Cruise Report as promised for cruise for which you have just received the 3 tapes (I hope). Pam

RRS Challenger | Cruise 16/87 | 8 June - 3 July 1987

SCIENTIFIC REPORT

1. Personnel :

P M Holligan	MBA, Plymouth	(Principal Scientist)
C Brownlee	"	
R N Head	"	
J W Wood	"	
R Easton	"	(1st leg)
J Aiken	IMER, Plymouth	(2nd leg)
I Bellan	"	(1st leg)
C Barrett	"	(1st leg)
S M Turner	UEA, Norwich	
G T Malin	"	(2nd leg)
S Watts	"	(2nd leg)
D Purdie	Southampton University	(1st leg)
G Parkes	"	(2nd leg)
I Dias	Bristol University	
L Dowling	Cambridge University	
J Robertson	UCNW, Menai Bridge	
R Powell	RVS, Barry	
G Knight	"	

2. Itinerary :

8 June	Departed Ardrossan
22-23 June	Faeroe Is (Personnel exchange)
3 July	Arrived Troon

The cruise track and station positions are shown in Figs. 1 & 2.

3. Scientific Programme : The main objectives of the cruise were:

a) To investigate the distributions of phytoplankton, especially coccolithophorids, and relevant hydrographic properties (temperature, salinity, oxygen, inorganic nutrients, light penetration etc.) in the NE Atlantic Ocean (55-65°N, 01-21°W).

b) To make further measurements of biogenic sulphur compounds in surface oceanic waters and the marine atmosphere.

c) To make a preliminary investigation of the production of particulate organic and inorganic carbon in relation to the CO_2 chemistry of surface waters.

d) To collect samples of glacial and post-glacial sediments for studies on sedimentation and geochemical processes.

These were successfully achieved, with only minor losses of operational time due to poor weather and equipment failures.

4. Results :

a) Hydrography and plankton sampling (Holliган)

Information on positions, surface water properties and types of sampling at each station is summarised in Tables 1, 2. Continuous measurements of temperature, salinity, chlorophyll fluorescence, light transmission (Sea Tech 660 nm), dissolved oxygen and inorganic nutrients were maintained along the cruise track, using the ships non-toxic water supply (intake depth $\sim$ 3 m). The CTD profiles to within about 5 m of the bottom included data for oxygen, chlorophyll fluorescence and light transmission. Additional data was obtained from tows of the Undulating Oceanographic Recorder (see below), and from XBT transects across the eastern slope of Rockall Bank (Fig. 3) and in the regions of OWS LIMA at 20°W 57°N (see Fig. 4) and of stations 18 and 19. Bottle samples for inorganic phosphate determinations were taken at each of the DMS/DMSP sampling stations (see Fig. 9). About 400 fluorimetric determinations of chlorophyll a were made during the cruise, and a representative set of 25 samples collected for analyses of plant pigments by HPLC. Samples for phytoplankton species identification counts were preserved in both Lugols iodine and neutralised formalin at the CTD and DMS/DMSP sampling stations. Zooplankton samples were obtained by vertical hauls of a paired WP2 net (200 µm mesh) from 100 m to the surface at 17 stations (Table 2).

The observations made around OWS LIMA as part of a collaborative project with MOD (ARE, Portland) are summarised in Fig. 4. Daily phytoplankton and chlorophyll samples are also being collected at this position between April and October by scientists from Swansea University.

Crossings of the Sub-arctic and Arctic fronts (see Figs. 1, 2) showed these boundaries to be poorly defined in terms of surface temperature structure, perhaps due to the calm weather conditions that persisted from mid-May to late June. However, they were characterised by relatively strong horizontal gradients in the temperature of water below the seasonal thermocline as indicated by XBT records. The depth of the surface wind mixed layer increased from $<$ 10 m during the first part of the cruise to $\sim$30 m after 28 June in response to a brief period of strong winds (Fig. 5).

Surface chlorophyll values were generally $<$1.5 mg m^{-3} except locally on the Faeroe Shelf where levels up to 5 mg m^{-3} were measured. A weak

sub-surface chlorophyll maximum was widely observed within the seasonal thermocline, but for daytime CTD and UOR profiles this feature was exaggerated due to the inhibition by light of phytoplankton fluorescence in surface water. Size fractionated determinations of chlorophyll a on the second leg of the cruise, using Nuclepore filters showed ranges of 54-98% associated with $< 10\mu m$ particles, and 8-47% with $< 3\ \mu m$ particles.

Coccolithophores were abundant in the area to the north and west of Rockall Bank, forming the dominant group of phytoplankton at stations 5, 11-14 and 23-26. During 28-30 June experimental and observational work was carried out within a developing coccolithophore bloom that was first identified from NOAA visible images on 24 June by staff at the satellite receiving station, Dundee University. The most abundant species was Emiliania huxleyi, for which cell and free coccolith densities as high as 5,000 and 100,000 ml^{-1} respectively were observed (see Table 5). This confirms that the high reflectance features seen on satellite images for previous years are due to coccolithophores.

Surface nitrate levels were generally high (2-5 μM) over the whole except to the north of the Arctic front (Station 18) where values $< 1\ \mu M$ were found. By contrast, silicate was strongly depleted in surface waters, with concentrations $> 1\ \mu M$ only present in low salinity ($< 35.05^{o}/oo$) sub-arctic waters at stations 8-19.

b) Undulating Oceanographic Recorder (UOR) tows (Aiken)

The UOR (Fig. 6) was towed 30 times (Figs. 1, 2) covering a total distance of 3,820 km with an aggregate tow time of ~ 244 h (Table 3). The instrument failed to undulate on tow 1 due to a broken electrical cable, and undulated only intermittently on tow 4 when the ship's speed dropped below 8 kts. During the remainder of the time a total of 2,100 undulations (double-oblique profiles, typically 0-60 m) and slow vertical profiles (to 100 m at the start and end of tows) were completed.

The new solid state logger (SSL) was extremely reliable, recording data from 11 sensors for tows 1-8 and 10-4, and from 15 sensors for tows 15-30. The only failure on tow 9 was unexplained. A total of 1.1 million data were recorded. Sensor reliability was high; three light sensor bodies were damaged on recovery on tow 5, and two electrical cables were frayed during tow 14.

The distributions of temperature and chlorophyll were very variable, but

could be related to a large extent to recognised properties of surface waters in the NE Atlantic. These include the main frontal boundaries between North Atlantic and sub-arctic waters (see Figs. 1, 2), meso-scale eddy structure over horizontal distances of 35-70 km, cold water masses which persist on the main banks (Rockall and Faeroe Banks, and also the Faeroe Shelf), shelf edge mixing, and the effects of wind mixing. For many tows, the variability was most pronounced in the sub-surface layers.

Two examples of the UOR data are illustrated - temperature and chlorophyll sections from tow 17 across the Arctic front (Fig. 7), and surface temperature, chlorophyll and optical transects for tow 25 where coccolithophores were present (Fig. 8).

The start of tow 17 shows weakly stratified Atlantic waters, with alternating bands of relatively warm and cold water perhaps associated with an eddy. The crossing of the Arctic front at 60 km was marked by slightly cooler, nutrient-poor surface water and much cooler sub-thermocline water. Also, within the more pronounced thermocline, a broad sub-surface chlorophyll maximum was observed which persisted for about 70 km. The vertical displacements of the isotherms were accompanied by corresponding changes in the vertical distribution of chlorophyll along the whole length of the tow.

The measurements of water colour on tow 25 showed the effects of light absorption of chlorophyll which is strong in blue (b) wavebands and relatively weak in the green (g), and also of changes in phytoplankton species composition particularly with respect to coccolithophores and associated coccoliths (see Table 5) which backscatter light strongly at all wavelengths. Both act to increase attenuation coefficients (K_b and K_g), but have opposing effects on reflectance (R_b and R_g) which is proportional to backscattering and inversely proportional to absorption. A further complication is that coccolithophores have accessory pigments that absorb light at green wavelengths.

On tow 25 the average chlorophyll concentration for the surface mixed layer varied between 0.2 and 1.8 mg m^{-3}, with corresponding changes in the attenuation coefficients for blue and green light. The reflectance values were relatively high, indicating the presence of coccoliths, but variations along the transect were not always in the same direction as those for attentuation. The highest attenuation coefficients and reflectances were measured on tow 26, with values for R_b and R_g reaching 20% and 14% respectively.

c) Sulphur measurements (Turner, Malin, Watts)

Organic sulphur compounds were extracted from seawater samples using a cryogenic purge and trap extraction technique and measured by FPD gas chromatography. Data for dimethyl sulphide (DMS) and its precursor dimethylsulphoniopropionate (DMSP) were obtained from 175 samples (Fig. 9) representing a range of hydrographic and biological conditions. Surface samples were taken at regular intervals along the ships track and some analyses were made for different depths while on station. Parallel samples were taken for chlorophyll, phosphate and phytoplankton cell counts. These data together with shipboard nutrient, oxygen and light measurements will be analysed as potential factors affecting the distribution of DMS, and intracellular and extracellular DMSP.

DMS concentrations ranged 30 to 3,000 ng S (DMS) 1^{-1} with corresponding total DMSP concentrations between 1,000 and 12,000 ng S (DMSP) 1^{-1}. These data will be used for the calculation of fluxes of volatile sulphur to the atmosphere.

Other related work included the isolation of bacteria from different depths in the water column for a laboratory study to determine the significance of bacterial utilisation of DMS/DMSP.

Atmospheric particulate samples were also collected with a high volume pump while the ship was steaming. The filters were frozen for laboratory analyses of the oxidation products of DMS (methane sulphonic acid, dimethyl sulphoxide etc.). The analysis of oxidised gas phase sulphur compounds was attempted on board ship but was abandoned due to technical problems. During the last few days of the cruise atmospheric DMS measurements were made.

d) Dissolved oxygen concentrations : depth distributions, and effects of primary productivity on surface saturation (Purdie)

The concentration of dissolved oxygen in surface waters was continuously monitored using a YSI oxygen electrode connected to the ship's non-toxic sea water supply. The oxygen values were displayed on a chart recorder and the signal data logged at 30 seconds intervals. The electrode was regularly calibrated from duplicate oxygen analysis using the precise Winkler titration system.

Vertical oxygen distribution was investigated using CTD system equipped with a Beckman polarographic dissolved oxygen sensor. The electrode was calibrated by analysing water samples collected up to 12 depths on each cast

using the 1.2 l Niskin rosette system. Water samples were routinely collected at the oxygen minimum and to a maximum depth of 3,000 metres. Vertical profiles of oxygen (Fig. 10) will be compared with total carbon dioxide measurements. Near surface samples were analysed for chlorophyll on each cast and samples taken for later bacteria counts (by DAPI staining technique) and DOC assay (CTD 1, 4, 23, 25 only).

Six experiments were conducted during the cruise to specifically determine the photosynthetic and respiratory activities of near surface waters containing coccolithophore populations. Sea water samples were collected in a 30 l Niskin bottle at the fluorescence maximum. Oxygen bottles were incubated in six on-deck incubators at a range of surface incident light intensities and at surface temperature for between 4-12 hours. Parallel incubations were conducted to determine carbon flux from $^{14}CO_2$ uptake rates and changes in total carbon dioxide (Table 4). Chlorophyll determinations were made at the start and end of each incubation.

e) Total CO_2, alkalinity and pH (Robertson)

Samples for onboard TCO_2 determinations, using an automatic gas handling procedure linked to a CO_2 coulometer, and for alkalinity measurements in the laboratory were collected both from the non-toxic surface water supply and from water bottles at 22 of the CTD stations. For each of the latter up to ten sampling depths were selected according the main gradients in dissolved oxygen, chlorophyll fluorescence, and light transmission. Changes in TCO_2 were also measured for four incubation experiments, in parallel with measurements of oxygen changes and $^{14}CO_2$ uptake (see Table 4).

About 350 values for surface TCO_2 were obtained. In general variations in TCO_2 followed those of temperature, except for regions of high chlorophyll concentrations where decreases up to 40 µmol C l^{-1} were noted particularly in the presence of coccolithophores. Vertical profiles for TCO_2 mirrored those for oxygen, with maxima and minima respectively occurring at the same depth (see Fig. 10 for examples of O_2 profiles). Near the surface the oxygen maximum was accompanied by a TCO_2 minimum, except within the coccolithophore bloom where the TCO_2 minimum was displaced upwards.

The preserved alkalinity samples included about 100 from surface waters and a further 150 from the CTD profiles. Until the analyses are completed, it is not possible to estimate pCO_2 values.

A new automated pH measuring system was tested at various times during

the cruise. On several legs pH was recorded continuously with this system, and also with a conventional pH electrode. The results indicate that the automatic method will be suitable for use on ships once various modifications have been made.

f) Primary production (Brownlee)

Three types of experiment (Table 4) were carried out -

i) Deck incubations at various irradiances to compare $^{14}CO_2$ uptake with changes in dissolved O_2 and TCO_2

ii) Laboratory incubations to measure $^{14}CO_2$ uptake and define photosynthesis - irradiance curves

and iii) Comparison of $^{14}CO_2$ and ^{45}Ca uptake, including effect of irradiance and time course incubations.

In each case filtrate samples were acidified and bubbled to determine the incorporation of ^{14}C into DOC. The parallel incubations with $^{14}CO_2$ and ^{45}Ca were carried out for water samples containing significant densities of coccolithophores (Table 5). For these experiments attempts were made to distinguish between organic and inorganic (calcite) ^{14}C by exposing the filters to acid, and between extracellular and intracellular $^{45}CaCO_3$ and $Ca^{14}CO_3$ by briefly reducing the pH of the samples before filtration.

g) Geochemical studies (Dias)

Samples of phytoplankton, zooplankton and bottom sediments were collected for analyses of fatty acids, sterols and alkanes. Of particular interest are the distributions and degree of unsaturation of long chained alkenones (C_{37} to C_{42}) synthesised by coccolithophores which provide information about palaeoclimatic conditions. Also a comparison of the different types of samples indicates the possible ways in which lipids are modified between synthesis by phytoplankton and incorporation into the sediments.

A total of 80 phytoplankton samples, including 16 from sub-surface chlorophyll maxima, were frozen in a 50:50 mixture of methanol and dichloromethane. From the zooplankton nets specimens of the dominant organisms (eg. copepods, salps) were picked out, starved to evacuate their guts of food material and frozen (total of 16 samples). From the sediment cores (see Table 6), 27 75g samples were removed and frozen, mainly from the top metre.

h) Sediment studies (Dowling)

A total of 41 samples of particulate material from turbid layers in the water column were collected at CTD stations 3-28. These were mainly from the bottom 10 m. Eight Kastenlot cores were recovered, and at six sites bottom photographs were taken (Table 6). X-ray sections were taken of the top of cores (except for cores 6 and 7). From each core subsamples were taken at different levels for analyses of water content (total 121) and of $CaCO_3$ content, clay mineralogy, particle size distribution and isotopic fractionation in foraminifera (total 131). Samples of surficial sediment at each site will be used for determinations of the relative abundance of different coccolithophore species for a comparison with the distributional patterns of the same species in surface waters of the NE Atlantic.

5. Working up of the results

Most of the analyses of samples and data should be completed within 6-12 months of the cruise. The longest delays are likely to be with the phytoplankton counts, and with the sediment samples. It is proposed to write up a brief account of the main interdisciplinary work of the cruise as this will be relevant to the planning of the BOFS programme. Otherwise the publication of results will be the responsibility of the individual scientists, and if further information is required these people should be contacted.

6. Scientific Equipment

In general only minor difficulties were experienced, including:

a) RVS equipment - all functioned well, the only minor problem being with the MBA Chelsea fluorometer on the CTD system which tended to give zero readings at low (ie. deep water) fluorescence values.

b) BBC logging system - occasional breakdowns due to mains interference which can be cured by a mains filter unit, and the failure of two interface input preamplifiers which should be protected. Considerable streamlining of the logging and plotting programmes was done during the cruise.

c) Automated pH system - many of the operating problems would be overcome by replacing the Apple computer and by placing the equipment in a protective box.

d) Nutrient autoanalyser - considerable difficulties were experienced with measurements of NO_2, Si and NH_4 which all showed low surface concentrations throughout the cruise. The reasons were not entirely clear, but one problem may have been other laboratory equipment causing noise on the mains supply.

e) Kastenlot Corer - the failure to obtain cores at the first three stations appeared to be early triggering of the nose cone springs. An old nose cone from which the springs had been removed cured this problem. The weight of the corer was also critical for preventing excessive penetration of the barrel. 250 to 300 Kg of lead would probably have been adequate at most stations.

7. Ship Operations

Working conditions on the deck and in the laboratories were generally excellent. During the short spell of poor weather on 27/28 June, there were some problems with an accumulation of water on the wet and fishing laboratory floors, apparently due to 'backing up' from the drains. Also water entered a vent in the main laboratory onto electronic equipment, but luckily caused no serious damage. The opening and closing of the heavy outer doors between the deck and laboratories is potentially hazardous for those not familiar with working on a rolling ship. The communication system between the main laboratory, after deck and bridge should be improved, the condition, siting and method of operation of the telephones is not good.

8. Conclusions

Most of the objectives of the scientific programme were achieved in full. The scientific support facilities and communal effort required for an interdisciplinary cruise of this type might have proved inadequate if the weather had been less favourable, and attention must be given to this problem during the preparation for programmes such as BOFS. In particular resources for the development of new biological/chemical techniques, and proper training of new personnel must be maintained if work on small ships in offshore waters is to remain effective.

P M Holligan

30 July 1987

TABLE 1. Station Details

STATION NO	DATE	TIME (GMT)	LAT (N) (Start)	LONG (W) (Start)	:	LAT (N) (End)	LONG (W) (End)	WATER DEPTH (m)
1	10/6/87	1544-2300	54°22.0N	16°30.2W	:	54°21.8N	16°28.7W	2250
2	11/6/87	0930-1214	55°14.0N	15.11.1W	:	55°14.5N	15°10.6W	2100
3	11/6/87	1352-1940	55°19.9N	15°22.8W	:	55°19.3N	15°25.7W	2000
4	12/6/87	1113-1818	56°30.0N	12°04.9W	:	56°30.8N	12°02.5W	2545
5	13/6/87	1435-1903	57°30.4N	17°30.1W	:	57°31.4N	17°27.9W	1300
6	14/6/87	0957-1139	56°29.9N	20°00.1W	:	56°30.1N	19°57.0W	1385
7	14/6/87	1518-1739	57°00.7N	19°59.9W	:	57°01.6N	20°00.8W	1005
8	14/6/87	2108-2305	57°31.6N	19°58.5W	:	57°33.0N	19°58.2W	1175
9	15/6/87	1236-1604	58°30.1N	20°00.0W	:	58°30.8N	19°58.9W	2595
10	15/6/87	1943-2212	57°59.5N	20°00.3W	:	58°00.3N	20°02.7W	1670
11	16/6/87	1030-2053	59°26.0N	17°59.1W	:	59°26.3N	17°58.0W	1955
12	17/6/87	1203-1350	58°59.6N	15°29.8W	:	59°00.4N	15°30.3W	1190
13	18/6/87	0230-0352	60°59.9N	13°59.9W	:	61°00.1N	13°59.2W	1710
14	18/6/87	1330-1900	59°52.4N	11°59.8W	:	59°51.3N	12°03.6W	1220
15	19/6/87	0918-1536	61°00.4N	09°59.4W	:	61°00.4N	10°01.5W	1120
16	19/6/87	2250-2337	61°15.4N	07°58.2W	:	61°14.8N	07°58.5W	885
17	20/6/87	1135-1237	62°50.4N	08°30.7W	:	62°52.3N	08°36.8W	500
18	21/6/87	0840-1327	64°33.4N	06°18.5W	:	64°34.4N	06°19.4W	2885
19	24/6/87	0632-1148	63°13.9N	03°59.9W	:	63°10.4N	03°58.7W	2565
20	25/6/87	0700-1035	61°27.5N	01°52.9W	:	61°27.2N	01°53.2W	800
21	26/6/87	0418-0828	61°00.1N	04°59.7W	:	61°01.3N	05°02.3W	820
22	26/6/87	1736-2159	60°20.1N	07°01.5W	:	60°25.1N	06°59.8W	1135
23	27/6/87	0831-1035	59°50.7N	09°59.8W	:	59°51.2N	10°01.1W	1230
24	28/6/87	1700-1906	57°50.9N	14°11.6W	:	57°52.6N	14°09.9W	235
25	29/6/87	0420-1243	58°23.7N	13°35.9W	:	58°29.8N	13°32.7W	1200
26	29/6/87	1755-2006	58°49.8N	12°11.5W	:	58°52.0N	12°11.5W	1700
27	1/7/87	1430-2038	56°29.9N	12°05.2W	:	56°29.8N	12°00.5W	2535
28	2/7/87	0630-0838	55°32.0N	10°00.0W	:	55°32.5N	09°58.1W	1770

TABLE 2. Surface (3 m) Hydrographic Measurements

Station No	Temp °C	Sal °/oo	Chlorophyll mgm^{-3}+	Phaeopigment $mg\ m^{-3}$+	Oxygen % Sat*	NO_3 µM	Si µM	T/M (%)	Secchi depth (m)	Sampling*
1	11.99	35.29	(0.31)	(0.04)	-	5.70	-	80	15	C
2	12.02	35.32	0.75	0.16	-	3.68	-	-	13	C
3	11.87	35.33	(0.63)	(<0.01)	-	3.56	-	-	-	C
4	11.11	35.30	(0.69)	(0.08)	-	5.52	0.58	-	10	C,Z
5	10.65	35.11	0.81	0.04	-	4.65	0.58	82	12	C,Z,K,Ca
6	11.39	35.21	0.43	0.09	-	4.45	0.33	80	13	C,Z
7	11.21	35.13	0.72	0.03	-	4.08	0.42	-	12	C,Z
8	10.88	35.02	1.01	0.29	-	4.11	0.25	77	9-10	C,Z
9	11.02	35.01	1.25	0.27	110.0	4.69	1.42	76	8	C,Z
10	10.99	35.04	1.44	0.25	-	3.68	1.25	78	-	C,Z
11	10.91	34.99	1.38	0.41	-	4.71	1.42	75	7.5-8	C,Z,W,K
12	10.57	35.15	1.18	0.04	-	4.92	0.75	80	12	C,Z,W
13	10.27	35.12	0.75	0.16	-	2.91	0.42	81	-	C
14	10.77	35.26	1.35	0.37		2.97	0.63	71	6	C,Z,W,K,Ca
15	10.35	35.05	0.36	0.09	106.5	3.56	0.75	77	13	C,Z,W,K,Ca
16	9.17	35.21	0.90	0.44	105.9	4.63	0.63	-	-	C
17	9.08	35.12	0.40	0.10	-	3.86	0.75	80	10	C,Z
18	6.99	34.72	1.05	0.25	-	0.65	-	76	9	C,Z,W
19	9.24	35.14	0.77	0.43	-	4.93	-	82	12	C,Z,W,K
20	10.51	35.28	0.68	0.23	107.3	4.16	-	84	15	C,W
21	10.33	35.21	0.67	0.20	-	3.86	-	80	13	C,K,Ca
22	10.21	35.18	1.32	0.35	-	3.74	-	76	8	C,K,Ca
23	10.93	35.24	0.59	0.13	107.9	2.50	-	81	9	C,Z,W
24	11.74	35.17	0.81	0.15	107.8	3.50	-	66	6	C,Z
25	11.23	35.13	0.98	0.23	-	3.45	-	65	7	C,Z,W
26	11.03	35.24	0.90	0.27	-	3.74	-	71	12	C
27	12.44	35.32	0.41	0.10	104.4	1.90	-	84	17	C,K
28	12.20	35.29	0.55	0.15	-	1.60	-	85	14	C
W (28/6)	11.50	35.16	1.06	0.20	-	2.26	-	68	6	W
W (30/6)	11.29	35.17	1.24	0.23	-	2.50	-	65	6	W

*C = CTD Profiles, W = 30 l water bottle also taken at 0720, 30 June 1987 at 50°49.6N, 14°44.1W

+Values in parentheses are for closely situated depths/positions.

*Values for other stations have not yet been calculated from the CTD and laboratory oxygen sensors.

TABLE 3

UOR TOW LIST

TOW NO	TIME GMT	EVENT	LAT (N)	LONG (W)	TOW TIME	TOW LENGTH (Km)	NO OF UNDS	SPEED (Knots)	COMMENTS
01	10.20	L	55°17'N	08°44'W				10.0	Stopped undulatir
09.06.87	12.16	R	55°10'N	09°11'W	1h56	32	3		
02	14.05	L	55°05'N	09°41'W				9.8	
09.06.87	21.15	R	54°52'N	11°36'W	7h10	126	69	10.1	
03	08.27	L	54°35'N	14°36'W				10.0	
10.06.87	15.32	R	54°22'N	16°30'W	7h05	126	65	9.6	
04	23.10	L	54°21'N	16°28'W				7.7	Few random
10-11.06.87	08.53	R	55°13'N	15°12'W	9h43	126	9	6.8	undulations + 2VI
04V	13.52	L	56°31'N	12°03'W				2.2	
12.06.87	14.20	R	56°30'N	12°04'W	0h28	2	1		
05	19.30	L	56°34'N	12°17'W				9.5	
12-13.06.87	14.34	R	57°31'N	17°29'W	19h04	335	199	9.4	
06	02.45	L	57°00'N	19°32'W				9.5	
14.06.87	06.19	R	57°00'N	20°32'W	3h34	61	34	9.6	
07	11.45	L	56°30'N	19°56'W				9.5	
14.06.87	15.18	R	57°00'N	19°59.9'W	3h33	56	33	9.6	
08	17.39	L	57°01'N	20°00'W				9.5	
14.06.87	21.00	R	57°31'N	19°58'W	3h21	56	31	9.6	
09	23.15	L	57°33.7'N	19°58.0'W				9.6	Logger failed.
14-15.06.87	12.39	R	58°30'N	19°59'W	13h54	236	138	9.6	
10	16.06	L	58°30'N	19°58'W				9.8	
15.06.87	19.38	R	57°59'N	20°00'W	3h32	58	34	9.8	
11	21.17	L	59°27'N	17°55'W				9.8	
16-17.06.87	05.15	R	59°54'N	15°53'W	7h58	151	80	10.0	
12	06.02	L	59°57'N	15°43'W				9.9	
17.06.87	12.01	R	58°59'N	15°29'W	5h29	110	62	10.0	
13	03.58	L	60°59'N	13°57'W				9.7	
18.06.87	13.25	R	59°52'N	11°59'W	9h27	166	94	9.5	
14	22.16	L	59°30'N	11°18'W				9.7	
18-19.06.87	09.10	R	61°00'N	09°59'W	10h54	182	108	9.5	
15	16.09	L	61°00'N	09°34'W				9.5	
19.06.87	22.32	R	61°16'N	07°56'W	6h23	112	63	9.6	
16	06.08	L	62°07'N	08°05'W				9.9	
20.06.87	11.34	R	62°50'N	08°30'W	5h26	84	55	9.7	
17	17.00	L	63°29'N	07°59'W				9.4	
20-21.06.87	03.48	R	64°59'N	06°31'W	10h48	182	105	9.3	
18	14.38	L	64°29'N	06°00'W				9.7	
21-22.06.87	02.20	R	62°44'N	07°07'W	11h42	205	115	9.7	
19	22.06	L	62°18.8'N	05°49.6'W					
23-24.06.87	06.07	R	63°14.2'N	04°01.4'W	8h01	140	77	9.5	
20	20.16	L	62°30.1'N	02°29.0'W					
24-25.06.87	06.44	R	61°27.3'N	01°52.8'W	7h33	130	73	9.5	
21	10.36	L	61°27.7'N	01°52.9'W					
25.06.87	14.54	R	61°00.34'N	01°00.0'W	4h18	71	40	9.5	
22	15.35	L	61°00'N	01°02'W				9.6	
25.06.87	23.18	R	60°59.5'N	03°30.9'W	7h43	136	76	9.2	
23	08.40	L	61°01.4'N	05°02.8'W				9.5	
26.06.87	13.45	R	60°55.0'N	06°34.6'W	5h05	87	52	9.5	
24	22.05	L	60°25.2'N	07°00.1'W				9.5	
26-27.06.87	08.23	R	59°49.7'N	10°02.5'W	10h18	182	105	10.0	
25	10.41	L	59°51.6'N	10°01.2'W				9.5	
27.06.87	17.17	R	59°52.4'N	12°11.5'W	6h36	123	68	10.2	
26	11.52	L	58°25.0'N	13°35.5'W				8.0	
28.06.87	16.55	R	57°51.0'N	14°11.7'W	5h03	73	43	8.4	
27	12.50	L	58°29.9'N	13°32.6'W				9.3	
29.06.87	17.55	R	58°49.8'N	12°11.3'W	5h05	87	48	9.3	
28	07.43	L	58°49.4'N	14°43.4'W				9.7	
30.06.87	16.15	R	58°49.7'N	12°11.1'W	8h32	147	83	9.8	
29	05.39	L	57°30.8'N	13°39.6'W				9.8	
01.07.87	14.16	R	56°29.2'N	12°05.9'W	8h37	149	85	10.0	
30	08.39	L	55°32.5'N	09°57.9'W				9.5	
02.07.87	13.46	R	55°31.0'N	08°30.7'W	5h07	91	53	9.6	

TABLE 4 Phytoplankton Experimental Work

EXPERIMENT NO	STATION/ POSITION	DATE	SAMPLE DEPTH (m)	INCUBATIONS
1	11	16/6	15, 30	$^{14}CO_2$ P/1 curve (lab.)
2	11	16/6	15, 30	$^{14}CO_2/O_2/TCO_2$ comparison (deck)
3	12	17/6	30	$^{14}CO_2/O_2/TCO_2$ comparison
4	12	17/6	30	$^{14}CO_2$ P/1 curve, ^{45}Ca uptake
5	14	18/6	30	$^{14}CO_2/O_2/TCO_2$ comparison
6	14	18/6	30	$^{14}CO_2$ P/1 curve, ^{45}Ca uptake
7	15	19/6	40	$^{14}CO_2$ time course
8	18	21/6	24	$^{14}CO_2/O_2$ comparison
9	19	24/6	30	$^{14}CO_2$ P/1 curve
10	20	25/6	20	$^{14}CO_2$ P/1 curve
11	23	27/6	30	$^{14}CO_2/O_2$ comparison
12	58 28N, 13 32W	28/6	3	$^{14}CO_2$, ^{45}Ca time course
13	25	29/6	15 (a)	$^{14}CO_2/O_2/TCO_2$ comparison
14	25	29/6	15 (b)	$^{14}CO_2$ P/1 curve, ^{45}Ca uptake
15	58 50N, 14 44W	30/6	5	$^{14}CO_2$ P/1 curve, ^{45}Ca uptake

TABLE 5 Provisional Coccolithophore Counts for Experimental Samples

Station	Sample depth (m)	Expt No	Chl a mg m^{-3}	T/M %	E. huxleyi Cells ml^{-1}	E. huxleyi liths ml^{-1}	C. pelagicus Cells ml^{-1}	C. pelagicus liths ml^{-1}	Other spp. Cells ml^{-1}
11	2		1.4	75	42	3,000	84	< 10	67
	15	1	1.6	-	10	< 1,000	68	< 10	124
	35	2	0.9	-	56	< 1,000	292	70	77
12	2		1.2	80	70	11,000	140	40	45
	30	3,4 (^{45}Ca)	0.6	-	154	< 1,000	346	70	40
14	2		1.3	71	2,016	48,000	250	40	92
	30	5,6 (^{45}Ca)	1.5	-	2,100	39,000	178	28	81
23	2		0.6	81	-	-	-	-	
	30	11	0.6	-	412	5,000	77	< 10	22
Bottle (28/6)	3	12	1.1	68	3,738	102,000	96	14	9
25	2		1.0	65	3,934	78,000	434	10	12
	15(a)	13	1.1	-	4,340	102,500	2,268(?)	< 10	52
	15(b)	14 (^{45}Ca)	1.1	-	2,086	47,000	135	< 10	25
Bottle (30/6)	5	15 (^{45}Ca)	1.2	65	1,540	49,000	82	< 10	16

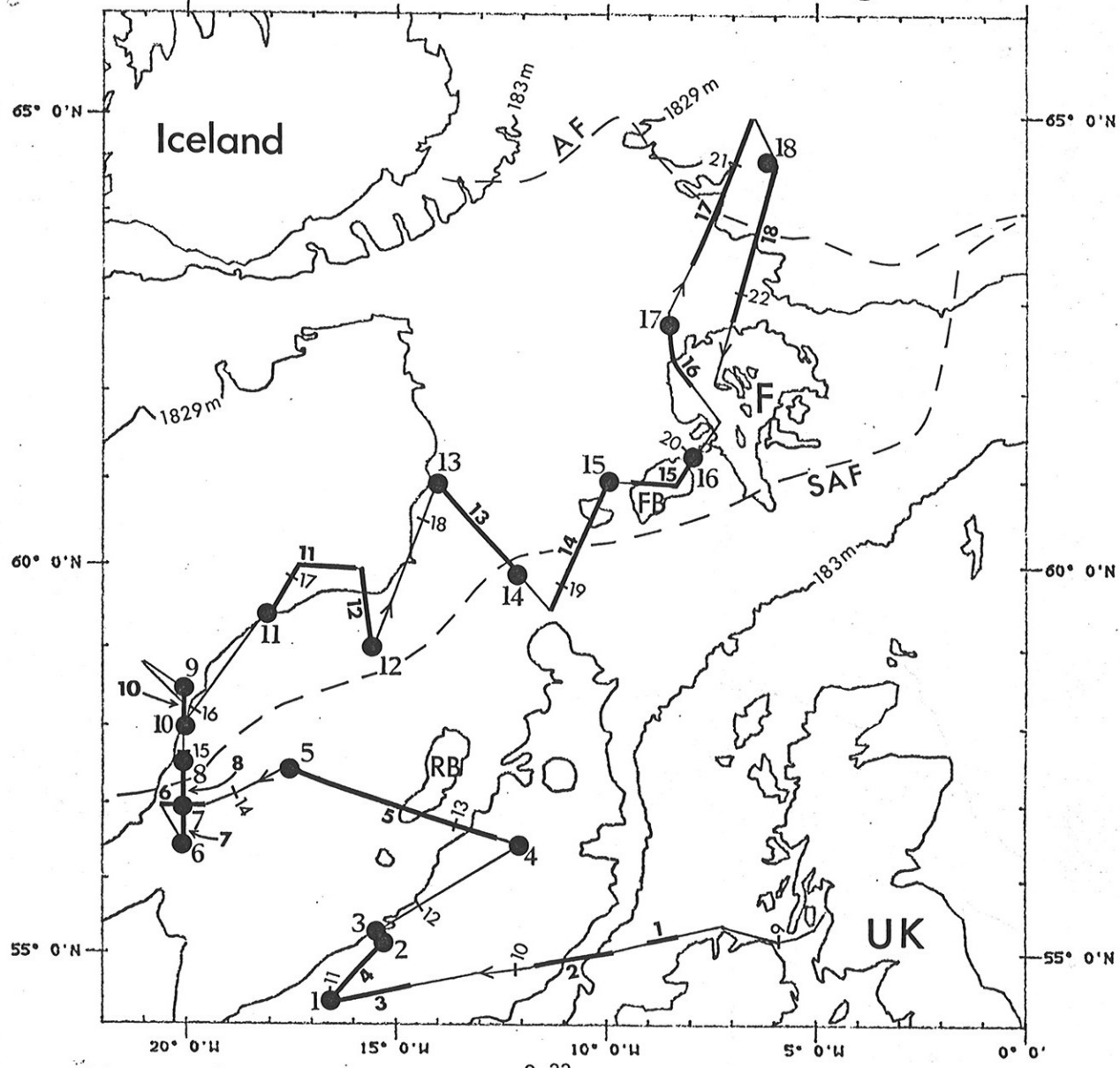
TABLE 6

Sediment Cores

CORE NO	STATION NO	POSITION	WATER DEPTH (m)	CAMERA	CORE LENGTH (m)	SURFACE LAYER
1	5	57 30.5N 17 29.0W	1300	✓	0.80	
2	11	59 26.2N 17 57.8W	1955		2.60	Pale brown, ? disturbed
3	14	59 51.6N 11 59.6W	1220	✓	2.10	Light grey
4	15	61 00.0N 10 00.7W	1120	✓	2.65	Brownish grey
5	19	63 10.3N 03 58.7W	2565		1.52	Brown
6	21	61 00.2N 05 00.3W	820	✓	2.75+	Brown at surface (?) to dark grey, disturbed
7	22	60 21.7N 07 00.6W	1135	✓	0.44	Brown, with sand
8	27	56 30.4N 12 04.7W	2535	✓	2.70	Brown at surface to light grey, disturbed

Figure 1

RRS Challenger Cruise 16/87 1st Leg 8 –22 June



Ships track — 9–22 Position and date at 0000h

1–18 UOR tow track and number — 1–18 Position and number of CTD station

F- Faeroe Is. RB- Rockall Bank FB- Faeroe Bank

AF Arctic Front , SAF Subarctic Front

Figure 2

RRS Challenger Cruise 16/87 2nd Leg 23 June – 3 July

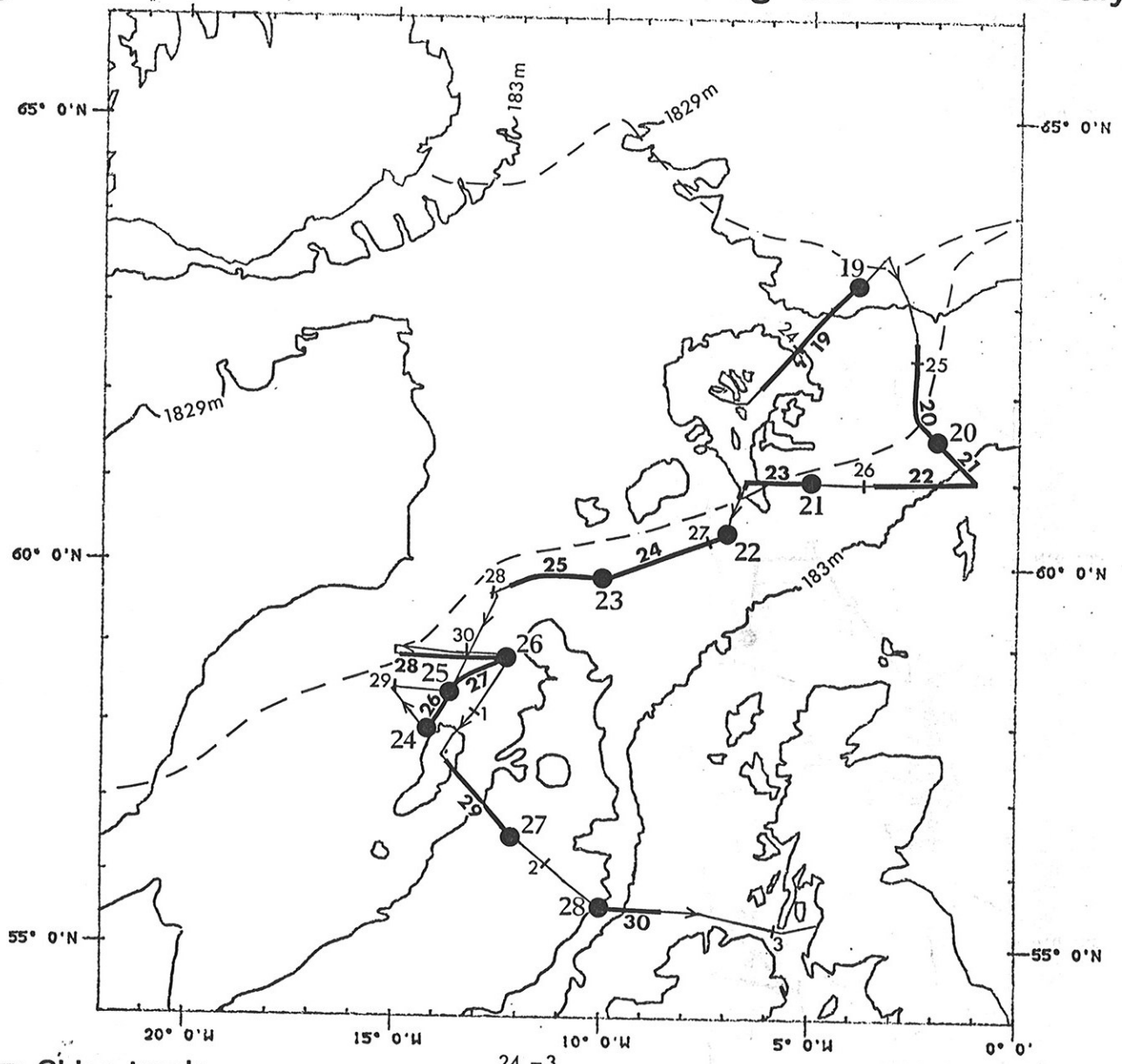


Figure 3

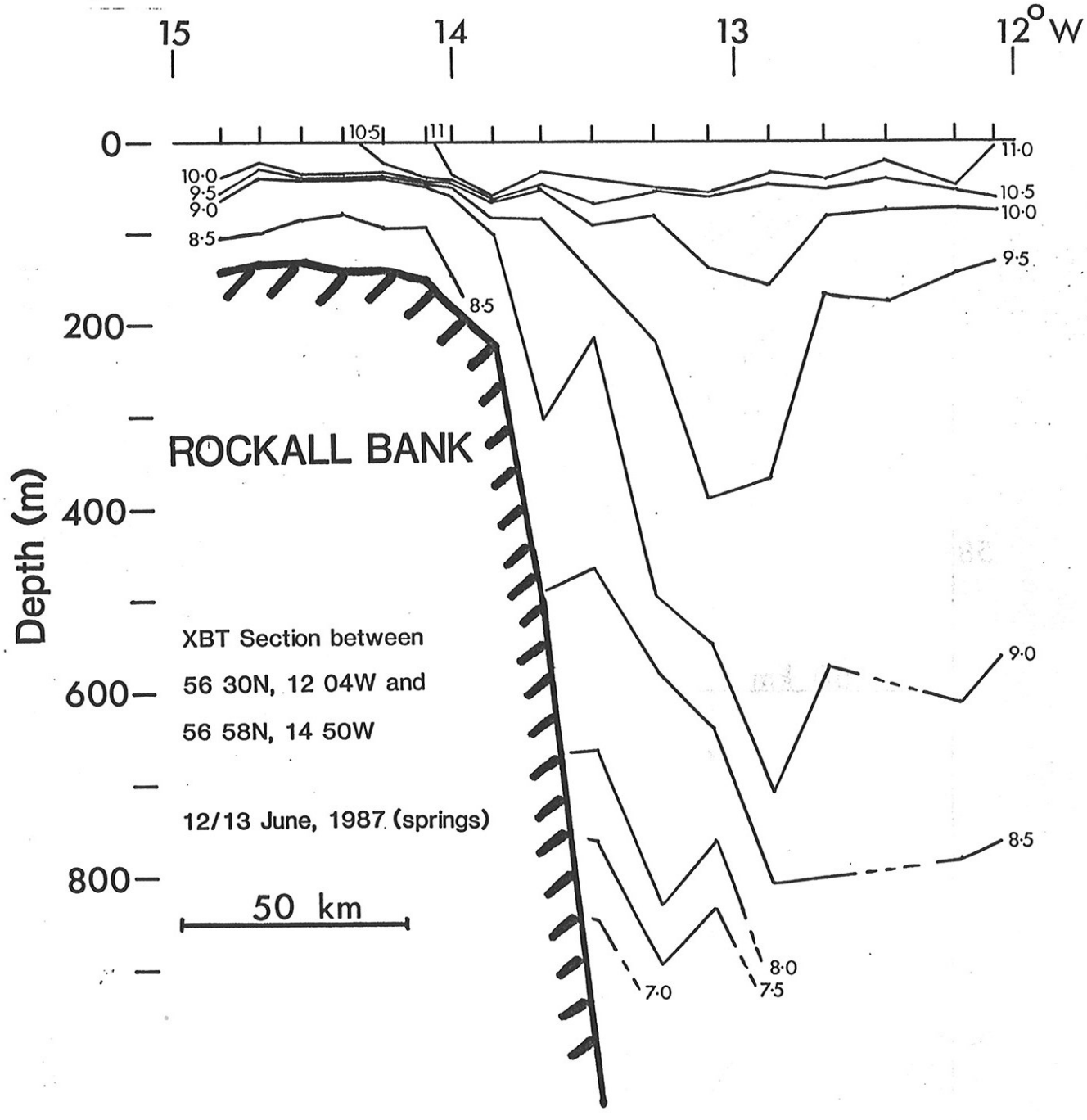

15
14
13
12°W
0
200
400
600
800
Depth (m)
10·5
11
11·0
10·0
9·5
9·0
8·5
10·5
10·0
9·5
8·5
ROCKALL BANK
XBT Section between
56 30N, 12 04W and
56 58N, 14 50W
12/13 June, 1987 (springs)
50 km
9·0
8·5
8·0
7·5
7·0

Figure 4 LIMA Observations

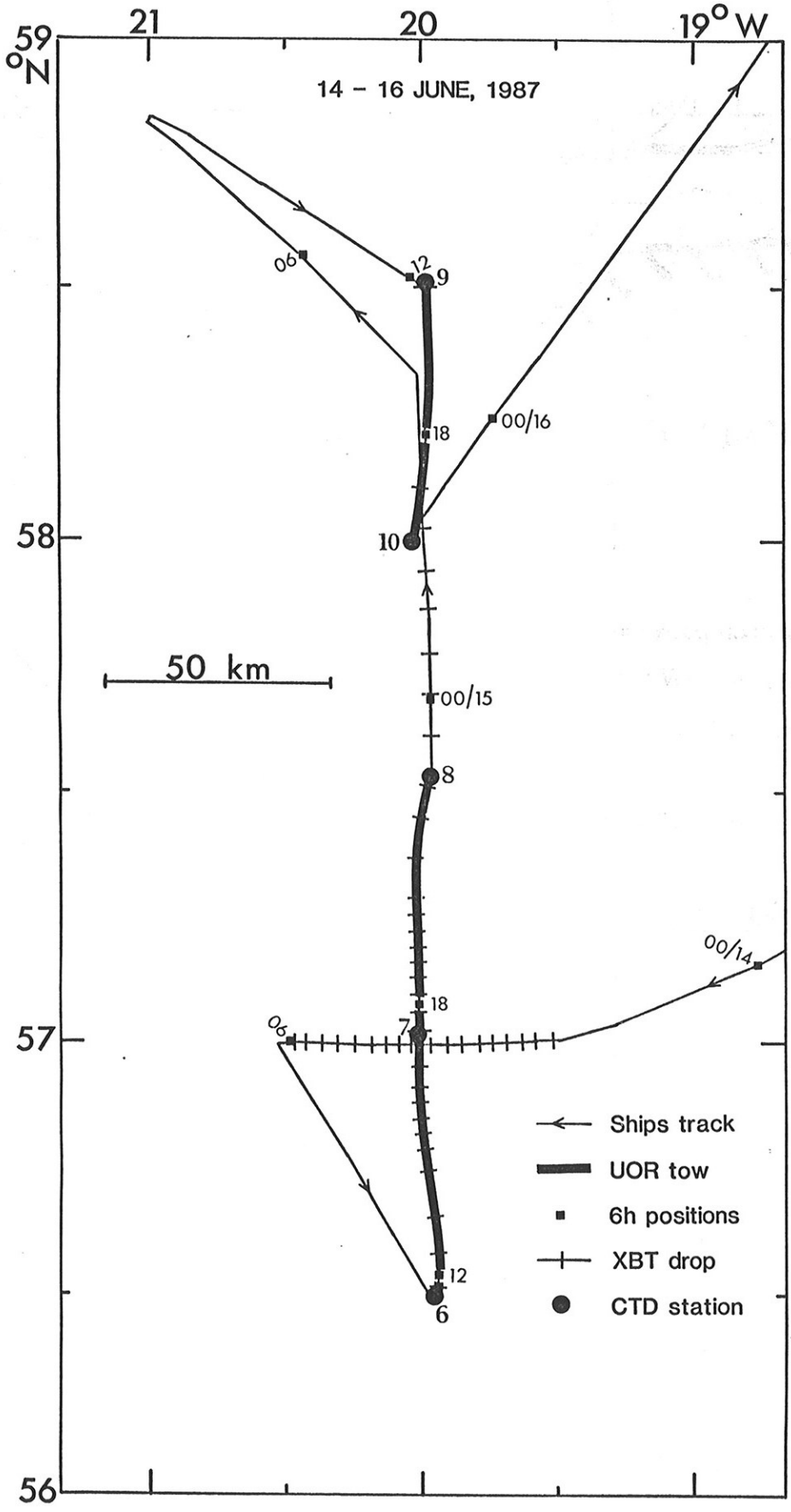


Figure 5

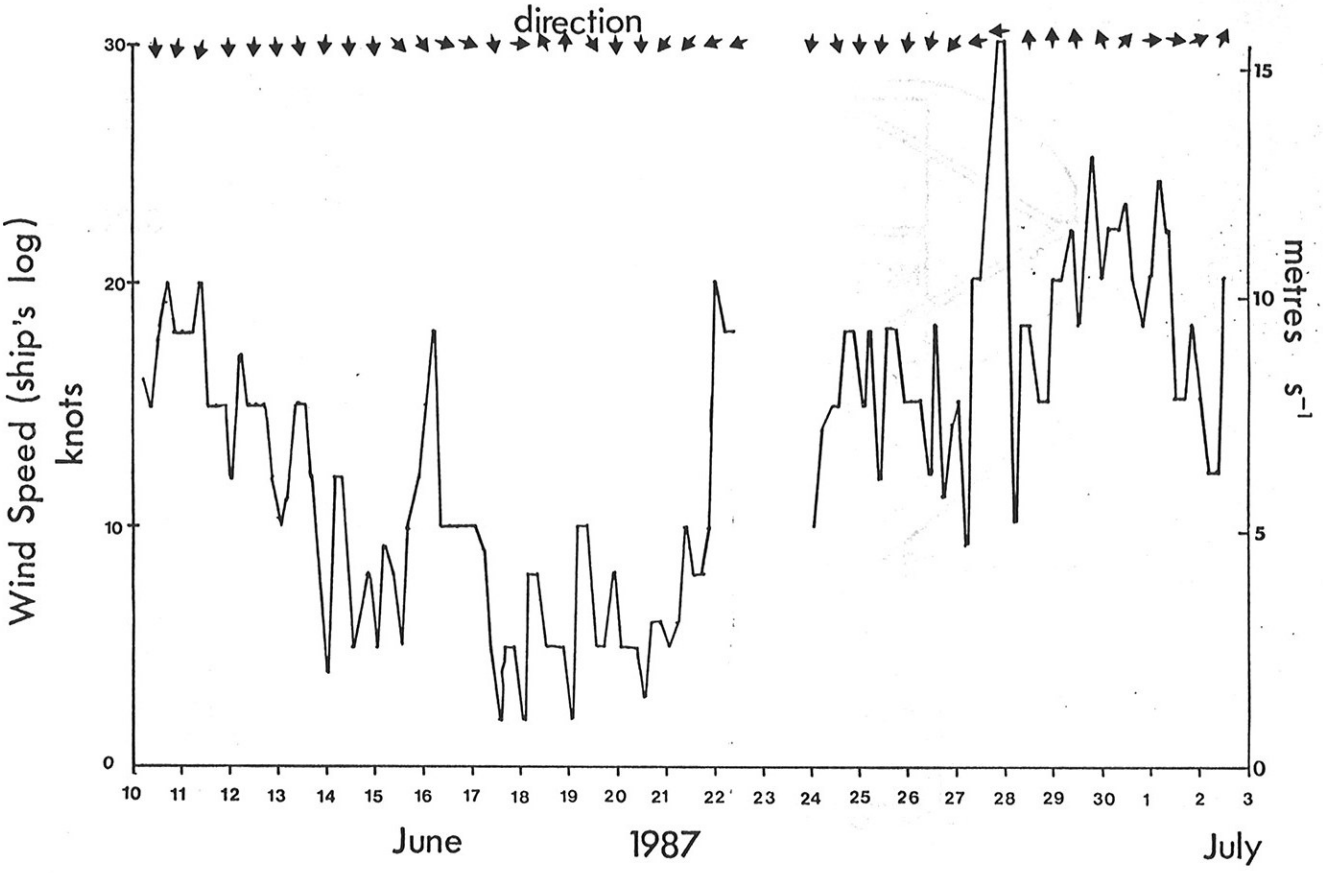
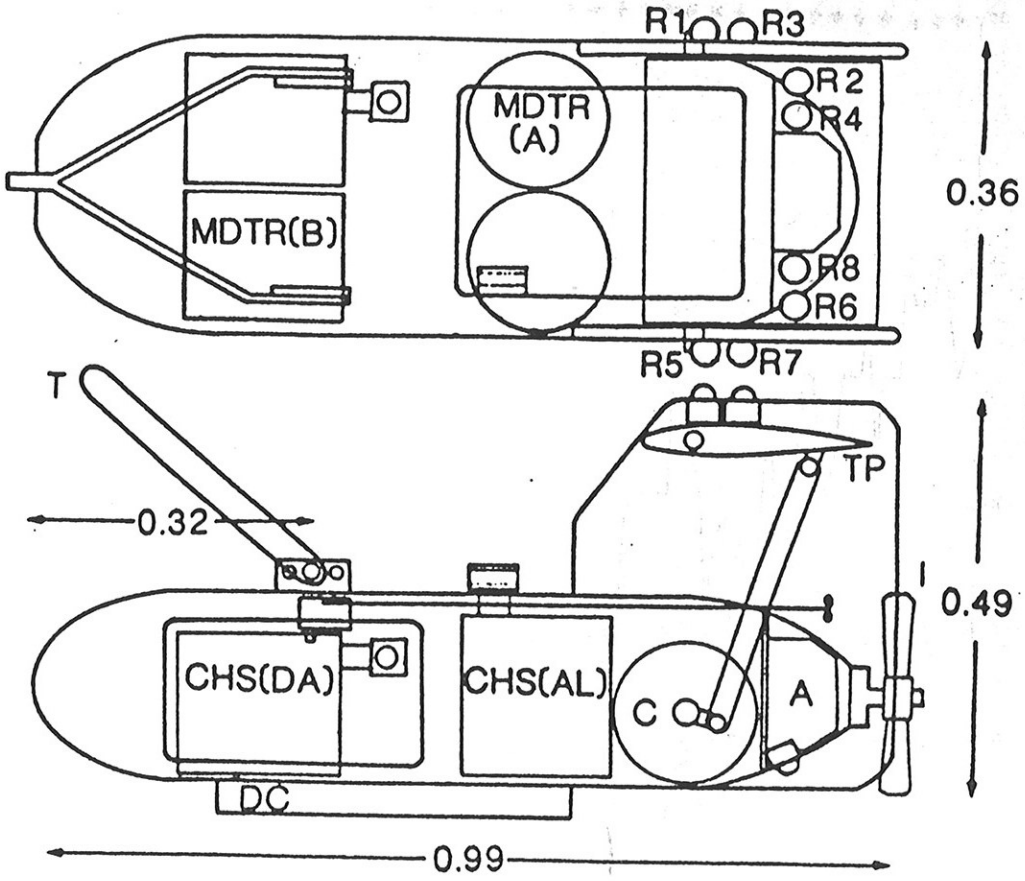

direction
Wind Speed (ship's log)
knots
metres s⁻¹
30
20
10
0
15
10
5
0
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 1 2 3
June
1987
July

Figure 6

U.O.R. Mark 2 for Ocean Colour



UOR Mark 2: Sensor Suite

Solid State Data Logger (SSDL). Sample period programmable, 5s, 10s, 15s etc.

Channel

1. Depth (pressure sensor)
2. Downwelling blue light 2π (450nm) A
3. Upwelling blue light 2π (450nm) A
4. Chlorophyll fluorescence
5. Temperature (thermistor probe)
6. Downwelling green light 2π (550nm) A
7. Upwelling green light 2π (550nm) A

Channel

8. Downwelling bl-gn light 2π (520nm) B
9. Upwelling bl-gn light 2π (520nm) B
10. Downwelling l-bl irradiance (490nm) B
11. Upwelling l-bl irradiance (490nm) B
12. Downwelling red irradiance (670nm) C
13. Upwelling red irradiance (670nm) C
14. Downwelling l-bl light 2π (490nm) C
15. Upwelling l-bl light 2π (490nm) C

FIGURE 7 UOR Tow 17

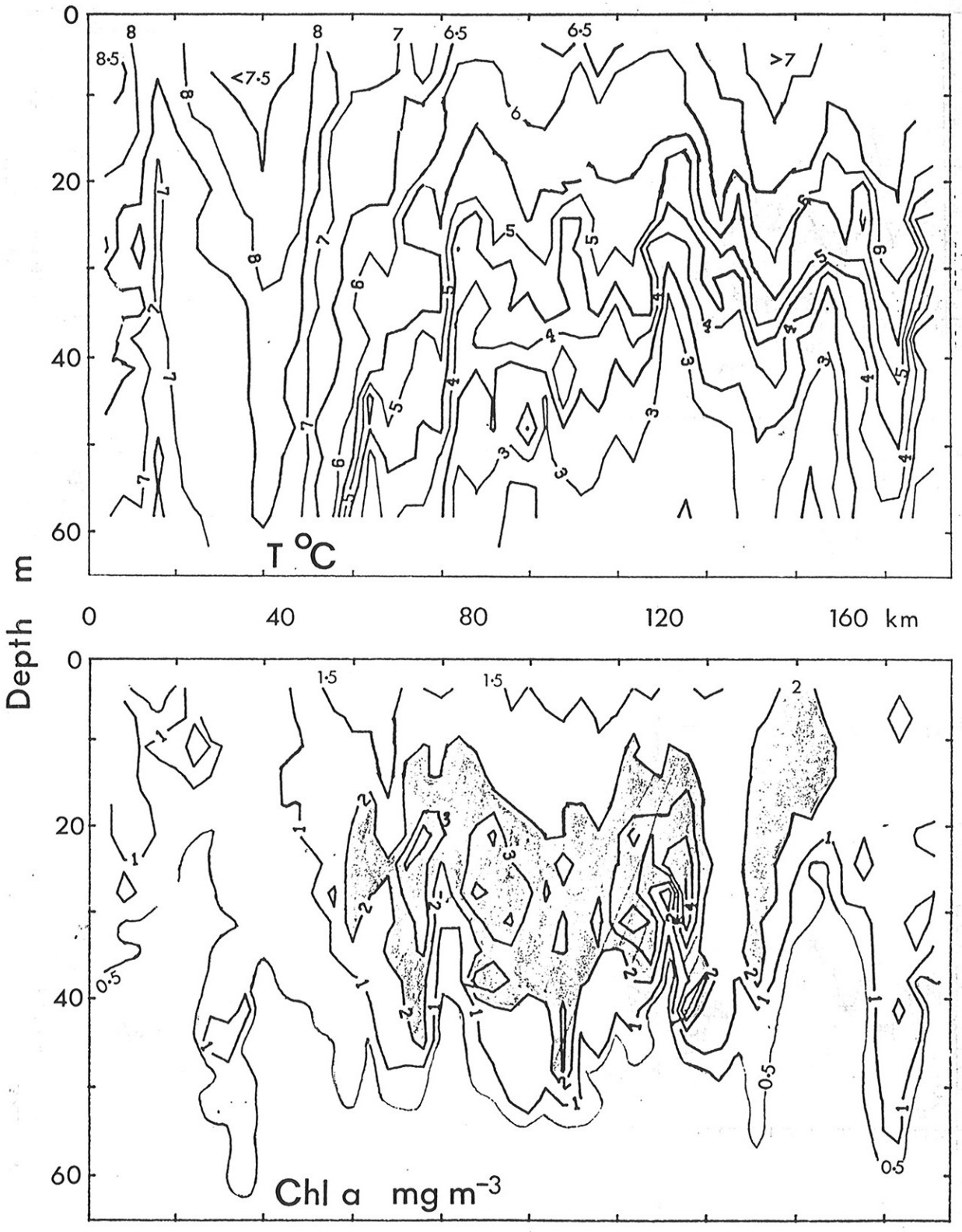


Figure 8 UOR Tow 25

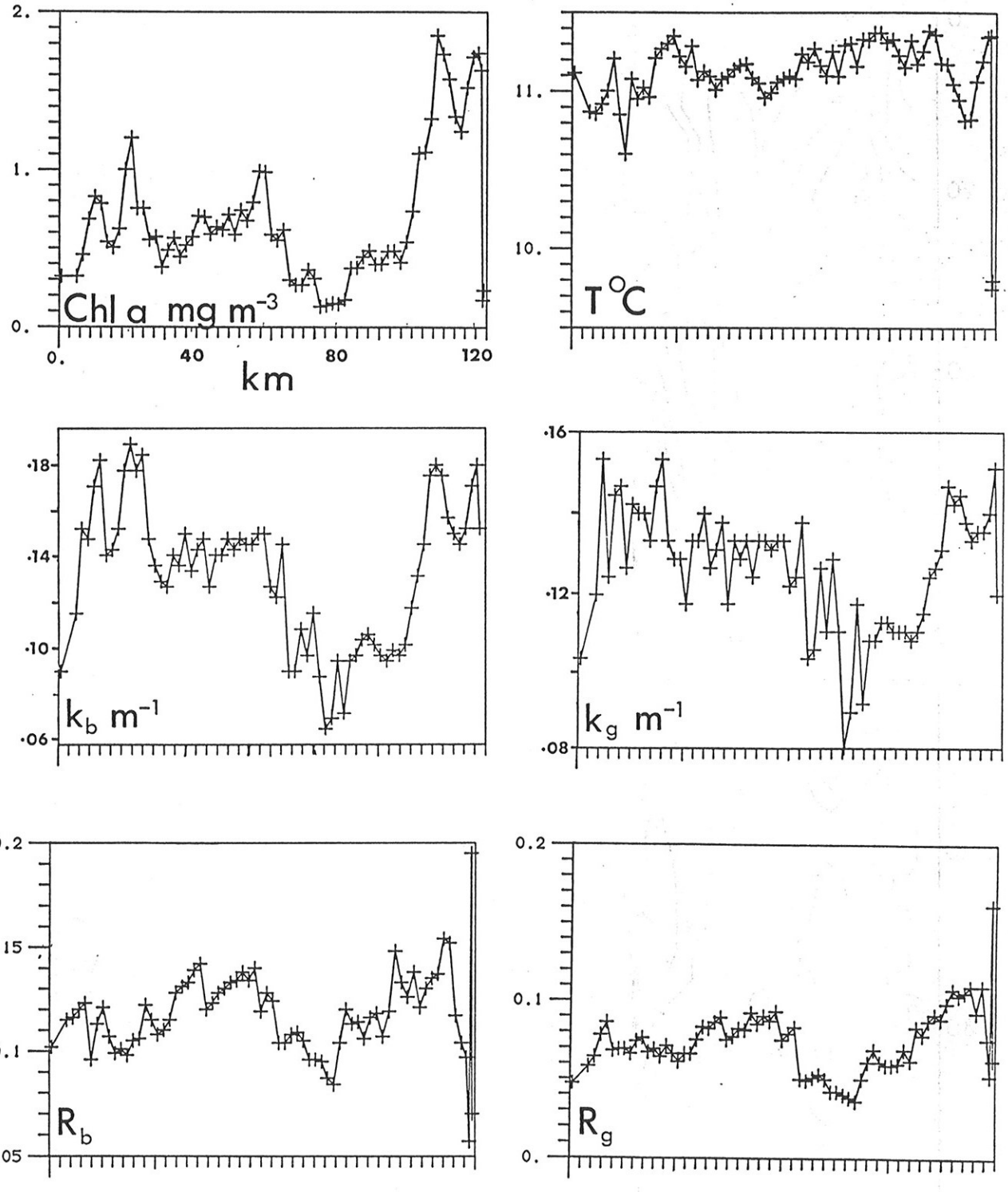
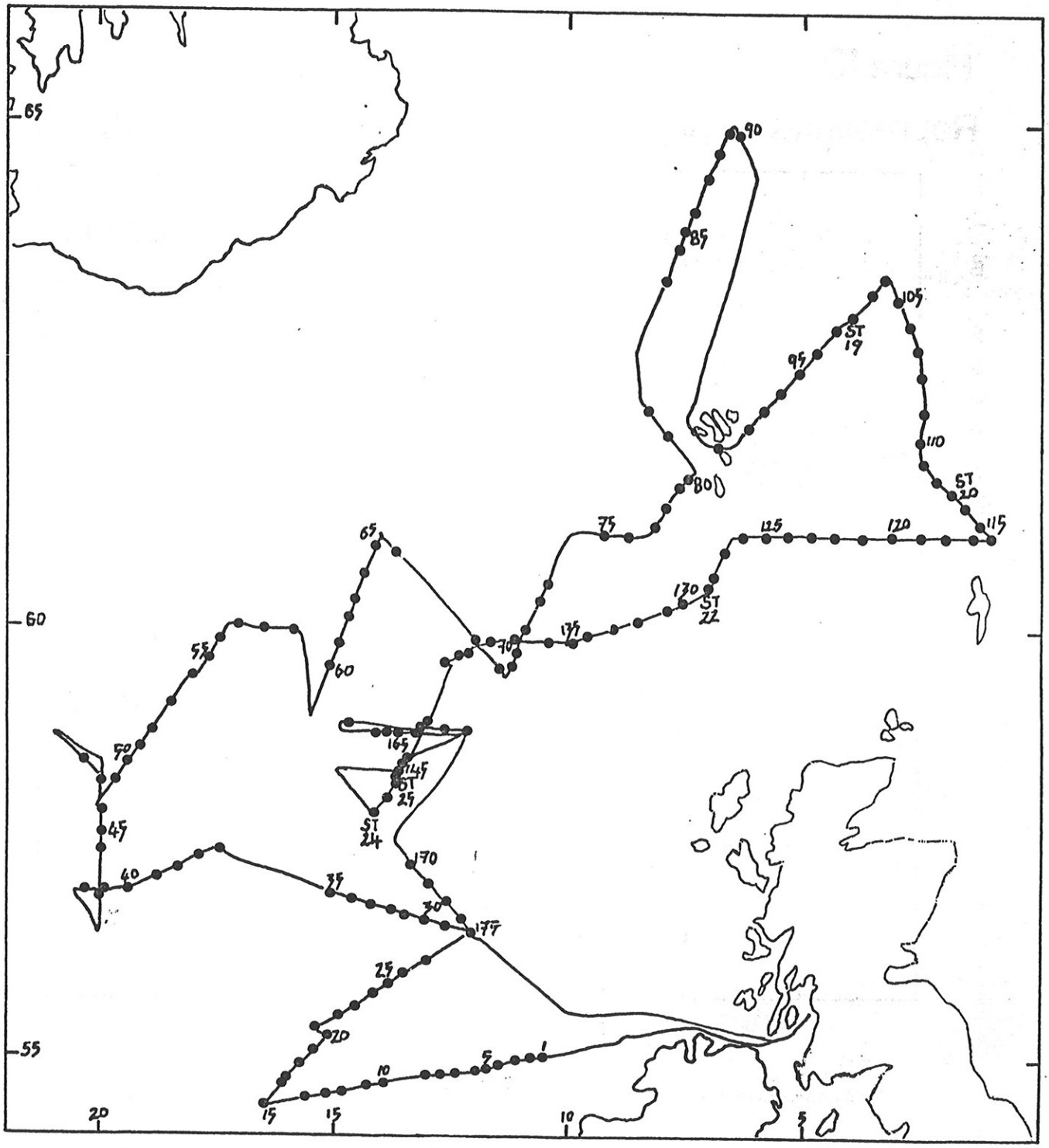


Figure 9

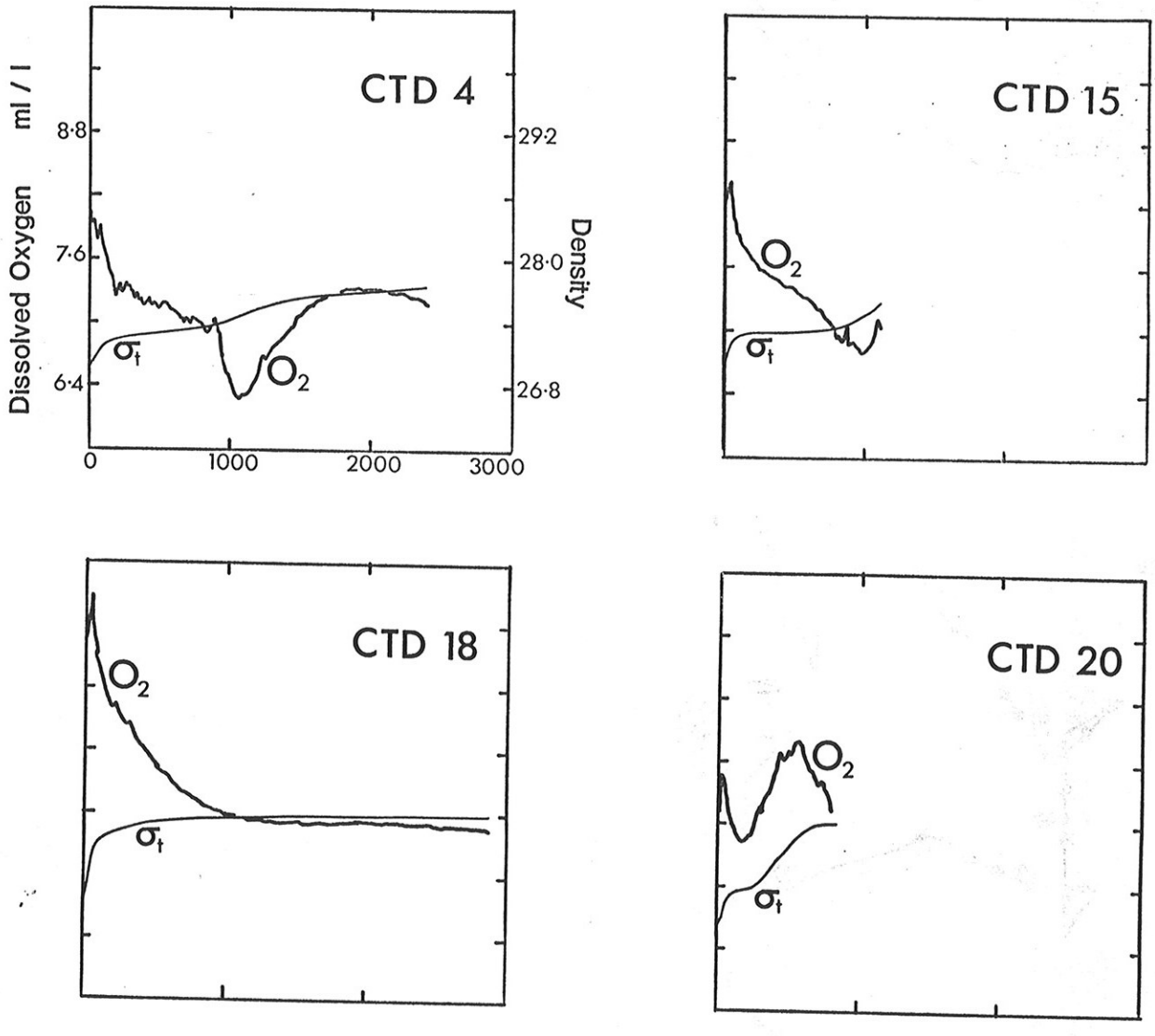
RRS Challenger Cruise 16/87 8 June – 3 July, 1987



DMS/DMSP SAMPLE POSITIONS + CTD PROFILE STATIONS

Figure 10

Representative profiles of dissolved oxygen and density



Calibrations of the oxygen sensor for individual profiles have yet to be applied.