS @ 15%			92,297
L.	TOTAL COSTS			$707,611

1. PYCNOSTADAL ANALYSES OF THE UPPER WATER MASSES AND CIRCULATION OF THE WORLD'S OCEANS

Michael S. McCartney

(617) 548-1400, ext. 530

Abstract

Distributions of pycnostads in the North Atlantic have revealed a family of subarctic mode waters. The patterns suggest a cyclonically turning circulation, with the modes being progressively cooled along the cyclonic path. The associated temperatures range from 13°C east of Newfoundland through 10°C west of Ireland, 7°C south of Iceland, 4° in the Irminger Sea, to 3.3° in the central Labrador sea. This final mode is identical to Labrador Sea water, and is traced as a pycnostad east and south from the Labrador Sea.

Proposed studies will complete the documentation of this distribution, and continue interpretation of its significance. Weather ship hydrographic data will be examined for year-to-year and seasonal signals. The cyclonic transport amplitudes will be estimated. Mode water formation and circulation interaction process modeling will be begun.

Long-Range Scientific Objectives

The principal investigator plans to study the circulation of the upper 1500 meters of the world's subtropical and subpolar gyres. The main data analysis technique will be pycnostadal analysis. The goal is to deduce source regions for the dominant modes of the main thermocline waters. Theoretical studies of the formation process and circulation dynamics will be undertaken.

a. Background for the Project

Each of the world oceans' subtropical gyres is characterized by its own tightly defined temperature-salinity relation--the so-called central water mass relation. This relation is usually nearly linear, from higher temperatures and salinities to lower temperatures and salinities. The covariation is usually such that there is only a small density change compared to that which either the temperature or salinity change alone would give. The tightness of these relations presents physical oceanographers with difficulties in the interpretation of circulation, because only in unusual circumstances are anomalies from these relations large enough to allow deduction of circulation paths and sometimes intensities. Examples of such large anomalies are the influences of Mediterranean Water and South Atlantic Water on the North Atlantic circulation (Worthington, 1976). In general, such large anomalies are geographically external in origin, coming from either adjacent seas or neighboring gyres. Locally originating anomalies--caused by, say, air-sea interaction--are either too small to be detected above the noise level of the temperature-salinity relation, or are somehow quickly destroyed in the rapid recirculation within the gyre.

Another difficulty with understanding the central water mass relation is that all or some of the water types defining it seasonally outcrop within the gyres. Thus care must be exercised in using familiar assumptions such as the dominance of lateral mixing over vertical.

There is a property derived from temperature and salinity which does possess a useful dynamic signal for the central waters, even when there are no detectable temperature-salinity anomalies from the standard central water mass relation. This property is a layer thickness function. With 18° water (Worthington, 1959) for example, one recognizes its existence by the extraordinary thickness of the 17 - 18° and 18 - 19° layers compared to the warmer or colder layers. Thickest values are found immediately south of the Gulf Stream, which is known to be the formation region--the area where the 18° water outcrops in late winter. Thinnest values are found in the extreme southern side of the Sargasso Sea, where the 18° water thickness ceases to be extrordinary. An extraordinarily thick layer has been given the name thermostad by Seitz (1967), defined as the antonym of thermocline.

This distribution can be quantified by the use of a calculated thermostadal strength, the inverse temperature gradient $\Delta Z/\Delta T$. At the time of convective overturning, this property is infinite, whereas, for the Sargasso Sea, the background main thermocline value is about 40 or 50 meters/degree Celsius. There seems to be a systematic trend in the distribution of this property around the Sargasso Sea gyre, a region which has no systematic pattern in the main thermocline temperature-salinity relation.

The first application of this thermostadal analysis technique was made by McCartney (1977). He defined a subantarctic mode water family analogous to 18° water, but found north of the circumpolar subantarctic front. These waters are a major component of the southern hemisphere subtropical gyres' central waters.

b. Methods

The basic data analysis tool is a pycnostadal analysis program. This takes edited individual station data, develops a running three-point Lagrangian interpolation to the temperature-depth and salinity-depth data, then computes an interpolated density-depth profile. From this density-depth profile the inverse density gradient is calculated as a function of density. In practice, the output is the Brunt-Väisälä period as a function of potential density at density increments of .02‰, with listings of the associated interpolated potential temperature, salinity and depth.

The choice of a pycnostadal calculation instead of a thermostadal calculation was made to increase the general purpose nature of the program. In many areas of the world--in the polar frontal zones of the Antarctic and Arctic, and the Labrador Sea water of the North Atlantic, for example--there are inversions in temperature and/or salinity. A program incrementing temperature or salinity alone encounters difficulties in such a situation, and could, for example, indicate a thermostad where there also was a halocline. The best indicator of homogeneity is density. This has a natural relation to the convective overturning process which creates many of the water masses in question. The onset of vertical convection occurs not when either temperature or salinity alone inverts, but rather when the surface density increases to that of the level below.

Present Status and Program over the Past Month

The originating proposal for this project was funded as an acceleration to contract number N00014-74-C-0262, NR 083-004. The funds were not received until May, 1978, so as of this writing (June, 1978) there is little progress yet to report. The basic data set for the northern North Atlantic has been processed. A first look at this data has yielded some interesting preliminary results. Over most of the region east of 60°W and north of 40°N two separate pycnostads are found: a warmer one in the upper 1000 meters and a cooler one near 3.5°C that represents the Labrador Sea water. Figure 1 shows the potential temperature of the near surface pycnostad, the family of which forms what can be called a subarctic mode water family. The general pattern was anticipated on the basis of 12 late winter stations in last year's proposal. As much as possible in Figure 1, winter and early spring data have been used. These include the *Atlantis II* cruise of 1964 in the Newfoundland Basin, the *Hudson* cruises of 1966 and 1967 in the Labrador Basin, Irminger Sea and Denmark Straits, parts of the *Erika Dan* section along 53°30'N

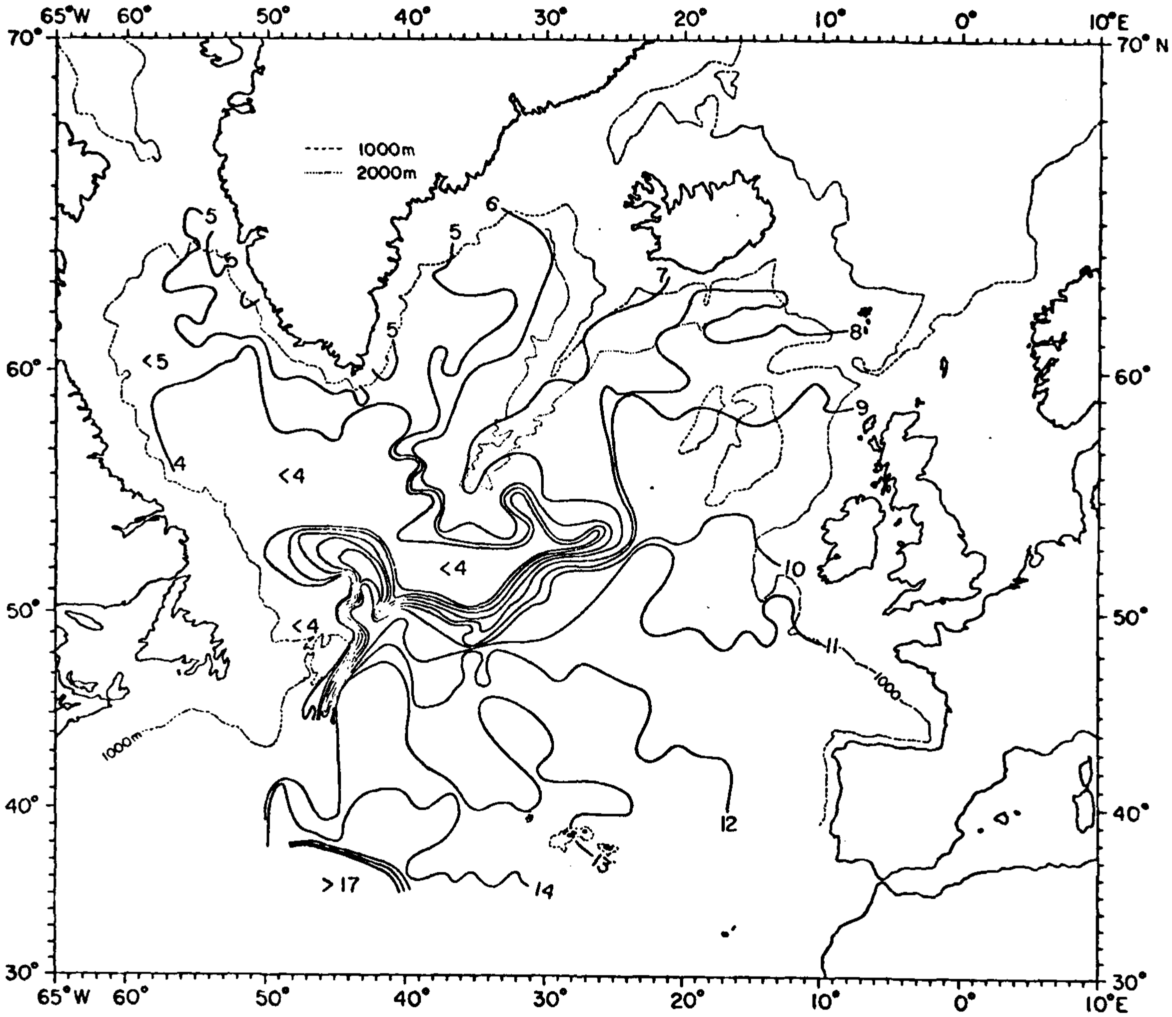

Figure 1. Temperature of the upper water pycnostad: the temperature at the depth of the maximum Brunt-Väisälä period.

and 59°30'N in 1962, Explorer data from the Iceland-Faroe-Shetland area in 1958, and part of the April 1958 Discovery II section from the Flemish Cap to the English Channel. These data have been augmented in the east by the other Discovery II data from later in the IGY, and by Labrador data in the Davis Straits from summer and fall 1965. The data editing and contouring is preliminary, since there has not been time to analyze it thoroughly yet.

The figure shows a cyclonic progression of modes, ranging from warmer than 14°C in the southwest, off the Tail of the Grand Banks, through 11°C off Spain, 9°C in the Rockall Channel, 4° to 6°C in the Irminger Sea, to less than 4°C in the Labrador Sea. This cold Labrador Sea water shows two spreading appendages, one to the south past the Flemish Cap off Newfoundland, the second to the east along 52°N towards the Gibbs Fracture Zone. This spreading will be further documented in a later figure.

Figure 2 shows the pycnostad strengths associated with the near-surface modes shown in Figure 1, expressed as the Brunt-Väisälä period. The hatched area is less than 50 minutes, the clear area is between 50 minutes and 100 minutes, and the cross-hatched area has periods greater than 100 minutes--i.e., is the most homogeneous. High strengths are found in the southwest associated with the 12 - 14°C mode water in the area of Worthington's "northern gyre." As a whole, the strengths decrease to the east towards the Bay of Biscay, then increase from there north around the cyclonically turning sequence. Thus a "tongue" of high strengths is found starting in the Rockall Channel, extending northwest south of the Iceland Faroe Ridge, then turning southeast along the south side of the Reykjanes Ridge, crosses this ridge where it is between 1000 and 2000 meters, then turning northeast up the other side. The tongue then turns north, then west, and finally southwest, following the continental slope off Greenland. The tongue passes south of Greenland, then to the northwest along the continental margin, with associated temperatures near 5.0°, forming a warm core beneath the cold near-surface layer of the East and West Greenland currents. The tongue turns across the Labrador Sea, with the highest values now being the 3.5° Labrador Sea water.

Throughout the northern North Atlantic data set, a deeper pycnostad is generally found with associated temperatures near 3.5°C. In Figure 3 the strength of this Labrador Sea water mode is shown. It suggests an interesting complementary picture to the near-surface mode distribution. Highest values are found in the central Labrador Sea, where renewal by vertical convection takes place. High strength

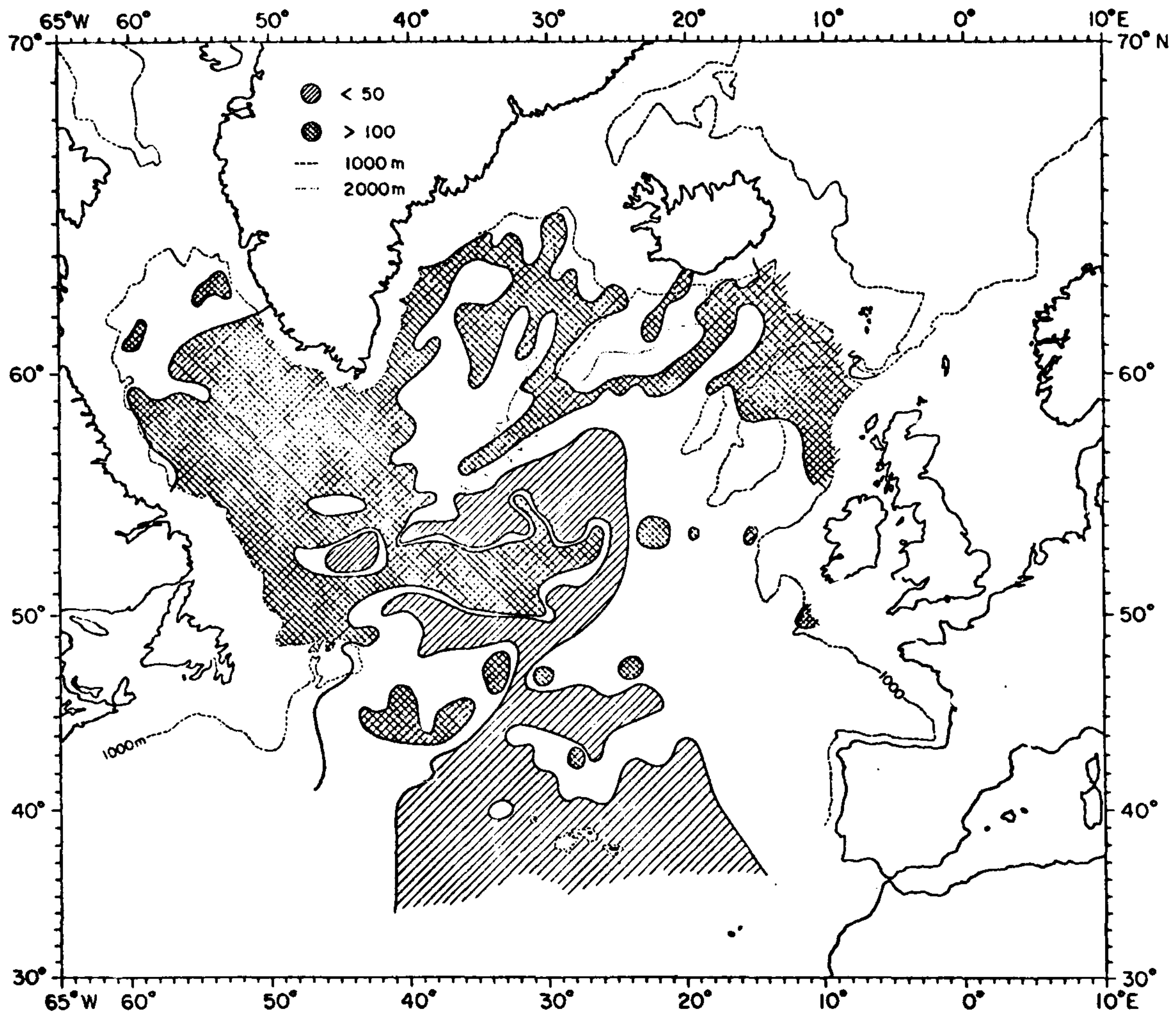

Figure 2. Pycnostadal strength: Brunt-Väisälä period in minutes at the maximum strength level of the water column.

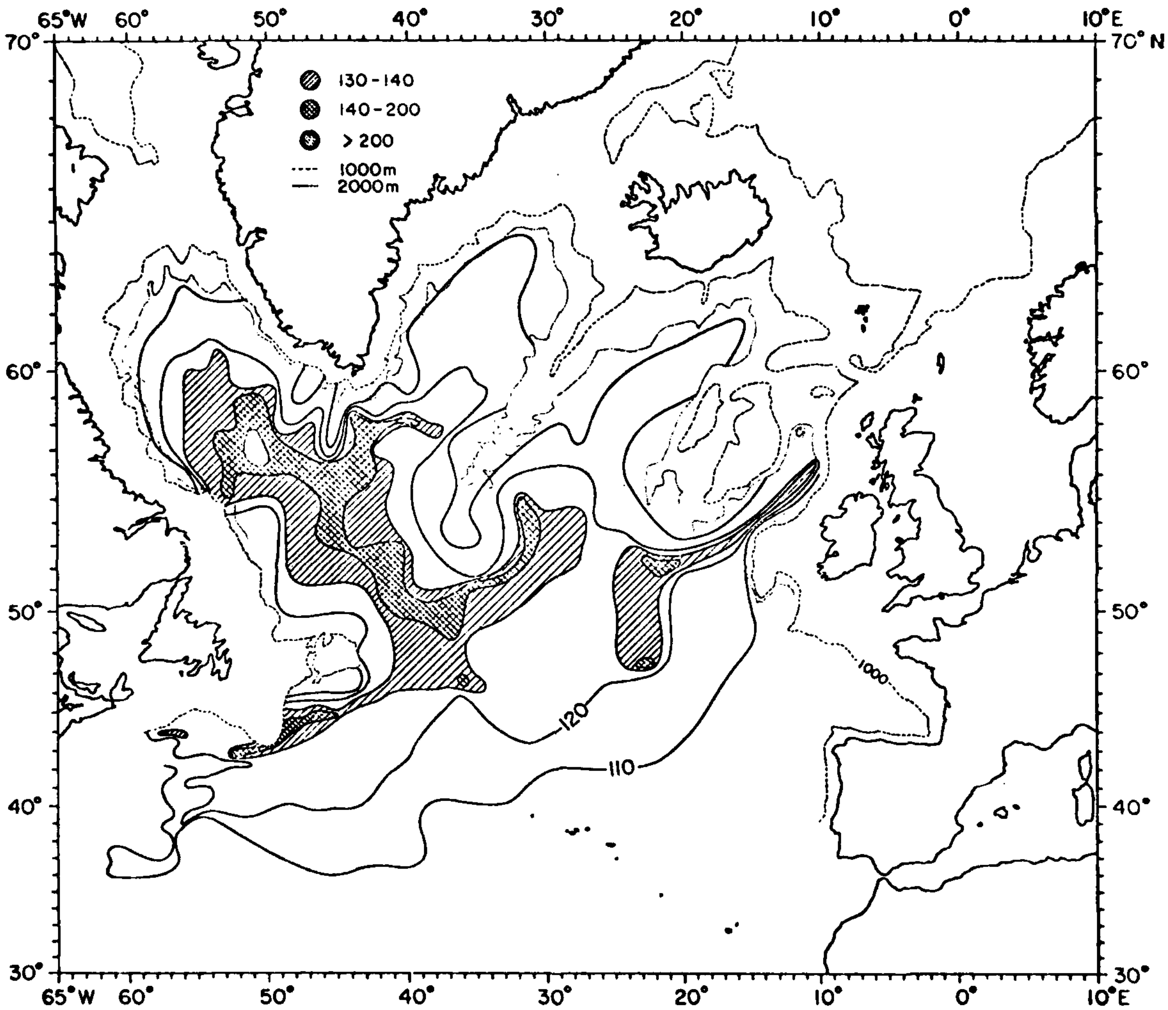

Figure 3. Pycnostadal strength: Brunt-Väisälä period at the deep maximum between 3° and 4°C, defining the Labrador Sea water.

tongues extend northeast into the Irminger Sea, and southeast. The latter divides into two, a southward one which turns west past the Flemish Cap, and an eastern one which crosses the mid-ocean ridge south of the Gibbs Fracture Zone, and then extends into the South Iceland and Rockall Channels. The tongue axis crossing the ridge south of the Gibbs Fracture Zone can be seen in Figures 1 and 2 to lie north of the North Atlantic current.

The principal investigator and a W.H.O.I.-M.I.T. Joint Program graduate student, Lynne Talley, have been working on this study. They plan to complete the basic description of the near-surface mode and Labrador Sea water mode during the summer of 1978 and to prepare a descriptive manuscript for publication.

Examination of weather ship data is just beginning. Juliett (52°N, 20°W) data from 1967 through 1971 have been obtained. We will use these station data to look for seasonal changes in the near-surface mode properties. The late winter data here show typically a deep 9.8° to 10.2° mixed layer. The data will be examined for evidence of a seasonal evolution of mode temperature indicative of advection of warmer modes from the south. The station is also nicely situated near the axis of the tongue of Labrador Sea water that turns northeast into the Rockall Channel, so perhaps some year-to-year variation in the deep mode properties will be seen.

Data for weather stations Alpha (62°N, 33°W), Bravo (56°30'N, 51°W) and India (59°N, 19°W) have been requested and will be processed shortly. The other weather stations are of less immediate interest. Delta (44°N, 41°W) could provide useful information concerning the northern gyre 13° modes. Charlie (52°45'N, 35°30'W) is near the eastward tongue of Labrador Sea water. Finally, Mike (66°N, 2°E) lies in the warm inflow into the Norwegian Sea, between Faroe and Shetland Islands. This last station has particularly thorough Nansen work throughout the year.

<u>Program for 1979</u>

Work will continue on the basic pycnostadal distribution in the northern Atlantic. This will include further analysis of the various data sets that were used in the preliminary Figures 1, 2 and 3. The weather ship hydrographic observations will be compared with the heat fluxes calculated by Bunker. Estimates of the volume flux of cyclonically circulatory mode water will be made by the following indirect method. Warren (1972) has demonstrated that the dominant signal in the mode water-column heat balance is the surface heat flux. The time and space distribution of this flux has been determined by Bunker. The present studies will give the geographic variation in the mode water properties. Thus the gradient of mode water temperature and thickness around the cyclonic path will be known. With the dominance of surface heat flux, a control volume balance then yields a transport as a function of these observed gradients and fluxes. A very preliminary estimate from the mode temperature field off Ireland, its volume distribution, and Bunker's heat fluxes gives a northward transport of 10°C mode water of 5×10^6 m^3 sec^{-1}, but this could be substantially changed by a more thorough analysis. Estimates of this kind will tend quite naturally to the question of how this cyclonic circulation fits into a general North Atlantic circulation scheme. This will probably be a major part of the 1979 activity.

On a more general interpretive level, the principal investigator has begun some mode water formation/circulation interaction modeling studies with John Lillibridge, another W.H.O.I.-M.I.T. Joint Program student. The basic question being addressed is how the seasonal cycle involved with the formation of mode water affects the dynamics. Worthington (1972, 1976) has pointed out that the historical collection of Gulf Stream baroclinic transports suggests a seasonal cycle, with the baroclinic transport relation to 2000 m varying from a low near 65×10^6 $m^3 sec^{-1}$ in late summer to a high of about 90×10^6 m^3 sec^{-1} in late winter. He has suggested that this represents a seasonal confluence of 18° water which depresses the main thermocline south of the Gulf Stream, thereby increasing the baroclinic transport.

Warren (1972) has made a simple model for the heat balance at the gyre center--where the main thermocline is deepest and advection is by definition zero. The heat equation integrated over the water column depth is then just a local balance between the surface heat flux, which is a function of surface temperature and meteorological parameters, and the time rate of change of the depth-averaged temperature. He prescribes plausible vertical temperature profile shapes corresponding to convective overturning during cooling and seasonal thermocline development during heating, arriving thereby at a nonlinear oscillator equation for predicting the surface temperature as a function of time. The model does quite well predicting the 18° water temperature and depth for the Sargasso Sea. It does this, however, for a frozen main thermocline, and thus must be regarded as an incomplete model, for it represents a solution only to the depth-averaged density equation, and not to the depth-averaged vorticity equation. The approach we have adopted is to add one additional free variable to the Warren 18° water model, the depth of the main thermocline, so there are now two variables. The system is closed by adding a second equation, the depth-averaged vorticity equation. The first calculations will be made without wind forcing, so the pure interaction of the 18° water formation cycle and the main thermocline depth alone can be seen. Later calculations will include a seasonal cycle of wind stress, so a comparison of the amplitude of the wind-induced thermocline displacements to that of the 18° water formation-induced displacements can be made. Longer-range, presently less well-defined studies will be directed towards the general question of the role of mode water formation in the three-dimensional gyre circulation.

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Personnel

Mary Raymer will oversee the computer data processing, editing, reduction, summarization and plotting, and drafting of figures. The Graduate Research Assistant support is for John Lillibridge who will work with the Principal Investigator on the studies discussed in the text; Lynne Talley has NSF support.

Pycnostadal Analyses of the Upper Water Masses and Circulation of the World's Oceans

12 months period
1 January - 31 December 1979

			ONR Man Months	Actual Man Months
Professional:				
	M. McCartney	Principal Investigator	3	3
Support Personnel:				
	M. Raymer	Research Assistant	4	4

		ONR Man Months	Actual Man Months
A.	1. Gross Regular Salaries (includes allowance for vacation, holidays, sick pay, etc. of $1,182 which is accounted for as employee benefits)	$9,847	
	2. Cruise Leave, Sea Duty Vacation & Overtime (includes Premium Pay of $ 0)	-	
	TOTAL		$ 9,847
B.	OTHER EMPLOYEE BENEFITS		2,457
	TOTAL SALARIES AND BENEFITS		12,304
F.	PUBLICATION COSTS		
	1. Graphic Services: 80 hrs @ $13/hr	1,040	
	2. Page Charges: 10 pages @ $80/pg	800	
	3. Reprint Costs	100	1,940
H.	COMPUTER COSTS		
	1. Sigma 7: 40 hours @ $155/hr		6,200
I.	MISCELLANEOUS COSTS		
	1. Shop Services	-	
	2. Programming	-	
	3. Shipping, Communications, and Postage	250	
	4. Laboratory Overhead	2,584	
	5. Xerox Charges	200	
	6. Six Months Graduate Research Assistant (John Lillibridge) 5 months @ $1,070/mo; one mont. . $1,155/mo	6,505	9,539
J.	TOTAL DIRECT COSTS		29,983
K.	INDIRECT COSTS - 15% of Total Direct Costs		4,497
L.	TOTAL COSTS		$34,480

2. TEMPERATURE MEASUREMENTS WITH XBTs IN THE NORTHWESTERN INDIAN OCEAN (an INDEX Proposal)

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Abstract

A series of expendable bathythermograph (XBT) sections obtained by using tankers along essentially the same sea lane off the Somali and Arabian coasts between 12°S to 22°N is proposed for the year of the First GARP* Global Experiment (FGGE). The on-going measurements to date as a pilot study along this sea lane constitute 15 tanker trips which have allowed us to study the eddy development during the southwest monsoon. The large prime Somali eddy has been observed for three consecutive southwest monsoons. During 1979 we plan a hydrographic survey from the USNS Wilkes during August in the eddy forming region to the northeast of the Somali Basin. A series of XBT stations are also planned on the Italian ship Bannock in January on a section across the tanker track.

Long-Range Scientific Objectives

The long-range scientific objectives of the proposed program are to attempt to understand the circulation dynamics of the western Indian Ocean particularly as it responds to the strong monsoonal winds. We hope to determine the time variations and horizontal scale of the eddy-like circulation associated with the commencement of the dominant southwest monsoon, the variation during an entire season and also from year to year, whether certain preferred modes exist in the current patterns (i.e., does the large eddy occurring off the Somali coast during the southwest monsoon and its associated eddies become arranged in recognizable or predictable ways from one year to the next), the decline of the flow upon cessation of the monsoon winds, the changes in the heat content of the mixed layer, the variations in the region of upwelling off the Somali and Arabian coasts, and the changes occurring in near-equatorial dynamic topography as a result of the Somali circulation.

It is felt that studies in this region might be important to the Navy because we are now obtaining considerable information about the unusually strong horizontal temperature gra-

*Global Atmospheric Research Program

dients which develop during northern summer off the Somali and Arabian coasts within a relatively short period (2 to 3 months for full strength). Variation in acoustic propagation patterns in this area would be quite large. Also the surface currents associated with these gradients are on the order of about twice that found in the Gulf Stream.

The proposed work will continue the present ONR program with an increased effort during 1979 for monitoring the thermal structure in the northwestern Indian Ocean by means of XBT observations from tankers and other available ships. It is a cooperative effort shared by the Woods Hole Oceanographic Institution and the University of Cape Town, South Africa. This study has been associated with INDEX (Indian Ocean Experiment), a program designed for examining the circulation dynamics by a series of pilot studies to help formulate the 1979 work during the First GARP Global Experiment. Other INDEX projects should be able to provide complementary measurements such as the satellite infrared program and coastal current measurements (Rosenstiel School of Marine and Atmospheric Science and NOAA) and hydrographic stations (Institute of Oceanographic Sciences, Great Britain).

Present Status and Progress over the Past Year

Background

Our observations in the last few years during the southwest monsoon have shown that the Somali Current may turn strongly offshore from the East African coast between approximately 6°N to 10°N (Swallow and Bruce, 1966; Bruce, 1968, 1973). At these latitudes the measurements indicate current speeds up to 7 knots with a directly measured volume transport of about 70×10^6 m^3 sec^{-1} (Swallow and Bruce, 1966) which during this season compares with transports found in the Gulf Stream. The circulation pattern is subject to considerable variation during a single monsoon season; within the period of a month we have found the current boundary to shift as much as 200 miles. The current appears to form large anticyclonic eddies which extend at least as far as 300 miles offshore during the southwest monsoon. At this time it is not clear to what degree the eddy field is changing, what initiates the current's turning offshore at different regions along the coast, or how similar the current pattern is from one southwest monsoon to the next. The area of maximum upwelling along the Somali coast has been found in the region where the current turned offshore, and changes in the location of the turning point appear correspondingly to change with that of the upwelling (Bruce, 1973). A similar situation may occur off the Arabian coast (Bruce, 1974) although currents appear to be somewhat weaker than off the Somali coast.

Studies that have been made of the low-level Findlater jet off the Somali coast (Bunker, 1965; Findlater, 1969) suggest a feedback mechanism associated with the cold surface water in this region. Our XBT sections which pass directly across the path of the jet allow us to monitor variations in the cold trough extending offshore to the left of the Somali current, and we hope to be able to correlate these changes with jet intensity. Findlater has been able to show that variations in jet strength may correlate with rainfall at stations in western India.

The region where the eddy structure appears most strongly developed is from the equator to about 12°N and from the Somali coast east to about 60°E. Off the Arabian coast the region extends up to 22°N and to about 200 miles offshore. To document these changes by repeated hydrographic surveys with close station density similar to those in 1964 (Swallow and Bruce, 1966) and 1970 (Bruce, 1973) would require two or more oceanographic vessels for the monsoon season, and costs would be quite high.

The large number of oil tankers operating between the Persian Gulf and Atlantic or South African ports follow essentially a sea lane along the northeast African and Arabian coasts about 150 miles offshore (Figure 1). The frequency of vessels is about 15 per day, with the largest companies such as Exxon scheduling about one a day along this route. Our present program utilizes these tankers for obtaining a temperature section with expendable bathythermograph probes (XBTs) approximately every three weeks, thus providing an excellent means of monitoring the variation of the Somali Current as it turns offshore. The tanker route passes through some of the large anticyclonic eddies observed during our past surveys (Figure 2). All the measurements obtained during the southwest monsoon (data from May through October from hydrographic surveys by the U.S., U.K., France and U.S.S.R.) which have been examined indicate that the current does turn offshore and would thus be discernible in the thermal structure along the tanker sea lane (Figure 2). From the thermal structure we can obtain approximations of geostrophic velocity and transport through the sections from 2°N to 22°N and observe changes occurring during a monsoon period. Subsurface salinity values can be estimated from the temperature-salinity characteristics obtained from past hydrographic observations. Surface salinity samples are collected at regular intervals along the section and used to estimate the extent of penetration of the relatively fresh Somali coastal water ($\sim$ 35.1 to 35.3‰).

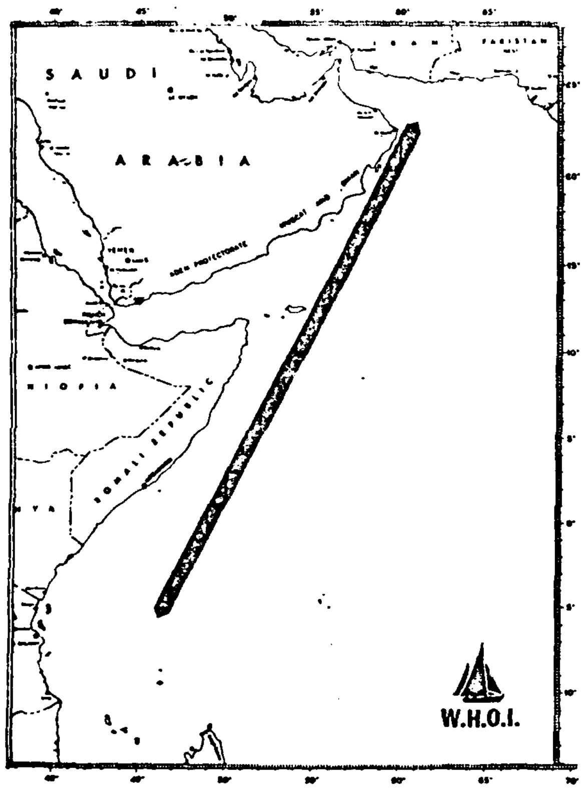

Figure 1. Sea lane used by tankers en route between Persian Gulf and Atlantic ports along which XBT sections are obtained.

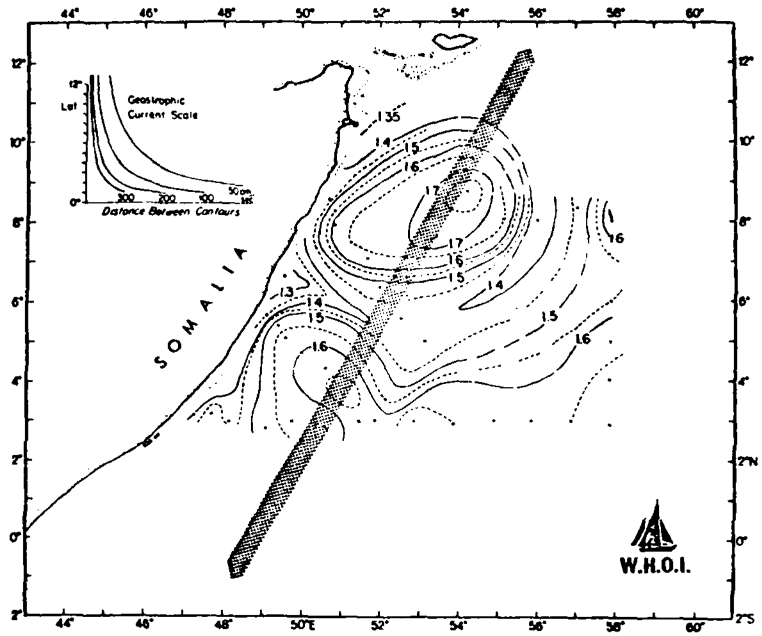

Figure 2. XBT sections along tanker sea lane (arrow) relative to eddy structure occurring during southwest monsoon. Lane in general passes directly across prime eddy shown here between 5°N and 10°N. Contours show topography in dynamic meters of the surface relative to 1000 dbr during August 1970 (see Bruce, 1973, 1978).

Present Work

Our present program for obtaining the XBT sections is in cooperation with Prof. E. S. W. Simpson, Head of the Department of Oceanography, University of Cape Town, South Africa. The University has furnished two observers to ride the tankers, provided laboratory space for equipment storage and data analysis, and is acting as local liaison with the tanker agents. By an agreement with the Exxon Corporation, we are able to place an observer with equipment aboard the vessels by helicopter at Cape Town with the observer remaining aboard on the passage to the Persian Gulf and return (round trip approximately 35 days). It should be noted that Exxon has borne all helicopter costs and furnished free room and board for the observers while at sea as well as carefully made arrangements for each of our trips once our schedule was given them.

Equipment necessary for each trip includes an XBT launcher, recorder and approximately 150 probes (type T-4, 65 per section plus 20 spares). Our T-4 failure rate has been about 12 to 15% although on the two most recent trips in 1978 the rate has increased to about 30%. Our station spacing along the track calls for approximately a 30-mile interval from 2°S to 5°N and from 12°N to 22°N, and a 20-mile interval from 5°N to 12°N.

Results

Starting in October 1975 we have now completed fifteen trips aboard tankers with another in progress at present. Six trips are scheduled for 1978 with special attention to the development of the southwest monsoon.

Combining our XBT data from the past three southwest monsoon seasons with those of our earlier hydrographic surveys, it appears that in general one of two circulation patterns of eddies tends to be established during June through October. Once established, that particular pattern tends to remain throughout the season. From our temperature sections we do not see strong evidence for migration of eddies from the equator northward up the Somali coast. There appears to be some shifting of the prime eddy on the order of 100 km northward in June 1977 during the development stages. We have observed similar shifting of the northern eddy boundary in previous measurements (Swallow and Bruce, 1966).

The fully developed thermal structure for each of the past three southwest monsoons is shown in Figure 3. During each year the prime eddy appears to form south of 12°N and extending south to about 3°N to 5°N. The data from 1975 and 1977 suggest that the mode of circulation was essentially that of the prime eddy south of 10°N and a smaller eddy off Socotra between 10°N and 13°N. The other mode occurred during 1976 when the prime eddy was slightly farther north extending from 12°N to 5°N. South of 5°N a southern eddy was observed, the circulation being similar to that found in 1970 (Bruce, 1973). The drogues placed by Regier and Stommel (1976) in 1976 indicated the general circulation pattern of the southern eddy. During each of these years, once the mode of circulation was established, it appeared to be maintained throughout the monsoon period and into the period of subsidence (late September to November). The prime eddy late in the monsoon exhibits a deep mixed layer 150 m to 180 m within the central region (~ 8°N) and the horizontal gradients occur below 400 m - 500 m.

The tanker sections pass approximately through the central portion of the prime eddy, and the changes in thermal structure are somewhat representative of the entire region in which the eddy circulation takes place: i.e., the Somali Basin which extends roughly from the east African coast out to 300 miles offshore. Our data suggest that the equatorial water as well is modified by this circulation. During the southwest monsoon the near surface water here is cooled, and a corresponding drop in dynamic height (relative to 400 dbr) on the order of 0.15 dynamic meters occurs. This change might well influence the equatorial undercurrent because a local slope of the sea surface which is negative westward might form. Taft and Knauss (1967) found no evidence of the undercurrent on the western side of the Indian Ocean during the months of the southwest monsoon.

Volume transports (relative to 400 dbr) of the offshore current associated with the northern portion of the prime eddy during the southwest monsoon range from 23×10^6 m^3 sec^{-1} (August 1976) to 42×10^6 m^3 sec^{-1} (October 1975). These values are of the same order as measured during our hydrographic surveys in 1964 and 1970 (Swallow & Bruce, 1966; Bruce, 1973). A comparable transport inshore was found in the southern part of the eddy generally between 4°N to 7°N. The smaller eddy found off Socotra, particularly noticeable in the XBT sections during 1975 and 1977, had transports of about 8 to 12×10^6 m^3 sec^{-1}.

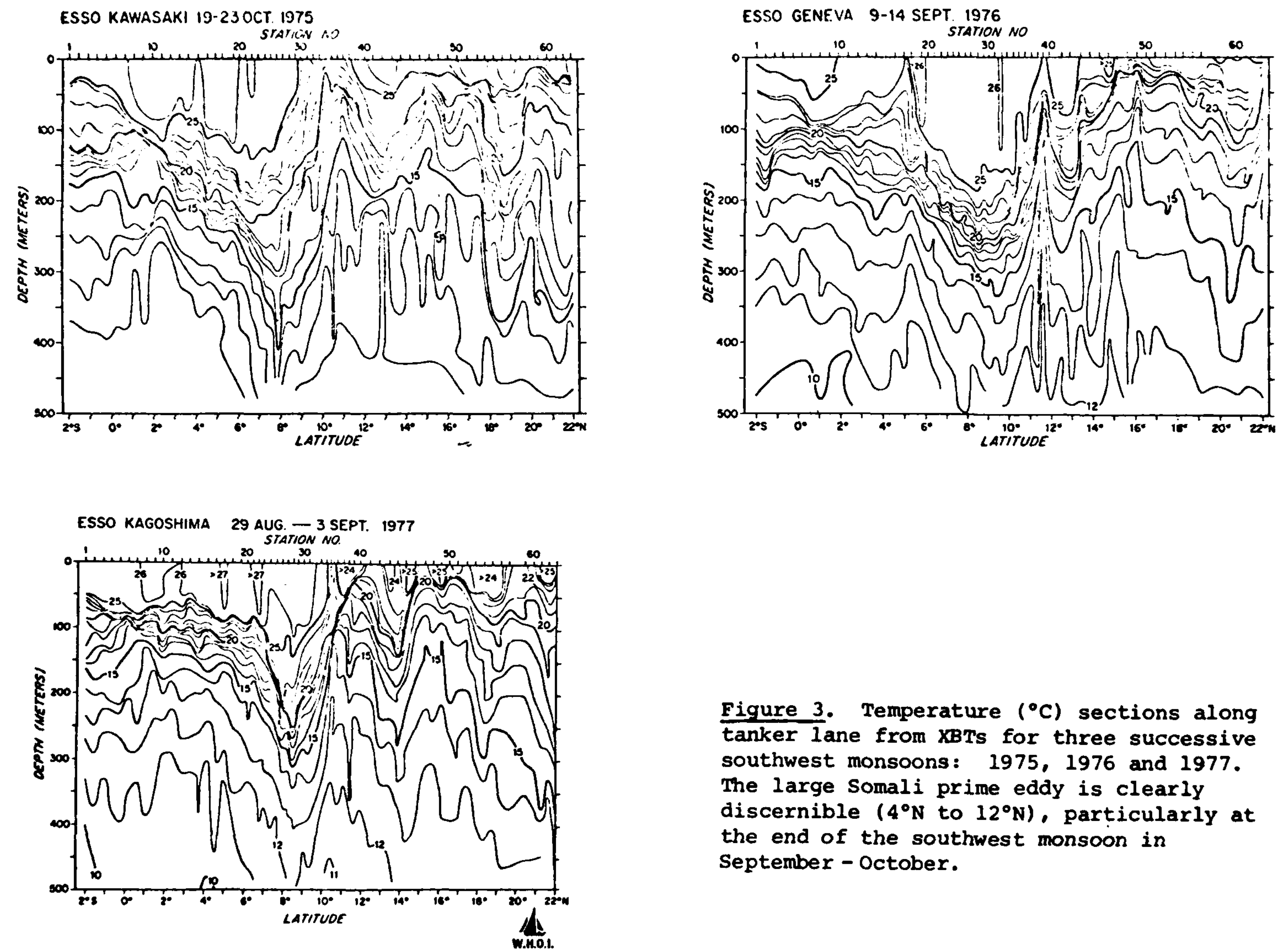

Figure 3. Temperature (°C) sections along tanker lane from XBTs for three successive southwest monsoons: 1975, 1976 and 1977. The large Somali prime eddy is clearly discernible (4°N to 12°N), particularly at the end of the southwest monsoon in September - October.

From the sections the heat loss in the upper 100 m over the southwest monsoon has been estimated. In both 1976 and 1977 when sections before and at the peak of the monsoon were run, the loss amounts to 2.7×10^{12} cal cm^{-1} along the section from 2°N to 12°N for both years. If it is assumed that the section is fairly representative of the coastal region to approximately 400 km offshore, then the area loss would amount to 1×10^{20} cal. Because of the deepening of the isotherms in the interior of the prime eddy, heat is essentially stored at deeper levels. Thus in 1976 whereas there was a heat loss in the upper 100 m, there was a gain of approximately 4.6×10^{12} along the section in the 100 to 450 m layer. In 1977 the gain was less than 1×10^{12} in this layer, in part apparently because of the prime eddy being somewhat smaller. During the southwest monsoon it would seem that the deeper layer of the eddy would act somewhat as a temporary heat storage basin which would tend to prevent rapid removal of near-surface heat during the monsoon but would then continue to release heat for a period after the cessation of the monsoon.

A series of bottom current measurements in the Indian Ocean is being examined with Dr. Earl Hays who obtained the data during a separate experiment in February, March 1977. Two sites 8 nautical miles apart near 5°N, 53°E in the Somali Basin at approximately 5000 m depth about 5 m above the sea bed show varying currents from approximately 0 to 6 cm sec^{-1} with generally tidal frequencies. There appears to be correlation above 2 cm sec^{-1} between the sites.

Monthly contoured maps of wind stress, τ_x and τ_y, have been constructed from National Climatic Center tapes and computed by A. Bunker using his C_D values (Bunker, 1976). From these data, maps of wind stress curl and transport are being determined. An average of stress values during the major months of the southwest monsoon is shown in Figure 4. Total transport off the northern Somali coast 7°N - 12°N amounts to 35×10^6 m^3 sec^{-1}, which is approximately that found in the North Atlantic by Leetmaa and Bunker (1978).

Using tanker wind data, a paper entitled "Spatial and Temporal Variation of the Wind Stress off the Somali Coast" by J. G. Bruce was published by the Journal of Geophysical Research, 83(C2), 963-967, 1978.

Program for 1979

The major portion of the oceanographic FGGE observational period in the Indian Ocean extends from March into August 1979 with considerable emphasis on the Somali Current and equatorial region at the onset of the southwest monsoon. A

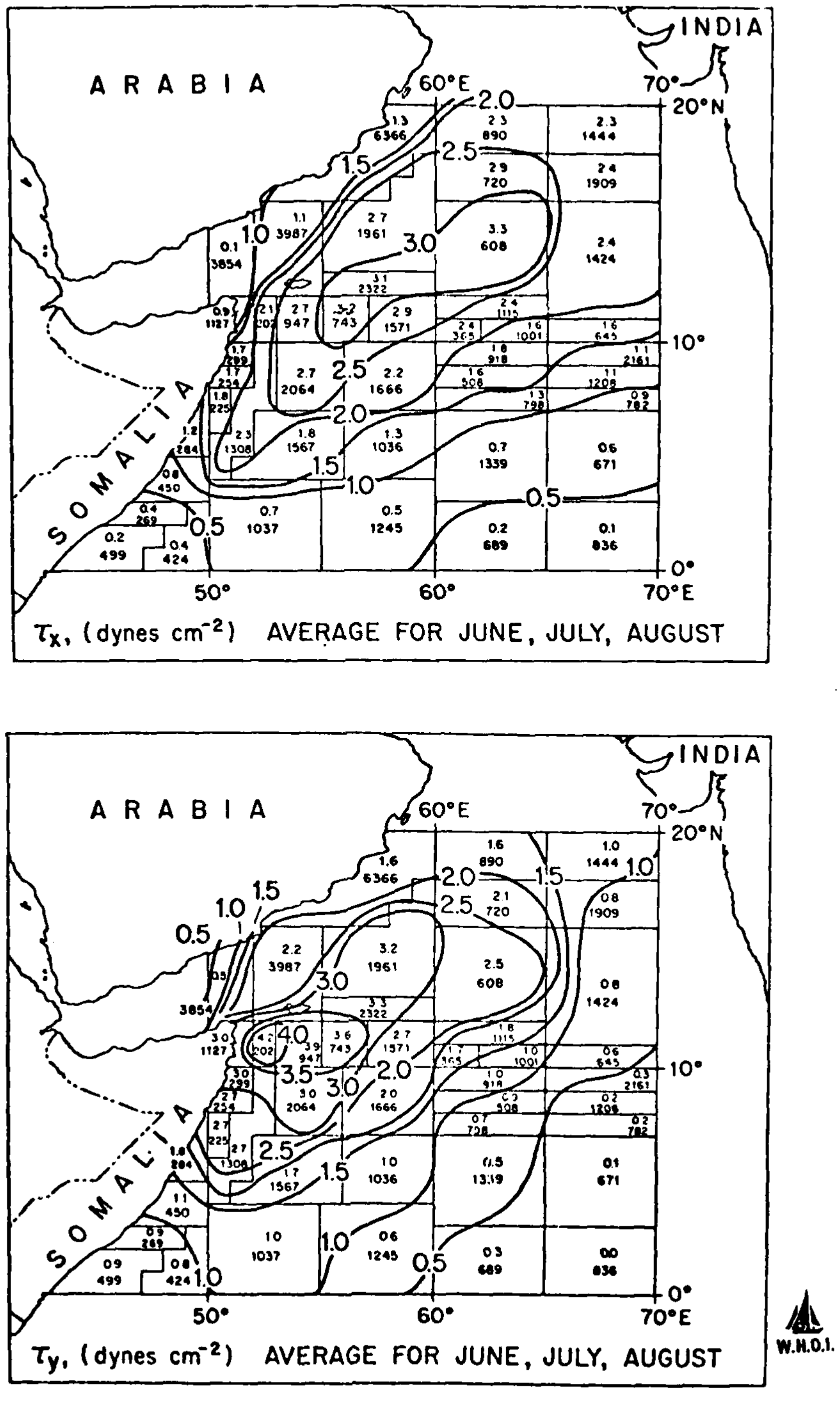

Figure 4. Wind stress at sea surface in dynes cm^{-2} during southwest monsoon. τ_x is zonal, + to east, and τ_y is meridional, + to north. Numbers in subdivision give stress and number of observations averaged from 1922 to 1972 (from Bruce, 1978).

plan outlining the various measurements to be made is given in the report to SCOR Working Group 47 by John Swallow (1978). During the year and particularly during this period we propose to continue our tanker XBT sections. Twelve trips (24 sections) are planned along the same track which we have been observing. In order to obtain sections also across the Southern Equatorial Current, we should like to extend the sections from 2°S - 22°N to 12°S - 22°N. Past data indicate that the currents in this region may turn northward along the East African coast at the commencement of the southwest monsoon and contribute considerably to the Somali Current as shown by the similarity in the T-S characteristics of the Southern Equatorial and Somali Currents. We have already obtained five sections from 12°S to 5°S during the early stages of our tanker XBT program, and these sections have been described by Mallory and Wolhüter (1978), this work being part of the University of Cape Town effort on this project. All sections indicated strong horizontal gradients between 9°S to 12°S whereas to the north of 9°S the sections indicate a weak and variable structure.

During each monsoon by late August and September the Somali prime eddy reaches its maximum development (i.e., deepest mixed layer in the center and largest horizontal range of the eddy diameter). Then the thermal gradients are found to occur as deep as and below 450 m (depth range of T-4 probes). For this reason it is felt that the sections obtained during this period should employ a number of T-7 (750 m) probes, and these have been requested in the budget. Our earlier work has suggested that the Somali eddy might be observed as late as February and March (Bruce & Volkmann, 1969), and the XBT sections from 1975 to mid-1976 suggest that possibly the eddy might have been maintained through the winter until the commencement of the next southwest monsoon. It is not clear that this also occurred between 1976 and 1977.

During August and early September we are requesting ship time aboard the USNS Wilkes. The purpose of this cruise, which would be made in conjunction with the ongoing XBT tanker sections, is to make a survey of the eddy field during the peak development period in the latter half of the southwest monsoon. In addition to helping describe the large eddy or eddies found each southwest monsoon in the Somali Basin, it is hoped that the survey would measure the extent of the circulation to the east and north of the Basin region. We would like to determine the size and number of eddies; the transport, velocities and energy associated with the near-surface eddy field. Very few sets of measurements during the southwest monsoon have been made outside the Somali Basin. Hydrographic sections along 5°N and 10°N obtained by Atlantis II during the 1963 International Indian Ocean Expedition survey clearly indicate large geostrophic velocities in both the Somali eddy and other eddies farther to the east. It is important to examine further the structure of these mid-Arabian eddies formed during this period, particularly in conjunction with other FGGE measurements. Wilkes time required would be 5 to 6 weeks with measurements by STD, XBTs, and surface temperature and salinity samples. The region of operation would be 0° - 15°N, Somali coast to about 65°E.

During January and February the Italian research vessel Bannock will act as a TWOS* near 0°, 62°E (SOP 1†). The ship's track both in going and returning to that position will pass through the northern Somali Basin and cross the tanker track at about a 70° angle just in the region where the prime eddy is normally observed during the southwest monsoon. It would be important to know the characteristics of the eddy field at this time, particularly since it is felt that it may influence the early stages of the reforming of the eddy or eddies during the following 1979 southwest monsoon. We have been invited on the cruise by the Italians, but we would have to furnish all equipment for the measurements. Although we would prefer to obtain a section of deep hydrographic stations along this track, the costs of instrumenting the ship would be quite high, and thus we hope instead to use XBTs with recorder and launcher from W.H.O.I.

Facilities

The facilities of the Woods Hole Oceanographic Institution will be used for planning, construction and testing of necessary equipment and for data analysis. It is also planned to use storage space and a staging area at the University of Cape Town where supplies are retained prior to placing aboard tankers at Cape Town. Ocean measurements will be made from twelve Exxon tanker round trips between Cape Town and the Persian Gulf and from the USNS Wilkes and the Italian research vessel Bannock.

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*Tropical Wind Observing Ships
†Special Observing Period 1

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Personnel

John G. Bruce, Research Associate at W.H.O.I., co-principal investigator, will be responsible for the planning and execution of the program, analysis of data and correlation with other INDEX data.

Bruce A. Warren, Associate Scientist at W.H.O.I., co-principal investigator, will help out with the program as needed.

Two Laboratory Assistants, to be assigned, will both assist in the analysis of XBT data and one will help obtain measurements aboard USNS *Wilkes*.

E. S. W. Simpson, Professor of Oceanography, University of Cape Town, will furnish laboratory space at Cape Town and observers to ride the tankers.

Two Observers from the University of Cape Town will make all measurements at sea from oil tankers.

Travel

International travel would include one trip to the University of Cape Town in June to coordinate the measurement program with the observers and another trip in late November or December to plan joint data reporting with the University. Funds have also been requested for J. Bruce and two assistants to join the U.S.N.S. *Wilkes* in Mombasa (or possibly Bombay) during August for 5 to 6 weeks to obtain measurements to the northeast of the Somali Basin.

Temperature Measurements with XBTs in the Northwestern Indian Ocean (an INDEX Proposal)

12 months period
1 January - 31 December 1979

			ONR Man Months	Actual Man Months
Professionals:				
	J. Bruce	Co-Principal Investigator	10	10
	B. A. Warren	Co-Principal Investigator	0	0
Support Personnel:				
	To be assigned	Laboratory Assistant	9	9
	To be assigned	Laboratory Assistant	9	9

A.	1. Gross Regular Salaries (includes allowance for vacation, holidays, sick pay, etc. of $3,893 which is accounted for as employee benefits)	$32,440	
	2. Cruise Leave, Sea Duty Vacation & Overtime (includes Premium Pay of $476)	3,365	
	TOTAL		$ 35,805
B.	OTHER EMPLOYEE BENEFITS		9,510
	TOTAL SALARIES AND BENEFITS		$ 45,315
C.	PERMANENT EQUIPMENT		
	1. One XBT launcher		275
D.	EXPENDABLE SUPPLIES AND EQUIPMENT		
	1. 2160 T-4 XBT probes (to be supplied by Fleet Numerical Weather Central)	N.C.	
	2. 500 T-7 XBT probes @ $30.85/ea	15,425	
	3. Parts to rebuild and repair existing current meters and recorders	2,000	
	3. Miscellaneous: recording paper, spare parts, etc.	400	17,825
E.	TRAVEL		
	1. Domestic	450	
	2. Foreign (see attached)	11,196	11,646
F.	PUBLICATION COSTS		
	1. Graphic Services: 80 hours @ $13/hr	1,040	
	2. Page Charges: 12 pages @ $80/pg	960	
	3. Reprint Charges	60	2,060
H.	COMPUTER COSTS		
	1. Sigma 7: 10 hours @ $155/hr		1,550
I.	MISCELLANEOUS COSTS		
	1. Shop Services: 60 hours @ $13/hr	780	
	2. Programming	--	
	3. Shipping, Communication, and Postage (plus 2500 XBT's in four shipments by GBL to Cape Town)	5,000	
	4. Laboratory Overhead	9,416	
	5. Xerox charges	--	
	6. Two observers from U. of Cape Town, 12 mos. ea. @ $650/mo/ea. plus $2,000 incidental expenses	17,600	32,796
J.	TOTAL DIRECT COSTS		$111,467
K.	INDIRECT COSTS: 15% of Total Direct Costs		16,720
L.	TOTAL COSTS		$128,187

E. TRAVEL

1. Foreign

2 round trips Boston to Cape Town @ $1,984/ea	$3,968	
2 car rentals @ $70/ea	140	
30 days travel expenses (15 each trip @ $35/da	1,050	
(J. Bruce, two visits to University of Cape Town)		$ 5,158
3 round trips Boston to Mombasa @ $1,756/ea	5,268	
2 car rentals @ $70/ea	140	
15 days travel expenses @ $42/da	630	
(3 people to join cruise)		6,038
TOTAL FOREIGN TRAVEL		$11,196

3. OCEANIC VARIABILITY AND DYNAMICS

Thomas B. Sanford

(617) 548-1400, ext. 549

Abstract

During 1978 a comprehensive paper was published on our observations of fine-structure around Bermuda and its relationship to larger-scale variability. We found high levels of fine-structure resulting from ocean eddies colliding with the island. An analysis of profile and microstructure data in a surface-mixed layer has been completed and submitted for publication. The feasibility of an expendable, free-fall temperature and velocity profiler (XTVP) has been demonstrated. About 100 XTVPs were deployed during the Local Dynamics Experiment of POLYMODE.

For 1979 we propose to focus on the analysis of the POLYMODE XTVP data and on the existing deep water profiles. The XTVP observations are extensive and contain examples of strong, small horizontal scale current structure and of wave-like motions above and around a strong topographic feature.

Long-Range Scientific Objectives

We seek to understand the properties of ocean currents and waves, particularly through studies of the vertical structure of velocity and density fields. Emphasis is placed on gaining new insight into the dynamical processes involved in low frequency eddies, the influence of the ocean bottom on currents, microstructure generation, and internal wave and acoustic propagation. Our principal observational tool has been the electromagnetic velocity profiler (EMVP) developed under this project. A subsidiary long-term goal is to exploit this technique to the point that it can have more widespread use.

Present Status and Progress over the Past Year

The principal effort of the current scientific program has been on the analysis of existing velocity profile data, especially those from the Fine and Microstructure Cruise. The publication or submission of several scientific papers has been achieved this year. In addition, we have completed the processing and plotting of all existing profile data for publication as a technical report. The engineering effort has produced expendable velocity and temperature profilers

(XTVPs) which demonstrate probe-to-probe repeatability of about 1 cm sec^{-1} r.m.s. Approximately 100 of these probes were deployed in the Local Dynamics Experiment of POLYMODE.

A. Results from the Fine- and Microstructure Cruise and Previous Data

Hogg, Katz and Sanford (1978) present analyses of the mean flow, internal waves and temperature fine-structure around Bermuda. Current analysis is devoted to open ocean observations of internal waves and a surface mixed layer. Over the past several years we have obtained several time series of velocity profiles, each at different times and locations. Sanford has taken these individual series, computed the series-mean profile, and subtracted the mean profile from each individual profile in the original series; the difference profiles consist of internal waves, primarily those having frequencies near the inertial frequency. A separation of the inertial period motions from the lower energy internal wave continuum is possible with the rotary, least-square analysis of Sanford (1975).

Spectra of the near-inertial and higher frequency internal waves are shown in Figure 1. One obvious feature of these spectra is that the vertical wave number dependence of the total internal wave spectrum is consistent with the model of Garrett and Munk (1975) having a high wave number power law of -2.5. More noteworthy, though, is that the wave number dependence is clearly not independent of frequency as was assumed by Garrett and Munk. The near inertial waves are more energetic at vertical wavelengths of 100 - 200 m and fall rapidly at shorter vertical scales. The higher frequency internal waves, on the other hand, have a -2 power law dependence and are more energetic at high wave numbers.

Cairns and Williams (1976) proposed a -2 spectrum based on temperature measurements. We think that they got this result because they greatly underestimated the near inertial contributions which have only weak vertical displacements. McComas and Bretherton (1977) have studied wave-wave interactions and predict energetic, high wave number, inertial waves. This theory is not consistent with our observations of most inertial energy at low wave number. It would be interesting for them to examine a model of a -2 spectrum for internal waves with rather isolated -2.5 to -3 near inertial components also present.

Another method for examining the vertical structure of internal waves it to compute rotary spectra. A velocity profile frequently has numerous zones in which the current

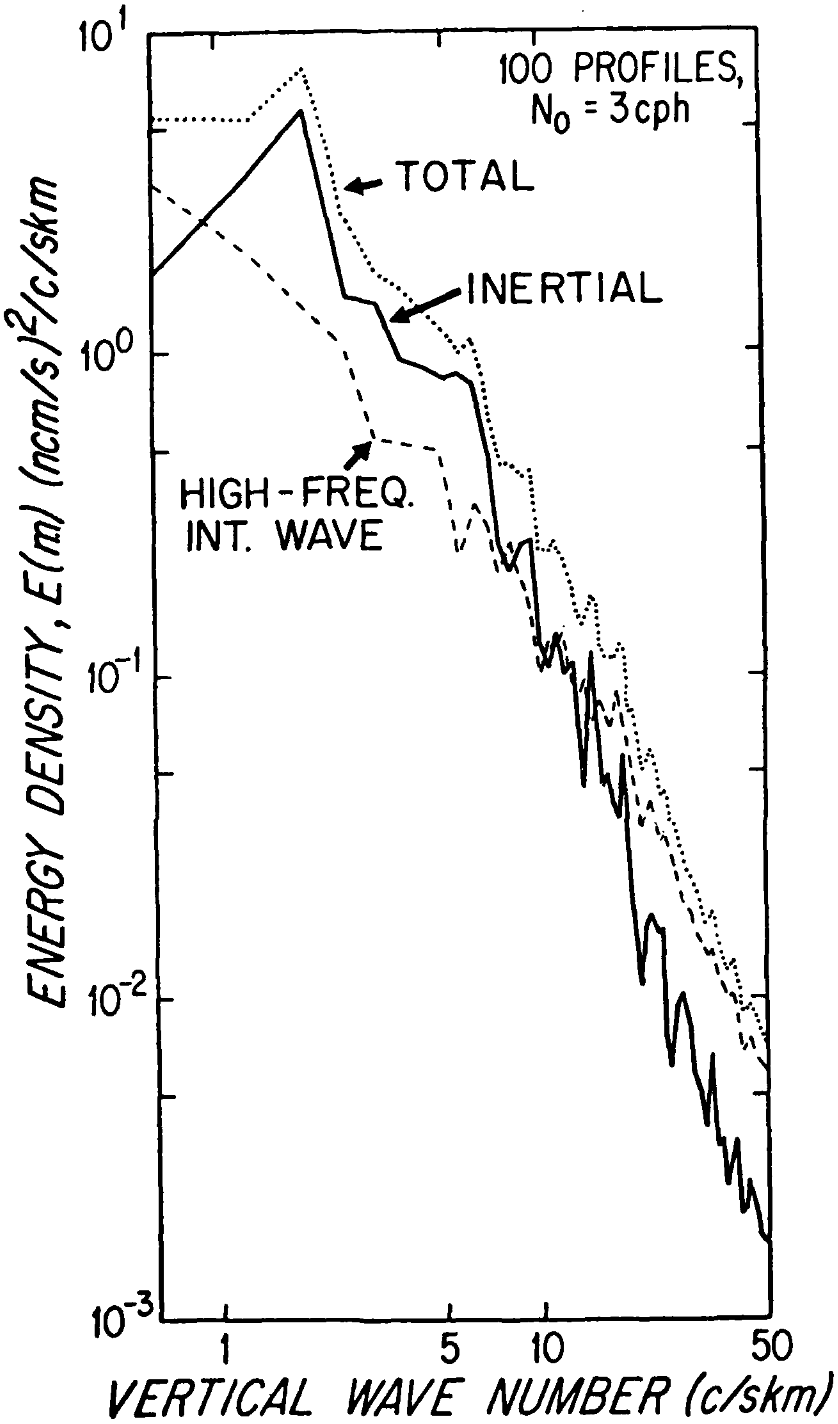

Figure 1. Spectra of horizontal kinetic energy for the total internal wave field, for the near inertial motions only, and for high-frequency internal waves. The high-frequency contribution is formed by subtracting the inertial wave from each of the individual amplitude profiles prior to spectral analysis. The energy and vertical wave number have been scaled by $N(z)/N_0$ according to WKBJ theory.

vector rotates with depth. A rotary spectrum determines the amount of kinetic energy at a given wave number which is represented by a spiral rotating clockwise (CW) with depth and by a counterclockwise (CCW) or anticlockwise (ACW) rotating spiral. It can be shown that, if the upward kinetic energy flux equals the downward, the CW contribution equals the ACW. Such a situation results in a vertical mode. Moreover, for near inertial waves the difference between the CW and ACW contributions determines the amount of energy asymmetry and the sign of the net energy flux.

Figure 2 presents, in an energy preserving form, the CW and ACW spectra for the inertial and higher frequency internal waves. Most of the inertial energy resides in the band of 100 - 200 m wavelength and the asymmetry is most pronounced there. At higher vertical wave numbers the energies are about equal. The higher frequency internal waves, on the other hand, show little asymmetry, but this may be expected, due to their higher frequencies as well as due to equipartition.

The model of Garrett and Munk assumed vertical symmetry at all wave numbers and frequencies. Clearly this symmetry is not present for the near-inertial waves. McComas and Bretherton have shown that wave-wave interactions tend to equalize the higher frequency internal waves but not the inertial. These aspects are borne out by these results.

We do not know why the 200 - 500 m wavelength band in the inertial is so dominant. Stern (1977) has proposed a theory which predicts such a vertical scale based on a surface mixed layer thickness. Not all of the data used in the average spectra had a surface mixed layer, yet the low wave number band dominates. Moreover, the dominance of the CW energy (downward energy flux) over the ACW is not consistent with Stern's "over-reflection" mechanism, which requires only slightly more energy in the CW domain. Perhaps there are additional wave-wave interactions yet to be found or there may be a shear limit encountered at a vertical wavelength of about 100 m in that shorter scale waves go unstable. The inertial shears are large, resulting in bulk Richardson numbers of about 2. A cascade of energy into shorter inertial waves may be efficiently dissipated. The role of shear instabilities in the open ocean is being studied.

During the Fine and Microstructure Cruise we were fortunate to observe a surface mixed layer (SML) which was actively mixing and which had an unusually large shear at its base. The evolution of the SML during the one-day observation period is evident in the temperature profiles from

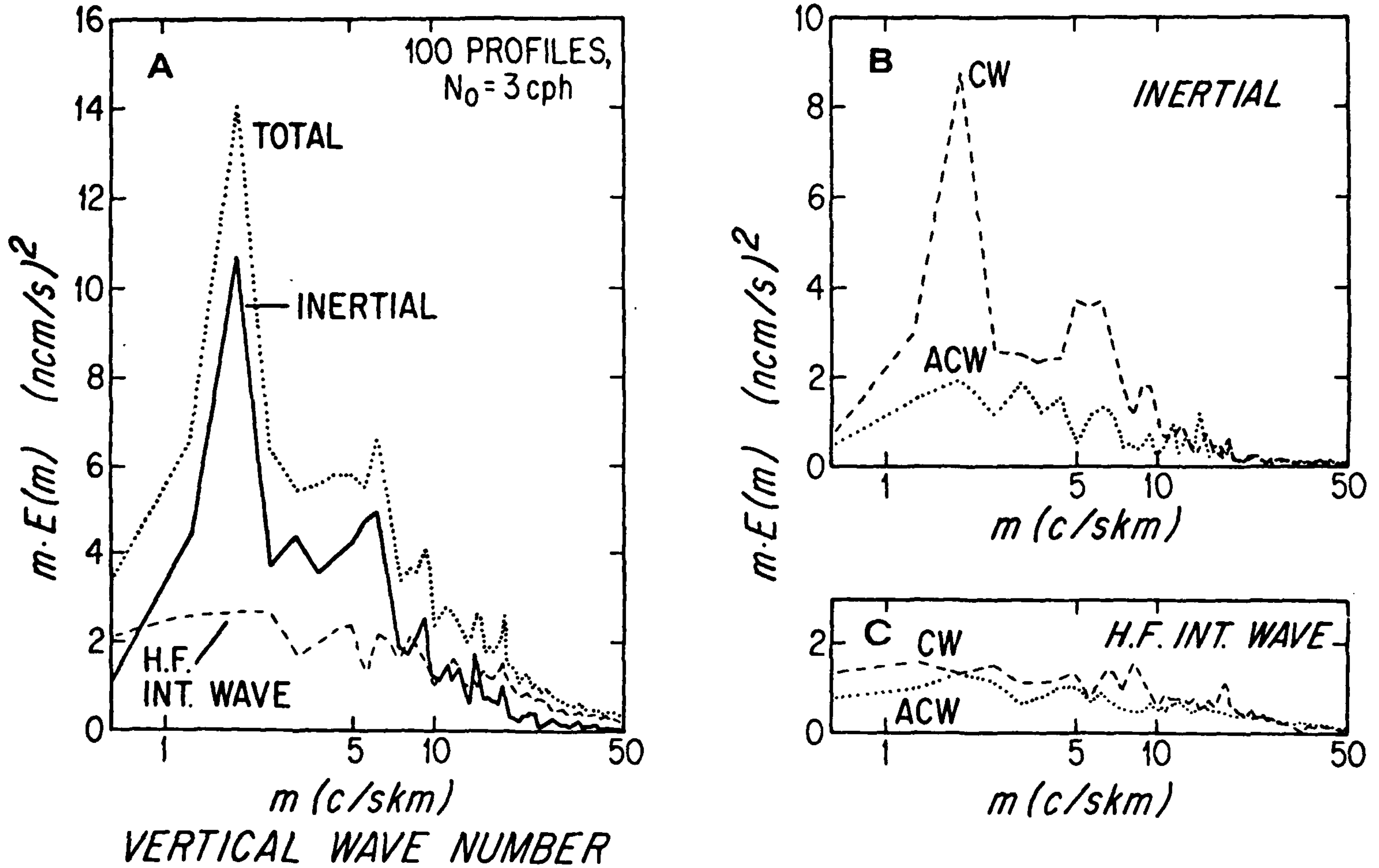

Figure 2. Same data as for Figure 1. A, energy conserving plot of Figure 1; B, clockwise vs. anticlockwise energy content for inertial wave; C, same as panel B except for high frequency internal waves.

several instruments shown in Figure 3. At the start of observations, the surface layer is not well mixed below 100 dbar. A change occurs rapidly, over the 5 hours between EMVP 320U and SCIMP 16, and for the rest of the time the surface layer appears well mixed to about 135 dbar, with only minor variations of thickness consistent with internal wave motions in the seasonal thermocline.

Velocity profiles from the EMVP and absolute velocity profiler (AVP) were obtained through the SML. Five drops of both instruments spaced every 6 hours were made, resulting in near surface velocity observations every 3 hours.

In Figure 4 the most dramatic vertical and temporal fluctuations occur in the upper 200 dbar. The temperature profiles from the EMVP, which are similar to those shown in Figure 3, show a mixed layer in the upper 100 dbar after drops 320 and 3, a transition zone of increasingly well mixed water between 100 and 140 dbar, and the start of the seasonal thermocline below 140 dbar. The principal shears occur below 100 dbar where shears as large as 10^{-2} sec^{-1} are found. Above 100 dbar, in the more mixed region, the shears are generally less than 10^{-3} sec^{-1} with the largest vertically persistent shears being on 320, 3 and 4. Profile 4U has a shear in the north component greater than 10^{-3} in the surface zone which is shown to be well mixed by CTD 75 to a pressure of 140 dbar. Beneath the SML the shears are about 10^{-2} sec^{-1}.

These data show a reduction in shear as the SML develops. There is, however, no absence of shear even when the layer is very well mixed. The shears at the base of the SML are caused mainly by inertial currents, although higher frequency components are also present.

The nearly simultaneous profiles agree to within less than 1 cm sec^{-1} r.m.s. between the surface and 1200 dbar. The most significant differences occur for 323U and 6U above 100 dbar. The time difference was about 7 minutes and the profilers were about 100 m apart. These time and space differences are typical of all EMVP and AVP paired launches. Considering the agreement of data elsewhere, the results above about 100 dbar indicate the presence of velocity fluctuations of periods of order 10 min and horizontal scales of 100 m or the SML depth. These data are insufficient to establish whether or not there exists a long-term mean shear in the SML, but they do reveal the presence of significant shear in the SML on a time scale of 10 min.

Gargett, Sanford and Osborn (submitted) have written a paper evaluating the energy input contributions for the wind,

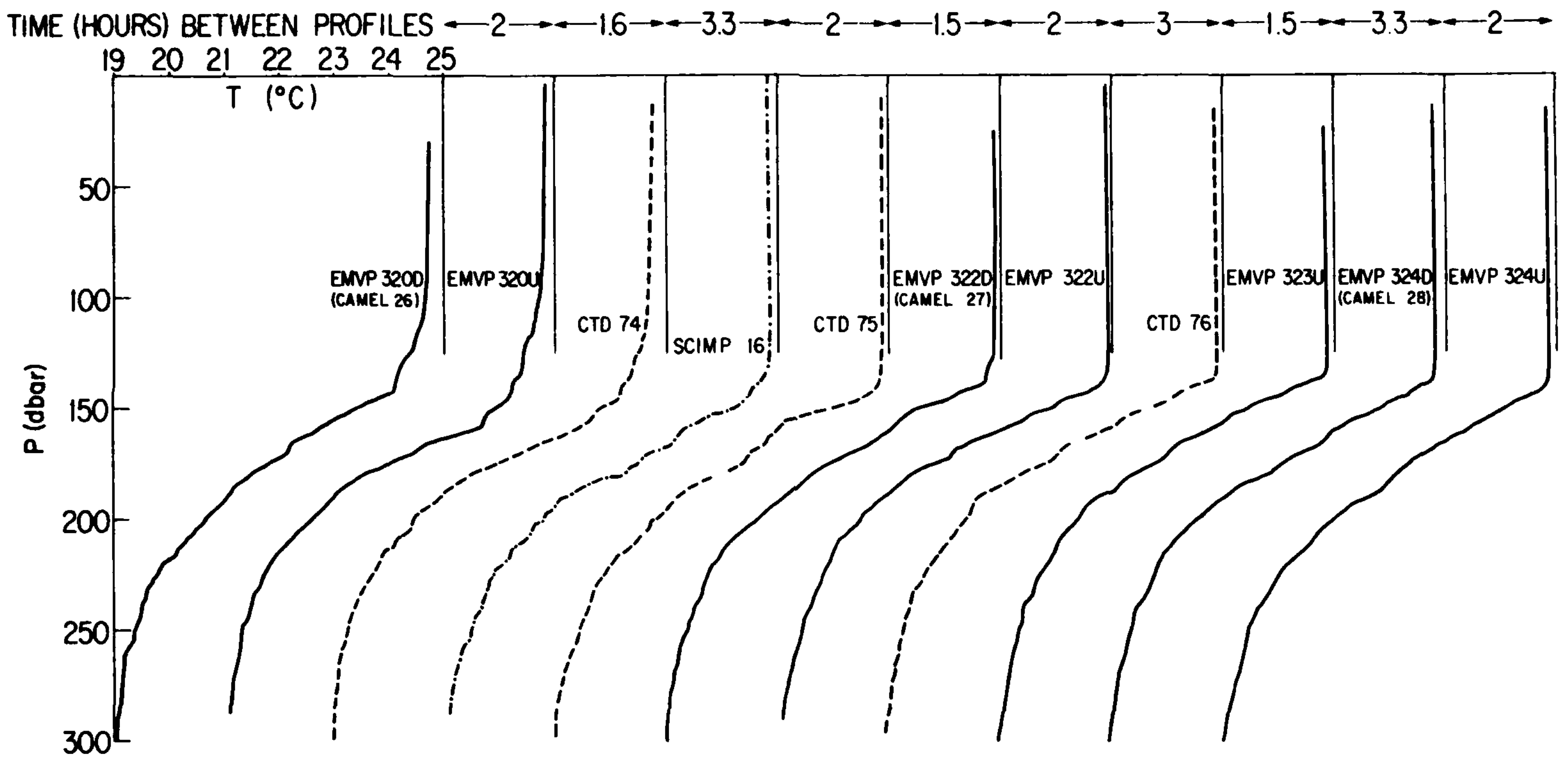

Figure 3. Temperature profiles taken during a surface layer mixing event. Consecutive profiles are displaced by 2°C, with 25°C marked as a vertical line from the surface to 125 dbar.

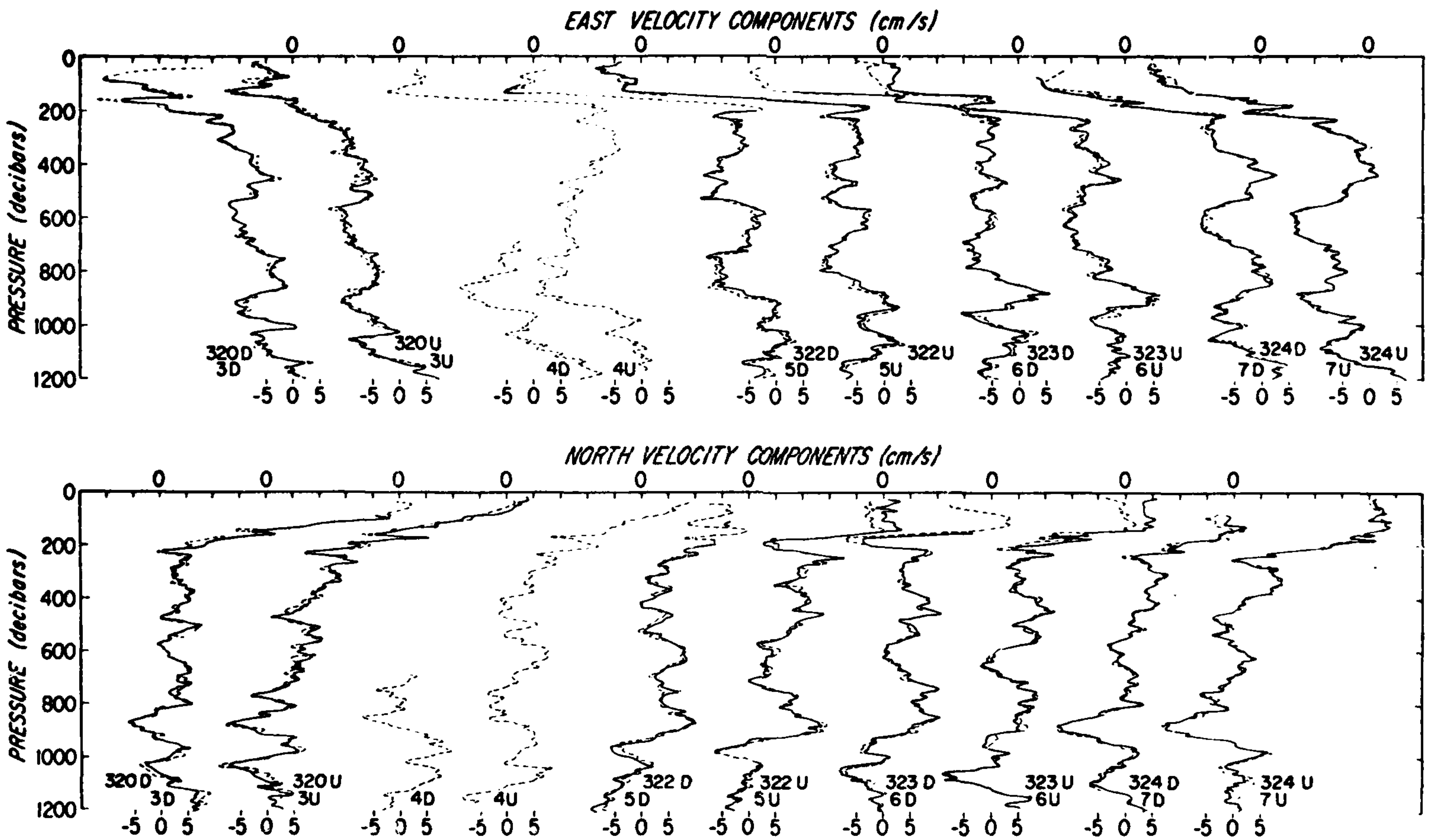

Figure 4. East and north velocity components for EMVP (solid line and denoted with three-digit number) and AVP (dashed line) during period corresponding to the temperature profiles of Figure 3.

buoyancy flux, and Reynolds stress acting on the strong shear. They have established that the wind input was too small to account for the kinetic energy dissipation and that the Reynolds stress contribution is potentially very large. They believe that this SML is being driven from its base by the large inertial period shear.

B. Atlas of Profile Data

During the first half of 1978 we assembled and plotted all usable profiles. To achieve this we had to reprocess some old data to correct problems and bring the data format up to date. In addition, we developed a profile plotting system which offsets profiles so that adjacent curves do not overlap. Later in the year we intend to assemble the necessary background information for each drop and issue a technical report on the entire set of velocity profiles.

C. Progress on the Expendable Temperature and Velocity Profiler (XTVP)

Under partial financial support of ONR Code 481, we have demonstrated the feasibility of making electromagnetically derived velocity profiles from an XBT-like probe. On Oceanus Cruise 42 in early April, 1978 we tested the newest version of the XTVP. This version differed from previous versions in some respects. Two circuit boards were used to eliminate components being on both sides of the boards, and temperature was telemetered to the ship as an FM signal in the band 200 - 500 Hz. Perhaps the most important change was in the way the high-level signals were applied to the bi-filar XBT wire. Laboratory tests and analytic studies had shown that interference and feedback were occurring between the high-level output ($\sim$ 1V) and the sensitive low-level input stages ($\sim$ 1 μV). Considerable effort was devoted to the elimination of these and other noise influences.

A brief time series of XTVP drops is shown in Figure 5. Drops 39-44 are not shown because they were tests of special units not intended to yield velocity profiles (e.g., temperature measurements only, etc.) The quadrature and inphase are orthogonal velocity components and correspond to east-west and north-south components, respectively. The stronger velocity features are reproduced on each profile, especially well on the quadrature component. The apparently higher levels of variability on some profiles, numbers 31 and 38 for example, are due to temperature effects on the electrodes. Electrodes installed with no thermal insulation from the surrounding water produce such strong electrochemical signals that the desired motional signal cannot be resolved.

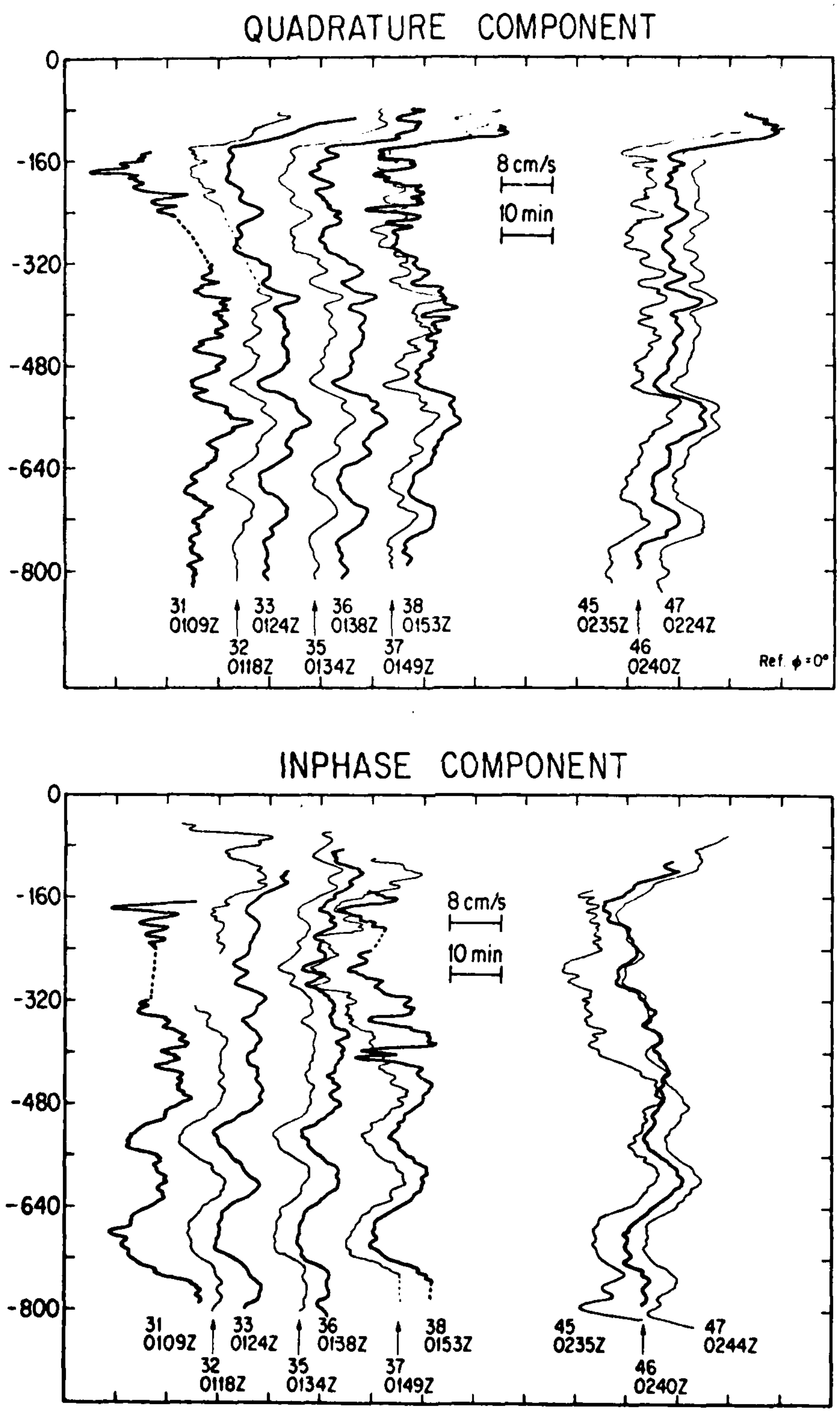

Figure 5. Inphase and quadrature (approximately east and north) velocity components of a time series of drops in one location.

Protecting the electrodes with a thick layer of agar significantly reduces the thermal interference. A wad of cotton, the protection most frequently used, does not shield the electrodes nearly as well as the agar coating.

Three profiles from the middle of the time series are shown in Figure 6. Over a time span of 14 minutes, the profiles are in agreement to within 1 cm sec^{-1} r.m.s., with somewhat larger differences evident between 80 and 160 m. This region is probably the most energetic and where the seasonal thermocline is the strongest.

Based on these results, we produced 100 probes for our POLYMODE work. These probes worked very satisfactorily and yielded some very interesting data on small horizontal scale variability. More will be said of these data in the next section.

Program for 1979

In 1979 the emphasis of our program will be on the analysis of existing profile data, especially those from the Fine- and Microstructure Experiment (FAME) and the expendable profiler from POLYMODE. In the case of the XTVP profiles, we propose to undertake the scientific analysis of these data with ONR Code 480 support. The engineering analysis and instrument development will continue as a separate endeavor funded by NORDA Code 500.

We are not proposing an observational program for 1979. Rather, we intend to finish the analysis and publication of the FAME measurements, to complete several joint research projects (e.g., with Gargett on shear comparison and Gregg on shear and microstructure), and to study the new profile data from the XTVP. The allocation of personnel reflects the above emphasis.

We wish to emphasize analysis of XTVP data not only because we have about 100 profiles in hand from POLYMODE, but also because we expect to collect more soon, and a great number will be obtained in several years. Thus the proposed research will advance our understanding of the oceanic velocity field and will assure the best performance for future probes.

The POLYMODE profiles consist of a series of drops simultaneous with AVP (Dunlap, Sanford and Drever, 1978) and MSR (M. Gregg's microstructure profiler), with E. Lange's survey with T-11 XBTs and over the isolated Caryn Seamount. At this time, so soon after the cruise, we have only looked at

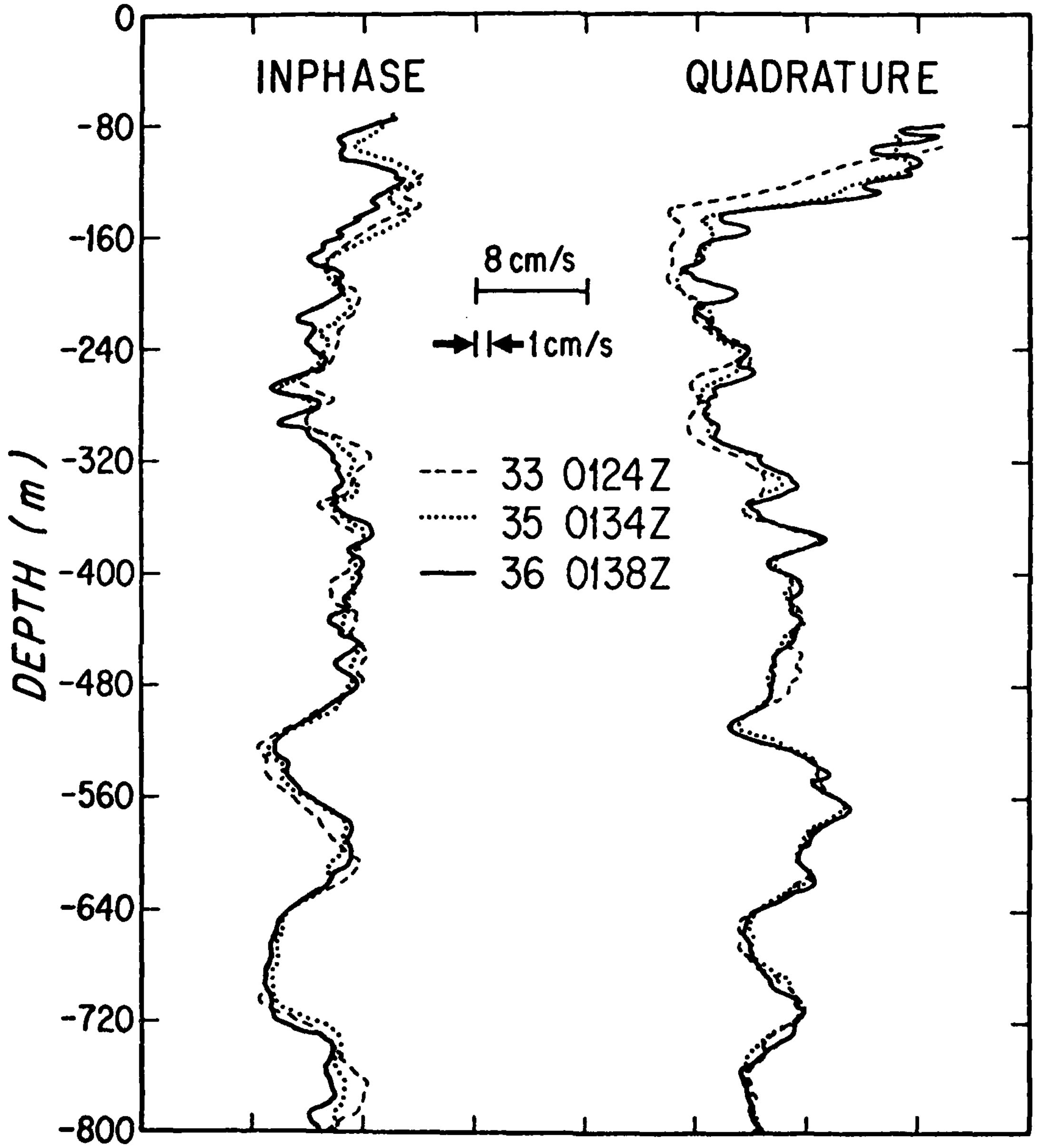

Figure 6. Inphase and quadrature velocity components for three closely spaced drops. Agreement is better than 1 cm sec^{-1}, where 1 cm sec^{-1} equals about 50 nanovolts at the probe electrodes.

the XTVP profiles over the Caryn peak and find there a very unusual, inertial frequency feature which seems to be associated with the seamount. That the inertial wave was wind-driven, being at the surface several days earlier, is an interpretation which is not consonant with our understanding of the large horizontal scale of wind-driven inertial waves. This wave was only observed within ~ 15 km of the seamount and then only extending on one direction from the peak. Presently we believe that the observed waves are generated by flow past the seamount. Using the AVP profiles to establish the flow onto the peak, we intend to examine the mechanisms of lee wave generation and internal wave-mean shear interaction. We also will investigate whether there is an observable stratified Taylor column on this peak (Hogg, 1973).

The comparison of shear measurements from FAME has progressed, but we find that shear spectra from different instruments differ by factors of 2-3. Regardless of how these differences are resolved, we think that the combined shear measurements should be published. From the EMVP we find a power law at low wave number of about -.5, but at a wavelength of about 10 m, the EMVP and Williams's SCIMP reveal a sharp spectral break with low shear until the microstructure region (~ 1 m and less) where large shears are found by Gargett.

In 1979 we propose to complete the analysis and description of the joint shear measurements and to study the near-island shear field. In particular, Drs. Sanford and Johnson will investigate the structure of shear around Bermuda, looking for evidence of anisotropy, such as more shear in the upslope velocity component compared with the along-slope component. We have found structural differences in shear as a function of distance to the island (Hogg, Katz and Sanford, 1978). However, we do not understand the causes or physical explanations for the observed differences. We hope to resolve whether or not the observed anisotropy is due to, for example, refraction as toward-island waves encounter the shoaling bottom, to internal wave-mean shear interaction, or to local generation such as at the sea floor.

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Stern, Melvin E., 1977. Interaction of inertia-gravity waves with the wind. Journal of Marine Research, **35**, 479-498.

Personnel

R. G. Drever is in charge of the development and testing of the expendable probes and the surface processing system.

J. H. Dunlap, a computer programmer, will assist T. B. Sanford.

C. H. Johnson, a Postdoctoral Investigator, will analyze and describe data from past EMVP drops and the POLYMODE XTVP drops.

Major Equipment and Supply Items

The shipping costs consist of expenses involved in shipping this program's equipment to the University of Washington, Seattle. This program has extensive instrumentation which will be taken with the principal investigator to his new appointment.

Travel

The international travel consists of a trip to England to attend a JASIN post-experiment meeting and to Australia to attend the IUGG assembly. The JASIN trip is contingent upon whether we participate in the experiment. At the IUGG meeting I expect to present a paper reviewing the profiler results.

Oceanic Variability and Dynamics

12 months period
1 January - 31 December 1979

			ONR Man Months	Actual Man Months
Professionals:				
T. B. Sanford	Principal Investigator		4	4
R. G. Drever	Research Specialist		1	1
J. H. Dunlap	Research Associate		6	6
C. L. Johnson	Post-Doctoral Investigator		12	12
Support Personnel:				
E. A. Denton	Senior Research Assistant		2	2
TBA	Secretary		2	2
A. 1.	Gross Regular Salaries (includes allowance for vacation, holidays, sick pay, etc. of $4,096 which is accounted for as employee benefits)		$41,187	
2.	Cruise Leave, Sea Duty Vacation & Overtime (includes Premium Pay of $ 0)		0	
	TOTAL			$ 41,187
B.	OTHER EMPLOYEE BENEFITS			11,482
	TOTAL SALARIES AND BENEFITS			52,669
C.	PERMANENT EQUIPMENT			--
D.	EXPENDABLE SUPPLIES AND EQUIPMENT			500
E.	TRAVEL			
1.	Domestic		3,517	
2.	Foreign (see attached)		4,934	8,451
F.	PUBLICATION COSTS			
1.	Graphic Services: 40 hours @ $13/hr		520	
2.	Page charges: 20 pages @ $80/pg		1,600	
4.	Reprint costs		200	2,320
G.	SHIP COSTS			--
H.	COMPUTER COSTS			
1.	Sigma 7: 120 hours @ $155/hr		18,600	
2.	H.P.: 80 hours @ $25/hr		2,000	20,600
I.	MISCELLANEOUS			
1.	Shop Services: 40 hours @ $13/hr		520	
2.	Programming		--	
3.	Shipping and Communication			
	a. Shipping gear to Seattle by truck	$3,000		
	b. Communication	800	3,800	
4.	Laboratory overhead		11,060	15,380
J.	TOTAL DIRECT COSTS			99,920
K.	INDIRECT COSTS @ 15% of Total Direct Costs			14,988
L.	TOTAL COSTS			$114,908

E. TRAVEL

1. Foreign

1 round trip Boston to Surrey	$ 829	
1 car rental	70	
14 days travel expenses @ $39/da	546	
(Sanford to attend meeting on results of JASIN)		$1,445
1 round trip Canberra, Australia	2,222	
1 car rental	70	
21 days travel expenses @ $57/da	1,197	
(Sanford to attend IUGG meeting)		3,489
TOTAL FOREIGN TRAVEL		$4,934

4. LARGE-SCALE CIRCULATION

Bruce A. Warren

(617) 548-1400, ext. 537

Abstract

Support is requested to work up and publish results from a hydrographic section across the Indian Ocean at Lat. 18°S, and to make two lines of hydrographic stations in the Central Basin of the Indian Ocean. The purposes of the latter are (a) to improve the general coverage in an area where few observations have been made; (b) to determine whether the deepest water in the Central Indian Basin enters from the West Australian Basin across low-latitude saddles on the Ninetyeast Ridge; and (c) to find out with more assurance than the data at 18°S permit whether mid-depth water is flowing northward along the eastern flank of the Central Indian Ridge, perhaps as a third deep western boundary current in the Indian Ocean.

Long-Range Scientific Objectives

The general objective of the principal investigator is to explore and interpret features of the large-scale ocean circulation and associated distribution of properties. These interests include the pattern and rate of deep circulation in the world ocean, the structure, behavior, and dynamics of the major ocean currents, and effects of bottom topography on oceanic flow. The long-range objectives are not specific, but relate to continued research in these areas.

Present Status and Progress over the Past Year

During April-June 1972 the R.V. *Chain* of W.H.O.I., the C.S.S. *Hudson* of the Bedford Institute of Oceanography, and the R.V. *Cirolana* of the Lowestoft Fisheries Laboratory conducted a survey of the region between the Grand Banks of Newfoundland and the Mid-Atlantic Ridge, including a grid of hydrographic stations, and two long lines of near-bottom current-meter moorings across the Gulf Stream and North Atlantic Current respectively. A long deferred manuscript reporting and discussing those data was completed in the present contract period by R. A. Clarke, R. F. Reiniger (both from Bedford), and myself; and it has been submitted to *Deep-Sea Research*.

The purpose of the expedition was to map the property distributions and current field where the Gulf Stream branches, in greater detail and with less ambiguity than hitherto; that material is described in the manuscript. Worthington's hypothesis that the current system there is not a branching Gulf Stream but portions of two separate (and non-geostrophic) gyres is criticized at length in terms of the observed property distributions; it is shown that, given a moderate degree of lateral mixing, they are consistent with the branching, geostrophic flow field, and that there is no need to abandon established physics in order to rationalize them. The deep motions recorded by the current meters on the line across the North Atlantic Current were very roughly suggestive of the prevailing flow field inferred at shallower levels, but no evidence of the Gulf Stream was found on the other line: rather, a burst of low-frequency eddy flow which masked any prevailing extension of the Stream into the near-bottom water. It had been hoped to use the current records to make better estimates of long-term mean transports than from the thermal-wind relation alone, but the large-amplitude eddy noise frustrated the attempt; synoptic estimates were made, but it seems unlikely that they represent well the long-term mean.

In July-August 1976 the Atlantis II occupied the first hydrographic section across the Indian Ocean (at Lat. 18°S) with density of observations comparable to that of the I.G.Y. sections across the Atlantic and the Scorpio sections across the South Pacific. Reduction and editing of those data are complete, and they have been deposited at the National Oceanographic Data Center. Two short reports have been published concerning some of these results, but the major publication is to be a set of large color plates (like the Scorpio plates) illustrating the property distributions observed along Lat. 18°S, accompanied by a text describing and interpreting the features. First-draft profiles of temperature, salinity, potential density (σ_θ), and the concentrations of dissolved oxygen, silica, and phosphate have been completed as of this writing (June 1978). Analysis for dissolved-nitrate concentration was also done on the cruise, but, as described in last year's proposal, during most of the cruise the analyses were done with a buffering solution that gave poor results. I have made various attempts to "correct" those measurements in terms of later analyses with a "good" buffer, but none of them worked out, and I was forced to reject most of the nitrate data. Consequently no transindian nitrate profile can be prepared.

Program for 1979

I. Transindian Hydrographic Section

I expect to have the profiles of temperature, salinity, oxygen, silica, phosphate, and potential density for the Atlantis II section across the Indian Ocean at 18°S drafted and inked in final form by the end of 1978. At that time bids will be sought for printing them in color in the style of the Scorpio plates, and the printing job will be done in 1979. At the same time I shall prepare a manuscript attempting to describe and interpret features of the property distributions illustrated by the color plates. Tentative arrangements have been made for publishing this material in Deep-Sea Research, with the editor keeping the option, of course, of rejecting it if he finds the manuscript wholly unacceptable.

I estimate, very roughly, that the cost of the color printing will be about $10,000. No support is requested for that in this proposal, because, as I explained in last year's proposal, there is enough surplus money in my contract from previous years to cover that expense. I again request permission to retain that surplus and use it for this purpose.

II. Hydrographic Stations in the Central Indian Basin

A. Deep Circulation of the Indian Ocean

The Indian Ocean, while smaller than the Atlantic or Pacific, has a more elaborate ridge system than either of the other two. Deep flow is thereby constrained to negotiate a more complex sequence of basins, and its delineation, accordingly, requires a comparably greater density of observations. The present coverage of observations vis à vis that for the Atlantic, however, is still of the opposite quality.

Figure 1, based mainly on a critical data review by Worthington and Day, designates approximately the degree-squares in the Indian Ocean in which at least one good-quality, deep hydrographic station has been occupied. "Deep" here means below 4°C (roughly 1500 m), and "good-quality" refers principally to salinities of modern conductivity standards. The chart is based on all data available from the National Oceanographic Data Center as of November 1973, with the addition of stations from (a) Conrad Cruise 17 in the southwestern Indian Ocean (January-April 1974), (b) the Atlantis II section along Lat. 18°S (July-August 1976), and (c) the GEOSECS Indian Ocean Expedition (January-April 1978). This presentation gives no idea of the adequacy of coverage in "occupied" degree-

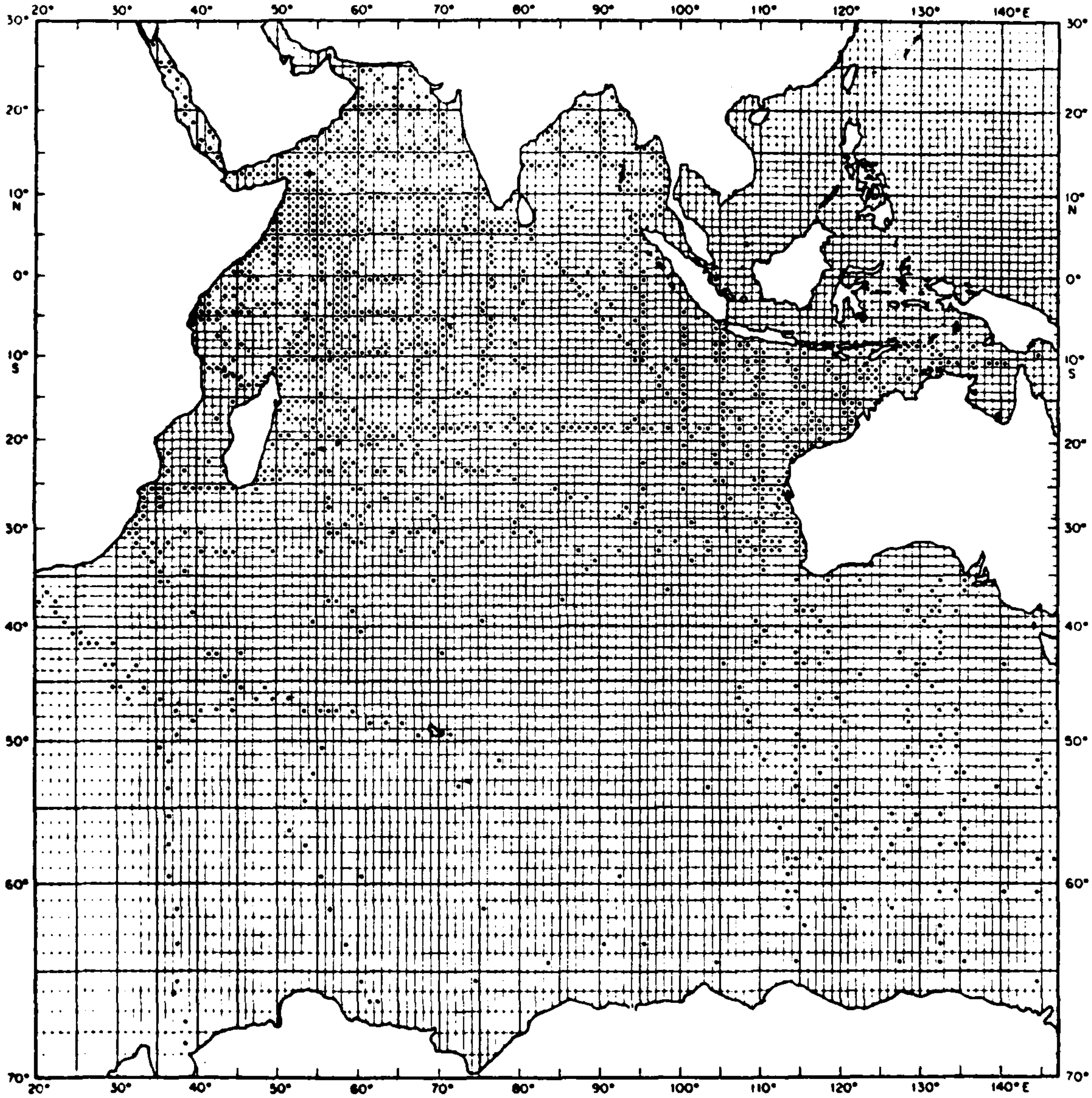

Figure 1. Degree-squares in the Indian Ocean in which at least one deep hydrographic station of modern standards has been occupied.

squares, of course, but it does show what a large portion of the Indian Ocean hasn't even a single good station. It shows as well that the greatest blank in Indian Ocean coverage north of the Southern Ocean is the Central Indian Basin (roughly 10°N - 30°S, 75-90°E), to which this proposal is directed.

All deep water in the Indian Ocean derives from the Southern Ocean, and it has been established that deep water west of the Central Indian Ridge (see Figure 2 for place names) is supplied by a deep boundary current flowing through the Crozet Basin, and then adjacent to Madagascar; while deep water east of the Ninetyeast Ridge is supplied by a boundary current flowing northward against the Ninetyeast Ridge. Between these ridges, in the Central Indian Basin, the deep flow system is much less certain. About the only data that give much indication of it are from the Atlantis II 18°S section, but when those stations were made, I had no idea what to expect in that basin, and the resulting station distribution does not define the flow features found with as much clarity as one would like.

Nevertheless, the indications are of a two-layered deep flow system there. The water at depths > 3500 m is slightly colder, fresher, and richer in dissolved-oxygen concentration in the eastern part of the basin than in the western; and these are diagnostics of water that has come comparatively recently from the Antarctic. It is not known whether there are passages through the southern boundary of the Central Indian Basin that are deep enough to admit a direct northward flow from the Antarctic at such levels, but in any case such an equatorward interior flow would not make dynamical sense in terms of deep-circulation theory (equatorward flow is "supposed" to occur only in relatively narrow western boundary currents). There are, however, deep saddles (depth 3500-4000 m) across the Ninetyeast Ridge at Lats. 3°S and 10°S (and only there), and it seems more likely to me that "Antarctic" water spills over those saddles from the deep boundary current on the other (eastern) side of the Ridge to supply a dynamically-consistent southward interior flow in the Central Indian Basin; and that that is the explanation for the relatively "Antarctic" character of the very deep water in the eastern part of the basin. Unfortunately, there is very little evidence available to tell whether the hypothesized overflow really exists.

At lesser depths, 2500-3500 m say, the 18°S section shows a pattern of isotherms and isopycnals sloping downward to the east above the eastern flank of the Central Indian Ridge. In the western half of this zone of sloping isopycnals, moreover,

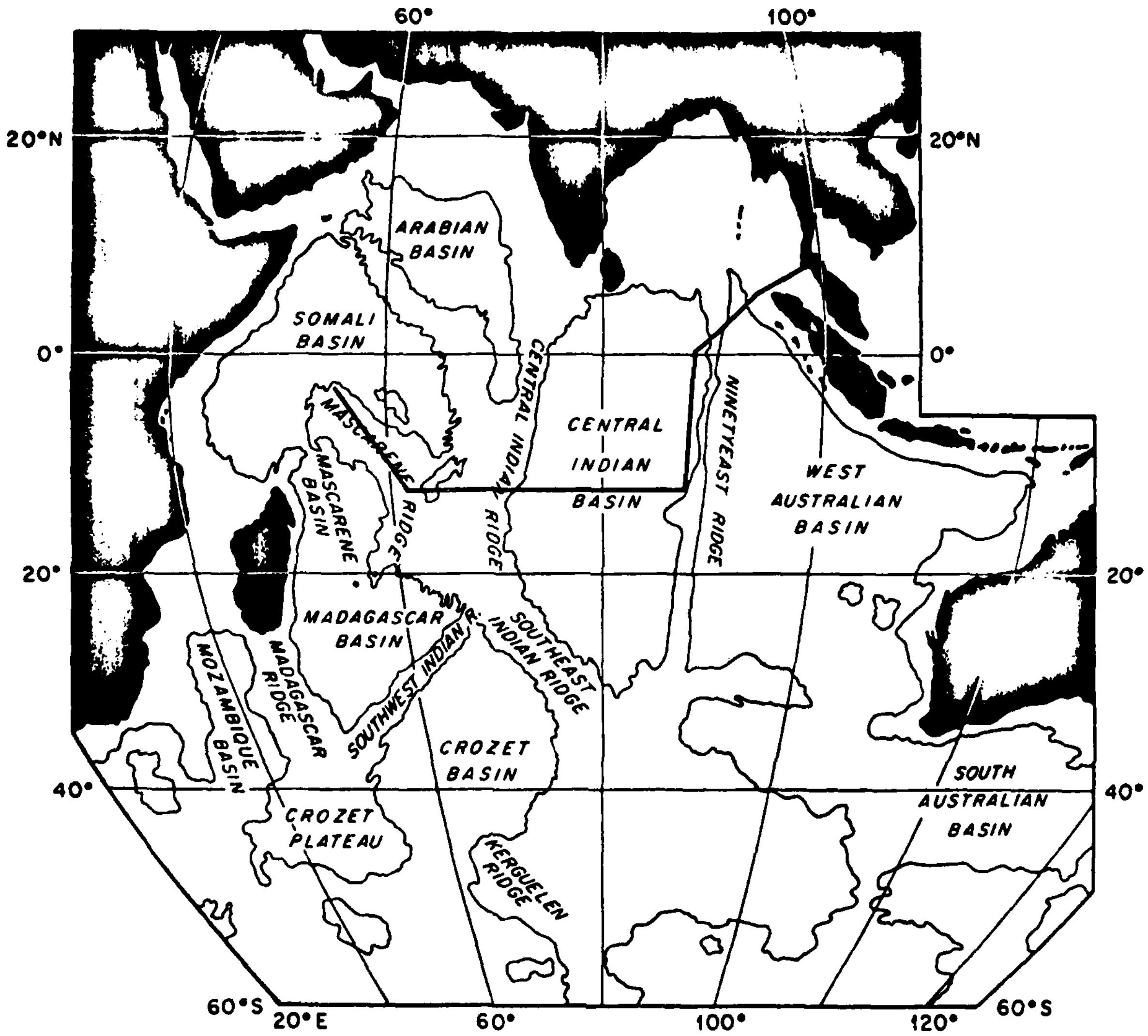

Figure 2. Proposed cruise track for R.V. Thomas Washington, 24 April - 23 May 1979; Port Victoria, Seychelles, to Phuket, Thailand.

oxygen values are slightly higher, and silica values slightly lower--diagnostics of Antarctic influence--than in the central part of the Basin at the same temperatures. This combination of features suggests a third deep western boundary current for the Indian Ocean, this one supplying water from the Antarctic to the Central Indian Basin at depths of 2500-3500 m; and certainly the southern boundary of the basin is deep enough to permit direct northward flow from the Antarctic at such levels. This interpretation is rather uncertain, however, because the temperature/density field has quite a different shape from that in the deep currents just east of Madagascar and the Ninetyeast Ridge, including a zone of reverse slope in those isopleths immediately adjacent to the Central Indian Ridge. Is it perhaps that the boundary current structure here is altered by the much gentler slope of the Central Indian Ridge (in comparison with that of the Madagascar platform or Ninetyeast Ridge), or perhaps that a boundary-current interpretation is just wrong? As implied above this unexpected structure was not well defined by the *Atlantis* II station spacing, and a sharper picture of it needs to be established for consideration of these points. Also, the cited differences in oxygen and silica concentrations are quite small, the data points are few, and more observations are needed to be sure that those features are real. Until more stations are occupied in the Central Indian Basin, then, this picture of the deep circulation there, with a low-latitude source for the bottom water and a high-latitude source for the mid-depth water, must be considered quite tentative.

B. Proposed Research

It seems to me that, as discussed above, the Central Indian Basin is the part of the Indian Ocean where we are least clear at present about the nature of the prevailing deep circulation. It is also the region most barren of good, deep hydrographic-station coverage (excepting the Southern Ocean), as shown by Figure 1. For these related reasons, I believe that it is the area of the Indian Ocean where it is most important now to extend our station coverage. Moreover, there are enough suggestions about the deep flow there, as discussed above, to plan critical sets of stations designed to settle important points about it.

I propose therefore to make about forty stations in that basin in 1979, these to be CTD casts combined with rosette sampling and Nansen bottle casts, to make measurements at thirty-forty levels per station of temperature, salinity, and the concentrations of dissolved oxygen, silica, phosphate, nitrate, and nitrite. The cruise track is illustrated in Figure 2. My plan is to make (a) a zonal section of about twenty-five stations across the basin along Lat 12°S, and (b) a meridional section of about fifteen stations just west of the Ninetyeast Ridge, from 12°S to the equator. The purpose of (a) is to confirm and define in better detail the circulation features that were seen somewhat dimly on the Atlantis II 18°S section, especially the apparent mid-depth boundary current along the Central Indian Ridge. (For the sake of overall station coverage alone, it would probably be better to occupy this section somewhat farther to the north, but the horizontal density gradients indicative of flow become smaller and much less readily discernible close to the equator; 12°S is a trade-off.) The purpose of (b) is to settle whether the bottom water of the basin originates from overflow across the Ninetyeast Ridge at Lats. 3°S and 10°S. Water entering the basin across those saddles would be easily detectable in low temperatures and salinities and high oxygen concentrations, and it ought to be possible to answer the question unambiguously.

This work has been tentatively scheduled for 24 April - 23 May on a leg of the Mariana Expedition of the R.V. Thomas Washington, running from Port Victoria, Seychelles, to Phuket, Thailand. The leg has been planned in collaboration with Susumu Honjo (NSF supported) of W.H.O.I., who, on an earlier leg of this expedition, will have deployed instruments for measuring carbonate-dissolution rates near 0°, 90°E; after my hydrographic stations are completed we would recover those instruments while en route to Phuket. This is an efficient and economical combination of forces, because Honjo and I have agreed that of the 33 days of ship-time required (including time in port), support for 12 days should be requested from NSF, and support for only 21 from ONR. That division was calculated in proportion with the amount of time Honjo would need to go from Port Victoria to Phuket if unencumbered with my program (17 days), and the amount of time I would need without Honjo's recovery work (30 days). Furthermore, Honjo will need to send three people to undertake his recovery operation, and since they would have nothing to do for him before then, they would be available to stand watches in my program. We have agreed to pro-rate their shipboard salaries (12 days to NSF, 21 to ONR) in the same way as the ship-time costs; Honjo's grant will assume their travel expenses.

In addition to these major programs, ancillary programs mandated by Scripps would also be carried out: neuston tows and underway echo-sounding and magnetics.

C. Personnel

The work proposed requires a sea-going staff of thirteen people. Three watches of three individuals each are needed. These would be headed by Warren (chief scientist), R. J. Stanley (who would also do the oxygen titrations), and W. Boicourt (guest investigator from The Johns Hopkins University, for whom travel but not salary support is requested); and staffed by two members of the W.H.O.I. CTD Group (R. Millard and one other, who would undertake overall responsibility for CTD operations as well as stand watches when needed), by Honjo's recovery team (J. Connell, R. Keir, P. O'Malley), and one assistant as yet unidentified. Z. Mlodzinska, assisted by two as yet unidentified individuals, would carry out Auto-Analyzer processing of the nutrient samples. G. P. Knapp would do the salinity analyses and the processing of the Nansen-bottle data. Stanley, Knapp, and Warren would also be spending time on pre-cruise preparations and on working up the results after the cruise. Shore-based CTD support requires instrument preparation by M. Swartz, cruise preparations by the as yet unidentified CTD technician, post-cruise data processing by R. Millard and N. Galbraith, CTD calibration by K. Schleicher, and computer maintenance by a computer technician.

D. Equipment

Most major equipment is available at W.H.O.I. (CTD fish, Rosette sampler, oxygen sensor, and computer; salinometers; Nansen bottles; thermometers; bottom-finding pingers). Back-up Nansen bottles will be borrowed from Scripps, as well as an Auto-Analyzer, in order to make the single unit at W.H.O.I. available for simultaneous work in the North Atlantic.

As this project's fair-share contribution towards general upkeep of our CTD Group's instrument inventory, money is requested to buy a time-base generator, resistance box, and memory multiplexor board.

E. International Travel

Support is requested for nine trips, Woods Hole to Port Victoria, and ten trips, Phuket to Woods Hole. Z. Mlodzinska will be doing nutrient analyses for W. Deuser on the previous leg of the cruise (Colombo to Port Victoria) and her outbound travel expenses would be borne by Deuser's NSF grant. As mentioned above, travel expenses for J. Connell, R. Keir, and P. O'Malley will be assumed by Honjo's NSF grant. Support is also requested for Warren to attend the I.U.G.G. meeting in Canberra (December 1979) to give an invited paper on the Antarctic contribution to the world ocean.

F. Ship Costs

The basic daily rate for the Thomas Washington has been set for the first half of 1979 at $5837. To this must be added $190/day for the required resident technician, and $370/day for a required computer technician. With 10.8% Scripps overhead, the total cost for the Washington comes to $7086/day. It is requested that these funds be supplied directly to Scripps; they are listed in this budget for information purposes only.

G. Other Major Budget Items

Although costs for CTD Group participation in this project are itemized in the budget, accounting for nutrient analysis at W.H.O.I. is done in terms of a facility, and a bulk charge for that support is entered in the budget.

The shipping cost is very high. This is unavoidable because the Washington will be at sea on the Mariana Expedition for a long time (July 1978 - September 1979), and there is too much demand for our limited stock of major equipment to put most items on the ship in San Diego and leave them aboard for the duration of the expedition. All CTD gear, salinometer, Auto-Analyzer, pingers, W.H.O.I. Nansen bottles and thermometers, and various lesser items must be air-freighted to and from the ship. Back-up Nansen bottles on loan from Scripps, as well as standard water and most chemicals, will be put aboard in San Diego for departure in July 1978 (money to pay for the chemicals and standard water is available in my 1978 contract, and no funding for that expense is requested in this proposal). Costs for the outbound shipment of equipment to be used on both Deuser's leg and mine have been included in his NSF proposal; costs for the return shipment are listed here. The shipment to Port Victoria would consist of 3900 lbs of gear, valued at $79,530. The 1978 shipping cost is $2.29/lb, to which must be added $0.10/lb for trucking from Woods Hole to Boston and customs brokerage fees; it is recommended that 16% be added for cost increases in 1979. With an additional 2% of cargo value for ship's agents fees, the total cost is $12,394. The shipment from Phuket to Woods Hole would consist of 5873 lbs of gear, valued at $136,832. The 1978 air freight cost, Bangkok to Boston, is $1.54/lb; with additions as above, plus an estimated $1000 for trucking from Phuket to Bangkok, the total cost of the return shipment is figured as $14,896.

Large-Scale Circulation

12 months period
1 January - 31 December 1979

		ONR Man Months	Actual Man Months
Professionals:			
B. Warren	Principal Investigator	11	11
R. Keir	Post-doctoral Investigator	.7	.7
Support Personnel:			
K. Schleicher	Research Specialist	.5	.5
R. Millard	Research Associate	2	2
R. Stanley	Senior Research Assistant	5	5
J. Connell	Research Assistant	.7	.7
N. Galbraith	Research Assistant	1	1
G. Knapp	Research Assistant	3	3
D. Moore	Research Assistant	3.5	3.5
P. O'Malley	Research Assistant	.7	.7
M. Swartz	Research Assistant	2.5	2.5
TBA (Three)	Research Assistants (2 months ea)	6	6
TBA	Computer Technician	.5	.5
TBA	Secretary	2	2

A.	1. Gross Regular Salaries (includes allowance for vacation, holidays, sick pay, etc. of $4,657 which is accounted for as employee benefits	$ 60,912	
	2. Cruise Leave, Sea Duty Vacation & Overtime (includes Premium Pay of $2,071)	9,439	
	TOTAL		$ 70,351
B.	OTHER EMPLOYEE BENEFITS		22,934
	TOTAL SALARIES AND BENEFITS		93,285
C.	PERMANENT EQUIPMENT		
	1. Time base generator H.P. Mod. 12-539C	550	
	2. Resistance box, Gen. Radio #1433C	550	
	3. Memory Multiplexor Board, NBIS	644	1,744
D.	EXPENDABLE SUPPLIES AND EQUIPMENT (see attached)		6,962
E.	TRAVEL		
	1. Domestic (see attached)	1,595	
	2. Foreign (see attached)	30,077	31,672
F.	PUBLICATION COSTS		
	1. Graphic Services: 80 hours @ $13/hr	1,040	
	2. Reprints (Deep-Sea Research)	50	1,090
G.	SHIP COSTS 21 days Thomas Washington - $148,806 (for information only)		
H.	COMPUTER COSTS		
	1. Sigma 7: 32 hours @ $155/hr		4,960
I.	MISCELLANEOUS		
	1. Shop Services: 80 hours @ $13/hr	1,040	
	2. Programming: 40 hours @ $19.60/hr	784	
	3. Shipping, Communication, and Postage	27,590	
	4. Laboratory Overhead	19,155	
	5. Xerox Charges	200	
	6. Nutrient Facility	5,950	54,719
J.	TOTAL DIRECT COSTS		194,432
K.	INDIRECT COSTS - 15% of Total Direct Costs		29,165
L.	TOTAL COSTS		$223,597

D. EXPENDABLE SUPPLIES AND EQUIPMENT

1. Vacuum pump for oxygen titration		$ 150
2. Glassware & hardware for oxygen titration		352
3. W.H.O.I. stockroom charges		1,150
4. Miscellaneous supplies (shop cord, clips, screws, nuts, etc.)		500
5. CTD supplies:		
a. H.P. computer supplies	$225	
b. W.H.O.I. stock room charges	200	
c. Supplies for instrument maintenance	500	
d. Two Beckman O_2 sensors @ $225/ea	450	
e. One NBIS conductivity cell	400	
f. O_2 thermistor	265	
g. 90 1/2" digital tapes @ $10/ea	900	
h. 45 1/4" audio tapes @ $13/ea	585	
i. General oceanics bottles Two 1.2 liter @ $135/ea One 1.7 liter @ $200/ea	470	
j. Vector underwater connectors	340	
k. One case standard water	125	
l. Calibration facilities supplies	100	
m. Mecca connectors	250	4,810
TOTAL EXPENDABLE SUPPLIES		$6,962

E. TRAVEL

1. Foreign

9 round trip Boston - Port Victoria Seychelles; Phuket, Thailand-Boston 8 economy @ $2,246/ea 1 first class @ $3,555 (for handi-capped)	$21,523	
1 way - Phuket to Boston	1,711	
5 round trip Woods Hole to Boston (car rental) @ $70	350	
airport tax @ $10/round trip	95	
57 days travel expenses (9 people join and 10 return for cruise)	3,536	27,215
1 round trip Boston to Canberra, Australia	2,222	
1 car rental	70	
10 days travel expenses @ $57/da (Warren to attend IUGG meeting)	570	2,862
TOTAL FOREIGN TRAVEL		$30,077

5. WATER MASS FORMATION AND WORLD WATER MASS CENSUS

Valentine Worthington

(617) 548-1400, ext. 487

Abstract

The energy exchange for the Atlantic and Indian Oceans and their adjacent seas is completed and will be published in 1979. The world water mass census has also been completed as far as existing data permit. These results will also be published next year. A paper defending the two-gyre hypothesis (Worthington, 1962, 1976) is in preparation and should be completed in the current year. Recent developments in the hydrography of the western North Atlantic will be the subject of a paper to be written in 1979. It will deal with substantial changes in the hydrographic regime brought about by the recent severe winters. A modest beginning of a field program to investigate large-scale fluctuations in Gulf Stream volume transport is proposed.

Long-Range Scientific Objectives

The principal investigator hopes to study the water masses of the world oceans and to learn as much as he can about the rate at which they are formed. He intends to produce an atlas which will include a fine scale census of the volume of these water masses. Since water masses are formed by the action of the atmosphere on the sea surface, he intends, with A. F. Bunker, to calculate the energy exchange between the oceans and the atmosphere. In particular, he wishes to investigate the effect of short term changes in atmospheric circulation on the physical characteristics of the oceans' upper layers, a region of interest to the Navy. He wishes also to investigate the influence of these short period changes on the general ocean circulation.

Present Status and Progress over the Past Year

As reported last year, we encountered an anomaly in our computations of the heat exchange of the Mediterranean and the Red Seas, in that our computations showed a net heat gain by those seas. This cannot, in fact, take place since both these seas expel relatively cool, dense water at depth and draw in relatively warm surface water from the oceans outside. As we suspected, this anomaly was mainly caused by the dryness of the upper atmosphere over these seas which results in greater than normal transparency to infrared radiation from the ocean to space. Our revised computations have reduced this error considerably, but a small positive heat flux remains unexplained. This anomaly has caused us to recompute the heat exchanges for the Atlantic Ocean, and there are small but possibly significant changes from our original charts. As proposed, we will have computed the heat exchange of the Indian Ocean by the end of 1978.

We expect to submit a joint paper on our revised heat exchange computations for the Atlantic during this year, and A. F. Bunker will submit a paper on the infrared radiation over the Atlantic and the Mediterranean and Red Seas.

The potential temperature-salinity census of the world oceans has been completed, as far as existing data permit. A combined fine-scale potential temperature / salinity diagram for the world oceans has been prepared. As expected, the greatest part of the world ocean volume is concentrated into relatively few modes, most of them in the deep Pacific. The richest mode--$\theta = 1.1° - 1.2°$, S = 34.68‰ to 34.69‰ --contains 26 million km^3. It is almost entirely confined to the North Pacific. Each ocean has characteristic water masses that are unique to it and presumably result from different conditions of water mass formation and water mass modification within the deep basins. An exception can be seen in the North Atlantic and South Atlantic Oceans which have many modes in common--particularly in the potential temperature range 1.9 - 3.0. This is consistent with the flow of North Atlantic Deep Water across the equator (Sverdrup et al., 1942; Worthington, 1976). In the Pacific, while there is a good deal of overlap, the modes tend to be far more distinct, consistent with the recent hypothesis (Worthington, 1977) that there is little exchange between them.

While each ocean has its own unique modes, there appears to be a greater degree of kinship between water masses between the Pacific and Indian Oceans. The large-volume modes in the Atlantic are separated from the rest of the oceans by a region on the θ/S diagram in which very little water exists. In the Southern Ocean, there are many rich modes in common from the Atlantic, Pacific and Indian Ocean sectors, a result of circumpolar circulation. Work is progressing on a computer program that will enable us to present the water masses of each ocean and of the world ocean graphically in a simulated three-dimensional display. I have received and read a preprint of a paper by Clarke, Reiniger and Warren entitled "Current System South and East of the Grand Banks of Newfoundland." Much of the remainder of 1978 will be spent in responding to this paper, which resulted from a joint Anglo-Canadian-U.S. cruise to the region in 1972. (The U.S. participation in this cruise was ONR sponsored.) This paper concludes that my earlier hypothesis (Worthington, 1962) that the circulation east of the Grand Banks consists of an anticyclonic gyre separate from the Gulf Stream System is incorrect. Their conclusion is based on the assumption that a great deal of lateral mixing takes place in this region. My original hypothesis was based on the assumption that mixing was relatively unimportant in regions of vigorous cirlation, and it remains to be seen whether or not this assumption can be justified.

I have collaborated with P. L. Richardson and R. E. Cheney on a paper entitled "A census of Gulf Stream Rings--Spring 1975" (J. Geophys. Res., in press). Much of the data for this paper came from my ONR-sponsored cruise in Knorr in spring 1975.

Program for 1979

The Woods Hole share of the energy exchange computations will have been completed and the charts drafted in 1978, and we will be negotiating with Dr. Nathan Clark at Scripps to see how we can best publish an atlas of energy exchange for the world oceans. This, we hope, will replace the earlier work of Budyko (1963).

The results of the World Water Mass Census will be submitted for publication early in 1979. One of the most significant results will be the coverage chart which will show the areas where reliable deep hydrographic data is not available. We hope that this will stimulate oceanographers to accelerate the acquisition of good, deep data when the opportunity presents itself. We do not feel that the data base justifies the production of a full-scale atlas of World Water masses at this time.

In 1979 I propose to write a paper on recent developments in the hydrography of the western North Atlantic. There has been a considerable influx of new, high quality data, much of it from ONR sponsored cruises. In particular, this paper will devote itself to the big differences which can be seen in the hydrographic regime between the period 1973 - 1975 which the winters were exceptionally mild and 1976 - 1978 when they were relatively severe. It will also deal with the variability of the baroclinic Gulf Stream transport. These variations in computed transport are very large. The least transport, relative to the bottom, is 81 million m^3/sec and the greatest 153 million. I also propose a modest beginning of a field program to investigate these variations. All available data indicate that the Gulf Stream is strongest in late winter and weakest in late fall. However, there are only 35 reliable sections that reach to 2000 m and only 9 reliable sections to the bottom, most of these made in the summer. What is needed is about four sections (spring, summer, fall and winter) each year for a few years. These can be made from Woods Hole ships that are scheduled to cross the Stream in connection with other projects. Eight days of ship time are budgeted for these sections. If these sections show the expected large seasonal signal in the baroclinic transport, I will propose a program of direct measurements. There is further evidence (Worthington, 1977) that severe winters stimulate the Gulf Stream circulation, but this evidence is fragmentary at present. A program of "piggy-back" CTD and/or hydrographic sections cannot fail to throw light on this question provided that we have the same sort of variations in climate that we have experienced during the last five years.

The hypothesis (Worthington, 1972) that the Gulf Stream gets the greater part of his energy through late winter mixing has not won many converts, but I feel that it can be tested quite simply by means of these sections and by a program of direct measurements at a later date if these appear to be justified. If large variations in the baroclinic density gradients are found in the station data, it will be important to have direct measurements both when these gradients are strong and when they are weak. It is conceivable that the barotropic mode is strong when the baroclinic mode is weak. If this were, in fact, the case, the net volume transport could remain unchanged.

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Personnel

A. F. Bunker will manage the meteorological program as outlined in the proposal.

R. L. Barbour will be responsible for the plotting of computer output and related data reduction.

R. J. Stanley and G. P. Knapp will participate in the "piggyback" cruises and help in data reduction.

Water Mass Formation and World Water Mass Census

12 months period
1 January - 31 December 1979

			ONR Man Months	Actual Man Months
Professionals:				
	V. Worthington	Principal Investigator	3	3
	A. Bunker	Associate Scientist	3	3
Support Personnel:				
	E. Soderland	Executive Assistant	1	1
	L. Barbour	Senior Research Assistant	9	9
	R. Stanley	Senior Research Assistant	2	2
	G. Knapp	Research Assistant	2	2
	To be assigned	Secretary	1	1

A.	1. Gross Regular Salaries (includes allowance for vacation, holidays, sick pay, etc. of $3,800 which is accounted for as employee benefits)	$37,823	
	2. Cruise Leave, Sea Duty Vacation & Overtime (includes Premium Pay of $788)	3,686	
	TOTAL		$ 41,509
B.	OTHER EMPLOYEE BENEFITS		12,038
	TOTAL SALARIES AND BENEFITS		$ 53,547
D.	EXPENDABLE SUPPLIES AND EQUIPMENT		
	1. 150 T7 XBT's @ $30.85/ea	4,628	
	2. Six rolls XBT's chart paper @ $12.03/ea	72	
	3. Miscellaneous supplies, chemical, etc.	1,000	5,700
E.	TRAVEL - Domestic		450
F.	PUBLICATION COSTS		
	1. Graphic Services: 40 hours @ $13/hr	520	
	2. Page charges: 10 pages @ $80/pg	800	
	3. Reprint Costs	50	1,370
G.	SHIP COSTS		
	1. Eight days Oceanus @ $3,433	27,464	
	2. Eight days Computer Technician @ $492/da	3,936	31,400
H.	COMPUTER COSTS		
	1. Sigma 7: 32 hours @ $155/hr		4,960
I.	MISCELLANEOUS		
	1. Service Department: 40 hours @ $13/hr	520	
	2. Programming: 40 hours @ $19.60/hr	784	
	3. Shipping and Communication	300	
	4. Laboratory Overhead	11,079	
	5. Xerox Charges	200	12,883
J.	TOTAL DIRECT COSTS		110,310
K.	INDIRECT COSTS: 15% of Total Direct Costs		16,547
L.	TOTAL COSTS		$126,857

6. OCEANIC FRONTS

Arthur D. Voorhis

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Summary Report

In the early 1960's the principal investigator and J. B. Hersey, then at Woods Hole, noticed for the first time that thermal fronts were a common surface feature of the western North Atlantic Subtropical Convergence. Since then he has spent considerable time in exploring the processes which generate these fronts and in observing how they tranport and mix properties at the sea surface. Research done by him (see Bibliography in Volume II) since the early observations has been funded entirely by the Office of Naval Research. It is rather gratifying that these interests are now shared by a number of other investigators, and, in fact, open ocean frontogenesis has become a lively subject of investigation.

Fronts occur in regions where horizontal gradients of temperature and density are present at and near the sea surface. On the largest scale in the subtropical convergence these gradients are meridional (Schroeder, 1965) and are the result of differential heat exchange with the atmosphere occurring, primarily, during the winter and late winter months. In detail, however, the surface temperature field is greatly modified by mesoscale and sub-mesoscale currents (Voorhis and Schroeder, 1976) which advect and distort the field into long tongues and plumes, thereby increasing surface gradients. This is very apparent in infrared satellite imagery. Most of the advection is passive, but this is no longer the situation when the lateral scale of the near surface density gradients is reduced much below about 10 km (approximately the Rossby radius of deformation appropriate to the near surface stability). Secondary inertial and nonlinear motions then become important (Hoskins and Bretherton, 1972; Williams, 1972). In particular, a shallow cross-gradient circulation, required to balance the accelerating flow along the gradient, intensifies and increases the gradient rapidly. In the last stage of frontogenesis, small scale motions (Garvine, in press), not too clearly understood, act to sharpen the gradients to the large values observed (1 to 2°C per 100 meters along the sea surface).

Present Status and Progress over the Past Year

At present the principal investigator is doing additional work on data from a field experiment in March 1977 in collaboration with A. Leetmaa from the Atlantic Oceanographic and Meteorological Laboratories, Miami. To date one paper has been accepted for publication (Leetmaa and Voorhis, in press), and some of the results were presented at the Oceanic Fronts Conference sponsored by ONR at New Orleans in October 1977. The observations were made in an area approximately 100 km square centered at 29°N, 69°W. The purpose was to observe and relate changes in the surface temperature field with baroclinic motions from the main thermocline to the surface with a spatial resolution extending from the mesoscale down to 10 km and with a temporal resolution sufficient to resolve possible frontogenesis. Four successive surveys were made of the area separated by one to three days with closely spaced XBT drops, continuous surface temperature sensing, and frequent surface salinity sampling. Between surveys, surface drogues were tracked in particular regions where frontogenesis was likely to occur.

The main accomplishments of our recent work are:

1. Surface frontogenesis was directly observed and the time scale was typically one to three days. A surface drogue at a depth of 15 m drifted into a frontal jet and accelerated from 30 to 80 cm sec^{-1} over a distance of about 100 km. These large speeds, however, occurred only near the surface. Another drogue at a depth of 75 m never exceeded a speed of 40 cm sec^{-1}.

2. Surface fronts not only separate water of differing temperature, salinity, and density but also water having markedly different potential vorticities. This vorticity in the upper few hundred meters was almost twice as large on the warm side of the front as on the cold. Assuming water motions conserve potential vorticity, this suggests that the upper few hundred meters, including the surface temperature field, moves as a coherent mass except for motions with quite small space and time scales, such as occur during frontogenesis.

3. Currents initiating frontogenesis appear to be due to sub-mesoscale baroclinic eddies which are most intense in the upper 300 to 400 meters. These eddies move rapidly (15 km day^{-1}), have diameters of 50 to 100 km, and persist for at least a week. Their origin is unknown.

4. Frontogenesis is irreversible. That is, fronts extract energy from the eddy field but do not give it back. Instead, it is rapidly advected away in the form of kinetic

energy by the surface jet. What happens to it is not clear, but we suspect it contributes to horizontal and vertical mixing and to internal wave generation.

5. Our data suggests that frontogenesis contributes significantly to the time-averaged surface kinetic energy budget. For this reason, estimates of 400 cm^2 sec^{-2} per unit mass made by recent investigators (Wyrtki, Magaard and Hagar, 1976) for the subtropical convergence may be too low by a factor of three or four.

Plans for 1979

The principal investigator is not requesting funds for next year. He plans to spend the period from September 1978 through August 1979 at the College of Marine Studies, University of Delaware, in Lewes, Delaware. Part of his time will be spent advising graduate students on thesis problems. The remainder will be used in completing previous work and exploring new possibilities for research. In particular, he is looking forward to collaboration with C. Mooers and R. Garvine, both at Lewes, on plans for research on fronts and with N. Huang at the nearby Wallops Island Flight Center on analysis and interpretation of sea surface topography from the SeaSat radar altimetry data.

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7. SPATIAL SPECTRA AND COHERENCE IN THE INTERNAL WAVE BAND

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Present Status and Progress Over the Past Year

When the joint Scripps Institution of Oceanography and Woods Hole Oceanographic Institution acoustic experiment was postponed, a short test cruise was made in January to investigate the in-situ performance of the Doppler-scattering acoustic current meter. By stripping off control signals and all other sensor signals from the tow system, the almost raw, Doppler-shifted frequency signal was transmitted to the ship. Analogue tapes were made for several hours of tows, and subsequent analysis has indicated that the Doppler return is almost, but not exactly, continuous. The drop-out is sufficient to explain questions about previous data. The solution is a discriminating counting system, and this will be implemented before any further work is done with the current sensing system.

The delayed acoustic experiment took place in March - April, and two series of tows were made at the site some 200 nautical miles southwest of San Diego. The first series consisted of four isopleth tows at 700 m, 450 m, 250 m and 150 m, of 6 to 8 hours duration each. The second was a yo-yo tow between 50 and 250 m which was aborted after 24 hours due to the heavy seas damaging the hydraulic system in the depth-controlling tow fish. Several attempts to repair the system at sea proved inadequate.

The region of study was found to be spatially inhomogeneous to an extreme. Analysis of the 700 m tow indicates that there were temperature inversions between the two towed sensors 10 m apart in the vertical 10% of the time. The coherence squared between the two signals drops to 0.5 at wavelengths of 2 kilometers, which is at larger scales than found on earlier tows in the Sargasso Sea and those predicted by internal wave models and suggests the influence of the inhomogeneities.

A comprehensive paper describing our five years of experience with towed bodies and sensor systems was completed. It is entitled "A Depth Controlled Tow System for Hydrographic and Current Measurements with Applications", by E. J. Katz and Warren E. Witzell, Jr., and has been submitted to Deep-Sea Research for publication.

VI. GULF STREAM RINGS

INTERDISCIPLINARY STUDIES

CYCLONIC GULF STREAM RINGS

Philip L. Richardson

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Abstract

The primary objective of the proposed work is to measure the movement of Gulf Stream rings and their changes with time. During 1979 I plan to concentrate on the analysis of data obtained during the interdisciplinary ring experiment, 1976-1977. A second objective is to measure the near surface circulation in the Slope Water region using four refurbished satellite drifters.

Long-Range Scientific Objectives

The long-range objectives are to measure some aspects of the general ocean circulation in an attempt to describe and understand them. The focus has been on the Gulf Stream System and Western Boundary Undercurrent. Recent research has concentrated on Gulf Stream rings, their distribution, movement, decay and importance to the general circulation. During the next few years I plan to investigate the eastern terminus of the Gulf Stream and the pathways of its recirculation.

Present Status and Progress over the Past Year

1. Joint ring experiment

In 1977 I participated in the interdisciplinary Gulf Stream ring experiment with several other investigators. During the experiment we were able to follow from birth to death two cyclonic Gulf Stream rings. The physical oceanographic data consists of numerous XBT surveys, CTD sections, satellite drifter trajectories plus some velocity and shear profiles in the rings. Four cruises were dedicated to studying the rings, and, in addition, several other cruises were used to add important data.

Because of the large effort spent on the measurement program, I have not proceeded far with the data analysis. Most of my time has been spent with the drifting buoy data and with integrating it with the XBT data and satellite infrared images. C. Maillard spent last year analyzing the CTD data from the first cruise, Knorr 62, and we are preparing a manuscript with Tom Sanford describing our observation of

Ring Al. Ring Al formed in September 1976 and split into two rings, Al and Art, in December 1976. Art coalesced with the Stream in January, and Al coalesced with the Stream in April 1977.

The second ring we studied, Bob, formed in February 1977 and coalesced with the Gulf Stream near Cape Hatteras in September 1977. Excellent satellite infrared images clearly document Bob's formation, and a cruise on the Endeavor in September (Randolph Watts, Chief Scientist) measured Bob's coalescence with the Stream. The Endeavor XBT surveys and four drifting buoy trajectories provide good observations of Bob's recapture. During Bob's life there were six cruises which obtained measurements in Bob; these provide good data of the time evolution of Bob.

2. Ring census

A series of cruises in 1975 have provided a nearly synoptic view of the distribution and number of Gulf Stream rings in the western North Atlantic. Twelve rings were identified; nine were cyclonic (cold core) rings and three were anticyclonic (warm core) rings. This is the largest number of rings ever observed during a short period of time (four months). A manuscript summarizing these results has been prepared and submitted for publication (Richardson, Cheney and Worthington, 1978).

3. Ring tracking

Over the last several years we have tracked, with free drifting buoys, twelve rings including two warm core rings. The buoys stayed in cyclonic, cold core rings for long periods of time, up to eight months. The movement of rings is complicated and appears to be related to the Gulf Stream, other rings, and strong topographic features such as the Blake Escarpment and the New England Seamounts. The usual fate of rings was to coalesce with the Gulf Stream, and one of the following three things seemed to happen: (1) the ring turned into an open meander of the Stream and was lost, (2) the ring was advected rapidly (with speeds up to 75 cm sec^{-1}) downstream in the Stream and was probably lost, (3) the ring became attached to the Gulf Stream and then split off again as a modified ring. Evidence suggests that a ring split into two pieces and that two separate rings collided. These results were presented at the spring 1978 meeting of the American Geophysical Union (Richardson, 1978), and a manuscript is in preparation.

Program for 1979

During 1979 I propose to do three things: first, to continue the analysis of the ring data, second, to analyze the drifting buoys in the Gulf Stream, and third, to continue a small effort using free drifting buoys to measure the surface currents in the Slope Water Region.

1. Ring data analysis

We have obtained an excellent data set of several Gulf Stream rings, and I plan to spend most of my time working with these data with emphasis on the drifting buoy trajectories. We need to know the trajectories of the rings and the velocity field as the rings decayed and interacted with other rings and the Gulf Stream. I plan to continue to analyze the drifter data in combination with satellite images, XBT and CTD profiles.

2. Buoy trajectories in the Gulf Stream

As the rings coalesced with the Gulf Stream, the buoys were frequently swept away in the Stream. We have now accumulated twenty buoy trajectories in the Stream east of 60°W; six of these buoys were funded by NSF and a few others were provided by other investigators (E. Kerut, R. Weir, D. Kirwan and A. Leetmaa). I want to begin analyzing these data with the objectives of obtaining information on the path, shape and structure of the Gulf Stream east of 60°W and obtaining information on the distribution of mesoscale variability and to relate this to the general ocean circulation. Three important results have already appeared in the data. The first is that the New England Seamounts strongly affect the path of the Gulf Stream and rings are frequently seen attached to the Stream over the seamount chain. The second is that we have evidence that anticyclonic eddies (stratified Taylor columns?) were generated over and in the lee of seamounts. The third is that, as the buoys reached the region between 40 - 50°W, they spread out into what appears to be three branches. Two of these branches pass across the Mid-Atlantic Ridge, one north and the other south of the Azores. The third branch consists of a southward and westward flow. We have just relaunched three buoys in the Gulf Stream, Labrador Current and Northern Gyre confluence near the Grand Banks; these data will be important in learning about the Gulf Stream system in that region. The relaunched buoys were recovered, repowered and launched from the USCGC Evergreen and USNS Lynch.

3. Drifter measurements in the Slope Water Current

As described above, we have numerous buoy trajectories in the Gulf Stream and have just launched three buoys in the region eastward of the Grand Banks; we have no drifter trajectories in the Slope Water region except in the extreme western part, and those buoys were entrained rapidly into the Gulf Stream. During 1979 I propose to launch four drifting buoys in the eastern Slope Water Region (along 55°W) to measure the surface currents there.

The objectives are (1) to measure the dominant circulation pattern in the Slope Water region; (2) to measure the scales of motion and energy levels in order to compare them to those of the Gulf Stream and other regions; and (3) to learn how the circulation fits in (connects) with the Gulf Stream on the south and the Labrador Current, the North Atlantic Current (Mann, 1967), and the Northern Gyre (Worthington, 1976) on the east. I propose to launch two drifters in the Slope Water Current (Fuglister, 1963; Mann, 1967; McLellan, 1957) which lies along the front joining the Labrador Slope Water on the north and the warm Slope Water on the south (Lee, 1970; Gatien, 1976), and one buoy north and one south of this front.

The buoy trajectories should help shed light on the controversy of whether the Slope Water Current passes around the southern tip of the Grand Banks and joins with a branch of the Gulf Stream and forms the North Atlantic Current as suggested by Mann (1967) or whether the Slope Water Current does not pass around the Grand Banks and has no connection with the Northern Gyre, a separate and distinct gyre, as suggested by Worthington (1976).

The buoys will be launched on one of the Coast Guard Ice Patrol cruises during the spring of 1979. Two of our buoys were launched by the Coast Guard Ice Patrol during 1978, and we plan to continue our collaboration in 1979. Five cases of XBTs are requested in order to locate the Slope Water Current and to measure the temperature structure in the vicinity of the launch sites. We plan to collaborate with Paul LaViolette (NORDA) who will be working in the vicinity of the Grand Banks during the spring of 1979. I expect that buoys in the Slope Water Current will pass eastward into his region, and his measurements (XBTs, CTD, satellite observations) could be very important in interpreting the buoy trajectories and vice versa.

The proposed experiment is clearly exploratory; it will not give the definitive mean circulation patterns. It should, however, give information about a region that is poorly understood and provide pilot data to assist us in planning a larger experiment in the future. If the present data yield sufficient information, I would consider proposing a larger experiment during the 1980's.

Personnel

The research assistant will aid in processing existing data, processing drifter data which is presently being obtained, and will oversee the arrangements for launching and processing the data of the four new buoys.

Major Equipment and Supply Items

Four COSRAMS satellite-tracked buoys, similar to others used during the ring experiment, are requested. These have a nine-month life, a drogue, a drogue sensor and a temperature sensor. In order to reduce costs, I propose to obtain the four POLYMODE, Soviet-mooring-motion-detectors (BTTS) and have them converted by Polar Research Laboratory into the usual buoy configuration. This should save $1800 per buoy (as compared to the price of a new buoy). Robert Heinmiller has tentatively agreed to make the four BTTS available to me in the fall of 1978. William Conant has reported that NASA will maintain the Nimbus F tracking satellite operational through 1979 and provide the tracking data. Five cases of T-7 XBTs are requested to assist in locating the buoy launch sites and to aid in analyzing the subsequent trajectories.

Travel

I plan to spend the first half of 1979 in Paris at the Laboratoire d'Océanographie Physique at the Muséum National d'Histoire Naturelle. During that time I plan to continue working on ring data and to continue my collaboration with C. Maillard. Trips to Kiel and London to visit oceanographic laboratories and to meet foreign scientists are requested. A round trip to Woods Hole is requested so I can meet with other ring investigators and prepare co-authored publications.

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Cyclonic Gulf Stream Rings

12 months period
1 January - 31 December 1979*

			ONR Man Months	Actual Man Months
Professional:				
	P. L. Richardson	Principal Investigator	8	8
Support Personnel:				
	To be assigned	Research Assistant	8	8
	To be assigned	Secretary	1	1

A.	1. Gross Regular Salaries (includes allowance for vacation, holidays, sick pay, etc. of $3,074 which is accounted for as employee benefits)	$26,600	
	2. Cruise Leave, Sea Duty Vacation & Overtime (includes premium pay of $459)	1,489	
	TOTAL		$28,089
B.	OTHER EMPLOYEE BENEFITS		7,432
	TOTAL SALARIES AND BENEFITS		35,521
D.	EXPENDABLE SUPPLIES AND EQUIPMENT		
	1. Four refurbished PRL buoys $3,069/ea	12,276	
	2. Five cases T-7 XBTs @ $370/case	1,850	
	3. Stockroom charges	140	
	4. Satellite photographs	1,000	15,266
E.	TRAVEL		
	1. Domestic	1,016	
	2. Foreign (see attached)	2,176	3,192
F.	PUBLICATION COSTS		
	1. Graphic Services: 50 hours @ $13/hr	650	
	2. Page Charges: 12 pages @ $80/pg	960	
	3. Reprints	100	1,710
G.	SHIP COSTS		—
H.	COMPUTER COSTS		
	1. Sigma 7: 25 hours @ $155/hr		3,875
I.	MISCELLANEOUS		
	1. Shop Services: 15 hours @ $13/hr	195	
	2. Programming: 50 hours @ $19.60/hr	980	
	3. Shipping & Communication	1,000	
	4. Laboratory Overhead	7,363	
	5. Xerox Charges	100	9,638
J.	TOTAL DIRECT COSTS		69,202
K.	INDIRECT COSTS: 15% of Total Direct Costs		10,380
L.	TOTAL COSTS		$79,582

*Included in Physical Oceanography Department Budget Summary.

E. TRAVEL

1. Foreign

1 round trip Paris to Boston	$879		
1 car rental Boston - Woods Hole	70		
7 days travel expenses @ $40/da	280		
(Richardson to spend one week in Woods Hole in April)		$1,229	
1 round trip Paris - London	151		
1 round trip Paris - Kiel, Germany	266		
5 days travel expenses, London, @ $67/da	335		
5 days travel expenses, Kiel, @ $39/da	195		
(to visit oceanographic laboratories and confer with scientists there)		947	
TOTAL FOREIGN TRAVEL			$2,176

THE BIOLOGY OF GULF STREAM COLD CORE RINGS

Peter H. Wiebe
PII Redacted
[redacted]

Abstract

The major objective in the Woods Hole zooplankton research program for the coming year will be to continue the counting of most of the zooplankton samples collected on the time-series cruises. Emphasis will be placed on enumerating the euphausiids, selected copepod species, and the chaetognaths. Statistical analysis of the data will focus 1) on both the intra-species and inter-species similarities and dissimilarities in the vertical and horizontal patterns of abundance in the vicinity of cold core rings, the Sargasso Sea, and the Slope Water, 2) on the relationship between a species and the environmental parameters measured, and 3) on the elucidation of the patterns of community structure. Work will continue on the development of mathematical models which are assisting us to understand the mechanisms which cause the cold water species expatriated in rings to become extinct and which should be helpful in evaluating physical models of circulation and mixing processes.

Long-Range Objectives

To study the impact of the biological composition of rings on the general distribution and mesoscale variability of the biota within the Sargasso Sea and the effect, on the biota, of the ring environment and its changes as the ring decays. To use the information gained in the rings time-series study concerning the relationships between the biotas and their environment to reach a greater understanding about the mechanisms responsible for the regulation of biogeographic boundaries.

Work Accomplished to Date

Biological sampling of the zooplankton and phytoplankton on all four time-series cruises (December 1976, April 1977, August 1977, and October/November 1977) was successfully carried out. The objectives of the zooplankton and phytoplankton studies for all cruises were:

1) to characterize the zooplankton and phytoplankton biomass structure and species composition in the upper 1000 m across a ring

and the adjacent waters of the Sargasso Sea, and to obtain comparative information from the Gulf Stream and Slope Water region;

2) to place particular emphasis on elucidating the species composition and the distribution of species of euphausiids and of particular copepods in the high velocity region of the ring (15° isotherm depths of 150 m to 450 m, especially as they relate to the physical-chemical environment;

3) to study the biochemistry (C, H, N, protein, lipid) and physiology (respiration) of selected Slope Water species of zooplankton present in the ring core waters to examine their response to the changing environmental conditions. Although our plan was to sample the same ring on all four of the cruises, as described by Richardson in more detail above, this was impossible because target rings failed to persist for the duration of our study.

Vertical profiles of the distribution of chlorophyll and phytoplankton species in the euphotic zone were made at a variable number of locations in the vicinity of the rings sampled on the cruises and in the Slope Water. Water samples for these analyses were collected with 5-liter Niskin bottles from between 9 and 12 depths from the surface to 200 m. Bottle spacing was usually adjusted to optimize fine scale sampling in the region of the chlorophyll maximum layer. On the last cruise (KNORR 71) several vertical profiles were made with a continuous *in situ* fluorometer system. These were used to supplement the bottle cast data.

In addition to vertical sampling, on the second cruise (KNORR 65), surface chlorophyll determinations were made during several transects across the cold core rings to document surface distributions on the ring's periphery.

Samples for analysis of the vertical distribution and abundance of zooplankton were collected with MOCNESS-1, a net system with nine 1 m^2 nets which are opened and closed sequentially upon command from the surface and with a built-in CTD equipped with a dissolved oxygen sensor. The depth strata normally sampled were 1000-850 m, 850-700 m, 700-550 m, 550-400 m, 400-300 m, 300-200 m, 200-100 m, 100-0 m. In the Slope Water this plan was altered in some instances to permit the bracketing of prominent hydrographic features such as a shallow mixed layer or a strong temperature and salinity inversion layer. In these cases, wider spaced sampling intervals were used at depth and more finely spaced intervals were used near the surface. On two occasions a shallow MOCNESS-1 tow was made in which the sampling interval was 25 m intervals from 200 m to the surface.

Our areal sampling strategy involved the taking of day and night oblique tows with MOCNESS-1 at each major station in the center of a ring and in the adjacent Sargasso Sea. For the most part, night tows were taken in the high velocity-high gradient region between ring center and Sargasso Sea. Figure 1 illustrates the placement of the MOCNESS-1 tows taken on the four time series cruises.

Zooplankton biomass (as displacement volume) has been measured on all samples (total = 617) collected on the time series cruises. The volumes have been summarized in the form of vertical profiles (Figure 2 a-d). For the most part these data provide additional support for our earlier findings concerning the influence of cold core rings on the biomass distribution in the Northwestern Atlantic which were published this year (Ortner, Wiebe, Haury and Boyd, 1978). In general, for at least a year after formation, rings have a higher zooplankton biomass than the surrounding Sargasso Sea. The higher zooplankton biomass occurs in the center of the rings and progressively declines on the ring flanks. Compared to either the Sargasso Sea or the parent Slope Water, an unusually large percentage of the 0-1000 m biomass in older rings is found at depths greater than 200 m. This distribution can be related to the hydrographic and biological changes associated with ring decay.

Counting of zooplankton species in the time-series collections is well underway. A number of taxonomic groups are being enumerated both at Woods Hole and elsewhere (see section on collaborators). As in the past, we are now concentrating on sorting and counting all euphausiid species in the sample. To date we have processed approximately 40% of the samples collected in 1977. Jerry Cheney has begun the counting of the chaetognaths as part of his Ph.D. thesis research project at Woods Hole and a selected group of copepod species are being counted by Tim Cowles and Susan Hoercher.

In addition to the counting of the euphausiids several special studies involving particular species are underway. Guest student investigator, Mike Brugger, is looking at the size frequency distribution of members of the genus *Euphausia* in an effort to determine what affect rings have on the size range and growth rates of these vertical migrating species. Another guest student investigator, Chris Wood, has sorted and counted euphausiids of the genus *Stylocheiron* which were present in shallow tows (0-200 m) taken on ring cruises prior to the time-series experiment. Two species, *Stylocheiron carinatum* and *S. suhmii* are of special interest in this study because in the coarser scale samples already worked up it appears that these two congeners overlapped in their vertical distribution to a considerable degree. Since ecological theory (competitive exclusion principal) predicts this is unlikely to occur, it is of interest to see if, with finer sampling resolution, this is still the case. Although our analysis is not yet complete, our preliminary findings suggest that the centers of distribution in the upper 200 m do not overlap nearly as much as first believed.

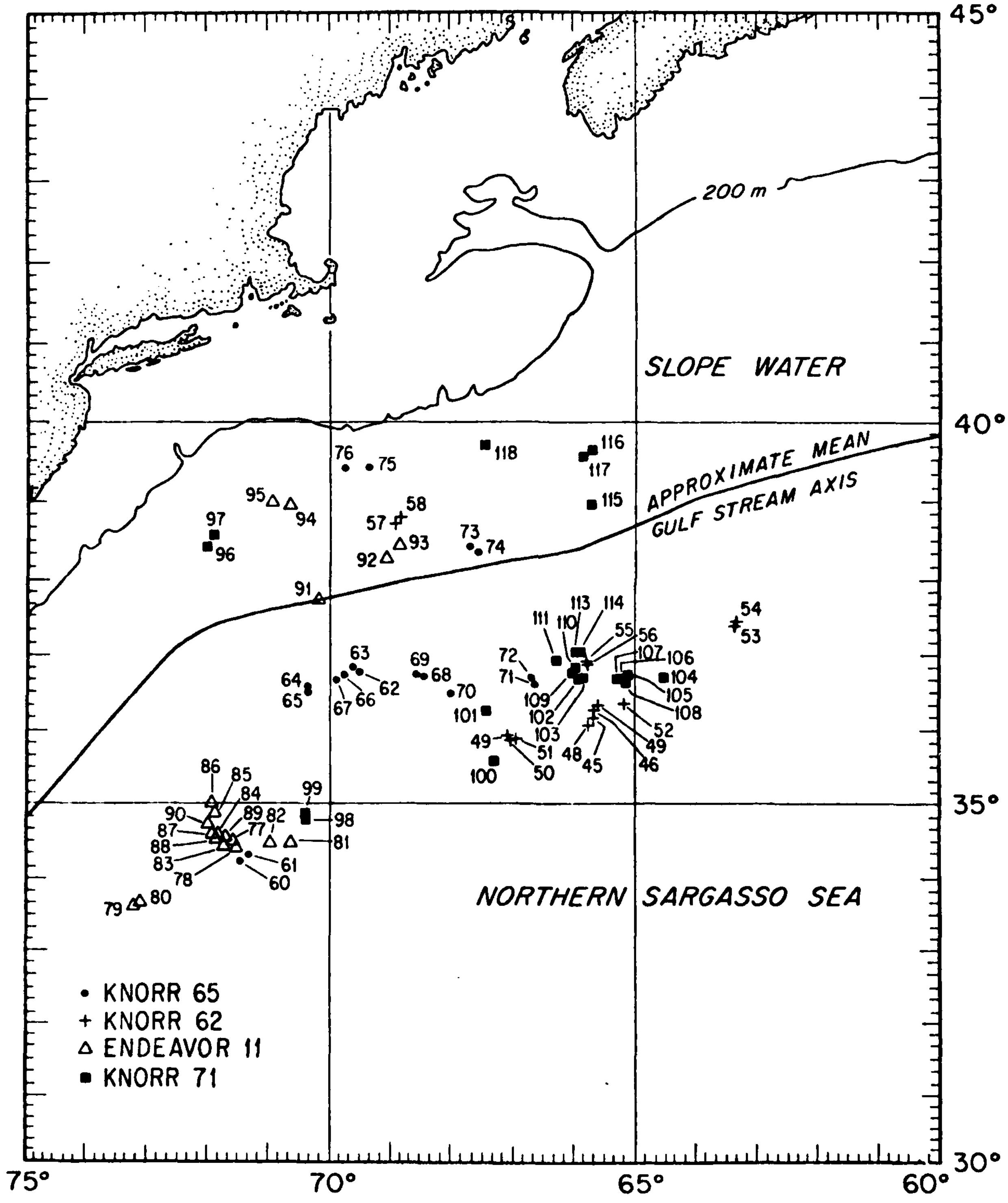

Figure 1. Distribution of MOCNESS-1 tows taken on time-series cruises.

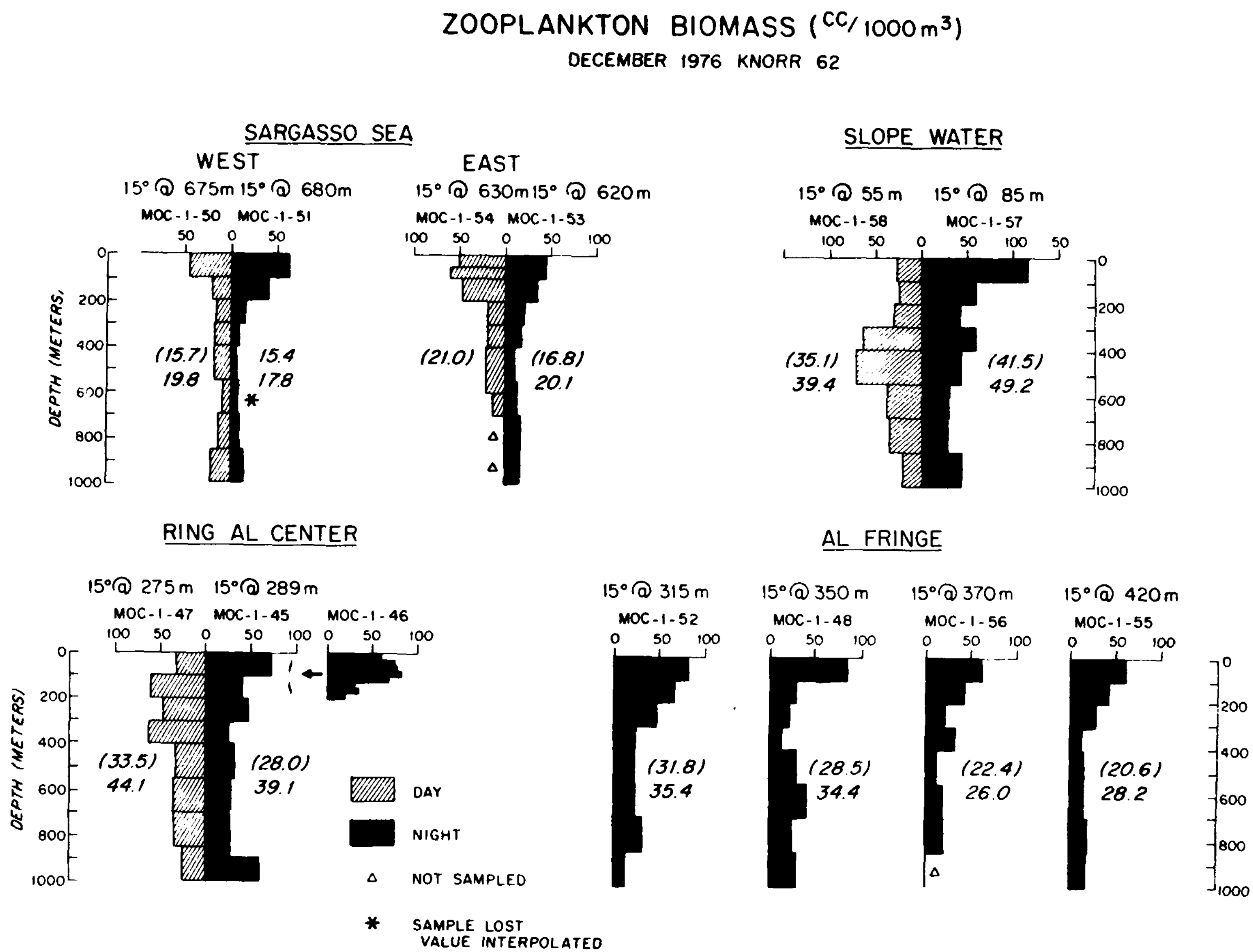

Figure 2a. R/V KNORR Cruise 62. Cold core ring, Slope Water, and Sargasso Sea zooplankton biomass values associated with each profile are cubic centimeters per square meters for the column to 800 m (top value in parentheses) and for the column to 1000 m (bottom value).

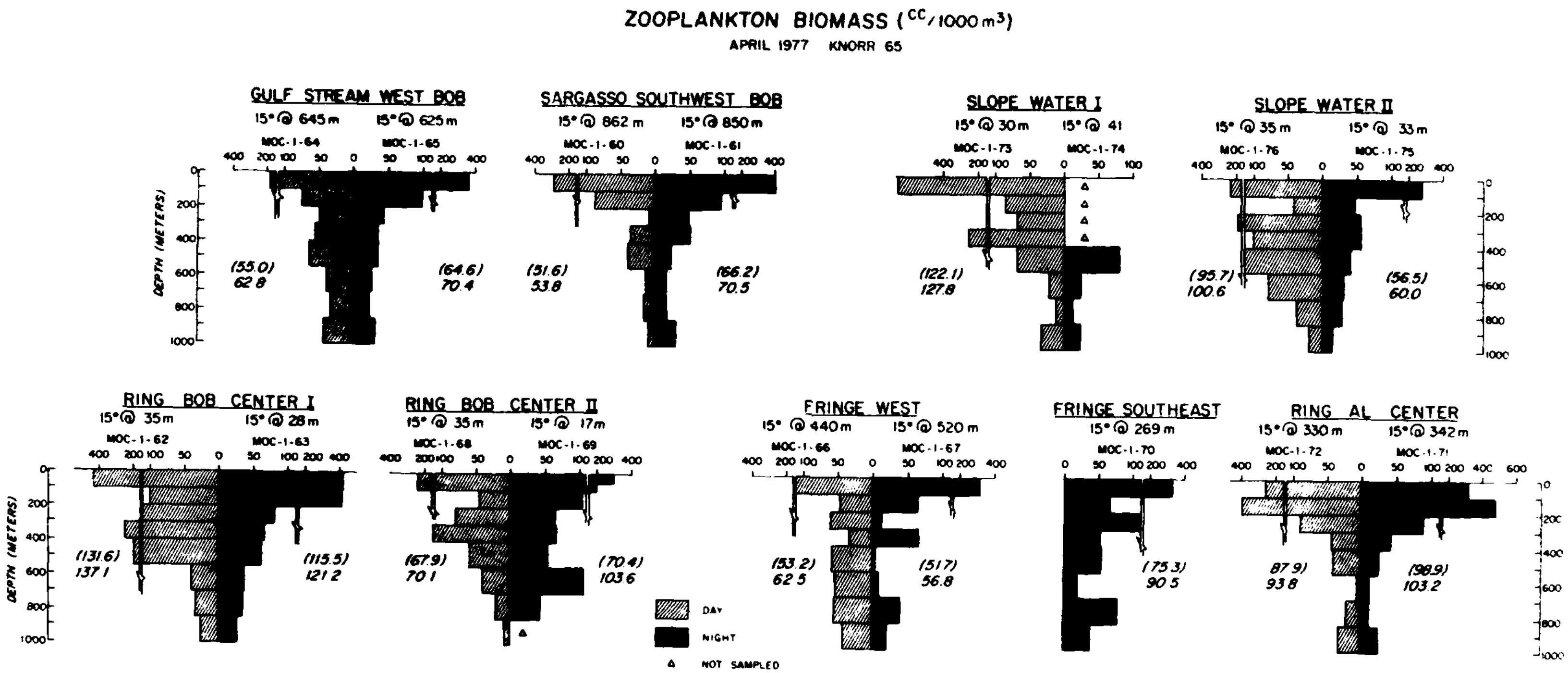

Figure 2b. As Figure 2a for R/V KNORR 65.

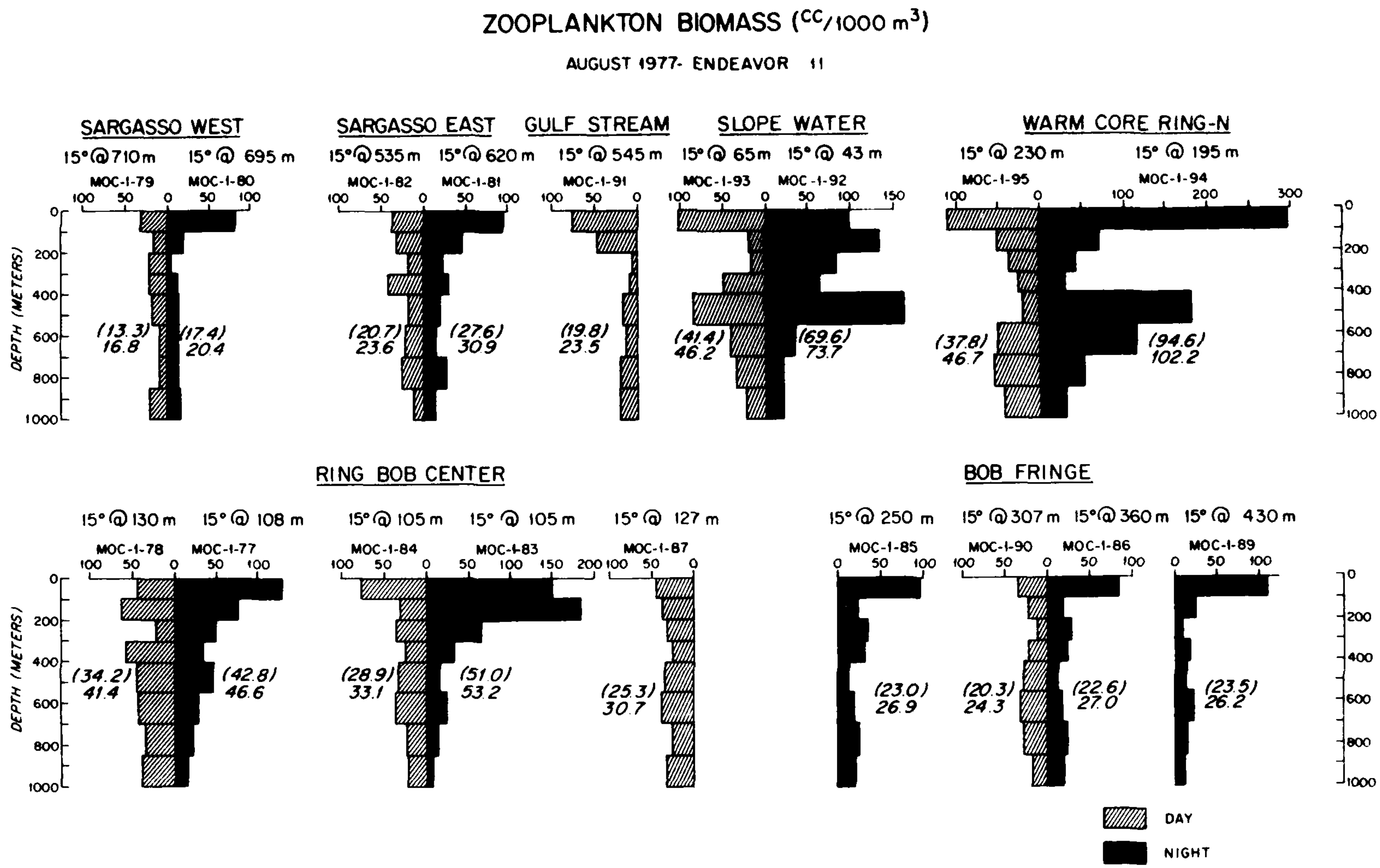

Figure 2c. As Figure 2a for R/V ENDEAVOR 11.

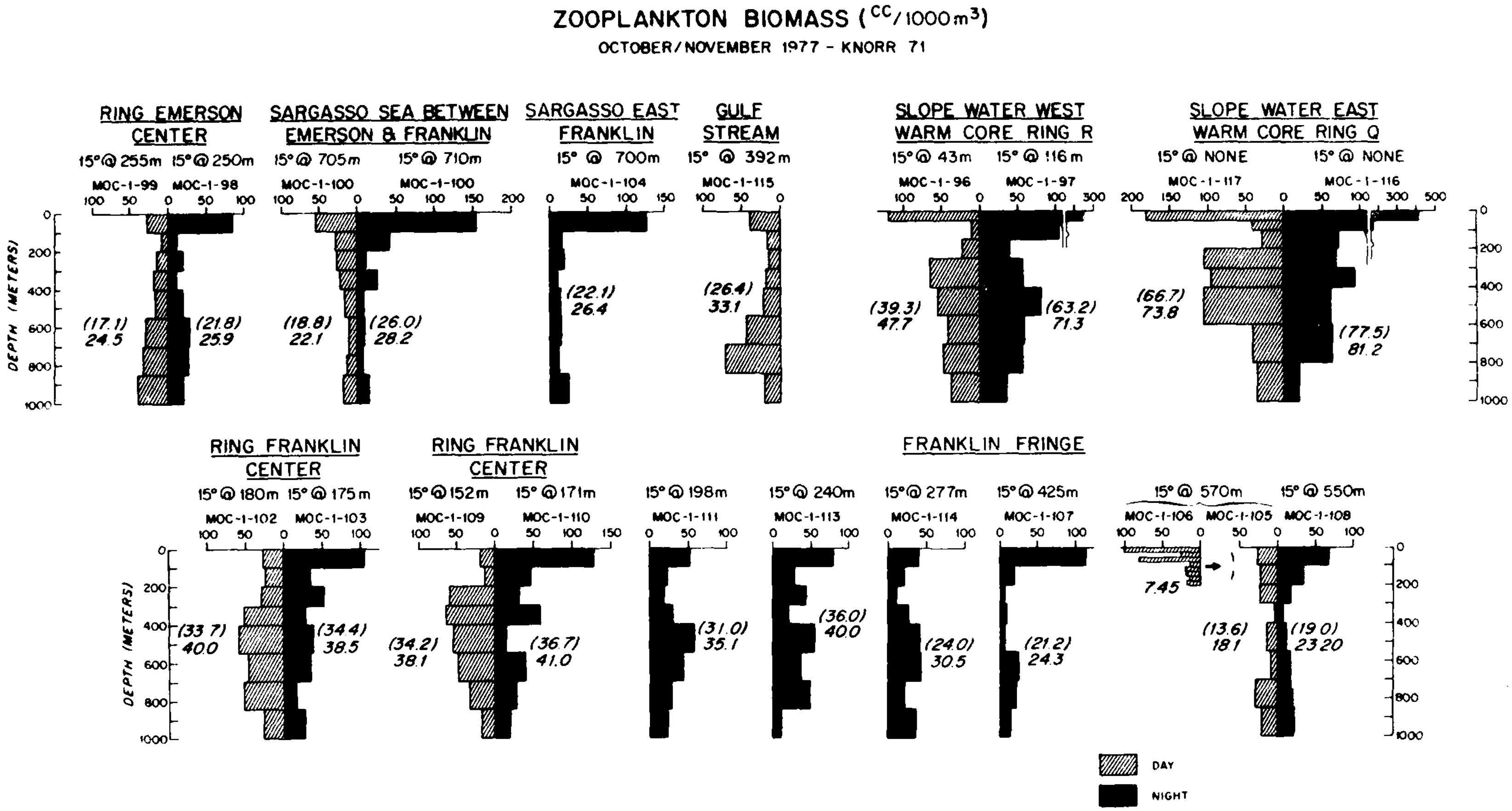

Figure 2d. As Figure 2a for R/V KNORR 71.

Both of these projects are an integral part of our overall study of the role that invading warm water species play in the ring ecosystem.

A third project being carried out by summer work study student, Bruce Davis, is a study of the net avoidance capability of *Nematoscelis megalops*. This work involves a comparison of the size specific catch rate (#'s/1000 m^3) of the MOCNESS-1 m^2 and 10 m^2 systems at a number of ring and Slope Water sample locations. The samples collected with these two net systems during the time-series experiment are uniquely suited for applying the avoidance theory presented by Barkley (1964, 1972). Sorting, counting, and weighing of both the MOCNESS-1 and the MOCNESS-10 samples to be used in this analysis are nearly complete and the data processing has been started. The results should be available by the end of the year.

Model Studies of Ring Populations

During the past year, Glenn Flierl and I have been developing mathematical models to assist us in evaluating the mechanisms which cause the cold water species expatriated in rings to become extinct. Our objective is to examine whether the decay of expatriated species is due to physical or biological causes. This analysis is essential for understanding the extent to which a cold core ring is a closed system.

The models have been based on a key indicator Slope Water species *Nematoscelis megalops*. They have been constructed to predict this species's seasonal cycle of abundance in the Slope Water and its distribution and abundance in rings of different ages. Our approach has been to construct two relatively simple models to examine purely physical effects and purely biological effects. In the present biological model, the *N. megalops* population biomass growth rate is determined solely by the primary production level. The population death rate resulting from predation is determined by both density dependent and density independent terms such that as the population increases, a slightly higher death rate is imposed. This model is calibrated to reproduce the Slope Water seasonal biomass cycle of *N. megalops*. The primary productivity cycle is then altered slowly from that typical of the Slope Water to that typical of the Sargasso Sea and the *N. megalops* biomass is calculated at appropriate intervals.

In the present physical model, *N. megalops* biomass follows the Slope Water cycle with an amplitude slowly decreasing at the ring center due to diffusion. This model is calibrated to reproduce the observed decay of temperature and salinity anomalies. Again, *N. megalops* biomass is calculated at appropriate intervals.

To evaluate the reality of the models, the predicted biomass changes with time are compared to our current set of observations of *N. megalops* biomass in rings of different ages.

A synopsis of our results to date are presented in Figure 3. The pattern of biomass decline in the biological model is strongly dependent upon the season in which the ring is formed. However, in virtually all of the biological model runs, the ring population biomass declines to near zero in approximately 12 months. In sharp contrast, the physical model predicts a more gradual decline of the ring population and the population persists for several years. We may summarize these tentative results by saying that the decay predicted by the physical model appears much too slow compared to the field results while the biological model compares well. This suggests that the ring is a relatively closed ecosystem dominated by *in situ* processes.

There are a number of refinements that must be made to these models before the results can be published. With regard to the biological model, we are not satisfied with the fit of the predicted Slope Water population biomass to that of the field data. The present model anticipates the peak biomass standing crop several months ahead of when it appears to occur in the field. Working under the assumption that the field data provide an accurate reflection of the Slope Water seasonal cycle, we will modify the model to give a better Slope Water match. However, there is also an acute need for a better Slope Water data base and a portion of the coming year will be spent improving this data base by working up the samples we now have on hand. Refinements are also required on the physical model to take into account losses due to physical processes other than diffusion. For example, Flierl has shown that the trapped portion of the ring becomes smaller with increasing depth. As the *N. megalops* individuals move deeper into the column with ring decay, they could move out of the trapped region of the ring and be lost. Another obvious step to take is to combine the biological and physical models to see what the combined effects are. Finally, the models should be calibrated for other indicator species such as the copepod *Pareuchaeta norvegica* to see if the models have a more general applicability.

Biochemical Studies of Expatriated Species

Vertical distribution, abundance, and physiological-biochemical condition estimates for the euphausiid *Nematoscelis megalops* and the copepod *Pareuchaeta norvegica* are now halfway complete. On each of the four time-series cruises, samples were removed from vertically stratified MOCNESS tows taken in the Slope Water and in the vicinity of cold core rings whenever sufficient numbers permitted. In addition, a modified 1 m net with an open/closing bucket was used to collect live individuals for study of their rates of respiration and the effect of starvation. Individuals removed from MOCNESS samples were immediately frozen at sea and are thawed in the laboratory for chemical analysis. For *N. megalops*, males and females are differentiated for individual analysis; for *P. norvegica*, stage V, males and females are individually run. Each individual is weighed (wet and dry) and percent water measured. Individuals are then used for analysis of total carbon, nitrogen and hydrogen, for total body lipid, or for total body protein.

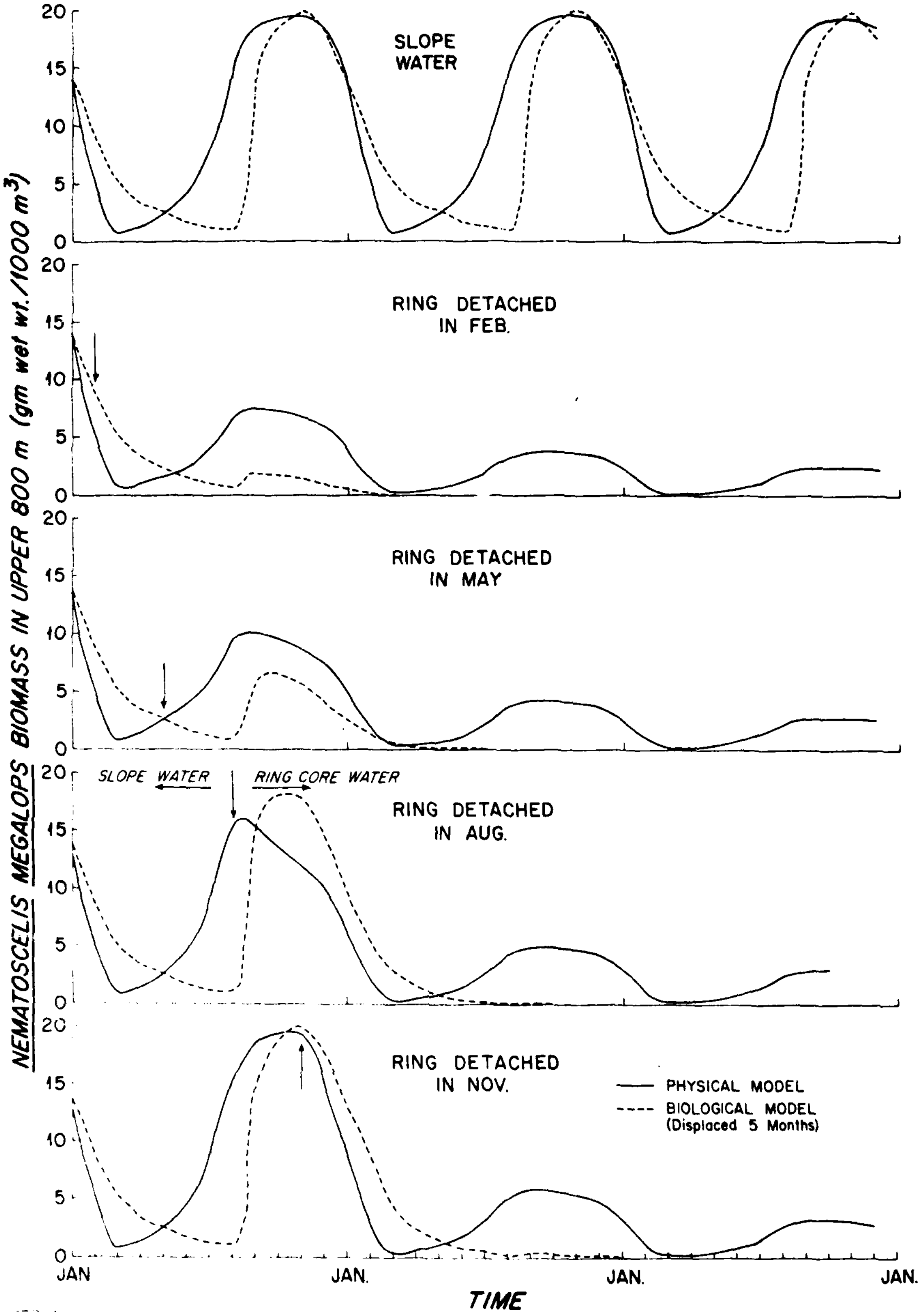

Figure 3. Biological (---) and physical (—) model predictions of the change in *Nematoscelis megalops* biomass versus time in the Slope Water and in a cold core ring formed in

While the emphasis continues on the changes in *N. megalops*'s overall condition, *P. norvegica* promises to greatly enhance our understanding of Slope Water and ring physiological dynamics. Preliminary interpretation of the Slope Water and ring vertical abundance data for this species suggests a slight vertical migration occurs at night (Figure 4). The adult females and stage V's appear to be most active. The three stages overlap with a tendency for the stage V's to be higher in the water column. In the Slope Water the population resides higher in the water column than in most rings. Also the ring population appears to deepen in its distribution parallel to the sinking of isotherms (e.g., 10°C isotherm, see Figure 4) in a fashion similar to that which we have observed for *Nematoscelis megalops* (Wiebe and Boyd, 1978).

The total water column abundances of *P. norvegica* of life stages V, adult male, and female in the Slope Water and ring vicinity are shown in Table 1. Because of the apparent extension of the ring population to below the maximum depth sampled (1000 m), comparison of ring populations with those in the Slope Water are complicated. There does, however, appear to be a reduction in abundance of both the ring center and fringe populations relative to the Slope Water. In addition, nearer the coldest parts of the ring, this species is more abundant.

Our present opinion is that *P. norvegica* is a good cold water indicator species which occurs in sufficient numbers to be extremely useful in assessing the ecological effects of ring decay. This species should also be helpful in the evaluation of physical models of circulation and mixing processes.

Symposium Attended

I attended the American Society of Limnology and Oceanography annual meeting at Victoria, British Columbia, Canada from June 18-23. For this meeting, Phil Richardson and I prepared an abstract of a paper describing the multidisciplinary time-series experiment that I presented while there. This paper was part of a symposium of invited papers entitled "Space and Time Scales of Interaction between Biological and Physical Processes".

1979 Scientific Program Objectives

It is our intention to have the euphausiid component of the zooplankton samples counted by June 1979. Highest priority is assigned to working up the MOCNESS-1 samples. Once these are completed, we will turn our attention to MOCNESS-10 samples and to meter net tows which were taken to supplement the MOCNESS-1 collections on time-series cruises or were taken from aboard ships of opportunity during the past several years. With sufficient funding, we should also have a good portion of the copepods currently under study done

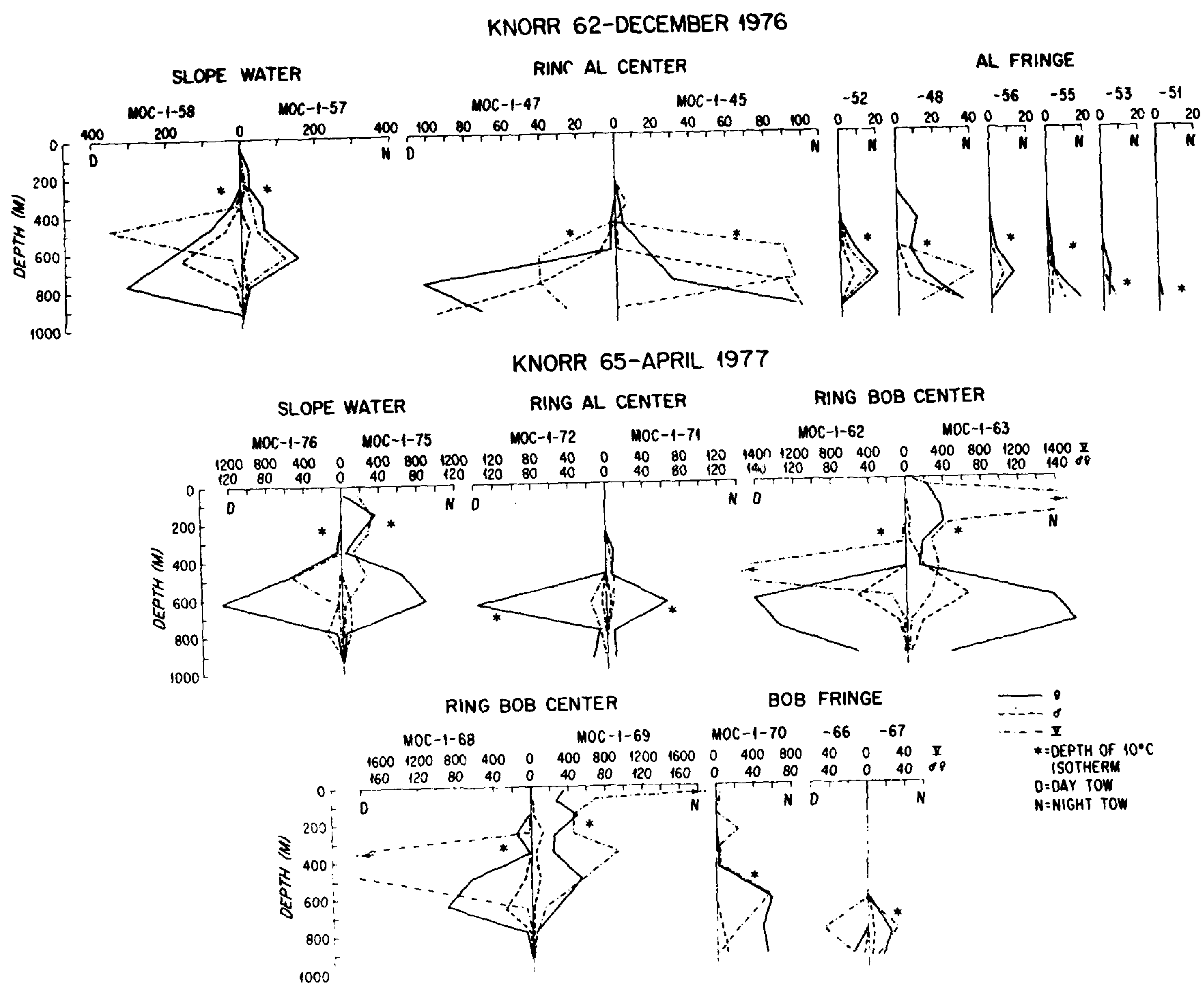

Figure 4. Vertical distributions of *Pareuchaeta norvegica* in the Slope Water and in rings "Al" and "Bob".

Table 1. *Pareuchaeta norvegica*

#/m^2 in upper 1000 m column

(KNORR 62)

Tow No.	Stage		
	V	♀	♂
SLOPE WATER			
MOC-58	57.5	51.8	32.8
MOC-57	32.9	47.1	8.4
RING CORE			
MOC-47	17.0	26.8	21.7
MOC-45	28.3	22.3	29.0
FRINGE AREA			
MOC-48	8.2	10.3	6.0
MOC-52	3.1	3.6	1.4
MOC-56	0.9	2.0	0
MOC-55	1.7	3.1	0.7
MOC-51	0	0.2	0
MOC-53	1.0	0.9	0

by this time as well. Because the work on the chaetognaths is a part of J. Cheney's Ph.D. thesis research, I anticipate that completion of this work will take longer.

Data analysis which is proceeding in parallel with the counting of the samples will continue along several lines. Analysis will continue to focus first on the vertical and horizontal distributions of single species. Histogram plots of abundance versus depth of all species will be constructed and will be analyzed for similarities and dissimilarities between stations for a given species especially as they relate to the ring environment. Also similarity comparisons will be made between pairs of species. Second, we will search for relations between the distributions of the species and the environmental parameters for which we have data. We believe that through this kind of analysis, we will develop an understanding about the mechanisms operating to regulate biogeographic distributions of a number of species similar to that which we have attained for *N. megalops* (Wiebe and Boyd, 1978; Boyd, Wiebe and Cox, 1978). Third, we will apply several different statistical procedures to groups of species in an effort to identify community structural patterns which are characteristic of the hydrographical regimes that we have sampled. A relatively recent method of community analysis which we plan to use extensively is that of correspondence analysis. The compter routines required for this analysis are part of the W.H.O.I. computer library and we have already used them on the data from the pre-time-series cruises with good results (Ortner, 1977). This analysis, which is closely allied with principal components and factor analysis, provides estimates of components (eigen values and vectors) which account for decreasing amounts of variability in the data set. As a part of the community analysis, we will investigate how these components relate to the environmental parameters used in the single species analyses.

We will continue to work with the mathematical models described above as part of our effort to understand the factors controlling species distributions and to assist in evaluating ring physical dynamical models. The major portion of this work will be continued in collaboration with Glenn Flierl. In addition, Dr. Joe Wroblewski at Dalhousie University, Halifax, Nova Scotia has been involved in discussions of studies aimed at modelling the effects of ring decay from the perspective of ecosystem trophe-dynamics and we will be continuing these discussions.

We plan to have the biochemical analyses of selected zooplankton species completed in early 1979. In the past, this kind of data has been immensely helpful in bolstering our interpretation of the field distributional data from earlier ring studies and we anticipate that this will be equally so with the time-series data. Emphasis will continue to remain on *N. megalops* and *P. norvegica*. However, we also have some specimens of midwater fish available for analysis and funds permitting, we will also work these up.

Instrumentation

Despite the cut-back in funds to work on our sampling instrumentation we have completed our re-evaluation of the light sensor design for use with MOCNESS and have settled on a design which is significantly reduced in complexity (and cost) from that we were previously working on. This sensor uses a photo-operational amplifier of sufficient sensitivity to permit downwelling light to be measured from the sea surface ($\sim 10^2$ to 10^4 $\mu W/cm^2$) down to approximately 10^{-6} $\mu W/cm^2$. Its spectral response will cover the blue-light range from 425 to 525 nm. We anticipate that a prototype light sensor will be constructed by the end of this year and that we will be able to field test it next spring. We also anticipate that we will need a small amount of time in the coming year to do a follow-up analysis of the light sensors field performance and to make modifications or adjustments to the design and construction where required. There is a tremendous need in studies of the vertical distributions of oceanic zooplankton to have water column measurements of downwelling light. In the past this kind of instrument has, for the most part been lacking and consequently investigators (including us) have had to rely on grossly inferior methods for calculating the water column light regime. It is our hope that with the completion of this relatively simple light sensor, a major step will have been taken to fill this need.

Collaboration with Other Biologists

Analysis of taxonomic zooplankton groups in the MOCNESS samples other than those we are presently working with are still being done by John Wormuth and graduate students (thecosomatous pteropods, cephalopods, and amphipods), Richard Backus (midwater fish and larvae), Richard Fairbanks and Allen Bé (Foraminifera) and Henry Donaldson (decapod shrimps). Support for the work being done by Fairbanks and Bé comes from NSF under a grant entitled "The environmental significance of chemical variations in the tests of living planktonic foraminifera".

Travel

Funds are requested to provide expenses in traveling to cold core rings workshops at Texas A & M, the University of Rhode Island, and the Massachusetts Institute of Technology. It is at these workships that most of the synthesis of the biological, chemical, and physical data will take place. Next year Jerry Cheney has the opportunity to work with Drs. Michael Reeves and Harding Owre Michel at the University of Miami on chaetognath rearing and taxonomy and funds are requested to cover his round-trip plane fare. I need to spend a week working with Dr. Edward Brinton on taxonomic problems that I have encountered with Northwestern Atlantic euphausiids and

I request travel and expenses to cover a five-day stay in La Jolla, California. In addition, I have included funds for a one-day trip to Washington, D.C. in case a meeting with ONR representatives is required.

Facilities Available

The facilities required to implement this research program are available at W.H.O.I.

Personnel

The principal investigator, Steven Boyd, Susan Hoercher, Tim Cowles, and Jerry Cheney will spend the major portion of the time sorting and counting the zooplankton samples, and computer processing and plotting the data. The division of labor is such that Steven Boyd and I will spend most of our time working with the euphausiids; Tim Cowles and Susan Hoercher will be working with the copepods; Jerry Cheney will be working with the chaetognaths. Phil Clarner's time will be spent performing the CHN analysis. In addition, as in the past, we will have the assistance of one or two guest student investigators who work on various aspects of this research program at no expense to ONR. Dick Nowak is the engineer who supervised construction of the light sensor and who will, if necessary, provide engineering assistance to improve its performance in the coming year.

Al Morton's time will be spent providing the technical assistance required to interface the CTD deck unit and tape recorder with the HP computer when we are processing the physical data obtained with the MOCNESS tows. He will also provide the technical assistance for the possible modifications and adjustments to be made to the prototype MOCNESS light sensor after the field trial performance evaluation.

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Wiebe, P. H. and S. Boyd. 1978. Limits of *Nematoscelis megalops* in the Northwestern Atlantic in relation to Gulf Stream cold-core rings. Part I. Horizontal and vertical distributions. J. Mar. Res. 36: 119-142.

BIOLOGY OF GULF STREAM COLD CORE RINGS *
1 January 1979-31 December 1979

	ONR Funded Man Months	Actual Man Months
Professional:		
Peter Wiebe - Principal Investigator	6	6
Timothy Cowles - Postdoctoral Investigator	6	6
Engineer-Research Specialist	1	1
Other Personnel:		
J. P. Clarner	1.5	1.5
Albert Morton - Sr. Research Assistant	1	1
Steven Boyd - Research Assistant	8	8
Susan Hoercher - Research Assistant	4	4
Summer Employee	3	3
Secretary	2 wks	2 wks
A. Gross regular salaries (including allowance for vacations, holidays, sick pay of $4,349 which is accounted for as employee benefits)	$ 42,975	
B. OTHER EMPLOYEE BENEFITS	11,874	
TOTAL SALARIES AND BENEFITS		$ 54,849
C. PERMANENT EQUIPMENT		
1. PET Floppy Disc System	1,000	
2. Water bath	410	
TOTAL PERMANENT EQUIPMENT		1,410
D. EXPENDABLE SUPPLIES AND EQUIPMENT (See attached)	1,500	
Miscroscope cleaning and repair	150	
TOTAL EXPENDABLE SUPPLIES AND EQUIPMENT		1,650
E. TRAVEL - Domestic		2,331
F. PUBLICATION COSTS		
1. Graphic services (130 hrs @ $13.00/hr)	1,690	
2. Page charges: J. Mar. Res. (20 @ $20/pg)	400	
TOTAL PUBLICATION CHARGES		2,090
H. COMPUTER COSTS		
1. Sigma 7 (15 hrs @ $155/hr)	2,325	
2. HP (20 hrs @ $25/hr)	500	
TOTAL COMPUTER COSTS		2,825
I. MISCELLANEOUS COSTS		
1. Shop Services (60 hrs @ $13.00/hr)	780	
2. Programming (80 hrs @ $19.60/hr)	1,568	
3. Shipping & Communication	820	
4. Laboratory overhead at 21% of Total Salaries & Benefits, exclusive of premium pay	11,518	
5. Xerox costs (5000 @ 06c/pg)	300	
6. Other Costs (Grad. Res. Ass't - 3 mos @ $1070/mo)	3,210	
7. CHN Analyses	3,000	
TOTAL MISCELLANEOUS COSTS		21,196
J. TOTAL DIRECT COSTS		86,351
K. INDIRECT COSTS @ 15% of TOTAL CIRECT COSTS		12,953
L. TOTAL COSTS		$ 99,304

*Included in Biology Department Budget Summary

W.H.O.I. Proposal #1224

D. EXPENDABLE SUPPLIES AND EQUIPMENT:

		TOTAL COSTS
1.	6 ml vials	$255.50
2.	15 ml vials	129.00
3.	Dropping bottles (12)	42.00
4.	Sample dishes (12)	12.84
5.	Forceps (10)	60.00
6.	Filters	49.80
7.	Tubing	8.80
8.	Chloroform (1 gal.)	18.50
9.	Methanol (1 gal.)	15.30
10.	Formaldehyde (10 gals)	200.00
11.	Methylene blue	1.84
12.	Neutral red	7.80
13.	Toluidine blue	15.40
14.	Cresyl blue	8.75
15.	CHN Miscellaneous supplies	50.00
16.	Millipore petri dishes	82.50
17.	Grinding apparatus	46.00
18.	Aluminum boats	36.16
19.	Miscellaneous stockroom supplies	75.00
20.	3 Denominator counters	385.00
		$1,500.19

MESOPELAGIC FISHES IN COLD-CORE GULF STREAM RINGS

Richard H. Backus
PII Redacted [redacted]

Abstract

Substantial progress has been made in identifying principal groups of fishes from 50 midwater trawls (MOCNESS-10) made during the cold-core rings time-series cruises. 1979 will be devoted to finishing the identifications and to studying and reporting the data.

Long-Range Objectives

The object of this work is to contribute to the understanding of the formation and decay of cold-core Gulf Stream rings by studying the midwater fishes of the rings and ring surroundings - Slope Water and Northern Sargasso Sea.

The midwater fish fauna in the region of study is very diverse. Many species occur so infrequently that their identification is not cost-effective for this study. The most useful, because they are abundant and because their Atlantic-wide distribution patterns are well known, are species in the families Myctophidae (lanternfishes). and Gonostomatidae (including the very abundant genus *Cyclothone*). Especially useful for the present study are certain species whose normal range-limit falls at the Slope Water - Gulf Stream boundary. Certain of these are found normally in the Slope Water and occur in the Sargasso Sea only when translocated by cold-core rings. Others occur normally in the Sargasso Sea and only in the Slope Water when translocated by warm-core rings.

Present Status and Progress

Midwater trawls were made at 50 stations on the four time-series cruises, KNORR 62, 65, and 71 and ENDEAVOR 11. Normally a trawl consisted of fishing a single opening-closing net from the surface to 1000 m, then fishing opening-closing nets successively from 1000-750 m, 750-500 m, 500-25 m, and from 250 m to the surface. A trawl took about four hours. Not all trawls were successful in having all five nets operate as planned.

The accompanying table (Table I) shows our progress in processing these collections. In addition to what is shown we have identified for all or most collections certain important species such as *Benthosema glaciale* and *Hygophum hygomii.*

Table I. Progress of fish identification in midwater trawl (MOCNESS-10) collections in cold-core Gulf Stream rings as of 1 July 1978

Cruise	First sort	Second sort	Gonostomatids*	Sternoptychids	Myctophids	Cyclothone
KNORR 62	x	x	x	x	x	x
KNORR 65	x	x	x	x	x	
ENDEAVOR 11	x	x	x	x		
KNORR 71	x	x	x	x		

*Exclusive of *Cyclothone* and *Vinciguerria.*

x = completed

Program for 1979

During 1979 we propose to complete the identification of principal groups of fishes from the 50 midwater trawls, i.e., do the parts shown as undone in Table I. Having done this, enough time should remain to write a manuscript describing the midwater ichthyofauna in and around rings and discussing it with respect to its physical and chemical surroundings. We also plan to circulate an internal memorandum making midwater fish data available to the project's other investigators for use in model-building and the like.

Although we had some initial reservations about the adequacy of the size of the samples that might result from oblique tows fished to and from 1000 m in the time available, the data derived so far from certain abundant species is coherent and interpretable. For instance, *Benthosema glaciale*, an abundant subarctic-temperate myctophid, was abundant in the Slope Water collections but absent in the Sargasso Sea ones as expected. The species was abundant throughout the water column in the core of Ring "Bob", abundant deep in the core or Ring "Franklin" but not vertically migrating upward, and almost wholly absent in the cores of Rings "Al" and "Emerson". Were one to judge from this evidence alone, one would say that "Bob" had started with a large core of Slope Water and was young at time of sampling, that "Franklin" had started with a large core or Slope Water and had aged somewhat by sampling time, and that "Al" and "Emerson" either had started with small cores of Slope Water or had greatly aged by sampling time or both.

In the proposal of a year ago we offered some ideas concerning the exploitation of rings by certain myctophid species (*Hygophum hygomii* and *H. benoiti*) that may be adapted for life in such boundary habitats. We are still greatly interested in this aspect of the work, but it seems probable that there will be no time in the coming year to devote to this end.

Historical Funding

In 1976 $20,000 of ONR funds were directed towards the study of Atlantic midwater fish distribution and $5,000 for the same purpose during 1 January - 31 March 1977. Although these funds were not explicitly given for the purpose of studying fishes in cold-core rings, we expended a considerable part of them for that purpose.

For the period 1 April - 31 December 1977 about $47,000 of ONR funds were devoted to the study of fishes in rings. Most of that applied to the salaries of R. H. Backus and J. E. Craddock (5.5 months' support each).

MESOPELAGIC FISHES IN COLD-CORE GULF STREAM RINGS *

1 January 1979-31 December 1979

	ONR Funded Man Months	Actual Man Months
Professional:		
Richard H. Backus - Principal Investigator	5	5
James E. Craddock - Research Specialist	5	5
Other Personnel:		
Secretary - To be assigned	2 wks	2 wks
A. Gross regular salaries (including allowance for vacations, holidays, sick pay of $2,879 which is accounted for as employee benefits)	$ 24,461	
B. OTHER EMPLOYEE BENEFITS	6,185	
TOTAL SALARIES AND BENEFITS		$ 30,646
D. EXPENDABLE SUPPLIES AND EQUIPMENT		450
E. TRAVEL - Domestic		790
F. PUBLICATION COSTS		
1. Graphic Services (40 hrs @ $13.00/hr)	520	
2. Page charges: (4 at $60)	240	
3. Reprints	200	
TOTAL PUBLICATION CHARGES		960
H. COMPUTER COSTS		
1. Sigma 7 (3 hrs @ $155/hr)		465
I. MISCELLANEOUS COSTS		
1. Programming (10 hrs @ $19.60/hr)	196	
2. Shipping and Communication	50	
3. Laboratory overhead at 21% of Total Salaries and Benefits	6,436	
4. Xerox costs	50	
TOTAL MISCELLANEOUS COSTS		6,732
J. TOTAL DIRECT COSTS		40,043
K. INDIRECT COSTS AT 15% OF TOTAL DIRECT COSTS		6,006
L. TOTAL COSTS		$ 46,049

*Included in Biology Department Budget Summary

W.H.O.I. Proposal #1224

GULF STREAM RINGS

Budget Summary

1 January 1979 - 31 December 1979

A.	Gross regular salaries (including allowance for vacations, holidays, sick pay of $ 10,302 which is accounted for as employee benefits)	$ 94,036	
	Cruise Leave, sea duty vacation and overtime (including premium pay of $ 459)	1,489	
	Total Salaries	95,525	
B.	OTHER EMPLOYEE BENEFITS	25,491	
	Total Salaries and Benefits		$ 121,016
C.	PERMANENT EQUIPMENT		1,410
D.	EXPENDABLE SUPPLIES & EQUIPMENT		17,366
E.	TRAVEL		
	Domestic	4,137	
	International	2,176	
	Total Travel		6,313
F.	PUBLICATION COSTS		
	Graphic Arts at $13.00/hr.	2,860	
	Page charges	1,600	
	Reprints	300	
	Total Publication Costs		4,760
H.	COMPUTER COSTS - Sigma 7	6,665	
	HP 2100	500	
	Total Computer Costs		7,165
I.	MISCELLANEOUS COSTS		
	1. Shop Services	975	
	2. Programming	2,744	
3.	3. Shipping & Communication	1,870	
	4. Laboratory overhead at 21% of Total Salaries & Benefits	25,317	
	5. Xerox costs	450	
	6. Other Costs	6,210	
	Total Miscellaneous Costs		37,566
J.	TOTAL DIRECT COSTS		195,596
K.	INDIRECT COSTS AT 15% of Total Direct Costs		29,339
L.	TOTAL COSTS		$ 224,935

W.H.O.I. Proposal No. 1224

VII. APPENDIX A

APPENDIX A

SHIPTIME SUPPORTING ONR INVESTIGATORS FROM OTHER LABORATORIES

In support of Lamont-Doherty Geological Observatory ONR Contract N00014-75-C-0210:

"Productivity, Composition and fluxes of Oceanic Particulate Matter"

Dr. Pierre Biscaye

Dr. J. Bishop

Dr. W. Gardner

Dr. J. Marra

Dr. A. Bé

Five ship days on R/V KNORR are proposed in the Panama Basin July-August 1979 during the Low Energy Benthic Boundary Layer Experiment (Dr. D. Spencer). Presently, twenty-one operating days are scheduled for this experiment. It is proposed to add an additional five days in support of Dr. Biscaye's request.

Five operating days R/V KNORR @ $5,396

TOTAL DIRECT COSTS	$26,980