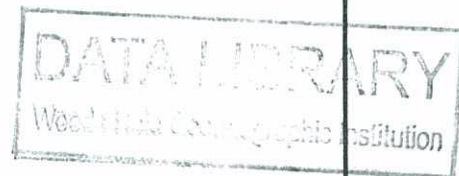


U.S. PROGRAM IN BIOLOGY
INTERNATIONAL INDIAN OCEAN EXPEDITION

NEWS BULLETIN NO. 5



NARRATIVE REPORT: ANTON BRUUN CRUISE 4-A

INTERNATIONAL
INDIAN OCEAN
EXPEDITION

The logo consists of a large circle. Inside the circle, there is a wavy horizontal line representing the ocean surface. Above the line, a thick black arrow points upwards and to the right. Below the line, a thick black arrow points downwards and to the left, creating a circular flow.

WOODS HOLE OCEANOGRAPHIC INSTITUTION

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CRUISE IV-A R.V. ANTON BRUUN

I. Objectives:

Cruise IV of the ANTON BRUUN was planned as a three-month multidisciplinary exploration of the Arabian Sea during the fall of 1963. The interests of participants ranged from chemistry and microbiology to taxonomy, distribution, and biochemistry of the large invertebrates and fishes. In addition, Cruise IV was scheduled as one of the cooperative cruises with the Bureau of Commercial Fisheries, U.S. Fish and Wildlife Service, whose personnel had planned an intensive bottom trawling program to determine the distribution and abundance of commercially valuable species of benthic fishes and invertebrates on the Continental Shelf on the periphery of the Arabian Sea.

As further interest developed in the Arabian Sea and Cruise IV, it became obvious that the highly diversified program envisioned could not be accomplished by a single cruise with an efficient deployment of scientific effort. In order to avoid a situation wherein the majority of scientific participants at any one time would be waiting for others to carry out their work, it was decided to split Cruise IV into two sections, IV-A and IV-B, both to work in the same general area but with different objectives, scientific programs and personnel.

Cruise IV-A was planned for the basic biological program of hydrography, chemistry, and plankton biology with extra sampling time provided for additional work in chemistry and microbiology. Cruise IV-B, in cooperation with BCF, would then concentrate on a benthic program with sampling by dredge and trawl. Each portion of Cruise IV was planned for a period of 6 weeks with the change-over to take place in Bombay.

The present report will be restricted to a narrative description of Cruise IV-A. A separate report on Cruise IV-B will follow.

II. Itinerary: (see Fig. 1)

Sept. 25	Depart Port Louis, Mauritius
Sept. 25 - Oct. 1	Occupied Stations 161-165
Oct. 1	Arrive Port Victoria, Seychelles
Oct. 4	Depart Port Victoria
Oct. 4 - 10	Occupied Stations 166-170
Oct. 10	Arrive Aden
Oct. 12	Depart Aden
Oct. 12 - 24	Occupied Stations 171-182
Oct. 24	Arrive Karachi
Oct. 28	Depart Karachi
Oct. 28 - Nov. 8	Occupied Stations 183-200
Nov. 8	Arrive, Bombay, terminate Cruise IV-A

III. Cruise Description:

Although the purpose of Cruise IV-A was to investigate the Arabian Sea, the cruise was begun at Mauritius, some 2500 miles to the south. In addition, equipment and supplies needed for the special work of Cruise IV-A were brought from U. S. aboard R/V ATLANTIS II and offloaded at Aden, requiring that the BRUUN call at that port before initiating work in the Arabian Sea. As a result, the time left for work in the latter region was severely limited and inadequate for coverage of the entire area.

The section Mauritius - Cape Guardafui (the tip of Somali) represented only a slight deviation from the original overall cruise plan to make basic hydrographic, chemical, and plankton studies along a series of N-S sections at every 5th meridian in the Western Indian Ocean. Stations 161-170 were roughly equivalent to the Northern half of the planned section along 55°E.

Midway through this section the ship passed through the Seychelle Islands, stopping at Port Victoria, Mahe, for three days. On the day following the arrival of the BRUUN at this port, she was joined by the new

British research vessel RRS DISCOVERY. Captain Alexander, Chief Scientist Hill, and the entire ship's complement graciously entertained, and opened the DISCOVERY to the inspection of the BRUUN personnel. Discussions with those members of the scientific party who had been aboard DISCOVERY during her preceeding cruise in the Arabian Sea helped in the planning of the BRUUN's program in the same area.

Departing Port Victoria, the BRUUN took a NNW heading for Cape Guardafui, occupying five more stations on the section, rounding the Cape, and running straight for Aden, arriving there on October 10. Here the ship took on scientific equipment, fuel, water, and three members of the scientific party (Drs. Dugdale, Goering, and Barsdate). After making adjustments to the level-wind mechanism of the main trawl winch and paying out and respooling the wire under proper tension, the cruise was resumed.

The main object of Cruise IV-A was to make a series of sections normal to the coast around the periphery of the Arabian Sea, across the Continental Shelf and into the deep central basin. Of special interest was the western side of the Arabian Sea, where upwelling of nutrient-rich subsurface water during the Southwest monsoon was suspected (and confirmed by DISCOVERY). The BRUUN's cruise was made during the calm, inter-monsoon period with the intention of comparing the conditions at that time with those observed earlier in the year, at the height of the monsoon and in the same area, by DISCOVERY and ATLANTIS II. It was also hoped to confirm the report by Soviet scientists of a deep layer of oxygen-deficient, sulfide-containing water observed by VITYAZ in the central Arabian sea during November, 1960.

As time did not permit the survey of the entire Arabian Sea, work was confined to the western side where three sections were made normal to the Arabian coast and two short sections across the mouths of the Gulf of Aden and Gulf of Oman respectively. In addition, the outer stations of the three sections which ran out from the coast were interspersed with other deep stations producing a section along the central basin of the Arabian Sea parallel to the Arabian Coast (see Fig. 1). The latter part of the cruise (27 stations) was interrupted by an emergency stop at Karachi on October 24 due to the illness of a member of the crew.

While at Karachi, the BRUUN was visited by Commander S. R. Islam, Chairman of the National Committee for Oceanographic Research in Pakistan, Dr. F. O. Quraishi, Director and Mr. M. A. Burney of the Pakistan Marine Department of Fisheries, and Mr. Tinker, Science Attache, U. S. Embassy. As the ship's visit fell on a weekend and unexpectedly ahead of schedule, plans for a cooperative scientific program by the Pakistan CSIR and the scientific party of the ANTON BRUUN were rescheduled for the following visit of the BRUUN to Karachi during Cruise IV-B.

IV. Scientific Program:

Hydrography and Chemistry

Complete hydrographic stations with measurements of temperature, salinity, dissolved oxygen, phosphate, nitrite, nitrate, and silicate were made at all 40 stations. On the southern part of the cruise (Mauritius - Aden) observations were made to 2000 m, but for the last 20 stations in the Arabian Sea observations were extended to the bottom.

Primary Productivity and Phytoplankton Pigments

Primary production was measured by the C^{14} technique at every station. Samples for this purpose were collected with an all-plastic sampler from depths

to which 100, 50, 25, 10 and 1% respectively of the incident sunlight penetrated, as determined with a submarine photometer.

The C^{14} -inoculated samples were incubated for 24 hours in cylindrical clear plastic tubes fitted with neutral density wire screens so as to simulate the light intensities at the sampled depths. Duplicate samples were incubated for 4 hours under artificial illumination of 1000 foot candles in a laboratory incubator.

Two-liter portions of the same samples used for productivity determinations were filtered for pigment determinations. In addition, extra samples from 125, 200, and 300 meters respectively were obtained and filtered for pigment determinations on Stations 164-175.

At Stations 176-200, three additional depths were sampled between the surface and bottom of the euphotic zone for both pigment determinations and measurement of C^{14} uptake at 1000 f.c. Thus throughout the Arabian Sea carbon assimilation and pigments were determined from eight depths within the euphotic zone.

Particulate and Dissolved Carbon and Particulate Phosphorus

Additional two-liter portions of the same water samples used for productivity and pigment determinations were routinely filtered through Whatman GF/C glass fiber filters for subsequent measurement of particulate carbon. Extra depths were sampled from Stations 161, 162, 163, 165, 166, 196 and 198. A special effort was made on the last two of these (Sta. 196 and 198) where 24 and 19 particulate carbon samples respectively were taken between the surface and ocean bottom. A total of 348 samples for particulate carbon were taken on the cruise. Similarly, 500-ml portions of the same water samples were filtered through AA millipore filters which were also preserved for laboratory determination of particulate phosphorus.

Water from all Nansen-bottom samples was filtered through AA millipore filters and five ml sub-samples of the filtrates ampouled and processed for subsequent determinations of dissolved organic carbon. A total of 591 samples were taken for this purpose.

Dissolved and Particulate Iron and Dissolved Molybdenum

The filtrates remaining from the Nansen-bottles samples, after removing sub-samples for dissolved organic carbon, were acidified and stored in plastic bottles for subsequent analyses for dissolved iron. The AA millipore filters through which these water samples were passed were also saved and later used for determination of particulate iron. Thus the two fractions of iron which will be reported as "dissolved" and "particulate" are, by definition, respectively that which passes through and that retained by a 0.8μ filter. Approximately 600 determinations each of dissolved and particulate iron were made from all stations and from all depths sampled.

At selected stations in the Arabian Sea the filtrates of samples passed through the Whatman GF/C glass fiber filters (for particulate carbon determinations) were used for measurement of dissolved molybdenum. Additional samples for this purpose were taken from deep water at several stations in the central part of the Arabian Sea.

Particulate and Dissolved Organic Nitrogen

A total of 276 300-ml water samples from 34 stations were filtered through Whatman GF/C glass fiber filters and both filters and filtrates were saved for subsequent determination of particulate and dissolved organic nitrogen. The eight depths within the euphotic zone were routinely sampled, taking sub-samples from the same water used for primary productivity, pigments, and particulate carbon and phosphorus so that the nitrogen fractions could be compared with these other variables. In addition deep samples were taken

from the stations in the central portion of the Arabian Sea.

Studies of the Nitrogen Cycle

Carboy-size samples were obtained with the plastic water sampler from various depths within the euphotic zone and inoculated with N^{15} -tagged nitrogen gas, ammonia, and nitrate. These samples were incubated either on deck in natural light, in the laboratory under artificial illumination, or in the dark. The water samples were then filtered and the filters saved for laboratory determinations of the rate of assimilation of these nitrogenous compounds by mass spectrometry.

At locations in the Arabian Sea where the bluegreen alga Trichodesmium was abundant, fine (#20 mesh) plankton nets were towed through the water at various depths within the euphotic zone. Healthy-appearing colonies of Trichodesmium were picked out of these plankton tows and inoculated into filtered surface water to which were added N^{15} -tagged nitrogen compounds. These were treated as described above for measurements of nitrogen assimilation by this common organism which is the dominant form and very frequently reaches bloom proportions in the Arabian Sea.

Additional carboy samples from different depths were inoculated heavily with ammonium salts and incubated both in the light and dark for periods of several days. These samples were monitored at frequent intervals for the appearance of nitrite, which would indicate the presence of nitrifying bacteria oxidizing the ammonia to nitrite. Where this process was detected the enrichment cultures were withdrawn and returned to the U. S. in a viable state for later isolation and study of the physiology and biochemistry of the nitrifying organisms involved.

Enrichment Experiments

On 10 occasions, each time in deep oceanic water away from the influence

of land, samples of surface water were collected and dispensed into bottles enriched with various combinations of nitrogen, phosphorus, iron, trace metals (Co, Mn, Zn, Cu, and Mo), silicate, and vitamins (B_{12} , thiamine, and biotin). The enriched samples were incubated at 1000 foot candles of fluorescent illumination in a laboratory incubator. In experiments 1-7, the entire enriched sample (150 ml) was incubated for 24 hours after which 10 microcuries of $C^{14}O_3^-$ were added. The relative rate of uptake of carbon was then measured over a four-hour period at the same light intensity of 1000 f.c.

In experiments 8-10, larger (4 liter) samples were enriched with the various mixtures and 150 ml aliquots were withdrawn each day for 4-7 days, inoculated with C^{14} , and carbon assimilation measured (over 4 hours at 1000 f.c. as before) as a function of the number of days after the surface water was enriched. Sub-samples of the different final populations of phytoplankton (4-7 days after enrichment) were preserved for identification and enumeration of the species which developed as a result of the different types of enrichment.

Plankton Sampling

Vertical plankton tows from 200 m to the surface were made at every station with the Indian Ocean Standard Net. These samples have since been sent to the Indian Ocean Biological Center at Cochin, India.

Vertical, 200 m surface tows with a fine-mesh (#25) plankton net, which had been a part of the basic program of the ANTON BRUUN on all earlier cruises, were made at Stations 161-163 but were then discontinued due to loss of the last microplankton net. However, at five stations in the Arabian Sea (184-186, 192, 194) a series of horizontal tows were made with five or six small (1' diameter), #20 mesh nets spaced at 10 m intervals from the surface to 40 or 50 meters. This was done to determine the vertical distribution of the phytoplankton in general and the bluegreen alga, Trichodesmium, in particular.

At 19 stations, including most of the deep stations, oblique plankton samples were taken with Bé, pressure-operated, multiple-oblique samplers. Depth intervals sampled were 0-125, 125-250, 250-500, 500-1000, and 1000-2000 meters. The operational record of the Bé samplers was not impressive, the units working as designed and collecting from the five planned depth intervals with no more than 65% success. Some sample was obtained but not from the intended depth interval another 10% of the time. Assuming a possibility of five samples with each lowering, the incidence of obtaining no sample at all was 25%. In many cases the cause of the malfunction was obvious but not easily correctable; in other cases no reason for the failure could be detected. When the sampler operated properly, an excellent series of samples was obtained. The abundance of deep-water organisms (1000-2000 m) sampled in the equatorial region was particularly striking, and the number of fish in the samples, including some as large as 10-20 cm (see illustration at end of report), was impressive. However, unless the basic design of the sampler can be modified to improve markedly its reliability, the advisability of its continued use is questionable.

In shallow water, or where time did not permit the use of the Bé samplers, oblique plankton tows were made to 500 m. Paired plankton nets, one mounted above the other, were employed for these tows, one of coarse mesh (#0) with a mouth opening 1 meter in diameter, and one of finer mesh (#3) with a mouth opening of 3/4 meter in diameter. The two nets were used because of the observations made on the earlier BRUUN cruises that the two mesh sizes apparently sampled two rather different components of the zooplankton population.

All plankton samples, with the exception of the Indian Ocean Standard Net vertical tows, have been sent to the Smithsonian Oceanographic Sorting Center, Washington, D. C.

V. Some Preliminary Results:

Discussion of the final results of Cruise IV-A must await both laboratory analyses of all chemical and biological samples and computation and analyses of the resulting data. The latter will appear as a separate final cruise report. Interpretation and discussion of the results will be published in the scientific literature by the individual participating scientists.

The completion of certain analyses, both on shipboard and at the Woods Hole Oceanographic Institution, permit the presentation at this time of some preliminary results and conclusions which are believed to be of general interest, particularly to those individuals who will be working in the Arabian Sea during the latter stages of the IIOE.

A. Hydrography, chemistry and primary productivity

Hydrographic and bathythermographic sections normal to the Arabian Coast made by DISCOVERY in July, 1963, showed an upward tilting of isotherms and phosphorus isopleths towards shore, with phosphate values as high as $2.0 \mu\text{gA/l}$ in the coastal waters. This is typical of a coastal upwelling situation and could be expected in that region during the summer, Southwest monsoon. Similar sections made in the same general area by the ANTON BRUUN in October-November, after the monsoon had ceased, revealed no evidence of upwelling. This can be seen from the three sections running from the coast seaward consisting of Stations 190-185, 193-199, and 175-180 (Figure 1) for which the vertical distribution of temperature, phosphate, and dissolved oxygen to 200 meters are shown in Figures 2-4 respectively. In none of the three sections do the isopleths tilt up in a shoreward direction as was observed in July.

From the set of the ship between stations and the drift while on station, it was obvious that a rather strong southerly flowing current was flowing out of the Gulf of Oman and along the Arabian coast. On the other hand, the drift was northeasterly at the stations occupied at the seaward end of the above-

mentioned sections, indicative of a clockwise gyre in the central part of the Arabian Sea. Presumably it is the front between these currents, some 150-200 miles from shore, that can be seen at Stations 186, 198, and most impressively at 179. On the shoreward side of this front the isopleths for temperature, phosphate, and oxygen bulge or dome upward, typical of an area of divergence. For example, water at 15°C, which lies at a depth of approximately 200 m on either side of the front, rises to nearly 100 m at the front itself.

The nutrients which were brought up into the euphotic zone by the divergence gave rise to extremely high rates of primary productivity. The resulting phytoplankton populations apparently spread in a southwesterly direction, for the entire area between shore and the divergence was characterized by dense blooms of the bluegreen alga Trichodesmium, the dinoflagellate Noctolua, and several species of diatoms, notably of the genera Rhizosolenia, Chaetoceros, and Skeletonema. These blooms were often patchy and highly localized, but the entire area was extremely rich and fertile in contrast to the clear water east of the current front.

It could also be argued that the dense phytoplankton populations encountered in these coastal waters were the end result of the earlier upwelling. However, it seems doubtful that unnourished populations could persist for very long, and the strong thermal stratification and nutrient impoverishment of the surface coastal waters do not suggest any recent instability. Whatever the cause, the levels of primary productivity in the general region were uniformly high and included values at two stations of 5.6 and 6.8 g. carbon assimilated/ m^2 /day, considerably higher than ever before reported for the open sea. Figure 5 shows these values for the three shore-sea sections and, for contrast, the annual mean rate of primary productivity for the Northeastern U. S. continental shelf as reported by Ryther and Yentsch (Limnol. and Oceanogr. 3:327, 1958).

The physical and chemical characteristics of the water in the central Arabian Sea are of interest for several reasons. These are illustrated by the vertical distribution of properties at Station 185 (Table II). A sharp thermocline was present at about 50 m, below which the concentrations of nutrients (phosphate, nitrate, silicate) increased sharply. At depths of 1000-1500 m concentrations were measured of $> 3.0 \mu\text{gA/l PO}_4\text{-P}$ and $> 40 \mu\text{gA/l NO}_3\text{-N}$, values which approach the highest levels known for these substances in any ocean. Silicate, too, reached exceptionally high concentrations ($> 160 \mu\text{gA/l}$) but increased steadily to the bottom rather than passing through a maximum at mid-depths as did phosphate and nitrate.

Accompanying and undoubtedly directly correlated with the sharp increase in nutrients with depth was a rapid decrease in dissolved oxygen concentrations to less than 1.0 ml/l at 100 m and to less than 0.1 ml/l at mid-depths of 500-1000 m at some stations. Although the concentrations increased again below 1000 m, they never approached saturation in the bottom waters.

It is noteworthy that no anoxic water was observed anywhere on the cruise and that hydrogen sulfide could not be detected analytically or by odor in the samples which contained low ($\leq 0.1 \text{ ml/l}$) concentrations of oxygen. This is in contrast to the situation reported by the Vityaz during their cruise in the same area in November, 1960 (Ivanorenkov and Rozanov, *Okeanologia* 1:443, 1961).

The presence of such unusually high levels of nutrients and low oxygen concentrations at or in close proximity to the base of the euphotic zone (50-75 m for most stations) is indicative of a situation which is potentially both highly productive and biologically unstable. Any process, such as the divergence described above, which causes even a slight degree of vertical transport may be expected to result in greatly enhanced biological productivity. By the same token, sinking and decomposition of the organic matter

so produced in water already low in oxygen could be expected periodically to create anaerobic conditions. Subsequent mixing of this anoxic water to the surface could easily lead to mass fish mortalities. While the latter situation was not actually encountered during Cruise IV-A, it is not difficult to reconstruct the history of such phenomena which apparently are well known in the Arabian Sea.

B. The distribution of dissolved and particulate organic carbon

The vertical distribution of dissolved and particulate organic carbon at Stations 196 and 198 are shown in Table III. Dissolved carbon decreased from 1 gram/m³ or more at the surface to about one third of that amount in deep water. Particulate carbon values were about one tenth those for the dissolved fraction and were also highest at the surface. These figures are typical of the values observed throughout the Arabian Sea.

Using the mean concentration of 1.0 mg/m³ of chlorophyll a in the 50 meter euphotic zone at Station 196 and assuming a carbon : chlorophyll ratio of 50 : 1 in the phytoplankton, it may be calculated that living carbon (excluding animals) constitute about one third of the total particulate matter in these surface waters, a negligible portion of the total in the water below this.

The total amounts of dissolved and particulate carbon integrated over a one-meter-square column of water from surface to bottom at Station 196 are 1275 and 123 grams respectively. When this is compared to the estimated standing crop of living phytoplankton within the same water column at the same station (some 2.5 grams of carbon) it is obvious that the latter is negligible compared to the vast reservoir of dead and dissolved organic matter in the sea.

No apparent correlation was observed between the concentration of dissolved organic carbon and the rate of primary production. The latter varied by two orders of magnitude in the Arabian Sea while dissolved carbon varied by only about three fold (Table IV). This fact suggests that the dissolved carbon is not an immediate by-product of phytoplankton growth. Confirmation for this is the presence of appreciable quantities of dissolved carbon in the deep water. Finally, significant variations in the concentrations of dissolved organic carbon in the deeper water may be correlated with the different water masses in the Arabian Sea, as distinguished by temperature-salinity characteristics. The latter subject will be considered in a separate publication by D.W. Menzel. The preceeding evidence leads to the conclusion that dissolved organic carbon in the ocean is extremely stable and refractory to decomposition, and may be considered one of the more conservative properties of seawater.

VI. Personnel:

Chief Scientist:	John H. Ryther Woods Hole Oceanographic Institution
Visiting Scientists:	Robert J. Barsdate (molybdenum) University of Alaska
	Peter Connors (meteorology) U. S. Weather Bureau
	Richard Dugdale (nitrogen cycle) University of Alaska
	Fernando Fraga (nitrogen chemistry) Inst. Invest. Pesqueras, Vigo, Spain
	John J. Goering (nitrogen cycle) University of Alaska
	David W. Menzel (carbon, iron chemistry) Woods Hole Oceanographic Institution
	M. E. Watson (ichthyology) Woods Hole Oceanographic Institution
	S. W. Watson (bacteriology) Woods Hole Oceanographic Institution

Permanent Scientific Staff:

Andrew Bakun	- Chemical Oceanographer
Don Fenner	- Biological Oceanographer
Mark Jones	- Chemical Oceanographer
Mahlon Kelly	- Biological Oceanographer
Sidney McGuire	- Physical Oceanographer
John Hall	- Biological Oceanographer
Alan Pease	- Physical Oceanographer
Bruce Rogers	- Biological Oceanographer

TABLE I

SUMMARY OF ACTIVITIES - CRUISE IV-A, R/V ANTON BRUUN

Date	Sta.	Tentative Position		Hydro Cast	Vertical IOSN #25	Plankton		Hor. Surface #20	Prim. Prod. #20	Particulate & Dissolved C, N, & Fe		¹⁵ N nitrogen cycle studies
		Latitude	Longitude			Oblique Be #3	Oblique Be #0					
25-26 Sep 63	161	19°14'S	56°27'E	x	x	x			x	x		
26 Sep	162	17°47'S	55°00'E	x	x	x	x		x	x		
27-28 Sep	163	14°39'S	54°59'E	x	x	x			x	x		
28 Sep	164	11°37'S	54°57'E	x	x		x		x	x		
30 Sep	165	08°12'S	55°00'E	x	x	x			x	x		
5 Oct	166	00°24'S	54°33'E	x	x	x			x	x		
6 Oct	167	02°45'N	53°51'E	x	x	x			x	x		
7 Oct	168	05°52'N	52°57'E	x	x	x			x	x		
8 Oct	169	08°57'N	52°18'E	x	x	x			x	x		
9 Oct	170	12°06'N	51°31'E	x	x		x		x	x		
9 Oct	170A	12°38'N	49°06'E					x				
12 Oct	170B	12°20'N	44°51'E					x				
13 Oct	170C	12°50'N	46°39'E				x					
15 Oct	171	13°11'N	51°29'E	x	x	x			x	x		x
15 Oct	172	14°44'N	51°03'E	x	x	x	x		x	x		x
16 Oct	173	15°26'N	52°50'E	x	x	x	x		x	x		x
17 Oct	174	16°27'N	54°40'E	x	x	x	x		x	x		x
17-18 Oct	175	17°26'N	56°30'E	x	x	x	x		x	x		x
18 Oct	176	16°28'N	57°09'E	x	x	x	x		x	x		x
19 Oct	177	15°20'N	57°42'E	x	x		x		x	x		x
19 Oct	178	14°21'N	58°19'E	x	x	x	x		x	x		x
19-20 Oct	179	13°16'N	58°59'E	x	x				x	x		x
20 Oct	180	12°15'N	59°44'E	x	x	x	x		x	x		x
21 Oct	181	14°11'N	61°07'E	x	x	x			x	x		x
22 Oct	182	15°58'N	62°34'E	x	x	x	x		x	x		x
28-29 Oct	183	23°42'N	66°21'E	x	x	x	x		x	x		x
29 Oct	184	22°34'N	65°50'E	x	x			x		x		x
30 Oct	185	20°37'N	64°40'E	x	x	x	x		x	x		x
30 Oct	186	21°33'N	64°05'E	x	x			x		x		x
31 Oct	187	22°23'N	63°33'E	x	x	x	x		x	x		x
31 Oct	188	23°21'N	64°52'E	x	x	x			x	x		x

TABLE I (Page 2)

SUMMARY OF ACTIVITIES - CRUISE IV-A, R/V ANTON BRUUN

	Date	Sta.	Tentative Position		Hydro Cast	Plankton				Prim. Prod.	Particulate & Dissolved C, N, & Fe		¹⁵ N nitrogen cycle studies
			Latitude	Longitude		Vertical IOSN #25	Oblique Be #3	Hor. #20	Surface #0 #20				
1	Nov 63	189	24°02'N	62°08'E	x	x	x	x		x	x		x
1	Nov	190	24°47'N	61°39'E	x	x	x	x		x	x		x
1-2	Nov	191	23°57'N	60°58'E	x	x	x			x	x		x
2	Nov	192	23°08'N	60°36'E	x	x	x	x	x	x	x		x
2	Nov	193	22°46'N	59°35'E	x	x	x	x		x	x		x
3	Nov	194	22°22'N	60°06'E	x	x	x	x	x	x	x		x
3	Nov	195	21°32'N	60°40'E	x	x	x	x		x	x		x
4	Nov	196	20°42'N	61°16'E	x	x	x	x		x	x		x
4	Nov	197	20°03'N	61°59'E	x	x	x			x	x		x
5	Nov	198	19°18'N	62°32'E	x	x	x	x		x	x		x
5	Nov	199	18°31'N	63°09'E	x	x	x			x	x		x
6	Nov	200	18°32'N	64°39'E	x	x	x	x		x	x		x

TABLE II

REDUCED DATA, R/V ANTON BRUUN - STA. 185
(depth and temperature unchecked)

Depth (m)	Temp. (°C)	Salinity (‰)	Diss.O ₂ (ml/l)	PO ₄ -P ugA/l	NO ₃ -N ugA/l	SiO ₃ -Si μgA/l
1	27.49	36.474	4.93	0.31	0.37	1.41
25	27.59	-	4.95	0.23	0.37	1.41
50	24.97	36.184	3.38	1.04	16.2	5.12
75	22.84	36.236	1.72	1.38	23.0	10.6
99	21.54	36.109	0.66	1.84	25.8	12.8
124	20.24	35.969	0.30	2.15	25.8	17.0
149	18.78	35.822	0.28	2.20	28.0	23.3
199	17.73	36.025	0.23	2.32	25.8	25.6
398	13.56	35.865	0.13	2.56	28.8	34.0
597	11.62	35.653	0.11	2.78	32.8	54.4
796	10.06	35.527	0.12	2.95	41.0	70.0
995	8.55	35.386	0.12	3.12	42.0	85.1
1293	6.48	35.174	0.46	3.18	42.9	107
1591	4.49	34.955	1.17	3.14	42.3	131
1989	3.03	34.849	1.92	2.89	39.5	146
2387	2.53	34.987 (?)	1.85	2.68	37.4	136
2785	1.89	34.767	2.67	2.60	39.4	163
3083	1.74	34.761	2.77	2.67	38.7	164

TABLE III
THE VERTICAL DISTRIBUTION OF PARTICULATE AND
DISSOLVED ORGANIC CARBON IN THE ARABIAN SEA

Station 196			Station 198		
Depth (m)	Part ₃ C (g/m ³)	D.O.C. (g/m ³)	Depth (m)	Part ₃ C (g/m ³)	D.O.C. (g/m ³)
1	.157	1.00	1	.057	1.48
6	.166	1.10	13	.068	----
12	.155	.92	20	.073	----
19	.204	.96	26	.079	----
29	.114	1.04	30	.064	.90
39	.086	.74	40	.084	.76
50	.040	.74	50	.048	1.04
75	.025	.84	75	.040	.72
100	.026	.76	100	.041	.72
150	.016	.82	150	.043	----
200	.018	.78	200	.026	----
250	.035	.50	397	.021	.22
300	.027	.46	596	.022	.46
400	.017	.64	795	.030	.54
500	.043	--	916	.051	.54
600	.054	.60	1201	--	.36
800	.021	.20	1492	.040	.20
1000	.031	.36	1892	.031	.48
1300	.049	.28	2291	--	.30
1600	.026	.36	2690	.032	.36
2000	.035	.34	3090	--	.36
2400	.045	.36	3390	.037	
2800	.053	.34			
3200	.030	.36			
Total (gC/m ²)	123	1275		118	1353

TABLE IV

THE RELATION BETWEEN PRIMARY PRODUCTION AND THE MEAN DISSOLVED
ORGANIC CARBON IN THE EUPHOTIC ZONE OF THE WESTERN INDIAN OCEAN

Station	Primary production (gC/m ² /day)	Dissolved organic carbon (g/m ³)	Station	Primary production (gC/m ² /day)	Dissolved organic carbon (g/m ³)
187	1.40	0.82	161	0.04	1.76
196	1.62	0.96	162	0.15	1.76
190	1.65	0.71	169	0.28	1.23
193	1.69	0.82	180	0.46	0.85
197	1.80	1.02	164	0.49	1.20
198	1.81	1.20	168	0.56	0.86
188	1.82	0.76	182	0.60	0.68
189	2.04	0.66	165	0.70	1.20
186	2.05	1.04	167	0.71	0.86
191	2.28	0.59	185	0.73	0.60
195	5.28	0.95	184	0.86	0.82
194	6.82	0.82	166	0.97	1.01
			163	0.97	0.82
			181	1.06	0.65
			199	1.09	0.88

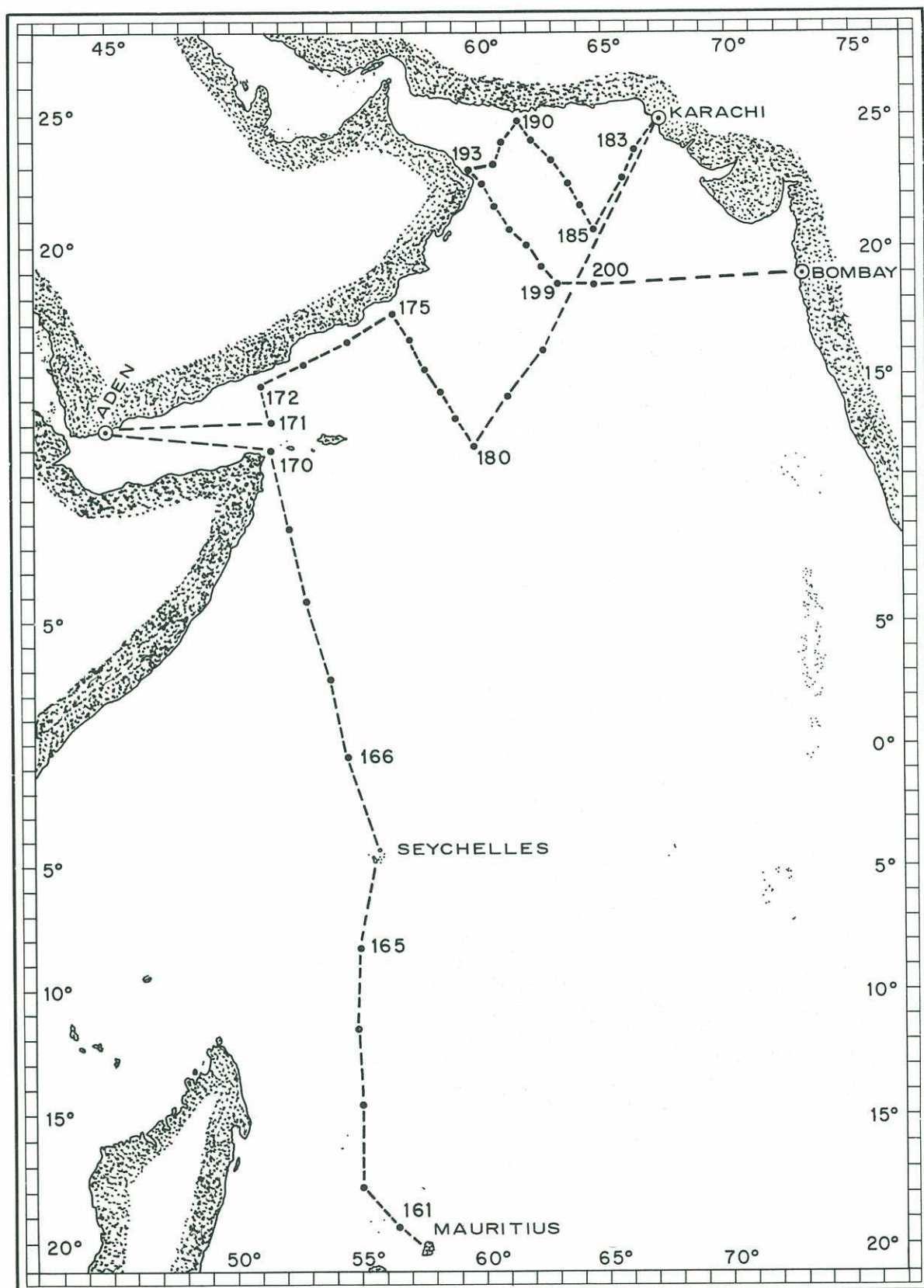


Figure 1. Track of Cruise IV-A showing station positions.

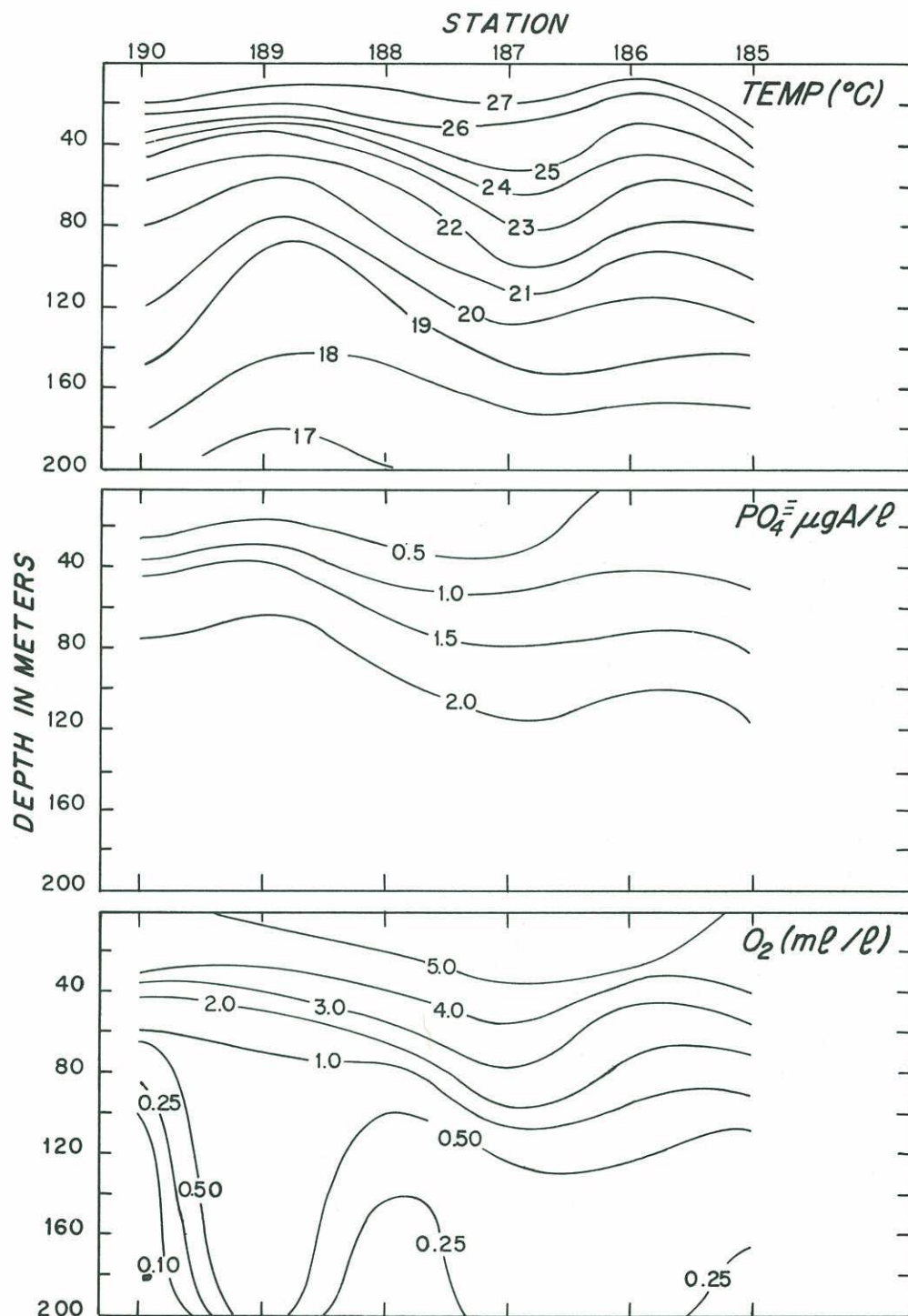


Figure 2. Distribution of variables along section formed by Stations 190-185.

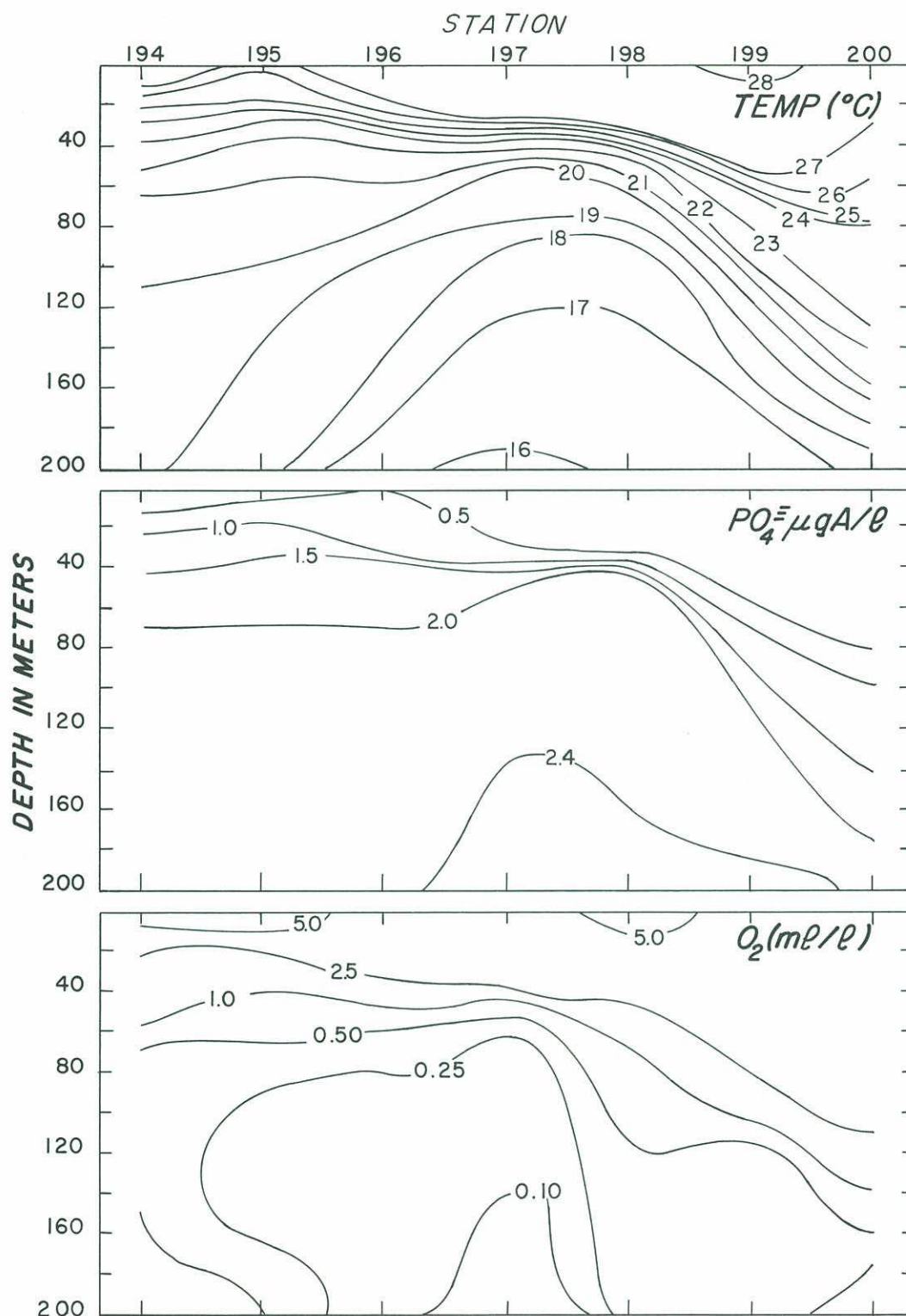


Figure 3. Distribution of variables along section formed by Stations 194-200.

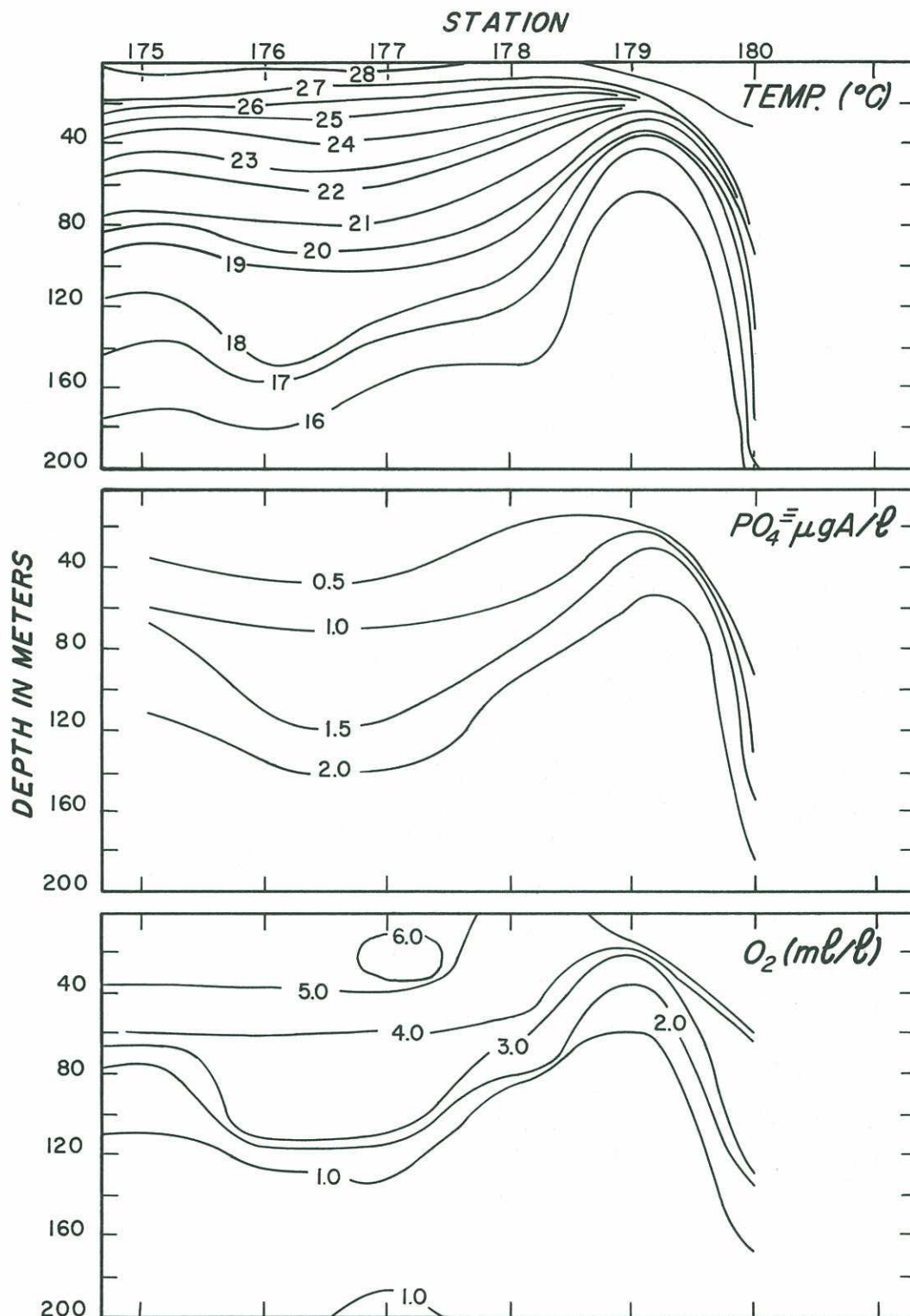


Figure 4. Distribution of variables along section formed by Stations 175-180.

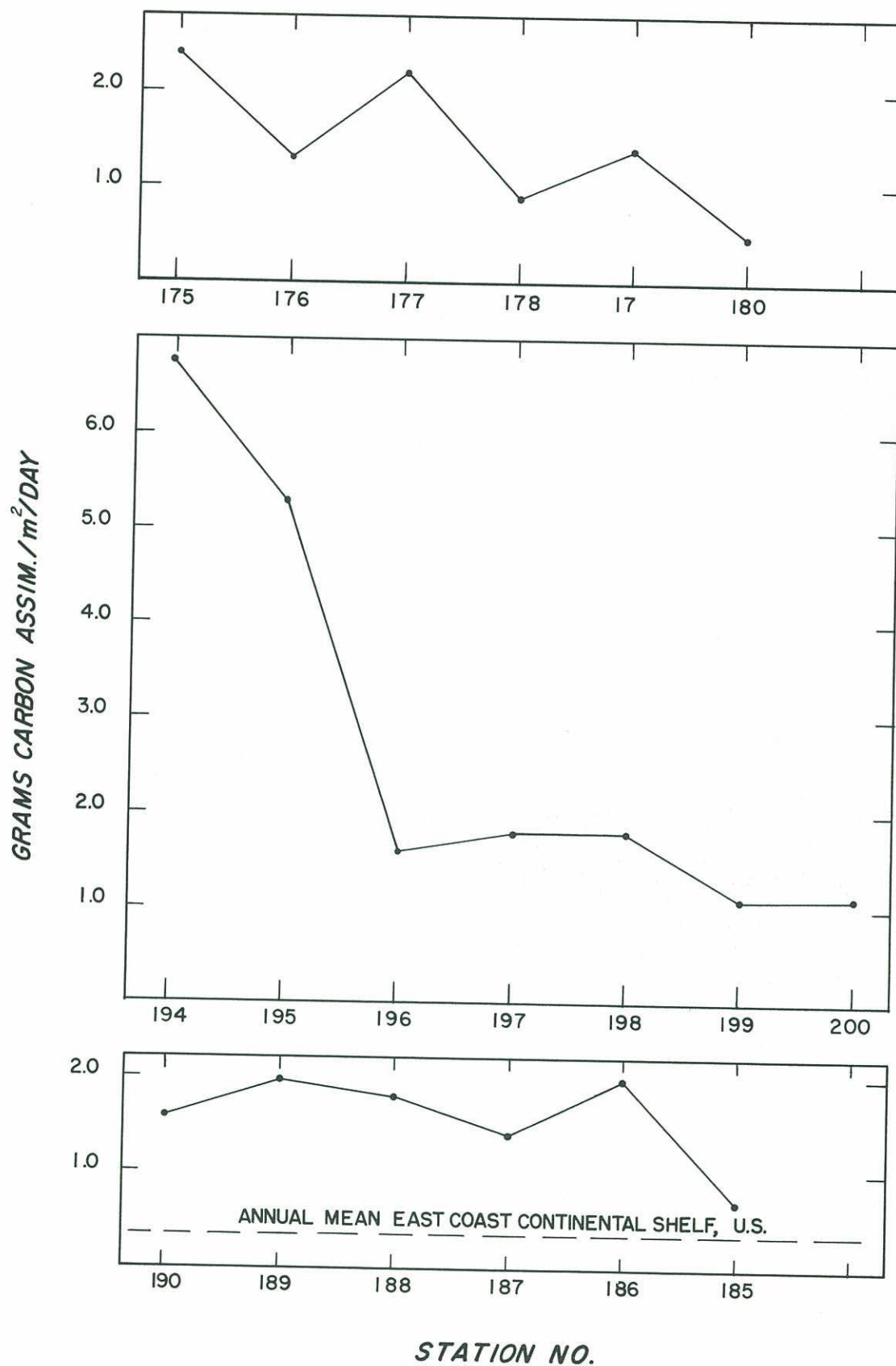


Figure 5. Primary production along three sections in the Arabian Sea. Broken line shows annual mean for U. S. East Coast Continental Shelf for comparison.

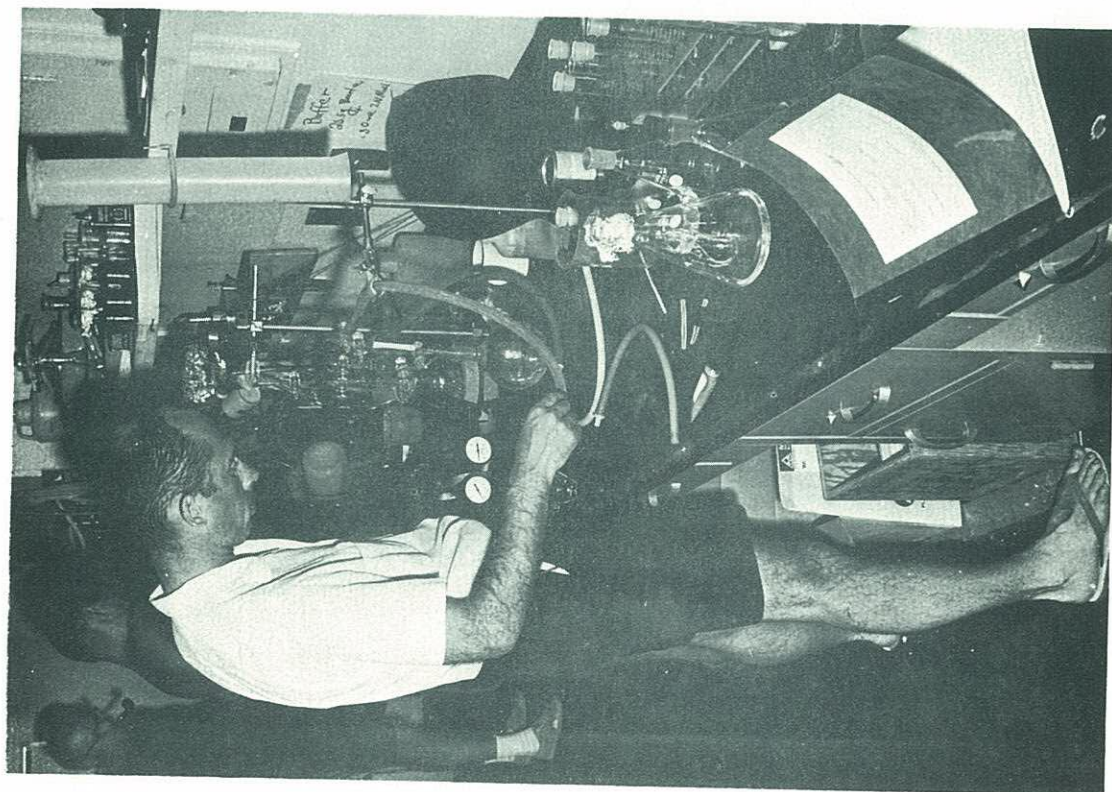


Figure 6. Equipment for measuring N^{15} assimilation by Trichodesmium (R. Dugdale).

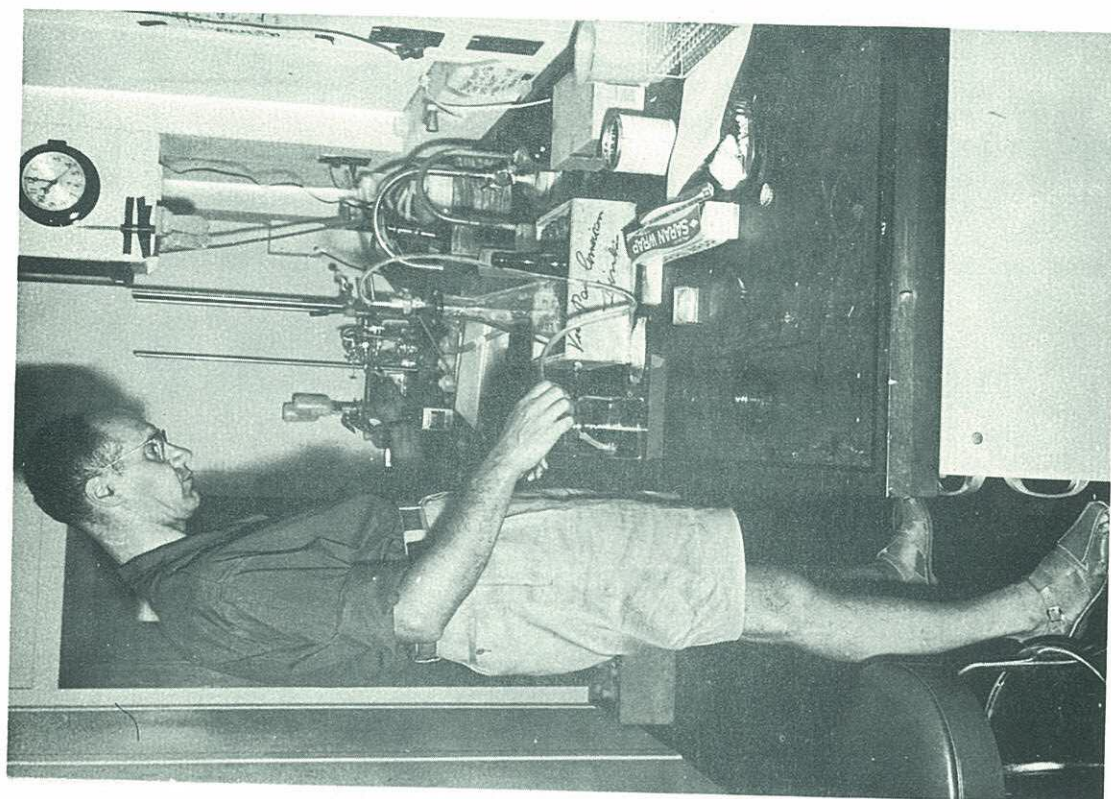


Figure 7. Filtering samples for particulate and dissolved nitrogen analyses (F. Fraga).



Figure 8. Sealing ampoules containing samples for dissolved carbon analyses (D. Menzel).

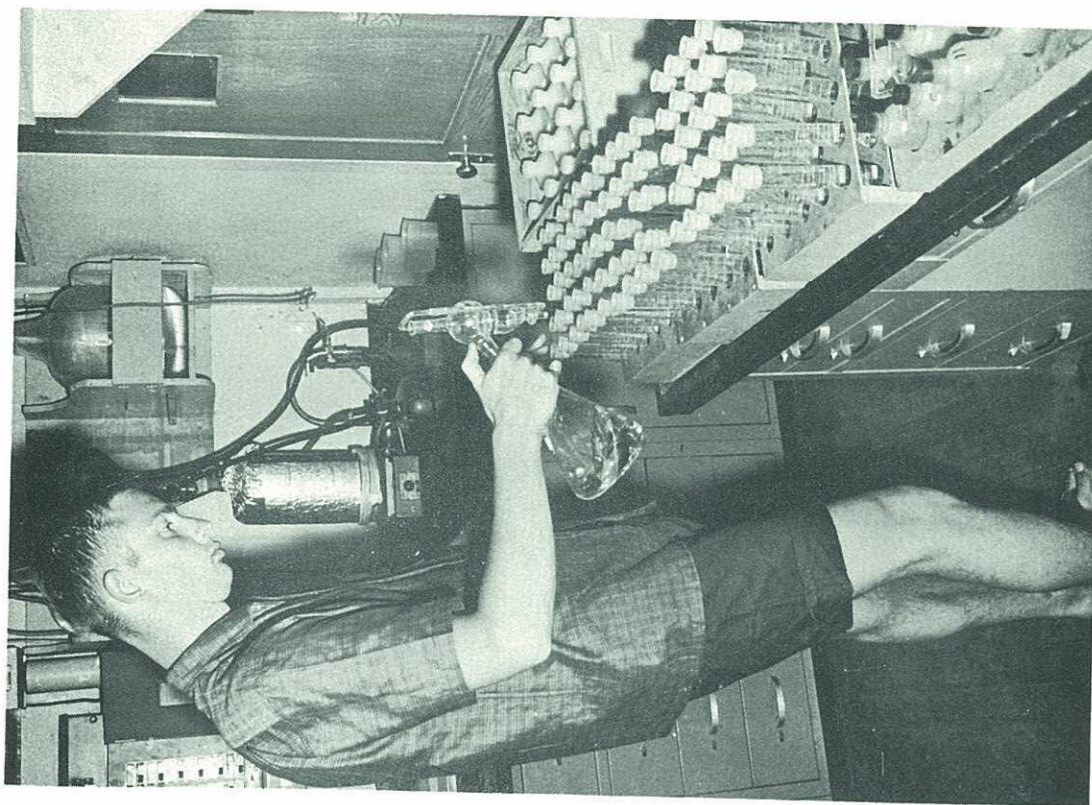


Figure 9. Dispensing samples for nitrate determinations (A. Bakun).

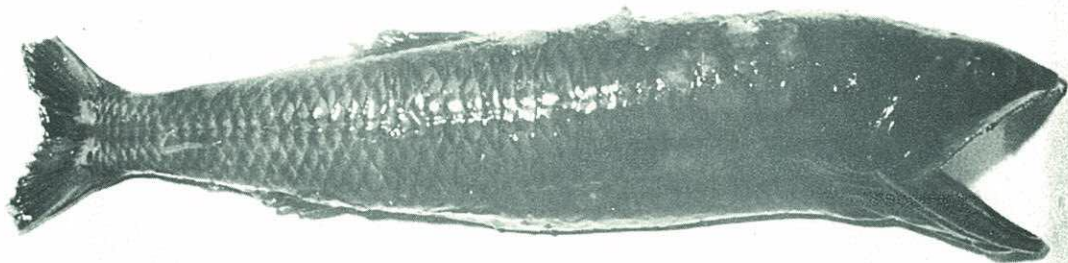


Figure 10. Midwater fish caught in Bé plankton sampler.

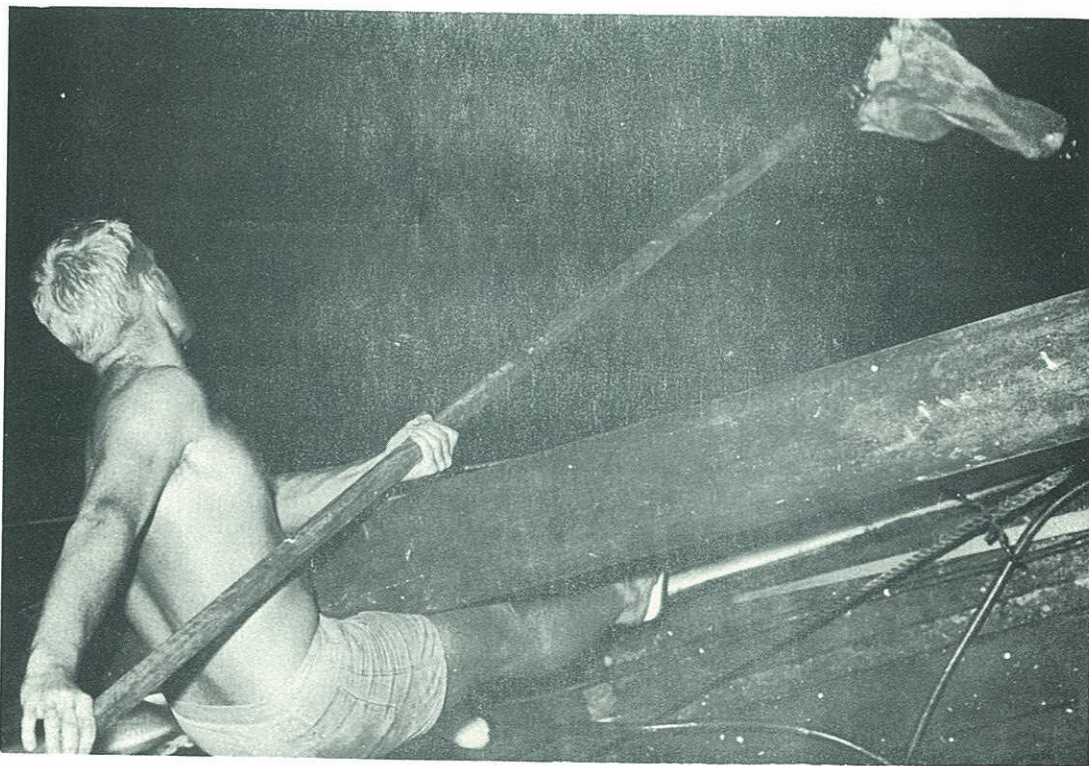


Figure 11. Dip netting at night (B. Rogers).