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1. BACKGROUND

The origins of ARABESQUE can be traced to an epic cruise in the Arabian Sea during 1986. That cruise involved scientists from the (then) Institute of Marine Environmental Research, Plymouth and from Germany, Netherlands and USA who were studying microbial biogeochemistry in the Arabian Sea aboard RRS CHARLES DARWIN. Each of us, within our own disciplines, was profoundly amazed and excited at the diversity of microbial activity and biogeochemical expression to be found in that fascinating ocean. Following that cruise and with our results published (a Special Issue of Deep Sea Research in 1993 (DSR 40: 1-849) and several papers in Nature and elsewhere), we felt it timely to use the springboard offered by the nascent JGOFS Processes Studies in the Arabian springboard to launch a follow-on investigation. Several new concepts had been generated since 1986 and these together with the advent of new technology (particularly remote sensing offered by SeaWiFS) would allow us to test ideas and hypotheses that were previously intractable.

A fundamental concept we wished to investigate was to scale the quantitative range of microbial biogeochemical cycling activities due to the strong seasonal forcing of the Arabian Sea by the two Asian monsoons. It had been known for some time that intense biological activity fuelled by upwelling of high nutrient waters, occurs throughout much of the Arabian Sea during the SW Monsoon in late summer. It had also been hypothesised (largely from satellite imagery) that biological activity reduces to very low levels during the intermonsoon periods. At these times, the basin was supposed to become a biogeochemical 'desert', particularly during May when the "blue water" period occurs To study the contrasting regimes of high and low activity periods, 2 cruises were required and our original shiptime submission was for cruises in May and in September. However, as we required SeaWiFS satellite data for linking remote sensing and seatruth data and since the SeaWiFS launch was postponed after our cruise submissions, to 'late in 1994', we requested our May allocation be changed for one in November/December. Although our request was granted, the launch of SeaWiFS was delayed still further and we were unable to 'tie-in' our sea data with multispectral remote sensing data on either cruise. This has left a considerable 'value-added' element of our work as yet unaddressed. In spite of this, we have achieved a

considerable range and depth of other scientific investigations in ARABESQUE, as will be gleaned from this report.

As has been identified above, ARABESQUE represents as a contribution towards JGOFS Process Studies of the Arabian Sea. The JGOFS Process Studies in this basin began in 1992/3 with a thorough study of the Somali Upwelling System by the Netherlands. Since then the UK and Pakistan have carried out their ARABESQUE and NASEER programmes respectively. At the time of writing, the US are midway through their 18 month study of the Arabian Sea and the Germans are just beginning their biogeochemical drift studies in this basin. Process Studies will therefore continue well into 1996. We are pleased ARABESQUE lies in the vanguard of these studies of this unusual and little understood ocean basin.

The report for ARABESQUE 1 (Chief Scientist: Fauzi Mantoura) has been produced. This report outlines the complementary science carried out on ARABESQUE 2. Copies of both reports are available from PML.

2: AIM, OBJECTIVES, *MODUS OPERANDI* AND ACHIEVEMENTS

Our aim in ARABESQUE 2 was to investigate the seasonal influence of the fall intermonsoon period on microbial biogeochemistry of the Arabian Sea. The cruise was designed to complement ARABESQUE 1 during which studies were made of microbial biogeochemistry during the SW monsoon period.

Our objectives were therefore:

- to investigate optical and physical oceanography of the surface mixed layer
- to investigate oxygen, CO_2, nutrients and other bioreactive constituents (DOC, DON, MA,CH_4, NH_3, N_2O) of the surface and oxygen depleted zone (ODZ);
- to quantify distributions of phytoplankton using taxonomy, flow cytometry and hplc pigment analyses;
- to quantify primary and new production in the basin;
- to quantify distributions of bacteria and their production;
- to quantify microzooplankton populations and their herbivorous and bacterivorous activities;
- to quantify vertical flux of particulate material using sediment traps, standard alone pumps (SAPS) and natural radionucleide distributions;
- to quantify water mass residence times using CFCs

In addressing these objectives, we departed Muscat on 16 November as planned and sailed for the Straits of Hormuz (25° 59.3'N 056° 35.00'E) to begin a 5 station transect of the Gulf of Oman (see Figure 1). There after we began our studies of the Arabian Sea with research at the UK reference station A1 (19°N 59°E). A short section was worked onto the Oman coast terminating in 50 metres water depth at station AS5 in Masira Bay (19° 30'N 58° 09'E). Thereafter we worked along a 900 nm transect towards the Maldives terminating at A7 (08° 00'N 067° 00'E). We then worked north towards the major denitrifying zone and ending our scientific investigations at A9 (14° 20'N 067° 00'E). ARABESQUE 2 ended in Muscat on 18 December.

Our main achievements were:

- full characterisation of the water column by CTD at a total of 19 stations;
- major rate investigations at 5 stations occupied for at least 24-h;

- drift experiments at 3 stations that were occupied for not less than 3 days. During this time the ship was allowed to drift tracking our free-floating sediment trap;
- At each station, many variables were measured. Water column temperature, salinity, fluorescence, O_2, transmissometry with depth were measured using the CTD system.
- Nutrients (NO_3, NO_2, PO_4, Si, NH_4) were measured as were dissolved organic carbon and nitrogen (DOC/N), CFC's, methylamines (MA's), TCO_2, pCO_2, N_2O, O_2, pigments, phytoplankton, flow cytometry, bacteria, nano and microzooplankton, using water bottles off the CTD rosette.
- A wide range of flux measurements were made encompassing primary and new production by ^{14}C, delta O_2, PI, and ^{15}N, bacterial production by tritiated thymidine, bacterivory by radiochemistry, microzooplakton herbivory by dilution and sedimentation. The latter involved radionucleide measurements as well as measurements by SAPS and sediment traps.
- Arabian Sea water masses were 'aged' using CFC's.
- Between stations, optical and physical oceanographic properties of the water were characterised using the UOR
- Extension of the observations made at the UK time series station at A1. These observations therefore span the period from July to November covering the height of the SW monsoon through its wane into the end of the intermonsoon.
- On 5 December, DISCOVERY met up with THOMAS G THOMPSON, the US-JGOFS ship, to carry out an intercomparison exercise. This exercise is an important constituent of JGOFS in which data sets from different scientists need to be compared and checked. This involved a comparison of optical oceanography parameters by UOR (UK) and SeaSoar (US), vertical profiles of nutrients and photopigments. Preliminary results from each of these is very promising.
- Through the latter part of the cruise, the winds gradually swung through a easterly arc. By the time we had reached station A7, the winds were blowing vigorously (>20 knots) from the NE. Surface waters in this region were patchy with populations of phytoplankton that varied quantitatively and qualitatively. On proceeding north-west at the end of the cruise, the winds subsided gradually reaching <5 knots in the Gulf of Oman. It therefore seems that the timing and extent of the NE monsoon varies across the Arabian Sea and that may create localised open ocean upwelling at A7.

- By way of summary, Table 1 shows our preliminary analysis of the surface mixed layer (ML) characteristics at the main stations during ARABESQUE 2. The main points are as follows: the ML deepened considerably from ca 40m to over 80m between stations A1 and A7/A9. Surface nitrate concentrations dropped from close to 900 to ca 50 nM/L along this transect as did concentrations of chlorophyll-a and rates of primary production. The overall picture perceived is one of increasing oligotrophy as we progressed along this transect towards to SE.

Table 1: Preliminary analysis of mixed layer (ML) characteristics at main stations during ARABESQUE 2.

	STATIONS					
	GOM 1 - 6	A1	A3	A5	A7	A9
Depth of ML (metres)	28 - 45	41	50	47	60	85
Temperature of ML (°C)	27.6 - 28.4	27.5	27.2	27.3	28.4	27.2
Nitrate (µM / L)	0.1 - 0.4	0.9	0.3	0.1	<0.05	nya
Chlorophyll (ng / L)	240 - 320	265	196	231	58	nya
Dominant accessory pigment	hex (prymnesio)	hex (prymesio)	hex (prymnesio)	hex (prymnesio)	divinylchlo- (prochloros)	nya
Phyto cell conc (x10E6/ L)	40 - 320	350	2,550	3,050	2,550	1,040
Prochloro conc (x10E6 / L)	10 - 120	190	1,800	810	2,400	520
Synech conc (x10E6 / L)	30 - 210	150	620	2,100	30	410
Primary Prod (mgC/m2/d)	600 - 900	280 - 330	280 - 460	670-813	472-565	750-794
Dominant size class	<2	<2	<2	<2	<2	<2
Bacteria (xE8 cell / L)	9 - 19	10 - 14	7.4 - 15.5	7 - 10	4.5 - 6.8	4.7 - 7.0
Bacterial Producuction (pmol thy incorp. / 1 / h)	1.8 - 5..3	2.7	1.2 - 6.9	2.9 - 4.4	0.8 - 3.4	1.1 - 2.8
Bacterivory (%loss / h)	3.9 - 4.6	3.4	0.6 - 1.2	A4; 1.8 A6 3.2	0.5 - 0.6	0.6 - 2.0
MZP herbivory (%phyt / d)	-	34 - 49	21 - 48	17 - 45	11 - 18	7 - 16
Sedimentation export	-	medium	n.i.	n.i	low	n.i.

3: PERSONNEL

Name	Responsibility	Institution
Burkill, Peter	Chief Scientist	[1]Plymouth Marine Laboratory, UK
Al-Hashimi, Khalid	Scientist	[2]Sultan Qaboos University, Oman
Bale,Tony	Scientist	[1]Plymouth Marine Laboratory, UK
Barnes, John	Scientist	[3]University of Newcastle, UK
Bateman, Alison	Scientist	[4]University of East Anglia, UK
Bellan, Ian	Scientist	[1]Plymouth Marine Laboratory, UK
Cummings, Denise	Scientist	[1]Plymouth Marine Laboratory, UK
Edwards, Elaine	Scientist	[1]Plymouth Marine Laboratory, UK
Fileman, Tim	Scientist	[1]Plymouth Marine Laboratory, UK
Gibb, Stuart	Scientist	[1]Plymouth Marine Laboratory, UK
Gilpin, Linda	Scientist	[5]Queen's University of Belfast, UK
Irwin, Brian	Scientist	[6]Bedford Institute of Oceanography, Canada
Ling, Roger	Scientist	[1]Plymouth Marine Laboratory, UK
Miller, Axel	Scientist	[1]Plymouth Marine Laboratory, UK
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Pomroy, Alan	Scientist	[1]Plymouth Marine Laboratory, UK
Shimmield, Graham	Scientist	[7]University of Edinburgh, UK
Stelfox, Claire	Scientist	[1]Plymouth Marine Laboratory, UK
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Weisse, Thomas	Scientist	[8]Max Planck Institute, Plön, Germany
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SHIP'S PERSONNEL

Name	Rank	Institution
Long, Geoff	Master	Research Vessel Services - Marine, UK
Leather, Ceri	Chief Officer	Research Vessel Services - Marine, UK
Warner, Richard	Second Officer	Research Vessel Services - Marine, UK
Holmes, John	Third Officer	Research Vessel Services - Marine, UK
Donaldson, Brian	Radio Officer	Research Vessel Services - Marine, UK
Adams, Andy	Chief Engineer	Research Vessel Services - Marine, UK
Holt, Martyn	Second Engineer	Research Vessel Services - Marine, UK
Jones, Taff	Third Engineer	Research Vessel Services - Marine, UK
Lutey, Doug	Electrical Engineer	Research Vessel Services - Marine, UK
Pook, Tiny	Bosun	Research Vessel Services - Marine, UK
Vrettos, Chris	Petty Officer Deck	Research Vessel Services - Marine, UK
Perkins, Joe	Seaman 1A	Research Vessel Services - Marine, UK
Olds, Arthur	Seaman 1A	Research Vessel Services - Marine, UK
Hebson, Harry	Seaman 1A	Research Vessel Services - Marine, UK
Avery, Roy	Seaman 1A	Research Vessel Services - Marine, UK
Crabb, Gary	Seaman 1B	Research Vessel Services - Marine, UK
Staite, Eddie	Catering Manager	Research Vessel Services - Marine, UK
Welch, George	Chef	Research Vessel Services - Marine, UK
Smith, Leo	Steward	Research Vessel Services - Marine, UK
Murphy, Ryan	Steward	Research Vessel Services - Marine, UK
Duncan , Andy	Steward	Research Vessel Services - Marine, UK
Bridge, Alan	Mechanic	Research Vessel Services - Marine, UK

4: SCIENTIFIC OPERATIONS

We operated in two sampling modes: a) SURVEY and b) STATION.

a) SURVEY MODE

In the survey mode, DISCOVERY continuously steamed on the tracks shown and the following parameters were measured:

Continuous Sampling: salinity, temperature, oxygen (electrode) fluorescence, transmissometer, ADCP, wind-speed, incident radiation and, on some sectors, nutrients (NO_3, PO_4, SiO_2, NO_2, Autoanalyser) and mixed layer broad band optics using the Undulating Oceanographic Recorder,.

Discreet Sampling: on some sectors pCO_2, TCO_2, Alkalinity, nutrients, DMS, MA's, HTCO-DOC, UV-vis absorbance, N_2O, CH_4, nanomolar NO_3 levels were measured on seawater samples obtained from clean pumping system. Biogases were sampled from the atmosphere. Particulate matter from pumped seawater were sampled for organic and carbonate-carbon, nitrogen and silica, phytoplankton pigments (HPLC and *in vitro* fluorometry), biovolume and taxonomy, bacterial counts, microzooplanton. Atmospheric aerosols were sampled for total and amino (MA's and acids) nitrogen compounds. Primary production parameters (P vs I) were measured from dawn samples obtained during the survey mode using standard ^{14}C techniques in a light gradient incubator (Photosynthetron).

b) STATION MODE

The stations and their positions are shown in Section 5. In order to ensure maximum efficiency station activity fell into two categories: Profiling and Rate Experiments.

Profiling: CTD/F/O2 + 12 bottle rosette profiling of the mixed and euphotic layer for all parameters shown for the Survey mode. Additionally U/Th ratios will be measured on particulate material.

Rate Experiments: 24 hour stations consisting of the Profiling sequence shown above, followed by

(1) *in situ* incubations for primary production (^{14}C, ^{15}N, TCO_2, DO_2) new production and size fractionated production.

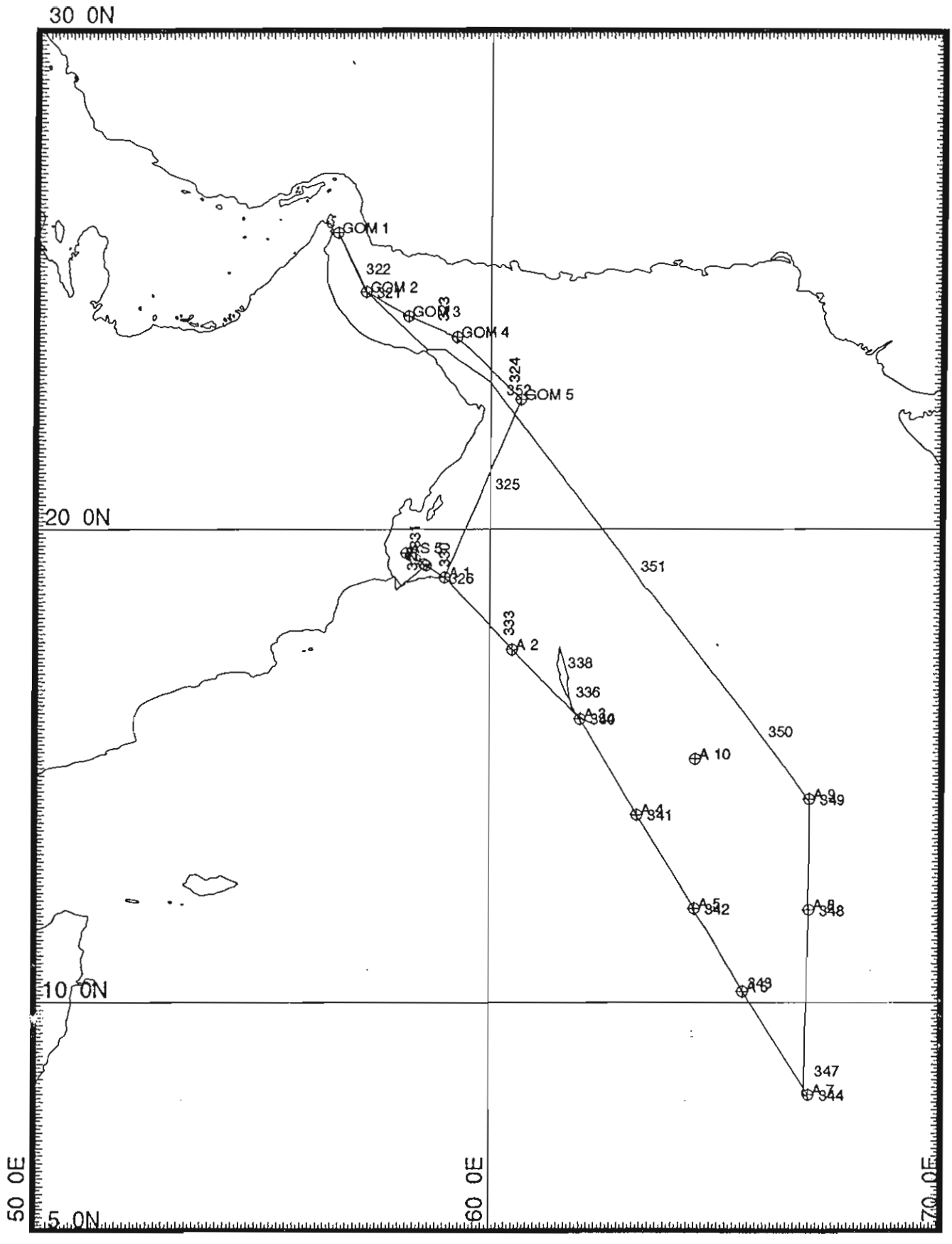
(2) in situ Stand Alone Pumping (SAPS) to 800 m for U/Th isotopic and biomarkers

(3) Bacterial rates measurements (^{3}H-thymidine, DO_2)

(4) diel cycles in biogases, nutrients, pigments and DOC.

(5) microzooplankton herbivory and bacterivory experiments.

(6) sedimentation by sediment traps



MERCATOR PROJECTION

GRID NO. 1

SCALE 1 TO 13000000 (NATURAL SCALE AT LAT. 0)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 0

Arabesque II Cruise track

5: STATION POSITIONS

Station	Latitude (°N)	Longitude (°E)	Location	Other inform'n	Depth (m)
Shake down	23° 43.9'	58° 30.7'	Gulf of Oman		70
GOM 1	25° 59.8'	56° 35.0'	St of Hormuz		112
GOM 2	24° 49.3'	57° 13.2'	Gulf of Oman	CD16 St11	1,255
GOM 3	24° 20.0'	58° 10.4'		CD16 St10	2,853
GOM 4	23° 55.0'	59° 15.0'		CD16 St 9	3,328
GOM 5	22° 39.4'	60° 40.7'		CD16 St 8	3,173
AS 5	19° 30.3'	58° 09.1'	Masira Bay		50
AS 4	19° 27.0'	58° 14.6'	Oman Shelf		200
AS 3	19° 23.3'	58° 20.6'	Oman Shelf		484
AS 2	19° 16.5'	58° 32.2'	Oman Shelf		1,206
AS 1	19° 15.0'	58° 35.4'	Oman Shelf		2,549
A 1	19° 00.0'	59° 00.0'	N Arabian Sea	ARABESQUE Ref Station	3,397
A 2	17° 30.0'	60° 30.0'	N Arabian Sea		3,914
A 3	16° 02.2'	62° 00.0'	N Arabia Sea	JGOFS Ref Station	3,927
A 4	14° 00.0'	63° 15.1'	C Arabian Sea		4,040
A 5	12° 00.0'	64° 29.9'	C Arabian Sea		4,211
A 6	10° 14.0'	65° 32.7'	C Arabian Sea		4,386
A 7	08° 00.0'	67° 00.0'	C Arabian Sea	CD16 St 3	4,705
A 8	11° 58.6'	67° 00.0'	C Arabian Sea	CD16 St 4	4,207
A 9	14° 20.0'	67° 00.0'	C Arabian Sea	CD 16 St 5	3,975
A 10	15° 11.4'	64° 30.2'	C Arabian Sea		3,856

6: SCIENTIFIC LOG

All times are local (i.e. GMT in UK and GMT+ 4 hours in Oman and at sea)

Friday 11th November (Julian day 315)

1600		Main PML contingent departs Plymouth for London Heathrow

Saturday 12th November (Julian day 316)

1000		Main scientific contingent departs LHR for Muscat

Sunday 13th November (Julian day 317)

1500		Loading scientific gear onto RRS DISCOVERY in Mina Qaboos

Monday 14th November (Julian day 318)

0900		Main scientific contingent join RRS DISCOVERY and set up equipment

Tuesday 15th November (Julian day 319)

		Setting up equipment
1200		Khalid Al Hashimi joins ship

Wednesday 16th November (Julian day 320)

0930		Stu Gibb joins ship
1500		Sail from Mina Sultan Qaboos for GOM 2
1555		PES Fish deployed
1630	SD1/1	CTD test at Shakedown Station (23°43.9'N 58°31.0'E)
		All bottles and instruments fully functional i/b 1738
1946		UOR deployed to tension wire
2128		UOR recovered

Thursday 17th November (Julian day 321)

0340		arrive GOM2 (24°49.3'N 57°13.0'E)
0440	GOM2/1	CTD for primary, new production, bacteria and bacterivory. i/b
0515		
0609	GOM2/2	CTD biogeochemistry shallow to 200m
0630		winch broke down; repaired 0715
0717	GOM2/2	CTD i/b
0814	GOM2/3	CTD biogeochemistry deep i/b 1032. steam to GOM1.
1230	GOM2/4	Optics cast ib 13/30
1318	GOM2/5	CTD for optics i/b 1402
2032		arrive GOM1 (25°59.3'N 56°35.0'E)
2037	GOM1/1	CTD biogeochemistry to 70m i/b 2135
2225	GOM1/2	Apstein net
2250		UOR deployed

Friday 18th November (Julian day 322)

0034		UOR i/b
0054		UOR deployed. i/b 0430.

0442 GOM2A/1 CTD for primary, new production, bacteria and bacterivory (25°14.8'N 57°00.2'E) i/b 0533.
0533 steam for GOM3
0553 UOR deployed i/b 1138
1153 Optics2. Radiometer deployment. i/b 1217
1232 CTD for optics. i/b 1325
1330 UOR deployed. i/b 1658
1723 arrive GOM3 (24°20.1'N 58°10.3'E)
1727 GOM3/1 CTD biogeochemistry shallow to 200m i/b 1836
1927 GOM3/2 CTD biogeochemistry deep to 2800m i/b 2217
2301 GOM3/3 Apstein i/b 2311
2324 steam to GOM4
2328 UOR deployed. i/b 0429

Saturday 19th November (Julian day 323)
0429 UOR inboard
0442 GOM4A/1 CTD for primary, new production, bacteria and bacterivory (24°00.1'N 59°00.1'E) i/b 0525
0542 UOR deployed i/b 0715
0740 arrive GOM4 (23°54.9'N 59°15.0'E)
0740 GOM4/1 CTD radiochemistry aborted 0754 due to shipping
0805 GOM4/2 CTD radiochemistry i/b 0858.
0928 winch problems
0940 GOM4/3 CTD radiocheistry i/b 1008
1104 GOM4/4 Apstein net i/b 1110
1111 GOM4/5 Apstein net i/b 1116.
1128 GOM4/6 CTD optics cast. i/b 1200
1217 GOM4/7 Optics at stern. i/b 1300
1313 GOM4/8 CTD biogeochemistry shallow to 200m i/b 1405
1506 GOM4/9 CTD biogeochemistry deep to 3300m i/b 1827
1840 steam to GOM5
1845 UOR deployed

Sunday 20th November (Julian day 324)
0433 UOR i/b
0440 vessel hove to due to winch problems
0451 GOM5A/1 CTD for primary, new production, bacteria and bacterivory (22°45.4'N 60°34.0'E). i/b 0528
0633 arrive GOM5 (22°39.5'N 60°40.7'E).
0637 GOM5/1 Optics Test 4. Optics profiler. i/b 0648
0658 GOM5/2 CTD biogeochemistry shallow aborted 0730 due to termination problems
1030 GOM5/3 CTD biogeochemistry shallow to 200m i/b 1117
1218 GOM5/4 Apstein netting i/b 1223
1247 GOM5/5 Optics5. Optics profiler i/b 1307
1330 GOM5/6 CTD for Optics5 i/b 1409
1450 GOM5/7 CTD for biogeochemistry deep to 3200m i/b 1740
1758 steam to A1.

1801		UOR deployed

Monday 21st November (Julian day 325)

0425		UOR i/b
0436		CTD for primary, new production, bacteria and bacterivory (20° 53.4' N 59°51.6'N) i/b 0512
0530		UOR o/b
1632		UOR i/b
1700		arrived on A1
1707	A1/1	CTD to confirm trap depth i/b 1731
1805	A1/2	Sedimentation trap deployed
1957	A1/3	SAPS deployed i/b 2328

Tuesday 22 November (Julian Day 326)

0100	A1/4	WP2 & Apstein nets
0336	A1/5	GoFlos for microzooplankton
0412	A1/6	CTD for primary, new production, bacteria and bacterivory
0511	A1/7	CTD for primary, new production, bacteria and bacterivory
0615	A1/8	Insitu rig deployed
0638	A1/9	CTD biogeochemistry shallow i/b 0728
1042	A1/10	Apstein nets
1057	A1/11	WP2 nets
1134	A1/12	CTD Optics
1220	A1/13	Stern Optics
1336	A1/14	CTD Radiochemistry aborted
1440	A1/15	CTD Radiochemistry
1610	A1/16	CTD Radiochemistry
1719		Production rig inboard
1842	A1/17	SAPS i/b 0340

Wednesday 23 November (Julian Day 327)

0439	A1/18	CTD for primary, new, bacterial production & bacterivory
0602	A1/19	in situ rig
0730	A1/20	CTD biogeochemistry deep to 3300m i/b 1004
1103	A1/21	Optics i/b 1147
1200	A1/22	CTD Optics i/b1240
1405	A1/23	CTD fine resolution i/b 1443
1652	A1/24	GoFlo
1742	A1/25	In situ rig i/b
1905	A1/26	SAPS to 200m i/b 2058
2104	A1/27	Apstein nets i/b 2112

Thursday 24th November (Julian Day 328)

0340	A1/28	GoFlos for microzooplankton
0415	A1/29	CTD for primary, new, bacterial production & bacterivory
0621	A1/30	In situ rig deployed
0649	A1/32	CTD biogeochemistry deep i/b 0934
1105	A1/33	Apstein nets
1142	A1/34	Optics i/b 1200

1220	A1/35	CTD Optics
1405	A1/36	CTD biogeochemistry to 200m i/b 1447
1627	A1/37	GoFlos
1726	A1/38	In situ rig i/b
2328		Mayday received, vessel proceeding to casualty at full speed

Friday 25th November (Julian Day 329)

0120		Vessel hove to 1.5' off PELICAN
0752		Vessel return to sediment trap
1002	A1/39	Sediment Trap i/b
1018		Proceed to AS1
1615	AS1/1	CTD biogeochemistry shallow i/b 1702
1801	AS1/2	CTD biogeochemistry deep i/b 2118
2207	AS1/3	Apstein nets
2228		Steam to A1

Saturday 26th November (Julian Day 330)

0605	A1/40	GoFlo for primary production
0805	A1/41	CTD test after fitting 6 new bottles
0834	A1/42	CTD biogeochemistry i/b 0923
1040	A1/43	CTD biogeochemsitry deep i/b 1337
1400	A1/44	Optics
1445	A1/45	GoFlos
1508		Steam to AS2
1854	AS2/1	CTD biogeochemistry i/b 2038
2131	AS2/2	Apstein nets
2149		Steam to AS3

Sunday 27th November (Julian Day 331)

0441	AS3/1	CTD for primary, new, bacterial production & bacterivory
0637	AS3/2	CTD biogeochemistry to 480m i/b 0747
0904	AS3/3	Apstein
0922		Steam to AS4
1044	AS4/1	CTD biogeochemistry i/b 1132
1200	AS4/2	Optics
1247	AS4/3	CTD Optics i/b 1311
1330	AS4/4	Apstein
1414	AS4/5	CTD radiochemistry i/b 1454
1454		Steam to AS5
1600	AS5/1	CTD biogeochemsitry i/b 1644
1630		Zodiac deployed for remote sampling
1929	AS5/2	Apstein

Monday 28th November (Julian Day 332)

0441	AS5/3	CTD for primary, new, bacterial production & bacterivory i/b 0509
0804		Steam to A2
0832		UOR deployed
0907		Pass through AS4

0945		Pass through AS3
1102		Pass through AS2
1122		Pass through AS1
1149		UOR recovered
1220		SHABAN SHALENDER alongside for fresh water
1255		UOR deployed

Tuesday 29th November (Julian day 333)

0403		UOR recovered
0445		On Station A2
0455	A2/1	CTD for primary, new, bacterial production & bacterivory
0600	A2/2	CTD for biogeochemsitry to 3900m i/b 0923
0939	A2/3	Apstein net
1031	A2/4	CTD biogeochemistry to 200m i/b 1113
1128	A2/5	Optics i/b 1145
1213	A2/6	CTD optics i/b 1249
1301		Steam to A3

Wednesday 30th November (Julian Day 334)

0142		UOR recovered
0210		On station A3
0300	A3/1	CTD to assess trap depth i/b 0328
0357	A3/2	Sedimentation Trap deployed
0410	A3/3	GoFlos
0437	A3/4	CTD for primary, new, bacterial production & bacterivory i/b 0511
0602	A3/5	In situ rig deployed
0814	A3/6	CTD biogeochemistry to 200m i/b 0905
1050	A3/7	Optics
1129	A3/8	CTD for optics i/b 1200
1237	A3/9	SAPS i/b 1606
1713	A3/10	Production rig inboard
2334	A3/11	WP2 net
2359	A3/12	Apstein net

Thursday 1 December (Julian Day 335)

0410	A3/13	CTD for primary, new, bacterial production & bacterivory i/b 0444
0526	A3/14	CTD for primary, new, bacterial production & bacterivory i/b 0538
0624	A3/15	In situ rig deployed
0751	A3/16	CTD radiochemistry i/b 1056
1120	A3/17	Optics
1157	A3/18	CTD for optics i/b 1230
1247	A3/19	Nets WP2 & Apstein i/b 1326
1339	A3/20	CTD fine resolution i/b 1420
1711	A3/21	Production rig inboard
1755	A3/22	SAPS i/b 0322

Friday 2 December (Julian Day 336)

0407 A3/23 GoFlo bottles i/b 0431
0440 A3/24 CTD for primary, new, bacterial production & bacterivory i/b 0515
0603 A3/25 In situ rig deployed
0800 A3/26 CTD biogeochemistry i/b 0854
1109 A3/27 Optics i/b 1136
1154 A3/28 CTD for optics i/b 1230
1304 A3/29 CTD radiochemistry i/b 1358
1710 A3/30 Production rig inboard

Saturday 3 December (Julian Day 337)

No scientific sampling

Sunday 4 December (Julian Day 338)

0335 A3/31 GoFlo bottles i/b 0357
0408 A3/32 CTD for primary, new, bacterial production & bacterivory i/b 0440
0507 A3/33 CTD for primary, new, bacterial production & bacterivory i/b 0523
0615 A3/34 in situ rig deployed
0622 A3/35 CTD biogeochemistry shallow i/b 0709
0826 A3/36 CTD biogeochemistry deep i/b 1148
1200 A3/37 Optics i/b 1246
1304 A3/38 CTD optics i/b 1339
1406 A3/39 CTD radiochemistry i/b 1424
1713 A3/40 Production rig inboard
1742 A3/41 SAPS i/b 1928
1935 A3/42 Apstein net i/b 1942

Monday 5 December (Julian Day 339)

0508 A3/43 CTD for Primary Production i/b 0546
0644 A3/44 Sediment trap recovered
0645 Steam course ca 164° to meet THOMPSON
0950 UOR test i/b 1158
1208 A3/45 CTD for intercomparison /b 1310
1325 THOMPSON launch alongside
1350 Launch away
1405 UOR deployed for intercomparison
1600 0.5 mile off THOMPSON
1956 alter course to port 10 degree per minute
2000 on course 120 T

Tuesday 6 December (Julian Day 340)

0433 A3/46 CTD for primary, new, bacterial production & bacterivory i/b 0512
0618 A3/47 CTD biogeochemistry shallow i/b 0705

0756 A3/48 CTD biogeochemistry deep i/b 1110
1125 A3/49 Optics i/b 1145
1208 A3/50 CTD radiochemistry i/b 1234
1250 Steam for A5 towing UOR i/b 0340

Wednesday 7 December (Julian Day 341)
0429 A4/1 CTD for primary production i/b 0505
0547 A4/2 CTD biogeochemistry shallow i/b 0628
0728 A4/3 CTD biogeochemistry deep i/b 1040
1053 A4/4 Optics i/b 1112
1130 A4/5 CTD optics i/b 1205
1220 Steam for A5 deploying UOR i/b 0244

Thursday 8 December (Julian Day 342)
0333 A5/1 GoFlos for MZP i/b 0351
0404 A5/2 CTD for primary production i/b 0528
0609 A5/3 Insitu rig deployed
0640 A5/4 Apstein net i/b 0657
0705 A5/5 CTD biogeochemistry shallow i/b 0745
0902 A5/6 CTD biogeochemsitry deep i/b 1208
1230 A5/7 Optics i/b 1250
1318 A5/8 CTD optics i/b 1346
1420 A5/9 CTD radiochemistry 1 i/b 1513
1535 A5/10 CTD radiochemistry 2 i/b 1551
1638 A5/11 production rig i/b
1646 Steam for A6
1701 UOR deployed i/b 0447

Friday 9 December (Julian Day 343)
0459 A6/A CTD for production i/b 0534
0534 Steam on to A6
0633 A6/1 CTD biogeochemsitry shallow i/b 0713
0825 A6/2 CTD biogeochemistry deep i/b 1104
1104 Steam for A7
1114 UOR deployed

Saturday 10 December (Julian Day 344)
0353 A7/1 GoFlos for MZP i/b 0408
0414 A7/2 CTD for production i/b 0440
0511 A7/3 CTD for production i/b 0525
0601 A7/4 production rig deployed
0733 A7/5 sediment traps deployed
0745 A7/6 CTD biogeochemsitry shallow i/b 0829
0930 A7/7 CTD biogeochemsitry deep i/b 1300
1313 A7/8 Optics i/b 1350
1355 A7/9 CTD optics i/b 1430
1500 A7/10 CTD radiochemistry i/b 1525
1638 A7/11 Sediment trap grappled to add extra floats

1738	A7/12	production rig i/b
1831	A7/13	SAPS deployed i/b 0400

Sunday 11 December (Julian Day 345)

0435	A7/14	CTD for production i/b 0512
0546	A7/15	in situ rig deployed
0757	A7/16	CTD radiochemistry i/b 1110
1133	A7/17	Optics i/b 1150
1205	A7/18	CTD optics i/b 1235
1330	A7/19	CTD biogeochemsitry hi-resolution i/b 1417
1426		Stealth test i/b 1600
1735	A7/20	Production rig i/b
1855	A7/21	SAPS i/b 2229

Monday 12 December (Julian Day 346)

0332	A7/22	GoFLOs for MZP i/b 0354
0409	A7/23	CTD for production i/b 0439
0508	A7/24	CTD for production i/b 0524
0600	A7/25	insitu rig deployed
0758	A7/26	CTD biogeochemistry shallow i/b 0846
0945	A7/27	CTD radiochemistry i/b 1042
1124	A7/28	plankton nets i/b 1228
1240	A7/29	CTD optics i/b 1320
1322	A7/30	Optics i/b 1508
1550	A7/31	CTD for nutrients i/b 1624
1717	A7/32	Production rig i/b
1819	A7/33	SAPS i/b 1957
2008	A7/34	Plankton net for SAPS i/b 2018
2256	A7/35	Apstein net i/b 2259
2307		WP2 net i/b 2323

Tuesday 13 December (Julian Day 347)

0044	A7/36	Sediment trap i/b
0044		Steam to A8 towing UOR i/b 1246
1315		UOR deployed i/b 0150

Wednesday 14 December (Julian Day 348)

0429	A8/1	CTD for production i/b 0502
0543	A8/2	CTD biogeochemistry shallow i/b 0626
0737	A8/3	CTD biogeochemsitry deep i/b 1104
1122	A8/4	Optics i/b 1136
1202	A8/5	CTD optics i/b 1225
1225		Steam for A9 towing UOR i/b 0305

Thursday 15 December (Julian Day 349)

0333	A9/1	GoFlos for MZP i/b 0358
0409	A9/2	CTD for production i/b 0441
0513	A9/3	CTD for production i/b 0529

0610	A9/4	production rig deployed
0646	A9/5	CTD biogeochemistry shallow i/b 0728
0835	A9/6	CTD biogeochemistry deep i/b 1131
1206	A9/7	Optics i/b 1226
1242	A9/8	CTD optics i/b 1317
1333	A9/9	Apstein nets i/b 1343
1357	A9/10	CTD radiochemistry i/b 1542
1618	A9/11	production rig i/b
1618		Steam for Muscat deploying UOR i/b 1921

Friday 16 December (Julian Day 350)

Steaming for Muscat

Saturday 17 December (Julian Day 351)

Steaming for Muscat

Sunday 18 December (Julian Day 352)

1600 Arrive Muscat

Monday 19 December (Julian Day 353)

1500 Disembark Ship

7.1: OPTICAL MEASUREMENTS & DESCRIPTIVE PHYSICAL OCEANOGRAPHY (UOR)

A. Bale, I. Bellan and M. Pinkerton

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OBJECTIVES

1. **Descriptive Physical Oceanography.** The towed UOR will be used to provide a description of the physical oceanography of the surface waters of the Arabian Sea within which the station work of Arabesque can be set. The sensors on the UOR give temperature, salinity, transmission (red) and chlorophyll fluorescence from near surface (5m approximately) to about 90m. This should be deep enough to cross the thermocline in most cases. First cut data output will be provided using on-board processing routines but the final data will be contoured at PML.

2. **Algorithm Development for Interpretation of Satellite Optical Imagery.** Data from the optics work on DISCOVERY will be used in two ways. Firstly it will be used to investigate how constituents in the water (phytoplankton pigments, DOC and particulate matter) affect spectral reflectance (the proportion of the light travelling downwards through the water which is reflected back up towards the surface). Secondly, it will be used to compare reflectance measured in the water (by the Satlantic profiler) with reflectance measured above the surface (the MARS) to investigate methods of correcting for skylight reflected from the sea surface. The UOR tows which took place during daylight hours may be used to investigate relationships between mixed-layer chlorophyll concentration, transmission and light attenuation over scales of 100s of km, provided that suitable calibration can be carried out.

3. **Calibration and Chlorophyll Fluorescence Yield.** Data from the UOR sensors which were attached to the CTD on all shallow casts will be used for calibration of our depth, conductivity and temperature. HPLC chlorophyll concentrations from bottle samples will allow changes in fluorescence yield to be investigated over

varying light levels through the day. This is required before any UOR data can be used for interpretation of reflectance.

Table 1.1. Details of the UOR Tows

DATE TOW NO.	GMT in/out	LAT' (N)	LONG' (E)	Tow Time	Length Depth	COMMENTS
16.11.94	1546	23 56.94	58 14.96	102 mins	30 km	Shakedown tow
Tow 1	1729	24 05.46	58 05.33		8-88m	
17.11.94	1849	25 59.57	56 35.40	106 mins	30 km	from GOM1 towards GOM 2;
Tow 2	2035	25 46.53	56 42.80		60-80m	Servo arm slipped
17/18.11.9	2055	25 44.44	56 44.14	216 mins	75 km	Continuing to GOM2
4	0031	25 17.53	56 58.26		5-80m	
Tow 3						
18.11.94	0153	25 14.6	57 00.6	347 mins	100 km	From GOM2 towards GOM3
Tow 4	0740	24 35.93	57 39.29		5-85m	
18.11.94	0940	23 35.86	57 38.49	196 mins	60 km	Continuing to GOM3
Tow 5	1256	24 21.09	58 08.18		5-85m	
18-	1928	24 19.49	58 11.86	302 mins	100 km	From GOM3 towards GOM4
19.11.94	0030	24 00.48	59 00.08		5-85 m	
Tow 6						
19.11.94	0142	23 59.13	59 00.29	93 mins	25 km	Continuing to GOM4
Tow 7	0316	23 55.36	59 13.90		5-85m	
19/20.11.9	1445	23 53.75	59 13.74	588 mins	200 km	GOM4 to GOM5
4	0033	22 45.4	60 34.00		5-80m	
Tow 8						
20/21.11.9	1400	22 38.31	60 40.67	625 mins	200 km	From GOM5 towards GOM6
4	0025	20 53.44	59 51.55		5-80m	
Tow 9						
21.11.94	0131	20 51.89	59 50.52	661 mins	225 km	Continuing to GOM6
Tow 10	1234	19 02.64	59 01.04		5-80m	
28.11.94	0429	19 30.36	59 09.85	201 mins	75 km	AS5 to A1 across shelf edge.
Tow 11	0750	19 13.17	58 37.73		5-45m	
28.11.94	0859	19 13.69	58 37.23	904 mins	275 km	A1 to A2 in deeper water
Tow 12	0003	17 33.86	60 26.21		10-90m	
29.11.94	0907	17 30.75	60 29.82	756 mins	250 km	A2 to A3
Tow 13	2206	16 03.70	61 58.73		5-95m	
5.12.94	0550	17 05.75	61 41.16	129 mins	30 km	From recovered trap towardsA3
Tow 14	0740	16 53.21	61 45.20		10-95m	
5.12.94	1009	16 53.16	61 43.99	612 mins	150 km	Thompson intercalibration tow
Tow 15	2021	15 56.84	62 14.90		5-90m	towards A3
6.12.94	0855	16 03.19	61 57.66	887mins	275 km	A3 to A4
Tow 16	2342	14 01.79	63 13.86		5-95m	
7.12.94	0827	13 58.93	63 14.31	858 mins	250 km	A4 to A5
Tow 17	2245	11 58.79	64 30.50		5-90m	
8.12.94	1247	11 58.51	64 28.79	720 mins	225 km	A5 to A6
Tow 18	0047	10 21.53	65 28.09		10-90m	
9.12.94	0714	10 14.36	65 32.64			A6 to A7; No data- logging
Tow 19	2338	07 59.70	67 00.13			failure.
11.12.94	1037	07 59.00	66 54.81	81 mins	25 km	Test of UOR "Stealth" body
Tow 20	1158	08 06.39	66 53.04		15-85m	
12-	2108	08 06.06	66 53.88	700 mins	200 km	A7 towards A8
13.12.94	0848	09 55.12	66 56.79		55-90m	
Tow 21						
13.12.94	0918	09 56.49	66 56.79	752 mins	225 km	Continuing to A8
Tow 22	2150	11 55.02	66 59.54		5-90m	

14.12.94	0838	11 59.49	66 58.49	868 mins	250 km	A8 to A9
Tow 23	2306	14 18.72	67 00.01		10-85m	
15.12.94	1225	14 18.56	66 58.65	176 mins	50 km	Trial of new PML servo and
Tow 24	1521	14 38.62	66 43.78		15-85m	control software

PROCEDURES

The UOR was towed in various configurations, depending on the ship speed, in order to achieve the optimum depth range required (5-95m). A standard sensor package containing temperature, salinity, chlorophyll fluorescence and light transmission was carried, as well as up- and down-welling light meters at six wavelengths. The details of tows undertaken are given in Table 1.1.

At about midday on most days, optical measurements were made over the stern of DISCOVERY, the ship being oriented with the stern facing into the sun to minimise hull-shading in accordance with the JGOFS optical protocols. Using the two aft telescopic cranes, an optical profile was taken simultaneously with measurements above surface to obtain the water-leaving radiance. The station positions and dates are given in Table 1.2.

Table 2. Details of the locations and station numbers of the optical profiles

Optical station	Station/cast	Date	Position	CTD	Station/cast
1	GOM2/4	17 Nov	N 25 02.0 E 57 05.6	Di12D005	GOM2/5
2	----------	18 Nov	N 24 35.9 E 57 39.3	Di12D008	----------
3	GOM4/7	19 Nov	N 23 54.6 E 59 15.0	Di12D015	GOM4/6
4	GOM5/5	20 Nov	N 22 39.4 E 60 40.7	Di12D021	GOM5/6
5	A1/12	22 Nov	N 18 59.9 E 58 45.2	Di12D028	A1/13
6	A1/21	23 Nov	N 18 58.4 E 58 29.3	Di12D033	A1/22
7	A1/34	24 Nov	N 18 54.4 E 58 14.3	Di12D038	A1/35
8	A1/44	26 Nov	N 19 00.0 E 59 00.0	301 GOFL	A1/45
9	AS4/2	27 Nov	N 19 27.0 E 58 15.0	Di12D048	AS4/3
10	A2/5	29 Nov	N 17 30.3 E 60 30.2	Di12D055	A2/6
11	A3/7	30 Nov	N 16 07.2 E 61 56.0	Di12D059	A3/8
12	A3/17	01 Dec	N 16 24.9 E 61 47.7	Di12D063	A3/18
13	A3/27	02 Dec	N 16 42.3 E 61 38.3	Di12D067	A3/28
14	A3/37	04 Dec	N 17 18.0 E 61 32.0	Di12D073	A3/49
15	A3/49	06 Dec	N 16 03.5 E 61 59.0	Di12D080	A3/50
16	A4/4	07 Dec	N 13 59.9 E 63 14.9	Di12D084	A4/4
17	A5/8	08 Dec	N 12 00.2 E 64 28.7	Di12D089	A5/9
18	A7/8	10 Dec	N 07 58.7 E 66 58.4	Di12D099	A7/9
19	A7/17	11 Dec	N 07 59.4 E 66 56.7	Di12D103	A7/18
20	A7/30	12 Dec	N 08 02.7 E 66 53.4	Di12D109	A7/29
21	A8/4	14 Dec	N 11 58.6 E 66 59.1	Di1294114	A8/5
22	A9/7	15 Dec	N 14 20.0 E 66 57.0	Di1294119	A9/8

During each optical slot, Satlantic light meters (upwelling radiance and downwelling irradiance at 7 SeaWiFS wavelengths) were profiled to a depth of 200m, the profiles

taking approximately 20 minutes but with the surface 100m traversed at a slower rate to improve vertical resolution.

Simultaneously, the Biospherics MER1010 Spectroradiometer was suspended at a height of 5m above the sea surface to measure water leaving radiance at 12 wavelengths spanning the SeaWiFS range. A 'deck cell' mounted on a spar projecting away from the spectrometer housing and clear of the jib shadow, measured downwelling sunlight intensity at four wavelengths in order to correct both the Spectroradiometer and the Satlantic data for changes in ambient light intensity during the measurements.

Following the vertical profile, the spectroradiometer was retrieved and oriented toward the zenith from an unshaded position on the aft deck. A few minutes of spectral data was then collected to characterise the sky colour so that the previous water leaving radiance data could be corrected for reflected skylight.

An essential part of the optical station was a CTD cast to 200m immediately following the light profile work and, when the wind direction allowed, the ship was oriented with the sun on the starboard (CTD) side of the ship to ensure good PAR measurements. Optical sensors and self-contained loggers were also attached to the CTD. Five water bottle samples were taken in the euphotic zone (upper 100m) for the following parameters to be determined:

1 **Suspended particle absorption:** One litre of sample was filtered onto a 25mm GF/F and the absorption measured using a UV/Vis spectrometer over the region 400-750nm. The pigments were then extracted using hot methanol per SeaWiFS protocols and the absorption spectra of the remaining detritus measured.
2 **Pigments:** Samples were filtered and extracted for HPLC pigment determination by D. Cummings (107 samples).
3 **Particle number and size:** Samples from 10 and 5m were analysed for particle numbers and size using flow cytometry by G. Tarran (44 samples).

4 **Dissolved organic carbon:** Samples were analysed for DOC from the 10 and 5m bottles by A. Miller (44 samples).

NB The optical CTD was undertaken in conjunction with Brian Irwin and water samples were taken opportunistically by other workers on several occasions.

RESULTS

UOR data was processed by RVS using the UNIRAS contouring package to provide depth-distance plots of temperature, salinity, transmission and chlorophyll fluorescence as soon as possible after the end of each tow. These were arranged in sequence and displayed onboard to give an overview of the water structure between stations. The UOR crossed the thermocline (which varied in depth from 40 to 90m) in virtually all undulations.

Optical profile data was obtained from 21 of the 22 casts and a spectral reflectance plot produced from each. This profiled data will be reprocessed after normalisation to ambient light and then related to water constituents and MARS data. 21 sets of MARS data was successfully collected and will be processed at PML. Water samples were collected successfully on all 22 optical casts and the results of the various analyses will be collated in due course. Light measurements made during the optical CTDs were used to estimate 1% light levels for the production cast the following morning.

Opportunistic experiments were carried out on two occasions to monitor the change in the spectral characteristics of skylight with time of day. In addition to the measurements of water leaving radiance measured in conjunction with the optical profiles, a series of five water leaving radiance spectra were taken with the MARS slung out to starboard (8m) whilst underway for subsequent comparison with similar measurements made on the Thomas G. Thompson.

In one series of vertical profiles, all the light meters from the UOR and profiling packages were deployed simultaneously in order to intercalibrate the various systems.

7.2: DISSOLVED OXYGEN AND APPARENT OXYGEN UTILISATION

Stuart W. Gibb

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INTRODUCTION

The oxygen depleted zone (ODZ) is a characteristic feature of the north-western Indian Ocean and is the thickest low-oxygen layer in the oceans today (Olsen *et al* 1993). From previous studies the ODZ in the Indian Ocean has been shown to lie between 150 and 1000m depth and is most pronounced in the northern Arabian Sea (Burkill *et al* 1993).

The oxygen concentration of subsurface oceanic regions is controlled by input of water from areas in which it is in contact with the atmosphere and by the consumption of free oxygen through oxidative processes, predominantly of organic matter. An oxygen budget constructed for the ODZ in the northern Arabian Sea supports the idea that near zero concentrations are maintained by moderate oxygen consumption in waters initially low in oxygen which pass through the layer at moderate speed (Olsen *et al* 1993). However, as well as having important implications to carbon fluxes and speciation, the reducing environment of the ODZ has important biogeochemical consequences for N cycling and is conducive to the microbially mediated generation of nitrogen from nitrate by denitrification.

CORE OBJECTIVE

1. To determine the spatial distribution of dissolved oxygen in the northern Arabian Sea and Gulf of Oman and to provide precise data for use in calibration of the CTD oxygen electrode.

METHOD

Oxygen was determined by automated Winkler titration (Williams and Jenkinson, 1982). Apparent oxygen utilisation (AOU) values were calculated from observed oxygen levels and from the salinity and potential temperature of the sampled seawater. Precision was determined to be <1% (n=4) for surface, intermediate and deep waters.

PRELIMINARY RESULTS

1. Supersaturated oxygen concentrations were generally observed in the surface mixed layer extending upwards of the chlorophyll maximum zone. Below this, pronounced oxygen depletion was recorded throughout the northern Arabian Sea (as also

observed in 1987 - R.R.S. Charles Darwin: Mantoura *et al*, 1993). In the cross-sectional transect from A1 to A7 the ODZ was found to extend from the bottom of the euphotic zone (sharp decline) to depths of around 1000m (*Figure 1*) as observed previously by Olsen *et al* (1993). This zone was found to be hypoxic (disaerobic) rather than anoxic (*i.e.* no concentrations < 1% saturation were recorded).

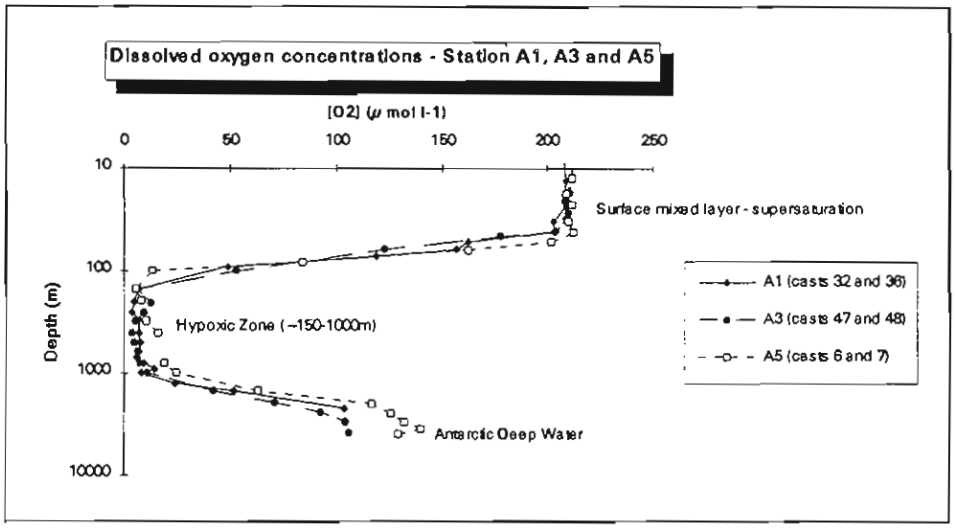


Figure 1: Vertical profile of oxygen content at three stations in the Arabian Sea

Below the hypoxic zone, deep water oxygen concentrations were observed to increase in association with the influx of Antarctic Bottom water with concentrations of > 140 μmol/l commonly observed below 3000m.

1. Regression of CTD oxygen electrode 'concentration' vs. Titrated oxygen concentration give multiple squared regression coefficients consistently excess of 0.99 (*e.g. Figure 2*) indicating good agreement between techniques.

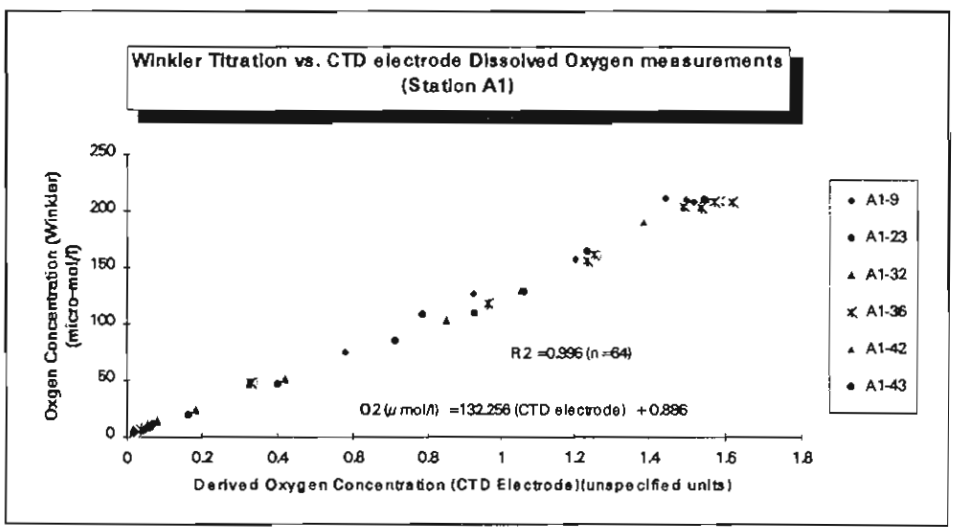


Figure 2: Calibration of the oxygen electrode on CTD.

Oxygen concentrations were measured and AOUs calculated for all bottle depths on the following CTD casts

'GOM' Stations	'AS' Stations	'A' Stations	
GOM 3-1, GOM3-2	AS1-1, AS1-2	A1-9, A1-23, A1-32,	A4-2, A4-3
GOM 4-6, GOM4-8, GOM4-9	AS2-1	A1-36, A1-43, A1-42	A5-6 A5-7
GOM5-3, GOM 5-7	AS3-2	A2-2, 2-4	A6-1, A6-2
(back calculated data is also	AS4-1	A3-6, A3-8, A3-20,	A7-7, A7-6, A7-19,
available for stations GOM1	AS5-1	A3-26, A3-35, A3-36, A3-48,	A7-26
and GOM2)		A3-47	A8-3, A8-2
			A9-5, A9-6,

FUTURE WORK

1. From recorded data, construct oxygen contour plots for the transects studied.
2. Together with concurrent shipboard determinants *i.e.* Freon, CFC, productivity, carbon fluxes, nutrients, denitrification rates and biogas concentrations (e.g. methane, nitrous oxide), calculate (a) residence time of water in the ODZ and compare with previous estimates *i.e.* Olsen *et al* (1993) ~10yrs; (b) construct oxygen budget for the ODZ to determine criteria for its spatial and temporal maintenance; and (c) interpret the consequences of these estimates to the biogeochemistry of carbon and nitrogen in the region.

7.3: CONTINUOUS AND DISCRETE PCO_2 & TCO_2

Roger Ling

(Plymouth Marine Laboratory, UK)

OBJECTIVES

1. To measure continuous surface pCO2 by NDIR absorption
2. To measure discrete pCO2 vertical profiles by gas chromatography
3. To measure discrete TCO2 vertical profiles by coulometry.

RESULTS

The continuous pCO_2 system which had not worked properly on Arabesque 1 was serviced and a new version of the operating software installed. It ran for a short time while in port but soon failed and it was difficult to restart it. The need to set up the other methods meant that further work had to wait until there was some free time. The discrete pCO_2 was set up without problems and was soon working correctly.

The discrete total CO_2 method was installed but the coulometer would not find an end-point. It had been shipped back to the UK agent for repair after Arabesque 1 and returned apparently in good working order. By re-adjusting the electronic configuration of the coulometer it was eventually possible to reach an end-point with good reproducibility but with a fixed offset. It was decided to use the coulometer calibrated in this way and to rely on the TCO_2 reference standards to make a final adjustment.

At the first opportunity when there was a break in the CTD stations the continuous pCO_2 system was worked on and a method found to start it. It ran without problems from then on apart from fouling of the equilibrator with iron deposits originating from the ships pipework.

See Table 1 for stations worked.

Table 1: Stations sampled.

Station	Date	Time Z	Lat. (N)		Long. (E)		Depth
GOM 2/2	17-Nov	02:10	24	47.3	57	13.7	1217
GOM 2/3	17-Nov	07:00	24	46.0	57	14.2	1220
GOM 1	17-Nov		25	58.0	56	37.0	80
GOM 3/1	18-Nov	13:28	24	21.0	58	7.0	2840
GOM 3/2	18-Nov	15:25	24	20.3	58	10.4	2840
GOM 4/8	19-Nov	09:15	23	54.3	59	14.8	3300
GOM 4/9	19-Nov	11:07	23	54.3	59	14.8	3300
GOM 5/3	20-Nov	06:30	22	39.2	60	40.9	3150
GOM 5/7	20-Nov	10:50	22	39.7	60	40.4	3150
A 1/9	22-Nov	02:38	18	59.9	58	50.8	3320
A 1/32	24-Nov	02:48	18	54.9	58	15.7	2230
A 1/36	24-Nov	10:02	18	54.3	58	9.0	1270
AS 1/1	25-Nov	12:14	19	14.6	58	34.5	2500
A 1/42	26-Nov	04:30	18	59.9	58	59.9	3370
A 1/43	26-Nov	06:40	19	0.0	58	59.9	3370
AS 2/1	26-Nov	14:55	19	16.4	58	32.3	1210
A 3/2	27-Nov	02:36	19	23.5	58	20.9	480
AS 5/1	27-Nov	12:00	19	30.2	58	9.1	45
A 2/2	29-Nov	01:30	17	29.9	60	29.6	3900
A 2/4	29-Nov	06:30	17	29.9	60	29.6	3900
A 3/6	30-Nov	04:15	16	5.4	61	51.4	3900
A 3/20	01-Dec	09:35	16	27.1	61	46.3	3900
A 3/26	02-Dec	04:00	16	39.6	61	38.9	3900
A 3/35	04-Dec	02:22	17	16	61	30.7	3840
A 3/36	04-Dec	04:25	17	16.9	61	31	3870
A 3/47	06-Dec	02:18	16	1.1	62	0.3	3920
A 3/48	06-Dec	03:56	16	2.4	62	0	3920
A 4/2	07-Dec	01:48	14	1.1	63	14.4	4000
A 4/3	07-Dec	03:28	14	1.5	63	14.4	4030
A 5/6	08-Dec	03:05	11	59.7	64	28.1	4200
A 5/7	08-Dec	05:00	11	58.6	64	29.2	4200
A 6/1	09-Dec	02:30	10	15.3	65	32.4	4380
A 6/2	09-Dec	04:25	10	13.9	65	32.8	4380
A 7/6	10-Dec	03:45	?	?	?	?	4600
A 7/7	10-Dec	05:30	7	58.7	66	58.8	4600
A 7/26	12-Dec	03:59	8	2.2	66	54.5	4600
A 8/2	14-Dec	01:44	11	57.1	66	59.3	4200
A 8/3	14-Dec	03:38	11	58.6	66	59.7	4200
A 9/5	15-Dec	02:47	14	15.6	66	58.2	4000
A 9/6	15-Dec	04:37	14	18.5	66	59.1	3970

7.4: MICRO AND NANO NUTRIENT SPECIES

Malcolm Woodward & John Stephens

(Plymouth Marine Laboratory, UK)

OBJECTIVES

1. To investigate the nutrient regimes of the oceanic sea area off the coast of Oman, in the Arabian Sea, during the inter-monsoon period, and at the onset of the north east monsoon season. These data to compare and contrast with the DISCOVERY cruise 210 carried out during the south-west monsoon earlier this year.
2. To investigate spatial and temporal variations within the coastal region, and to follow an offshore transect towards the deep ocean oligotrophic area.
3. To quantify the outflowing Persian Gulf water nutrients.

ANALYTICAL METHODOLOGIES

Continuous segmented-flow automated colorimetric analysis of seawater was carried out for the following micronutrients: Nitrate, Nitrite, Phosphate, Silicate, and Urea. A new semi-continuous fluorescence analytical technique was employed for ammonia, capable of nanomolar detection levels, these being undetectable by the colorimetric system. Under oligotrophic conditions a nanomolar chemiluminescent analysis system for nitrate and nitrite was employed. All analysis methodologies are detailed in 'Nutrient Analysis Techniques', June 1994, (EMS Woodward). Analyses were carried out for CTD profiles, and for underway continuous transects.

Table 1: Samples were analysed for nutrients from the following CTD stations:

SHAKEDOWN 5 depths: 5-65 m	
GOM - 2/1, Production: 10 depths, 0-50m	A3/20, High Resolution, 12 depths, 11-80m
GOM - 2/2, Shallow, 12 depths, 5-200m	A3/24, Production, 12 depths, 1-80m
GOM - 2/3, Deep. 12 depths, 225-1195m	A3/26, Shallow, 12 depths, 7-199m
ARABESQUE Reference STN. A1 - 11depths, 5-500m, from Cruise 211	A3/32, Production, 10 depths, 1-80m
GOM - 1/1, 12 depths, 5-65m	A3/35, Shallow, 12 depths, 11-198m
GOM - 2A/1, Production: 10 depths, 1-60m.	A3/36, Deep, 12 depths, 307-3638m
GOM - 3A/1, Brian Irwin: 2 depths, 10-58m.	A3/43, Production, 10 depths, 1-80m
GOM - 3/1 Shallow, 12 depths, 5-200m	A3/-, Intercalibration CTD with the Thomas Thomson. 12 depths, 5-500m
GOM - 3/2, Deep, 12 depths, 225-2818m	A3/46, Production, 10 depths, 1-80m
GOM - 4A/1, Production: 10 depths: 1-60m	A3/47, Shallow, 12 depths, 6-200m

GOM - 4/8, Shallow: 12 depths: 5-200m
GOM - 4, Deep,12 depths: 300 - 3300m
GOM - 5A/1 Production, 10 depths, 1-60m
GOM - 5/3, Shallow, 12depths, 5-200m
GOM - 5, Deep, 12 depths, 100-3120m
GOM - 5B/1 Production, 10 depths, 1-60m
A1/6, Production, 10 depths, 1-45m
AI/9, Shallow, 12 depths, 5-200m
A1/18, Production, 10 depths, 1-45m
AI/23, Shallow High Resolution, 12 depths, 4-76m
A1/29, Production, 10 depths, 1-45m
A1/31, Deep, 12 depths, 251-2211m
AI/36, Shallow, 12 depths, 8-200m
AS1/1, Shallow, 12 depths, 7-200m
AS1/2, Deep, 12 depths, 503-1504m
A1/40, Production, 2 depths, 10-35m
AI/42, Shallow, 12 depths, 7-200m
A1/43, Deep, 12 depths, 250-3200m
A1/45, Production, 2 depths, 10-35m
AS2/1, 12 depths, 7-1100m
AS3/1, Production, 10 depths, 1-45m
AS3/2, 12 depths, 7-454m
AS4/1, 12depths, 6-174m
AS5/1, 6 depths, 5-40m
AS5/3,Production, 10 depths, 1-30m
A2/1, Production, 10 depths, 0-50m
A2/2, Deep 12 depths, 220-3807m
A2/2, Shallow 12 depths, 6-199m
A3/4, Production, 10 depths, 1-60m
A3/6, Shallow, 12 depths, 6-199m
A3/13, Production, 10 depths, 1-80m
A3/18, Production13/9, 10 depths, 0-60m
A3/48, Deep 12 depths, 256-3852m
A4/1, Production, 10 depths, 1-80m
A4/2, Shallow, 12 depths, 7-200m
A4/3, Deep, 12 depths, 257-4008m
A5/2, Production, 10 depths, 1-80m
A5/6, Shallow, 12 depths, 7-199m
A5/7, Deep, 12 depths, 307-3997m
A6/A/1, Production, 10 depths, 1-70m
A6/1, Shallow, 12 depths, 8-201m
A6/2, Deep, 12 depths, 258-3278m

A7/2, Production, 10 depths, 0-80m
A7/6, Shallow, 12 depths, 12-200m
A7/7,Deep, 12 depths, 300-4500m
A7/14, Production, 10 depths, 1-100m
A7/19, High Resolution, 12 depths, 46-111m
A7/23, Production, 10 depths, 1-100m
A7/-, Shallow, 12 depths, 12-200m
A8/1, Production, 10 depths, 1-100m
A8/2, Shallow, 12 depths, 12-200m
A8/3, Deep, 12 depths, 250-4158m
A9/2, Production, 10 depths, 1-100m
A9/5, Shallow, 12 depths, 12-200m
A9/, Deep, 12 depths, 256-3903m

Table 2: Continuous underway analysis was carried out over the following periods:

Start date/time	End date/time	Between stations
28/11 -0317	29/11 - 0032	AS5 - A2
29/11 - 1004	30/11 - 0002	A2 - A3
5/12 - 1210	5/12 - 2016	Intercalibration with Thomson
6/12 - 1041	6/12 - 2130	A3 - A4
7/12 - 0837	8/12 - 0039	A4 - A5
8/12 - 1325	8/12 - 2347	A5 - A6

Ammonia Regeneration Experiments.

A collaborative series of experiments were carried out analysing samples from ammonia regeneration experiments as described by Thomas Weisse in his cruise report. The nanomolar ammonia analysis system was employed for the analysis of these samples.

Table 3: Experimental details of Ammonia Regeneration Experiments:

DATE	EXPERIMENT	SAMPLE NUMBER
22nd November	Trial	17
24th November	II	18
26th November	III	24
27th November	IV	18
29th November	V	18
4th December	VI	24
6th December	VII	24
7th December	VIII	24
9th December	IX	24
10th December	X	24
12th December	XI	24
13th December	XII	24
14th December	XIII	24
15th December	XIV	24
15th December	XV	20

RESULTS

The Technicon autoanalyser performed almost faultlessly throughout the cruise for all 5 channels. Normally the colorimetric system would have been run for ammonia as well as the new nanomolar methodology. However due to a legacy from cruise 211 there was a broken transformer that could not be repaired. The new fluorimetric analyser for ammonia is still being developed, however it worked well for the whole cruise, with modifications and improvements being tested during the cruise. The NOX-Box was only called upon for a few stations, but again produced good reliable data.

The Gulf of Oman stations exhibited nutrient depletion (nanomolar nitrate) at the Straits of Hormuz station, with the nutrients starting to increase out eastwards towards the Arabian sea, with the surface nitrate at GOM5 around 0.3 umoles.

The major investigation for the cruise was the transect from AS5 in the shallow coastal region off the Oman coast, working stations offshore to complete the transect at A7, situated in the oligotrophic area of the Indian ocean.

At AS5 the nitrate was surprisingly deplete in the upper 20 metres of the water column compared to D210 in September when the upwelling was influencing the coastal region. Nitrate concentrations now were only 0.22 μmoles. However as the transect worked offshore the concentrations increased in the surface mixed layer to around 0.7-1.0 μmoles. A continuous surface transect then further offshore showed a surprisingly

variable surface nitrate concentration, which was reflected in the other measured variables like fluorescence, salinity, etc. as well as the other nutrients. At A2 nitrate was elevated at the surface to 1.5 µmoles, and then further offshore at A3 it was depleted to 0.4 µmoles. It was presumed that as we then went further offshore then the oligotrophic ocean would be in evidence. However at A4 the nitrate was back up to around 1 umole, however, from here there was still surface variation but the general trend was down. By the time we reached A6 the system was oligotrophic at around 15-20 nanomoles, this was reflected at A7 where similar oligotrophy was found. However the final two stations at A8 and A9 were again out of the oligotrophic area with surface mixed layer nitrate of 0.1 and 0.7 µmoles respectively.

The initial results of the intercalibration CTD with the RV Thomas Thomson are very encouraging, the nitrate, nitrite, phosphate and ammonia results being in very close agreement. The silicate was not in agreement and so we are investigating whether it is a method error, standards, or whatever. I have made a new set of stock standard that agree with the original, which cancels out that possible problem with our system. We will investigate further. A very successful cruise which will yield much new information about this interesting and variable ocean area.

7.5: DETERMINATION OF DISSOLVED ORGANIC CARBON & NITROGEN

Axel E J Miller

(Plymouth Marine Laboratory, UK)

INTRODUCTION

With the exception of atmospheric CO_2, more carbon is held in the oceanic reservoir of dissolved organic matter (DOM) than in any other compartment of the global carbon pool. However, in spite of the accepted importance of Dissolved Organic Carbon (DOC) in global biogeochemical cycling, historical and contemporary uncertainties in the methods of determination have limited the availability of analytically verified studies of global distributions.

Rapid and precise techniques are now available for the determination of DOC. Increasingly used for this purpose is high temperature catalytic oxidation (HTCO). Such techniques involve the direct injection of acidified and decarbonated sea water onto a platinised alumina catalyst, at high temperatures (680 - 900°C), under an atmosphere of oxygen or high purity air. Quantitative production of CO_2 gas allows DOC concentrations to be determined using a CO_2-specific infrared gas analyser (IRGA). Plymouth Marine Laboratory perform these measurements with a *Shimadzu TOC 5000* analyser. Incorporation of a *Licor 6252*, solid-state IRGA allows high precision measurements to be made against the noisy background of an ocean-going research platform.

Recent purchase of a nitrogen-specific chemiluminescence detector provides an opportunity for measurements of Total Dissolved Nitrogen (TDN) to be collected in the field. Combustion of nitrogenous compounds under an oxygen atmosphere at 680°C (in the *TOC 5000* furnace) leads to quantitative production of the nitric oxide radical. Subsequent reaction with ozone produces excited nitrogen dioxide species, which emit quantifiable light energy upon decay to their ground state. When finalised N-based nutrient data are available, the TDN concentrations can be corrected, giving a

measure of Dissolved Organic Nitrogen (DON), complementary to HTCO-DOC measurements.

OBJECTIVES

1. Determination of HTCO-DOC in a range of contrasting waters, from: eutrophic coastal and oceanic upwelling, through mesotrophic, to oligotrophic systems of the Arabian Sea.

2. Elucidation of variability in the relationships between HTCO-DOC and Apparent Oxygen Utilisation (AOU), through deep water column studies in coincidence with high-precision oxygen measurements (Stuart Gibb, PML).

3. Continued field testing of the Antek 705D Nitrogen-Specific Chemiluminescence Analyser; in order to quantify HTCO-DON concentrations in various oceanic environments.

4. Preliminary investigation of the relationship between photochemical decomposition of deep sea DOC and production of photosynthetic particles (Glenn Tarren, PML), through time-series on-deck incubation.

5. Biogeochemical comparison of data with measurements made during *R.R.S. Discovery* cruise 210, 27th August - 4th October, 1994.

6. Opportunistic intercomparison of underway surface DOC measurements with Paula Coble (USF), aboard the University of Washington's *R.V. Thomas G. Thompson*, as part of the JGOFS Indian Ocean programme.

PRELIMINARY OBSERVATIONS

Measurements of HTCO-DOC have been made across the whole range of contrasting oceanic environments encountered during the cruise. Precision on replicate analyses

was generally better than ±5%, with many replicated analyses closer than ±2%. The analytical blank, resulting from the *TOC 5000* was quantified at around 8-10μM C. Blank-corrected DOC concentrations ranged from 120-140μM C in coastal surface waters, approaching the Strait of Hormuz (Stations GOM6-GOM1), to around 90μM C at lower latitudes. Deeper waters showed DOC concentrations fluctuating between approximately 40-60μM C. A deep sea oceanographic profile is illustrated in Figure 1.

Determinations of TDN were successfully made at a number of stations. Lack of nutrient data have prevented quantification of DON contributions, but the vertical distribution suggests oceanographic consistency. For example, at Station A5, TDN values increase from the surface (<2μm N) down to around 600m (8μM N), but remain fairly constant below this depth.

Figure 1 Vertical profiles of HTCO-DOC and AOU at A1, the ARABESQUE Reference Station, 19°N, 59°E. For clarity, error bars have only been plotted for waters at 200m and below; these values are typical of variation throughout the water column.

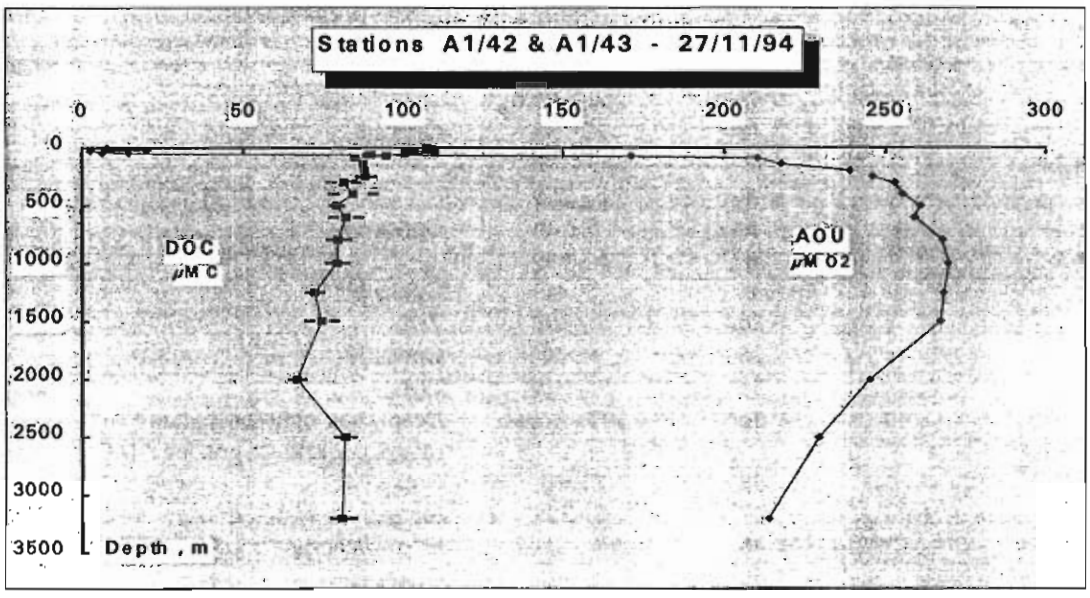


Table 1 Stations sampled for HTCO-DOC measurements; listing analyses performed in addition to standard Biogeochemistry Casts.

Station	Cast no.	Depth Range , m	Additional Work	Date
GOM1	1	5 - 65		17/11
GOM2	2	5 - 200		17/11
	3	225 - 1195		
	5	5 , 10	Optics 1	
GOM3	1	5 - 200	Optics 2	18/11
	2	225 - 2818		
GOM4	6	5 , 10	Optics 3	19/11
	8	5 - 200		
	9	300 - 3300		
GOM5	3	5 - 200		20/11
	6	5 , 10	Optics 4	
	7	150 - 3120		
AS1	1	7 - 200		25/11
AS2	1	7 - 1100		27/11
AS3	2	7 - 454		28/11
	3	5 , 10	Optics 9	
AS4	1	6 - 174		28/11
AS5	1	3 - 40	[High Resolution]	28/11
A1	9	5 - 200		22/11
	13	5 , 10	Optics 5	
	22	5 , 10	Optics 6	23/11
	23	4 - 76	[High Resolution]	
	32	2200	Precision experiment	24/11
	35	5 , 10	Optics 7	
	42	7 - 200		2711
	43	250 - 3200		
	45	10 , 35	Optics 8	
A2	2	220 - 3807		29/11
	4	6 - 299		
	6	5 , 10	Optics 10	
A3	6	6 - 199		30/11
	8	5 , 10	Optics 11	
	26	7 - 199	TDN	01/12
	28	5 , 10	Optics 13	
	35	11 - 198	TDN	04/12
	36	307 - 3638	Deep water light incubation [T0] Microzooplankton grazing / 14C	
	38	5 , 10	Optics 14	
	47	6 - 200	Microzooplankton grazing / 14C	06/12
	48	256 - 3852	Deep water light incubation [T2]	
	50	5 , 10	Optics 15	
A4	2	7 - 200	Deep water light incubation [T3]	07/12
	3	257 - 4008		
	5	5 , 10	Optics 16	
A5	6	7 - 199	TDN	08/12
	7	307 - 3997	Deep water light incubation [T4]	
	9	5 , 10	Optics 17	
A6	1	8 - 201	TDN	09/12
	2	257 - 4008	Deep water light incubation [T5]	

A7	6	12 - 200	Deep water light incubation [T6]	10/12
	7	300 - 4500		
	9	5 , 10	Optics 18	
	18	5 , 10	Optics 19	11/12
	19	46 - 111	[High Resolution]	
	26	12 - 200		12/12
	27	500	Precision experiment	
	29	5 , 10	Optics 20	
A8	2	12 - 200	TDN	14/12
	3	250 - 4158		
	5	5 , 10	Optics 21	
A9	5	12 - 200	TDN	15/12
	6	256 - 3903		
	8	5 , 10	Optics 22	
Thomas G. Thompson	T33-T42	Non-toxic	Intercalibration Deep water light incubation [T1]	05/12

7.6: OCEANIC AND ATMOSPHERIC DISTRIBUTION OF METHYLAMINES AND AMMONIA

Stuart W. Gibb

(Plymouth Marine Laboratory / University of East Anglia, UK)

INTRODUCTION

Nitrogen, a biologically essential element in the marine environment, is found in a variety of inorganic and organic forms in oxic seawater ranging from the thermodynamically most stable species, nitrate, to reduced compounds such as ammonia and its methyl derivatives, the methylamines (monomethylamine, MMA; dimethylamine, DMA and trimethylamine, TMA). These are biogenic compounds widely distributed in the marine environment and intimately involved in oceanic nitrogen fertility (King, 1988; Carpenter and Capone, 1983). By virtue of their volatility they are capable of evasion across the air-sea interface and may be an important source alkali to the troposphere and so subsequently play a significant role in the regulation of atmospheric and rainwater pH (Quinn *et al.*, 1987, 1988; Van Neste *et al.*, 1987).

An understanding of the marine distribution and biogeochemical cycling of these compounds has largely been restricted through the absence of a sensitive and selective analytical technique capable of their individual quantification at the nano-molar levels characteristically found in the marine environment. Only recently has it been possible to reliably analyse ammonia (Jones, 1991) and the methylamines (Yang *et al.*, 1993; Abdul-Rashid 1991) at the concentrations (nM-μM) typically found in natural waters.

CORE OBJECTIVES

1. To characterise the spatial distribution of the methylamines and ammonia in the surface waters and overlying atmospheric phases of the N.W. Indian Ocean and estimate their contribution to the marine budget of reduced nitrogen.
2. To establish the magnitude and direction of their air-sea exchange fluxes and interpret the results of these studies within the context of the biogeochemical cycle of nitrogen

METHODS

Methylamines and ammonia were determined by *Flow Injection Extraction-Ion Chromatography* (FIE-IC). This novel technique, recently automated for shipboard deployment permits the simultaneous measurement of MA's and ammonia at the nano-molar concentrations typical of oceanic waters. (l.o.d. ~2nM; co. of variation 2-6% at 20nM for methylamines).

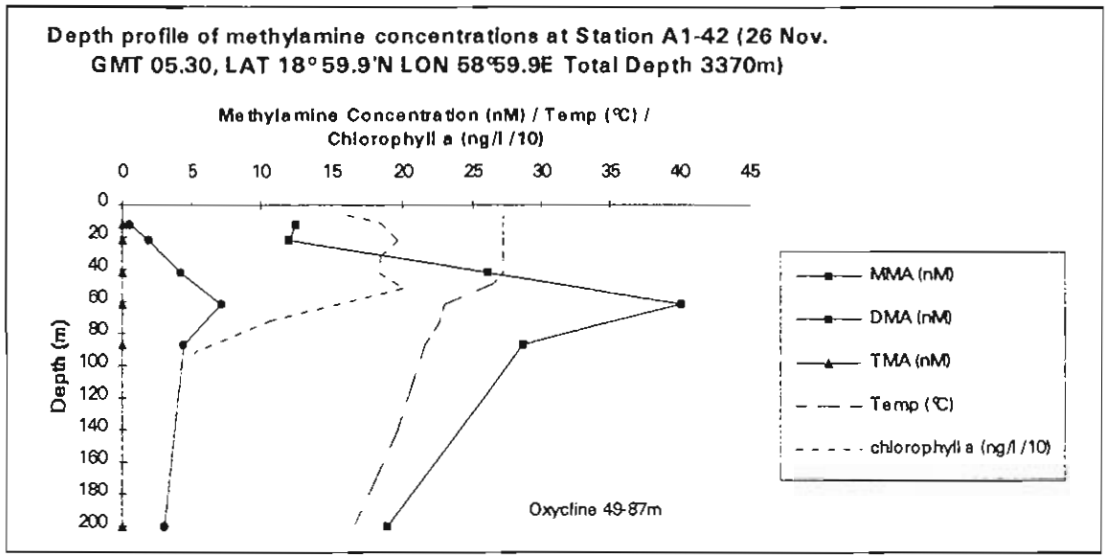
Tandem filter systems (Teflon and acid impregnated paper filters) equipped with cyclone separators were employed in the collection of particulate and gaseous atmospheric methylamines and ammonia. Following treatment of filters, analysis was performed by FIE-IC.

PRELIMINARY OBSERVATIONS

1. ***Oceanic distribution*** - methylamines and ammonia were observed to be relatively ubiquitous in the upper water column, but subject to considerable spatial variability. Concentrations of ammonia generally exceeded those of the methylamines by 1-2 orders of magnitude. MMA was consistently the most abundant methylamine whilst TMA was measured generally at only trace levels (<3 nM).

During the Aug.-Oct period highest surface concentrations of methylamines were recorded in the shallow productive coastal waters of AS4 and AS5. In Nov. and Dec. a more complex less defined picture emerged of the A1 to AS5 transect and with greatest concentrations being observed further offshore at station A1 (again a more productive station at the time).

In depth profiles studies during Aug.-Oct, a strong MMA and DMA signal was often found at the base of the fluorescence maximum zone / top of thermocline. During Nov.-Dec. this signal was a rarer occurrence, only recorded at more productive stations (*e.g.* A1-*Figure 1*). Both concentrations of methylamines and the intensity of this signal declined with transgression into oligotrophic conditions.



2. ***Atmospheric Concentrations*** - although methylamines were detected in both gaseous and particulate atmospheric sample ammonia was found to be the dominant nitrogenous base in both particulate and gaseous atmospheric phases (concentrations ~ 2 orders of magnitude greater than those of the methylamines). Concentrations of methylamines appear to be generally lower than those for the period Aug.-Sep. (Discovery 210) in the same region.

Methylamine and ammonia analysis was performed on the following samples

CTD profiles (Selected depths from the following casts)			**On-way samples**	**Atmospheric samples**
Arabian Sea	***Gulf of Oman***	***Coastal transect***		
			~ 45 analyses	1 x wet deposition
A1-32, A1-36,	none	AS1-1, AS1-2,	along AS1-A7	
A1-42, A1-43		AS2-1	transect	5 sets of gaseous
A3-26 / 67		AS3-2		samples + blanks
A7-6, A7-7		AS4-1		
		AS5-1		5 sets of particulate samples + blanks

FUTURE WORK - TO INCLUDE

- Full data work up
- Chlorophyll and carotenoid pigment correlation studies to elucidate potential chemotaxonomic production of methylamines. Estimation of the contribution of methylamines to DON.

- Establish direction and estimate magnitude of interfacial air-sea exchange fluxes of ammonia and the methylamines from data collected from simultaneous from surface seawater and atmospheric measurements.

7.7: NITROUS OXIDE AND METHANE IN VERTICAL HYDROCASTS

John Barnes

(Dept of Marine Sciences, University of Newcastle, UK)

The dissolved seawater concentrations of two important greenhouse biogases, nitrous oxide (N_20) and methane (CH_4), were determined simultaneously to high precision using a fully automated headspace equilibration -gas chromatographic technique. A total of 35 vertical hydrocasts were successfully analysed, covering each of 15 oceanographic stations in detail (Table 1). In all over 400 individual dissolved gas analyses were made. In addition, N_20 and CH_4 were determined in samples of ambient air from the same locations. These data, in conjunction with data collected on cruise 210, represent the most detailed coverage of N_2O and CH_4 distributions in the Indian Ocean to date, and their detailed analysis should provide important insights into the sources of these important biogases.

Analytical data are presently available in the form of detector responses (peak areas). These require significant salinity and temperature-based corrections in order to produce true concentrations, and the appropriate data will become available post-cruise. Nevertheless, a number of preliminary observations can be made at this stage. Firstly, in waters above the thermocline CH_4 is typically enriched by about 10-35 % relative to ambient air , similar to the situation found in the majority of open ocean waters north of 70o S. Concentrations decrease in deeper waters to below present day air-equilibrium values, and overall the profiles are consistent with a combination of water mass age considerations and coupled production-consumption reactions. N_2O distributions shows two important features. At the open ocean sites, large positive concentration anomalies occur in the oxygen depleted zone (ODZ), at ~ 500-1200m, similar to the situation found previously in the N.W. Indian Ocean. These elevated deep water N_2O concentrations were also reflected in the coastal upwelling zones.

Overall, these data should aid in the refinement of our present estimates of the production fluxes of N_2O in the ODZ, and help to improve calculations of the

ventilation fluxes of N_2O and CH_4 to the atmosphere. In addition short term temporal effects due to monsoonal linked upwelling may be characterized.

Table 1: Summary of CTD stations processed for N_2 0 and CH_4

Station	Date	Time Z	Lat. (N)		Long. (E)		Depth
GOM 2/2	17-Nov	02:10	24	47.3	57	13.7	1217
GOM2/3	17-Nov	07:00	24	46.0	57	14.2	1220
GOM 1	17-Nov		25	58.0	56	37.0	80
GOM3/1	18-Nov	13:28	24	21.0	58	7.0	2840
GOM3/2	18-Nov	15:25	24	20.3	58	10.4	2840
GOM 4/8	19-Nov	09:15	23	54.3	59	14.8	3300
GOM 4/9	19-Nov	11:07	23	54.3	59	14.8	3300
GOM 5/3	20-Nov	06:30	22	39.2	60	40.9	3150
GOM 5/7	20-Nov	10:50	22	39.7	60	40.4	3150
A 1/9	22-Nov	02:38	18	59.9	58	50.8	3320
A 1/32	24-Nov	02:48	18	54.9	58	15.7	2230
A 1/36	24-Nov	10:02	18	54.3	58	9.0	1270
AS 1/1	25-Nov	12:14	19	14.6	58	34.5	2500
A 1/42	26-Nov	04:30	18	59.9	58	59.9	3370
A 1/43	26-Nov	06:40	19	0.0	58	59.9	3370
AS 2/1	26-Nov	14:55	19	16.4	58	32.3	1210
A 3/2	27-Nov	02:36	19	23.5	58	20.9	480
AS 5/1	27-Nov	12:00	19	30.2	58	9.1	45
A2/2	29-Nov	01:30	17	29.9	60	29.6	3900
A 2/4	29-Nov	06:30	17	29.9	60	29.6	3900
A 3/6	30-Nov	04:15	16	5.4	61	51.4	3900
A 3/20	01-Dec	09:35	16	27.1	61	46.3	3900
A 3/26	02-Dec	04:00	16	39.6	61	38.9	3900
A 3/35	04-Dec	02:22	17	16	61	30.7	3840
A 3/36	04-Dec	04:25	17	16.9	61	31	3870
A 3/47	06-Dec	02:18	16	1.1	62	0.3	3920
A 3/48	06-Dec	03:56	16	2.4	62	0	3920
A 4/2	07-Dec	01:48	14	1.1	63	14.4	4000
A 4/3	07-Dec	03:28	14	1.5	63	14.4	4030
A 5/6	08-Dec	03:05	11	59.7	64	28.1	4200
A 5/7	08-Dec	05:00	11	58.6	64	29.2	4200
A 6/1	09-Dec	02:30	10	15.3	65	32.4	4380
A 6/2	09-Dec	04:25	10	13.9	65	32.8	4380
A 7/6	10-Dec	03:45	?	?	?	?	4600
A 7/7	10-Dec	05:30	7	58.7	66	58.8	4600
A7/26	12-Dec	03:59	8	2.2	66	54.5	4600
A8/2	14-Dec	01:44	11	57.1	66	59.3	4200
A8/3	14-Dec	03:38	11	58.6	66	59.7	4200
A9/5	15-Dec	02:47	14	15.6	66	58.2	4000
A9/6	15-Dec	04:37	14	18.5	66	59.1	3970

7.8: MEASUREMENTS OF CFC'S

Andrew Watson
(Plymouth Marine Laboratory,UK)

Alison Bateman
(University of East Anglia,UK)

INTRODUCTION

The chlorofluorocarbons CFC-11 (CCl_3F) and CFC-12 (CCl_2F_2) have been shown to be useful as transient tracers of ocean ventilation, and have been measured for this purpose on a regular basis since the early 1980s. These compounds are sourced to the atmosphere by industry, where they have been building up in concentration since they were first manufactured in the late 1940s. They have no natural sources and are long lived in the ocean, having lifetimes in excess of 100 years. Therefore, water which has been at the surface of the ocean since 1950 contains dissolved CFCs in concentrations which are near to equilibrium with the atmosphere at the time that the water was subducted. Under favourable circumstances, a "freon age"can be estimated from the ratio of the concentrations, for the ratio CFC-11/CFC-12 increased continuously up to the mid-seventies. Since that time it has remained nearly constant so that for recently ventilated water the two tracers give the same information.

Recently, we have developed a technique for the accurate determination of CFC-113 ($CCl_2FCClF_{2)}$ and carbon tetrachloride (CCl_4) at the same time as CFC-11 and 12. The two new compounds greatly extend the range of ages over which transient tracers can be used. Carbon tetrachloride has been released by human activity since the second decade of this century, while F113 has appeared in the atmosphere only since the early seventies, and is continuing to increase relative to the other gases CFC-113 therefore gives information on recently ventilated water. Figure 1 a and b show the atmospheric histories and ratios of these gases, since 1940.The data are taken from Haine, 1992, with and references therein.

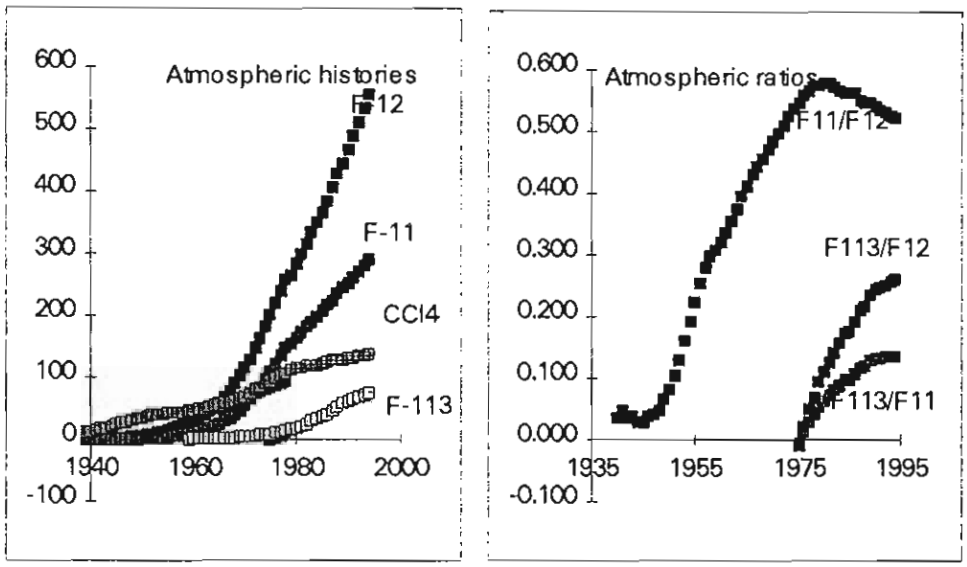


Figure 1(a) : Atmospheric histories in parts per trillion by volume of CFCs 11, 12, 113 and CCl_4. & (b) Ratios of the atmospheric concentrations. F113 has continued to increase relative to the other gases since the 1970s to the present day.

METHODS

The analytical technique we used on this cruise was developed by combining elements from the methods of Gammon et al. (1982), Haine (1992) and Krysell and Nightingale, (1993). Samples were withdrawn from Niskin bottles using 100ml syringes, which were stored in low-CFC water and analysed as rapidly as possible after collection. A measured volume was purged of volatiles using nitrogen/1% hydrogen, previously passed over a hot palladium catalyst to hydrogenate any CFCs present in the gas. The CFCs were then immobilised in a trap at -140 to -185 degrees C, cooled using liquid nitrogen vapour. Finally, the contents of the trap were heated and injected onto a DB 624 "megabore" column (J&W Scientific) held at 50 degrees. Detection was by electron capture detector (ECD). The compounds of interest elute in the space of 8 minutes, and a forward-flushed pre-column was used to switch out later-eluting compounds.

Precision: Our system gives excellent detection limits for all compounds, but the precision for CFC-11 and CFC-12 is worse than the 1% for the standard "packed column" technique described by Bullister and Weiss, a price that must be paid in order to have the resolution necessary to detect the other compounds. Duplicate samples were taken from all casts to determine precisions, and though we do not have a value

for the entire cruise as yet, in one exercise involving multiple (5) samples of surface water from cast A-20, we obtained figures of 2.7%, 1.7%, and 4.8% for F-12, F-11, and F113 respectively. The lower precision for CFC-113 is to be expected as this compound is present at much lower concentrations than the others.

RESULTS

Table 1 lists the stations from which we took samples. A typical cast results are shown in fig 2a and b. All four compounds reduce to zero within the top 1000 m. We generally saw lower levels of CFCs at depths greater than 500 m than reported by Olson et al., which may result from the improvements in controlling contamination which has occurred since the mid eighties when those measurements were made. However, our results confirm their overall conclusion that there is comparatively recently ventilated water to surprising depth within the de-oxygenated zone. In most of our casts we also saw a rapid fall-off of CFC-113 on entering entered the oxycline however, indicating that the water at the top of the deoxygenated layer has ages in excess of 10 years and is very little influenced by the penetration of younger water from above. In fig 3 we have made a first attempt at ageing the upper 500 m of water from our measurements; the absolute ages are liable to change as the calculation is refined, and in any case cannot be interpreted too literally as calendar ages, but the general conclusion that the water immediately below the oxycline is 10 years or more in age will likely not change. Thus our estimate of the age of the de-oxygenated water as a whole (down to 1000m) is likely to come out as being rather older than the 10 years suggested by Olson et al.

Carbon tetrachloride always fell off rapidly to zero in the de-oxygenated zone, and we take this to indicate that it is not long-lived in low oxygen water, and cannot be interpreted as a transient tracer in these regions. .

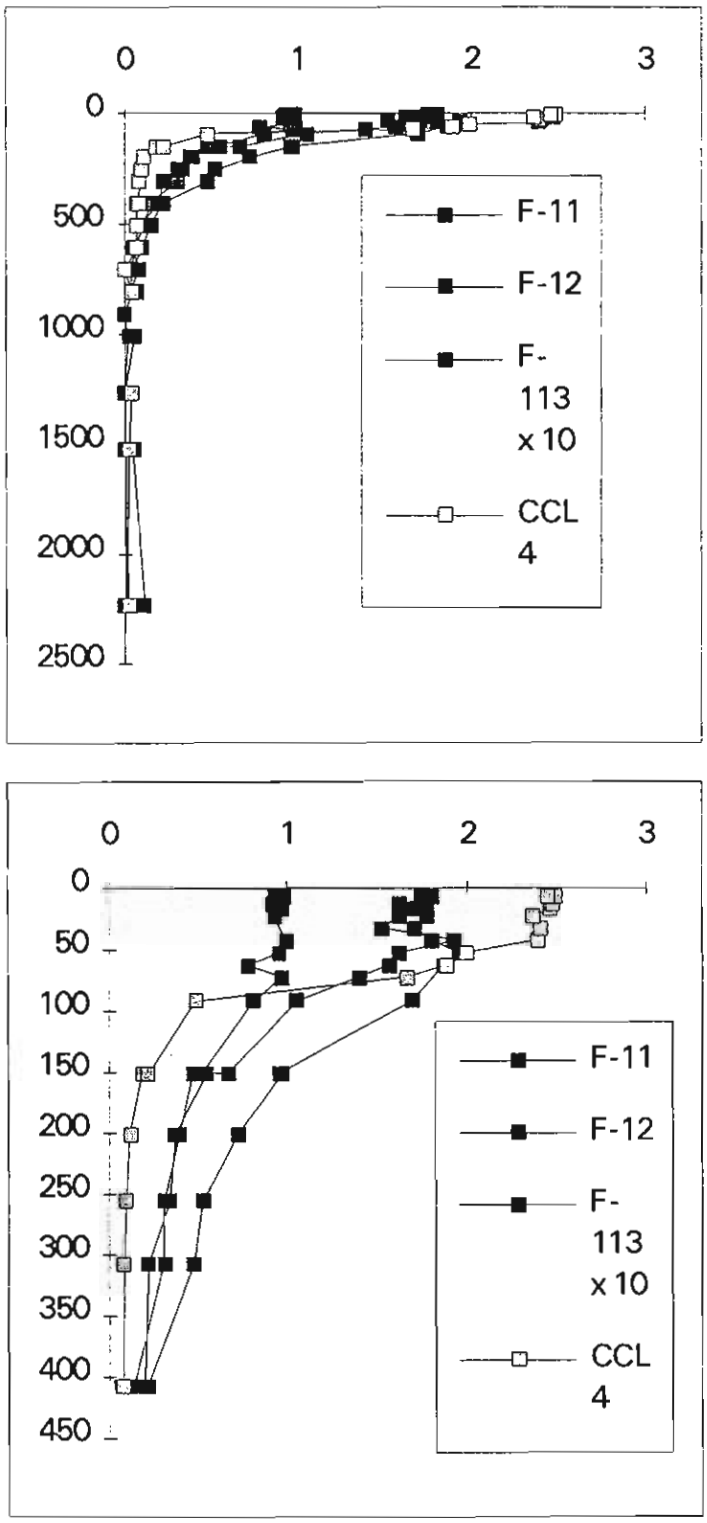


Fig 2: Results from Casts A1/32 and A1/36. The upper plot shows the entire water column, while the lower one shows the upper section at larger scale. Note that CFC 113 falls off more rapidly than CFC-11 and 12, while CCl_4 falls off more rapidly still going into the de-oxygenated zone. The ratio of CFC-113 to 11 can be used to derive an "age" for the samples. However, the behaviour of CCl_4 suggests it is breaking down in the anoxic water and is not therefore a conservative tracer.

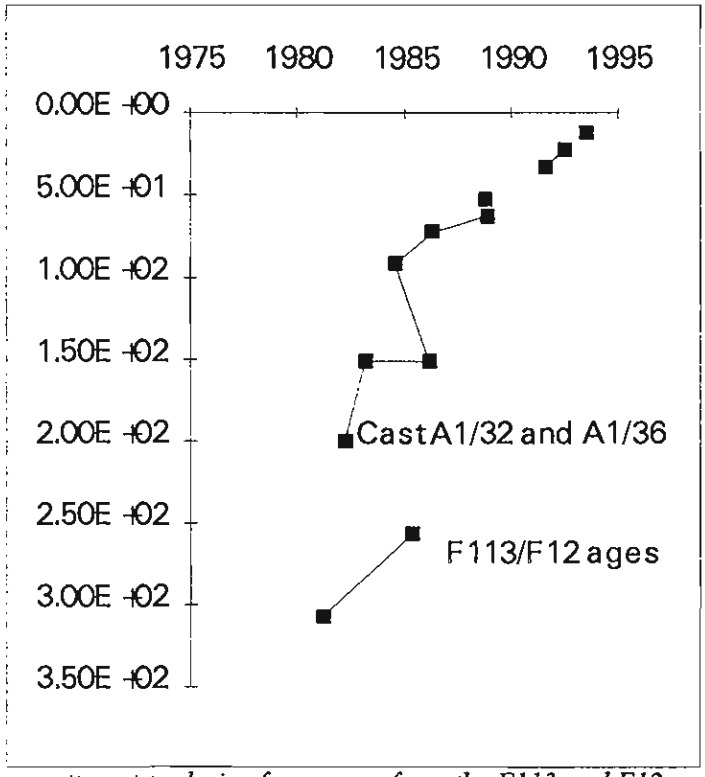


Fig 3: A preliminary attempt to derive freon ages from the F113 and F12 measurements given in Fig 2. The value of the F113 measurements has been reduced by 10% in order to give ages which are less than 1995 everywhere -- an adjustment which may reflect a systematic error in the assumed history of F113 in the atmosphere, or in the measurement of F113 in the ocean.

Table 1: Casts from which CFC samples were taken.

Station	Date	Time Z	Lat. (N)	minutes	Long. (E)	minutes	Depth
GOM 4/8	19-Nov	9:15	23	54.3	59	14.8	3300
GOM 4/9	19-Nov	11:07	23	54.3	59	14.8	3300
GOM 5/3	20-Nov	6:30	22	39.2	60	40.9	3150
GOM 5/7	20-Nov	10:50	22	39.7	60	40.4	3150
A 1/32	24-Nov	2:48	18	54.9	58	15.7	2230
A 1/36	24-Nov	10:02	18	54.3	58	9.0	1270
A 1/42	26-Nov	4:30	18	59.9	58	59.9	3370
A 1/43	26-Nov	6:40	19	0.0	58	59.9	3370
AS 2/1	26-Nov	14:55	19	16.4	58	32.3	1210
A2/2	29-Nov	1:30	17	29.9	60	29.6	3900
A 2/4	29-Nov	6:30	17	29.9	60	29.6	3900
A 3/6	30-Nov	4:15	16	5.4	61	51.4	3900
A 3/20	1-Dec	9:35	16	27.1	61	46.3	3900
A 3/26	2-Dec	4:00	16	39.6	61	38.9	3900
A 3/35	4-Dec	2:22	17	16	61	30.7	3840
A 3/36	4-Dec	4:25	17	16.9	61	31	3870
A 3/47	6-Dec	2:18	16	1.1	62	0.3	3920
A 3/48	6-Dec	3:56	16	2.4	62	0	3920
A 4/2	7-Dec	1:48	14	1.1	63	14.4	4000
A 4/3	7-Dec	3:28	14	1.5	63	14.4	4030
A 5/6	8-Dec	3:05	11	59.7	64	28.1	4200
A 5/7	8-Dec	5:00	11	58.6	64	29.2	4200
A 6/1	9-Dec	2:30	10	15.3	65	32.4	4380

A 6/2	9-Dec	4:25	10	13.9	65	32.8	4380
A 7/6	10-Dec	3:45	?	?	?	?	4600
A 7/7	10-Dec	5:30	7	58.7	66	58.8	4600
A7/26	12-Dec	3:59	8	2.2	66	54.5	4600
A8/2	14-Dec	1:44	11	57.1	66	59.3	4200
A8/3	14-Dec	3:38	11	58.6	66	59.7	4200
A9/5	15-Dec	2:47	14	15.6	66	58.2	4000
A9/6	15-Dec	4:37	14	18.5	66	59.1	3970

7.9: DISTRIBUTION OF CHLOROPHYLL AND CAROTENOID PIGMENTS

Denise Cummings

(Plymouth Marine Laboratory, UK)

OBJECTIVES

(1) To track the varying concentrations of chlorophyll and carotenoid pigments in the Arabian Sea just before the NE monsoon period in order to determine the chemotaxonomic distribution of phytoplankton in eutrophic, mesotrophic and oligotrophic waters.

(2) To simultaneously determine the distribution patterns of chlorophyll degradation products (phaeopigments) in the water column and in sediment traps to ascertain the flux and degradation of the chlorophyll biomass.

(3) To compare concentrations of chlorophyll and carotenoid pigments with midday optical profiles.

SAMPLING & METHODS

Samples of 1-2 L were drawn from all shallow biogeochemistry CTD casts, filtered onto GF/F filters, and immediately stored frozen in liquid nitrogen until analysis. Pigments were extracted into 90% acetone. An aliquot was injected onto a C-8 reverse phase column for high pressure liquid chromatographic separation and quantification of some 20 chlorophyll and carotenoid pigments using both absorbance (440 nm) and fluorescence (Ex 405 nm; Em 670 nm) detection. Details of the CTD sampling are presented in Table 1. Other subsamples were taken from pooled water samples used for primary production studies (Table 1). Further samples for pigment analysis were also drawn from sediment trap material, SAP pump filters, and the underway non-toxic seawater supply. Details of trap and SAP sampling are given in Tim Fileman's report. All CTD samples were analysed on board *Discovery*.

PRELIMINARY RESULTS

A range of chlorophylls and carotenoids were detected in the Arabian Sea, including chlorophylls *a*, *b*, c1c2, c3,divinyl chlorophyll *a*, peridinin, butanoyloxyfucoxanthin, fucoxanthin, hexanoyloxyfucoxanthin, diadinoxanthin, alloxanthin, zeaxanthin and alpha and beta-carotene. In addition 1 to 3 phaeophorbide *a*'s and 1-2 phaeophytin *a*'s

were also detected. Chlorophyll *a* concentrations were relatively high in the inshore environment of the Gulf of Masirah (735 ng/L at AS5) and steadily decreased at each station along the south eastery cruise track into oligotrophic waters. Surface chlorophyll a concentrations were as low as 33ng/L at station A7. The detection of divinyl chlorophyll *a* at these stations indicates the presence of prochlorophytes. Hexanoyloxyfucoxanthin indicates the presence of prymnesiophytes. Zeaxanthin indicates the presence of cyanobacteria and/or prochlorophytes.

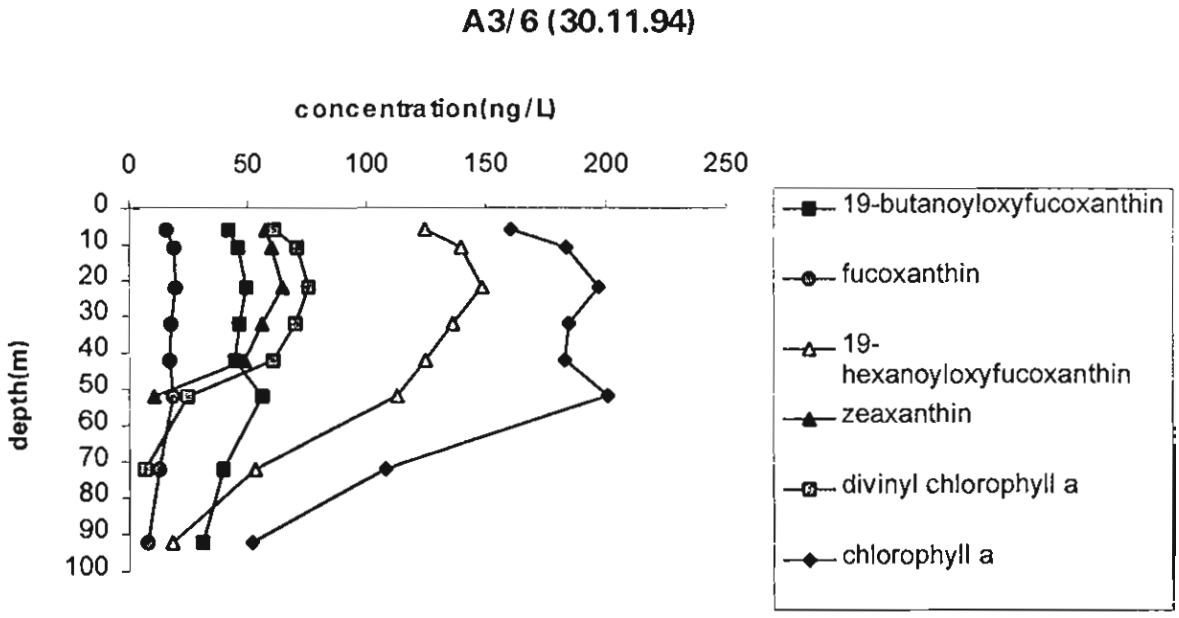


Figure 1: Vertical profile of photopigments determined by HPLC at station A3.

Table 1. Sampling for Pigments

Date	Station	Biogeochemical cast & depths	Optics Cast & depths	Primary production depths
17/11/94	GOM2	5-200m		
17/11/94	GOM1	5-65m	5-200m	
18/11/94	GOM3	5-200m	5-200m	
19/11/94	GOM4	5-200m	5-200m	
20/11/94	GOM5	5-200m	5-200m	
22/11/94	A1	5-200m	5-200m	1-45m
23/11/94	A1	5-60m	5-60m	
23/11/94	A1	4-76m		
24/11/94	A1		5-60m	
25/11/94	A1	8-200m		
26/11/94	AS1	7-200m		
26/11/94	A1	7-200m	non toxic-35m	
26/11/94	AS2	7-100m		

27/11/94	AS3	7-77m		
27/11/94	AS4	6-100m	1-40m	
27/11/94	AS5	3-40m		
29/11/94	A2	6-81m	5-60m	
30/11/94	A3	6-115m	5-60m	
1/12/94	A3		5-60m	
2/12/94	A3	7-126m	5-60m	
4/12/94	A3	11-198m	5-60m	
6/12/94	A3	6-101m	5-60m	20-100m
7/12/94	A4	7-101m	5-60m	
8/12/94	A5	7-81m	5-60m	
9/12/94	A6	8-102m		
10/12/94	A7	12-102m	5-100m	1-80m
11/12/94	A7	46-111m	5-100m	
12/12/94	A7	12-101m	5-100m	
14/12/94	A8	12-121m	5-100m	
15/12/94	A9	12-111m	5-100m	

Table 2 Intercalibration with RV THOMAS G THOMPSON

Date	Station	Depths sampled
5/12/94	A3	5-60m

7.10: PHYTOPLANKTON IN THE SURFACE WATERS

Khalid A Al Hashimi

(Sultan Qaboos University, Oman)

SCIENTIFIC WORK

Water was collected from the surface 50m of Gulf of Oman and Arabian Sea using a rosette of bottles mounted on the CTD, for analysis of nanoplankton (2-20 μm). Apstein netting, with a pore size of 20 μm, was used to collect samples of microplankton (20-200 μm) for analysis. All samples were preserved by the addition of formalin. Samples were collected from all Arabesque II stations, GOM 1-5, AS 1-5 and A 1-9.

No results have been obtained as yet; analysis of the samples will be carried out at the Sultan Qaboos University.

ACKNOWLEDGEMENTS

I would like to thank everyone who has spared me part of their precious time during Arabesque II to explain the answers to my questions. Truly, I have not felt like a stranger during this cruise. I am grateful to all the scientists onboard for their understanding of my situation and for helping me to learn as much as I could from their experience and knowledge. I have improved both my understanding of the science conducted onboard and the individual techniques and instruments used. I have gathered a lot of information regarding chlorophyll, nutrients and the regional oceanography to give me a better understanding of the science of the waters of the Gulf of Oman and the Arabian Sea.

This is my first scientific cruise which makes it a uniquely profitable experience for me. Having five weeks to see and experience so much of the new technology used in marine science has been a priceless opportunity. I would like to give special thanks to Dr Burkill who gave me this great chance.

I was given the time to take up the opportunity to join Arabesque II as part of the policy of the Sultan Qaboos University to allow academic and technical staff gain experience and knowledge in advanced science so that they can take part in the development of their new university.

Finally, I would like to say that have been very impressed by the amount of effort, time and skill devoted to the advancement of marine science on this cruise. Truly, Arabesque II D212 was Science In Action.

7.11: SIZE-FRACTIONATED PRIMARY PRODUCTION.

Linda Gilpin

(The Queen's University of Belfast, UK)

OBJECTIVES

Primary productivity measurements were carried out using the ^{14}C technique in order to determine production in the euphotic zone of the study area during the inter monsoon period. The size distribution of the major producers was assessed using size-fractionation.

METHODS

The depth of the euphotic zone was estimated for each station using available light data and water samples were collected from a pre-dawn CTD cast at 10 depths selected to represent 97, 55, 32.6, 19.9, 13.8, 6.9, 4.6, 3, 2.1 and 1% surface incident irradiance. Samples were treated in accordance with JGOFS Level 1 protocols. Triplicate 60ml samples and one dark bottle from each depth were inoculated with 100µl ^{14}C bicarbonate in subdued light conditions and incubated for 24hrs. Where *in situ* incubations were not practical, an on deck incubator was used to simulate the *in situ* light level and spectral quality at each depth using a series of filters. Following incubation, samples were fractionated under minimal vacuum using 18, 2 and 0.2µm polycarbonate membrane filters in a cascade system. The filters were fumed in HCL and desiccated overnight prior to the addition of scintillant. The particulate incorporation of labelled bicarbonate was measured using a LKB Scintillation Counter and used to estimate the rate of carbon uptake per day for each fraction. The resulting production profiles were used to determine the depth integrated primary production over the euphotic zone at each station. A total of 31 *in situ* and on deck incubations were carried out including 6 *in situ* / on deck comparisons; over 3900 filters were analysed. Stations and depths sampled are detailed in Table 1.

Size-fractionated chlorophyll measurements were carried out fluorometrically following acetone extraction using the same water samples as the primary production determinations.

The levels of ^{14}C-DOC produced during the incubations were determined for each depth at the main *in situ* stations; the filtrate was acidified and bubbled for 1 hr in order to drive off any remaining inorganic carbon. After the addition of scintillant, samples were counted in the LKB Scintillation Counter. Stations and depths sampled are detailed in Table 1.

Date	Station	Depths (m)										In Situ	Deck	14C-DOC
17.11.94	GOM 2/1	1	7	12	18	22	29	33	38	42	50		Y	
18.11.94	GOM 2/A	1	8	14	21	26	35	40	46	50	60		Y	
19.11.94	GOM 4/A	1	8	14	21	26	35	40	46	50	60		Y	
20.11.94	GOM 5/A	1	8	14	21	26	35	40	46	50	60		Y	
21.11.94	GOM 5/B	1	8	14	21	26	35	40	46	50	60		Y	
22.11.94	A1/6	1	6	11	16	19	26	30	34	37	45	Y		
23.11.94	A1/18	1	6	11	16	19	26	30	34	37	45	Y		
24.11.94	A1/29	1	6	11	16	19	26	30	34	37	45	Y	Y	Y
27.11.94	AS3/1	1	6	11	16	19	26	30	34	37	45		Y	
28.11.94	AS5/3	1	4	7	11	13	17	20	23	25	32		Y	
29.11.94	A2/1	1	7	12	18	22	29	33	38	42	50		Y	
30.11.94	A3/4	1	8	14	21	26	35	40	46	50	60	Y		Y
1.12.94	A3/13	1	11	19	28	34	46	53	61	66	80	Y	Y	
2.12.94	A3/24	1	11	19	28	34	46	53	61	66	80	Y		
4.12.94	A3/32	1	11	19	28	34	46	53	61	66	80	Y	Y	
5.12.94	A3/43	1	11	19	28	34	46	53	61	66	80		Y	
6.12.94	A3/46	1	11	19	28	34	46	53	61	66	80		Y	
7.12.94	A4/1	1	11	19	28	34	46	53	61	66	80		Y	
8.12.94	A5/2	1	11	19	28	34	46	53	61	66	80	Y	Y	Y
9.12.94	A6/A	1	9	17	25	30	41	46	53	58	70		Y	
10.12.94	A7/2	1	11	19	28	34	46	53	61	66	80	Y		Y
11.12.94	A7/14	1	13	24	35	43	58	66	76	83	100	Y	Y	
12.12.94	A7/23	1	13	24	35	43	58	66	76	83	100	Y		
14.12.94	A8/1	1	13	24	35	43	58	66	76	83	100		Y	
15.12.94	A9/2	1	13	24	35	43	58	66	76	83	100	Y	Y	Y

Table 1: Details of stations and depths sampled for primary production measurements.

RESULTS

The size-fractionated distribution of primary production paralleled the size-fractionated chlorophyll *a* concentration and was dominated by the picoplankton fraction (0.2-2μm) at all stations. A typical vertical profile of primary production is illustrated in Figure 1 where total integrated production over the euphotic zone at station A3/32 was 461.5 mg $C/m^2/d$.

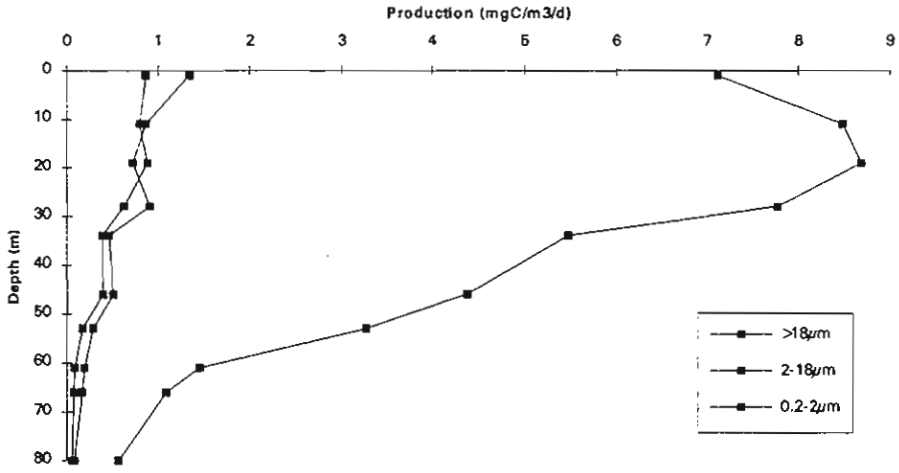


Figure 1: Primary production profile from Station A3.

7.12: PHYTOPLANKTON NEW PRODUCTION AND REMOTE SENSING

Louisa Watts

(Dept of Marine Sciences, Newcastle University, UK)

AIMS AND OBJECTIVES:

The overall aim of this project is to develop regional models and algorithms for the use of remotely sensed data for estimation of phytoplankton new production. The specific objective of the D212 cruise is to obtain information on phytoplankton nitrogen assimilation rates in the North West Indian Ocean, just prior to the occurrence of the North-East monsoon (December to March 1994). This is to be achieved through the execution of ^{15}N ship-board experiments. The information obtained is to be used in combination with that obtained from concurrent primary production experiments to give an estimation of new production in the Arabian Sea. Measurements of the key optical properties of the water column, which are also being carried out on the cruise, conform to the SeaWiFs optics protocol so that empirical relationships between the optics and ^{15}N data can be used for the development of new production models. These can then be used to calibrate remotely sensed data.

METHODS AND TECHNIQUES:

Nitrogen assimilation experiments were carried out on 16 occasions at a series of stations spanning a transect from the Gulf of Oman to close to the equator. Dates and locations of the stations can be found in Table 1. The experiments consisted of two types of incubations: *in situ* and on-deck. These were carried out simultaneously, wherever possible, in order that comparisons could be made between them to test the validity of results obtained from the less accurate single, on-deck incubations. This could only be achieved however, when the ship remained on station for at least 12 hours, covering the period from dawn to dusk. Eight such parallel experiments were carried out during the course of the cruise. The remaining 8 experiments were single, on-deck incubations.

The sampling strategy used for both types of incubation was to collect seawater from 6 different depths before dawn (between 0400 hrs and 0500 hrs), using a CTD rosette fitted with 10 litre Go-Flo bottles. The 6 different depths were chosen to cover the depth of the photic zone i.e. the depth at which the measured irradiance was only 1 % of that measured at the surface. The 6 depths were thus chosen to represent the depths at which there was 1 %, 4.6 %, 13.8 %, 32.6 %, 55 % and 97 % of the surface irradiance respectively. The depth of the photic zone was determined either from optical profiles of the subsurface irradiation measured on the previous day, or from real-time CTD profiles from which the mixed-layer depth (taken as being equal to the photic zone) could be approximated. Depths for each station are detailed in Table 1.

At each depth 600 mls of water were dispensed into 8, clear polycarbonate, Nalgene bottles (4 duplicate pairs). Additions of 1 μ mol l^{-1} ^{15}N-NO_3, 0.1 μ mol l^{-1} ^{15}N-NO_3, 0.1 μ mol l^{-1} ^{15} N-NH_4 and 0.1 μ mol l^{-1} ^{15}N-urea were then added to the 4 duplicate pairs respectively. These additions were chosen to saturate the uptake mechanisms of the phytoplankton. The bottles were then incubated for 12 hours (0600 hrs to 1800 hrs) using an on-deck and/or an *in situ* method of incubation. The on-deck incubations involved placing the 6 sets of bottles from the 6 different depths into 6 polypropylene crates each covered with a sealed polyethylene blue filter, the shading of which was designed to simulate the *in situ* light level found at that particular depth. Surface seawater was continually flowed through the crates throughout the incubation in order to prevent a potential increase in temperature, from solar irradiation, affecting the rate of algal uptake of ^{15}N. *In situ* incubations were carried out by attaching the six sets of bottles at the 6 appropriate depths with cable ties, to a free-flowing rig, which was then deployed prior to sunrise. The rig was recovered at sunset and the bottles were placed in darkness until dawn (0600 hrs), as were the bottles from the on-deck incubations. The incubations were therefore of 24 hrs duration. When the incubations were finished the samples were transferred to a dark fridge where they were stored prior to filtering. Filtering was carried out under vacuum (15 - 20 inches Hg) using 25 mm GF/F filter papers and a 60 ml filtered seawater rinse. The filters were then placed in a domestic freezer for preservation of the algal cells and storage.

The filters are to be transported to Newcastle University in dry-ice where the atom % ^{15}N levels on the filters will be determined using isotope ratio mass-spectrometry. This data, combined with those obtained from the concurrent ^{14}C, primary production measurements, will give regional estimates of new production levels in the Arabian Sea, prior to the North-East monsoon event in December.

Table 1: Sampling strategy for ^{15}N assimilation experiments.

DATE	STATION NUMBER	POSITION LAT/LONG	SAMPLE DEPTHS (m)	TYPE OF INCUBATION (D: Deck, R: Insitu)
17/11/94	GOM 2/1	24° 48.55' N 057° 13.45' E	1, 7, 12, 22, 33, 50	D
18/11/94	GOM 2/A	25° 14.95' N 056° 59.97' E	1, 8, 14, 26, 40, 60	D
19/11/94	GOM 4/A	24° 02.07' N 059° 01.50' E	1, 8, 14, 26, 40, 60	D
20/11/94	GOM 5/A	22° 45.70' N 060° 34.00' E	1, 8, 14, 26, 40, 60	D
22/11/94	A1/6	18° 59.86' N 058° 52.13' E	1, 6, 11, 19, 30, 45	R + D
24/11/94	A1/29	18° 55.80' N 058° 17.80' E	1, 6, 11, 19, 30, 45	R + D
27/11/94	AS 3/1	19° 23.32' N 058° 20.44' E	1, 6, 11, 19, 30, 45	D
28/11/94	AS 5/3	19° 38.10' N 058° 09.11' E	1, 4, 7, 13, 20, 30	D
29/11/94	A2/1	17° 29.83' N 060° 29.60' E	1, 7, 12, 22, 33, 50	D
01/12/94	A3/13	16° 21.10' N 061° 48.20' E	1, 11, 19, 34, 53, 80	R + D
04/12/94	A3/32	17° 14.2 ' N 061° 29.40' E	1, 11, 19, 34, 53, 80	R + D
06/12/94	A3/46	16° 02.30' N 061° 59.80' E	1, 11, 19, 34, 53, 80	D
08/12/94	A5/3	12° 00.00' N 064° 29.03' E	1, 11, 19, 34, 53, 80	R + D
10/12/94	A7/2	08° 00.02' N 067° 00.18' E	1, 11, 19, 34, 53, 80	R + D
12/12/94	A7/23	08° 01.00' N 066° 54.03' E	1, 13, 24, 43, 66, 100	R + D
15/12/94	A9/2	14° 18.25' N 066° 59.42' E	1, 13, 24, 43, 66, 100	R + D

7.13: PHOTOSYNTHESIS / IRRADIANCE EXPERIMENTS

Brian Irwin

(Bedford Institute of Oceanography, Canada)

OBJECTIVE

The objective on this cruise was to obtain PI parameters over a large geographical area in the NE Indian Ocean.

METHODS

Water samples were collected from the CTD Rosette at the early morning productivity casts and at the Optics casts near midday. Aliquots of water were inoculated with sodium bicarbonate ^{14}C and incubated for three hours at 30 different light levels. At the end of the incubation, the phytoplankton cells were harvested onto GF/F glass fibre filters for later analysis. Samples for Chlorophyll, Particulate Organic Carbon, Particulate Organic Nitrogen and Absorption Spectra were taken for each experiment. All samples will be processed at the Bedford Institute of Oceanography after completion of the cruise.

Date	Station	Depth (m)	I.D.	Dec 1	A3/13	11	112659
Nov 17	GOM2/1	12	112611		A3/13	34	112660
	GOM2/1	42	112612		OPTICS 12	112661	
	OPTICS 1	10	112613		OPTICS 12	40	112662
	OPTICS 1	33	112614	Dec 2	A3/24	11	112663
Nov 18	GOM2A	8	112615		A3/24	34	112664
	GOM2A	40	112616		OPTICS 13	10	112665
	OPTICS 2	10	112617		OPTICS 13	40	112666
	OPTICS 2	58	112618	Dec 4	A3/32	11	12667
Nov 19	GOM4A	8	112619		A3/32	34	112668
	GOM 4A	40	112620		OPTICS 14	10	112669
	OPTICS 3	10	112621		OPTICS 14	40	112670
	OPTICS 3	33	112622	Dec 5	A3/43	11	112671
Nov 20	GOM5A	8	112623		A3/43	34	112672
	GOM5A	26	112624	Dec 6	A3/46	11	112673
	OPTICS 4	10	112625		A3/46	34	112674
	OPTICS 4	31	112626		OPTICS 15	10	112675
Nov 21	GOM 5B	8	112627		OPTICS 15	40	112676
	GOM 5B	40	112628	Dec 7	A4/1	11	112677
Nov 22	A1/6	11	112629		A4/1	34	112678
	A1/6	37	112630		OPTICS 16	10	112679
	OPTICS 5	10	112631		OPTICS 16	40	112680
	OPTICS 5	40	112632	Dec 8	A5/2	11	112681
Nov 23	A1/18	11	112633		A5/2	34	112682
	A1/18	37	112634		OPTICS 17	10	112683
	OPTICS 6	10	112635		OPTICS 17	40	112684
	OPTICS 6	35	112636	Dec 9	A6A	9	112685
Nov 24	A1/29	11	112637		A6A	58	112686
	A1/29	37	112638	Dec 10	A7/2	11	112687
	OPTICS 7	10	112639		A7/2	66	112688
	OPTICS 7	35	112640		OPTICS 18	10	112689
Nov 26	A1/40	10	112641		OPTICS 18	70	112690
	A1/40	35	112642	Dec 11	A7/14	13	112691
	OPTICS 8	10	112643		A7/14	76	112692
	OPTICS 8	35	112644		OPTICS 19	10	112693
Nov 27	AS3/1	11	112645		OPTICS 19	75	112694
	AS3/1	26	112646	Dec 12	A7/23	13	112695
	OPTICS 9	10	112647		A7/23	76	112696
	OPTICS 9	20	112648		OPTICS 20	10	112697
Nov 28	AS5/3	11	112649		OPTICS 20	70	112698
	AS5/3	112650		Dec 14	A8/1	13	112699
Nov 29	A2/1	12	112651		A8/1	58	112700
	A2/1	38	112652		OPTICS 21	10	112701
	OPTICS 10	10	112653		OPTICS 21	60	112702
	OPTICS 10	25	112654	Dec 15	A9/2	13	112703
Nov 30	A3/4	8	112655		A9/2	58	112704
	A3/4	46	112656		OPTICS 22	10	112705
	OPTICS 11	10	12657		OPTICS 22	50	112706
	OPTICS 11	35	112658				

Table 1. Experiments carried out on cruise.

7.14: BACTERIAL PRODUCTION

Alan Pomroy

(Plymouth Marine Laboratory, UK)

The activity of heterotrophic bacteria has been determined by two similar methods; the incorporation of tritiated thymidine into nucleic acids and the incorporation of tritiated leucine into protein. The majority of experiments were undertaken on the same water, from the pre-dawn casts, as the primary production and **P/I** experiments. All incubations were undertaken at in situ temperatures. This will make it possible to determine what proportion of the primary production measured in the <2-0.2 micron fraction is due to the incorporation of ^{14}C labelled DOC by bacteria. A total of 2390 samples were processed. Full details of the stations and depths sampled are given in the following table.

The normal duration of an incubation was 1-1.5 hours before the extraction of the nucleic acids or proteins with ice-cold trichloroacetic acid. In order to confirm that the uptake of label was linear over this period, a number of short time course incubations were completed. These are also listed in the following table.

As the cruise progressed, it became increasingly evident that many of the microbiological processes within the upper water column were showing pronounced diurnal rhythms and that the rates of bacterial production measured using water from the pre-dawn casts were likely to be significantly lower than those determined later during the day. In order to confirm this, a number of time course experiments were completed at the sediment trap stations, with water from the pre-dawn casts being sampled at 3 or 4 hour intervals for 24 hours. Replicate water samples were incubated at in situ light levels and in the dark to determine if the bacterial production was dependant on the release of DOC by phytoplankton.

Finally, on three occasions, at the sediment trap stations, the influence of temperature on the rates of heterotrophic activity were determined using a gradient of 24 temperatures from 2-40^{o}C. These experiments are also listed in the following table.

Bacterial numbers

Bacterial numbers were determined on all samples used for the measurement of bacterial production and on all the time intervals during time course incubations. Samples were fixed with 2.5% glutaraldehyde and stained with the fluorochrome diamidino phenylindole (DAPI). These were then filtered and counted using epifluorescence microscopy. All the samples listed in the following table have been processed for bacterial numbers.

Table 1. Samples for bacterial numbers and heterotrophic activity

Date	Station	Depths sampled (metres)										
17/11/94	GOM2/1	1	7	12	18	22	29	33	38	42	50	
18/11/94	GOM2/A	1	8	14	21	26	35	40	46	50	60	
19/11/94	GOM4/A	1	8	14	21	26	35	40	46	50	60	
20/11/94	GOM5/A	1	8	14	21	26	35	40	46	50	60	
21/11/94	GOM5/B	1	8	14	21	26	35	40	46	50	60	
22/11/94	A1/6	1	6	11	16	19	26	30	34	37	45	
23/11/94	A1/18	1	6	11	16	19	26	30	34	37	45	
23/11/94	A1/22	1	200	Temperature gradient								
24/11/94	A1/35	10	35	Diel experiment								
24/11/94	A1/36	8	13	17	22	32	42	52	62	72	91	150
26/11/94	A1/40	10	35	Diel experiment								
27/11/94	AS3/1	1	6	11	16	19	26	30	34	37	45	
28/11/94	AS5/3	1	4	7	11	13	17	20	23	25	32	
29/11/94	A2/1	1	7	12	18	22	29	33	38	42	50	
30/11/94	A3/4	5	10	20	30	40	50	70	90	105	118	130
30/11/94	A3/48	10	200	Temperature gradient								
1/12/94	A3/13	1	11	19	28	34	46	53	61	66	80	
1/12/94	A3.13	11	Time course									
2/12/94	A3/24	1	11	19	28	34	46	53	61	66	80	
4/12/94	A3/32	1	11	19	28	34	46	53	61	66	80	
5/12/94	A3/43	11	34	Diel experiment								
6/12/94	A3/46	1	11	19	28	34	46	53	61	66	80	
7/12/94	A4/1	1	11	19	28	34	46	53	61	66	80	
8/12/94	A5/2	1	11	19	28	34	46	53	61	66	80	
9/12/94	A6/A	1	9	17	25	30	41	46	53	58	70	
10/12/94	A7/2	1	11	19	28	34	46	53	61	66	80	
11/12/94	A7/14	1	13	24	35	43	58	66	76	83	100	
12/12/94	A7/23	1	13	24	35	43	58	66	76	83	100	
12/12/94	A7/23	13	Diel experiment									
14/12/94	A8/1	1	13	24	35	43	58	66	76	83	100	
15/12/94	A9/2	1	13	24	35	43	58	66	76	83	100	

7.15: STUDIES OF MICROBIAL ECOLOGY BY FLOW CYTOMETRY

Glen Tarran

(Plymouth Marine Laboratory, UK)

INTRODUCTION

During Arabesque 2, flow cytometry was used to study a number of aspects of the microbial ecology of the Arabian Sea (listed below). These included the quantification of the planktonic community in terms of distribution, population and size structure of specific nano and picoplanktonic groups (prochlorophytes (size, 0.5μm) and cyanobacteria (size, 1μm)) , phytoplankton activity in the mixed layer, mortality of phytoplankton due to microzooplankton grazing and the partitioning of grazing by different size classes of microzooplankton.

STUDIES UNDERTAKEN

1. Distribution, abundance and community structure of nano and picoplankton to 200m at CTD stations
2. The mortality of phytoplankton through microzooplankton grazing in diel experiments. Successive samples taken over a 24 hour period using a combination of the dilution technique and flow cytometry (collaboration with Elaine Edwards).
3. The contribution of different size classes of microzooplankton grazers to phytoplankton mortality using a combination of the dilution technique and flow cytometry.
4. Cellular ^{14}C assimilation of phytoplankton using a combination of the dilution technique, flow cytometry and ^{14}C incubation (in collaboration with Elaine Edwards, Alan Pomroy, Linda Gilpin and Peter Burkill).
5. Size fractionation of phytoplankton communities from the mixed layer to determine median cell diameters for pico-eucaryotes, prochlorophytes, and cyanobacteria.

1) Grazing experiments

Three types of grazing experiment were conducted during the cruise as follows:

a) On deck diel experiments with *in situ* comparisons to quantify the daily turnover of phytoplankton standing stock by microzooplankton and also to study times of day when grazing was most intense. Sampling for cell enumeration by flow cytometry was carried out at 0, 4, 8, 14 and 24 hours for the on deck bottles and 0, 12 and 24 hours for the *in situ* bottles.

b) Size fractionated experiments to determine the grazing contribution of <5μm and <2μm grazers to total turnover of phytoplankton standing stocks by microzooplankton.

c) Parallel experiments, with and without spiking with ^{14}C labelled bicarbonate to investigate cellular carbon assimilation rates of phytoplankton and to compare cell enumeration, chlorophyll, and carbon assimilation approaches to the dilution technique.

Table 1: Grazing experiments carried out with daily turnover rates of phytoplankton standing stock

Date	Station	Position	Sample depth m	Experiment type	Experiment name	Phytoplankton turnover d^{-1} %
22 Nov	A1/5	19.0N 58.9E	10	Diel	MZP1	50
24 Nov	A1/28	18.9N 58.1E	20	Size frac.	MZP2	49
30 Nov	A3/3	16.1N 62.0E	20	Diel	MZP3	46
2 Dec	A3/23	16.7N 61.7E	10	Size frac.	MZP4	17
4 Dec	A3/31	17.3N 61.5E	30	^{14}C	MZP5	52
8 Dec	A5/1	12.0N 64.5E	10	Diel	MZP6	18
10 Dec	A7/1	08.0N 67.0E	10	Diel	MZP7	16
12 Dec	A7/22	08.0N 67.0E	10	Size frac.	MZP8	8
15 Dec	A9/	14.3N 67.0E	10	^{14}C	MZP9	20

1) Phytoplankton community structure and abundance

Using flow cytometry it was possible to characterise and enumerate specific components of the phytoplankton community based on their light scattering and fluorescence properties. The phytoplankton could be divided into 3 groups; cyanobacteria, prochlorophytes and eucaryotic phytoplankton. Samples were collected at all available depths from the shallow biogeochemistry casts. 400μl samples were analysed by flow cytometry to provide vertical profiles of phytoplankton abundance per litre (Table 1).

Table 2: CTD casts sampled for phytoplankton community structure with abundances at 20m

			Cell numbers per litre			
Date	Station & CTD cast	Position	Total pplk 1.00E+08	Cyanobac 1.00E+08	Prochloro 1.00E+08	Eucaryote 1.00E+06
17-Nov	GOM1/1	26.0N 56.5E	3.15	1.8	1.28	4.12
17-Nov	GOM2/2	24.5N 57.3E	2.4	1	1.1	4.29
18-Nov	GOM3/1	24.3N 58.1E	3.2	2.1	0.95	4.56
19-Nov	GOM4/8	23.9N 59.3E	0.43	0.28	0.11	1.16
20-Nov	GOM5/3	22.7N 60.7E	1.7	0.59	0.43	3.33
25-Nov	AS1/1	19.3N 58.6E	2.51	1.3	1.1	2.37
27-Nov	AS3/2	19.4N 58.4E	3.2	1.2	1.1	4.63
27-Nov	AS4/1	19.5N 58.3E	2.08	1.8	0.18	5.6
27-Nov	AS5/1	19.5N 58.2E	3.58	3.2	0.33	3.97
22-Nov	A1/9	19.0N 58.9E	3.5	1.5	1.9	1.65
23-Nov	A1/23	19.0N 58.5E	2.32	0.95	1.3	1.55
24-Nov	A1/36	18.9N 58.2E	2.5	0.9	1.3	0.78
26-Nov	A1/42	19.0N 59.0E	1.5	0.73	0.7	1.58
29-Nov	A2/4	17.5N 60.5E	1.36	0.79	0.48	3.63
30-Nov	A3/6	16.1N 62.0E	2.55	0.61	1.8	3.7
1-Dec	A3/20	16.5N 61.8E	2.18	0.61	1.5	2.68
2-Dec	A3/26	16.7N 61.7E	2.58	0.58	1.75	4.08
4-Dec	A3/35	17.3N 61.5E	2	0.59	1.3	4.14
6-Dec	A3/47	16.0N 62.0E	2.6	0.68	1.6	3.82
7-Dec	A4/2	14.0N 63.2E	1.7	0.62	0.93	5.49
8-Dec	A5/6	12.0N 64.5E	3.05	2.1	0.81	6.59
9-Dec	A6/1	10.3N 65.5E	2.6	0.02	2.5	0.94
10-Dec	A7/6	08.0N 67.0E	2.55	0.03	2.4	1.17
11-Dec	A7/19*	08.0N 66.9E	2.22	0.03	2.1	0.93
12-Dec	A7/26	08.0N 66.9E	2.47	0.03	2.4	0.89
14-Dec	A8/2	11.6N 67.0E	2.33	0.16	2.1	2.69
15-Dec	A9/	14.3N 67.0E	1.04	0.41	0.52	4.25

* from 46m depth

3) Size distribution of phytoplankton by size fractionation

Mixed layer water samples were gravity filtered through 10, 5, 2, 1, 0.8, 0.6, 0.4 and 0.2 μm Nucleopore filters and the filtrate analysed by flow cytometry to enumerate the phytoplankton. The cell counts were then compared to unfiltered seawater cell numbers by plotting % cells remaining compared to unfiltered seawater against filter pore size.

The median cell diameters were read off the X axis where they intersected with the 50% line on the Y axis (Table 3)

Table 3: Median cell diameters (μm) at Arabesque trapping stations

Station	Eucaryotes	Cyanobacteria	Prochlorophytes
A1	1.43	0.90	0.68
A3	1.25	0.76	0.58
A7	1.15	0.89	0.60

SUMMARY

Turnover of phytoplankton by microzooplankton grazing was found to be high (nearly 50% d^{-1}) at the far northwest stations and decreased in the oligotrophic waters (Table 1).

All the diel experiments showed a very marked periodicity in grazing activity. Between dawn and early afternoon (0-8 hours) there was insignificant grazing, but between mid afternoon and dawn (8-24 hours) grazing was intense, turnover rates sometimes exceeding 100%.

The results of the CTD vertical profiles showed that total phytoplankton abundance was typically in the range of 2-3 $x10^8$ cells per litre. The highest cell numbers were generally encountered at the nearer shore stations and decreased further offshore in the oligotrophic waters. The community composition also varied greatly according to the proximity to shore (and higher nutrients). Eucaryotes ranged in concentration from $5.5x10^6$ per litre nearshore to less than $1x10^6$ per litre at the most oligotrophic stations. Cyanobacteria, consisting mostly of *Synechococcus* sp. were also found to be most abundant at near-shore stations. The variation in concentrations from near shore to oligotrophic waters was dramatic, numbers plummeting by 2 orders magnitude from $3x10^8$ cells per litre at AS5 to $3x10^6$ cells per litre at A7. Numbers of prochlorophytes mirrored those of the cyanobacteria. Lowest numbers were encountered at the near-shore stations, being an order of magnitude lower than the cyanobacteria. However, at the oligotrophic stations prochlorophytes exceeded $2x10^8$ cells per litre and numerically dominated the phytoplankton, making up at least 95% of total phytoplankton numbers.

7.16: MICROZOOPLANKTON COMMUNITY STRUCTURE & FUNCTION

Claire Stelfox

(Plymouth Marine Laboratory & Southampton University, UK)

OBJECTIVES

1. To characterise and quantify microzooplankton (phagotrophic organisms <200μm in length) populations in the surface mixed layer of the Oman Basin and Arabian Sea.
2. Determine microzooplankton standing stocks.
3. Determine protistan grazing rates on phytoplankton via uptake of fluorescently labelled algae in eutrophic and oligotrophic conditions.

METHODS

Microzooplankton Biomass

Water samples were collected from each shallow biogeochemical CTD cast and fixed as follows:

i. 1% acid lugol's iodine for the determination of species composition and total microzooplankton biomass.

ii. 2 % hexamine buffered formaldehyde for identification and enumeration of autotrophic microzooplankton.

iii. 5% bouin's solution for the taxonomic identification of ciliate species by silver protargol staining..

iv. 0.3% glutaraldehyde for enumeration of autotrophic and heterotrophic nanoflagellates (2-20μm) - see Elaine Edwards' cruise report.

The above samples will be analysed by inverted/fluorescent microscopy at the PML.

Phytoplankton

100mls of water from upper 200m biogeochemistry CTD casts was fixed in acid lugol's and neutral formalin. Underway samples were also collected from the clean water supply. These samples will be analysed by Derek Harbour at PML.

Apstein net

For the qualitative assessment of the larger and less delicate microzooplankton species vertical Apstein net hauls (20μm mesh size) were conducted in the upper 100m of the water column. 200mls was fixed in 1% acid lugol's and 50mls was used for immediate live observation using an inverted microscope fitted with Nomarski Interference Contrast and fluorescence. Photographic and video images were taken of the live cells which include tintinnids, ciliates, dinoflagellates and phytoplankton cells.

Fluorescently Labelled Algae Experiment

A culture of *Chlorella stigmatophora* (2-4 μm) was stained with the fluorescent dye 5-(4,6-dichlorotriazin-2-yl) aminofluorescein (DTAF) following the protocol of Rublee & Gallegos (1989) and Sherr *et al* (1991). The FLA is used as a tracer method to assess taxon specific microzooplankton herbivory. Water samples collected from the pre-dawn 30-L Go-Flo casts were inoculated with a known concentration of the FLA and incubated for upto 60 minutes under ambient conditions. Sub samples were taken at 0, 5, 10, 20 and 60 minutes and fixed in 1% acid lugol's. Prior to analysis by settlement microscopy, the Lugol's is cleared using 2 drops of saturated sodium thiosulphate. Preliminary results show total heterotrophic microzooplankton cell concentrations were low in the Oman Basin (3,000 cells l^{-1}) and higher at stations A3 and A5 (8,000 cells l^{-1}). Uptake of the FLA by the ciliated microzooplankton was highest at A5, showing a rapid increase within the first 5 minutes after which FLA/cell levels off due to digestion. These results are shown in Figure 1.

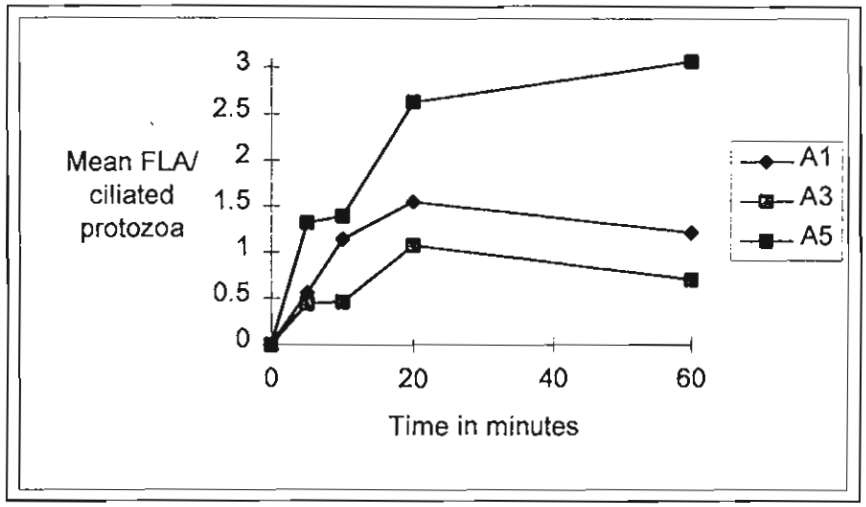


Figure 1. Uptake of fluorescently labelled algae (FLA) by microzooplankton at 3 stations.

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Rublee P.A. & Gallegos C.L. (1989) Use of fluorescently labelled algae (FLA) to estimate microzooplankton grazing *Mar.Ecol. Prog. Ser.* 51:221-227

Sherr E.B., Sherr B.F. & McDaniel J. (1991) Clearance rates of <6μm fluorescently labelled algae (FLA) by estuarine protozoa: potential grazing impact of flagellates and ciliates *Mar. Ecol. Prog. Ser.* 69:81-92

Table 1: Samples collected and experiments performed on ARABESQUE 2.

DATE	STATION	SAMPLING EVENT
17.11.94	GOM2	Lugol's 5-100m
		Phytoplankton 5-200m
		Glutaraldehyde 5-100m
	GOM1/1	Lugol's 5-65m
		Phytoplankton 5-65m
		Glutaraldehyde 5-65m
		Apstein 50m
18.11.94	GOM3/1	Lugol's 5-100m
		Phytoplankton 5-200m
		Glutaraldehyde 5-100m
		Apstein 50m
19.11.94	GOM4	Apstein 50m
		Lugol's 5-100m
		Phytoplankton 5-200m
		Glutaraldehyde 5-100m
20.11.94	GOM5/3	Lugol's 5-100m
		Phytoplankton 5-200m
		Glutaraldehyde 5-100m
	GOM5/4	Apstein 50m
21.11.94	GOM5 - A1	Underway phytoplankton sampling
22.11.94	A1	FLA#1 10m
		Apstein 50m
		Lugol's 5-150mm
		Phytoplankton 5-200m
		Glutaraldehyde 5-86m

23.11.94	A1	High resolution CTD
		Phytoplankton 4-76m
24.11.94	A1	Apstein 50m
		Phytoplankton 4-299m
25.11.94	AS1	Lugol's 7-101m
		Phytoplankton 7-200m
		Glutaraldehyde 7-101m
		Apstein 50m
26.11.94	A1/42	Lugol's 4-81m
		Phytoplankton 4-200m
		Glutaraldehyde 4-81m
	AS2	Lugol's 7-100m
		Phytoplankton 7-100m
		Glutaraldehyde 7-100m
		Apstein 50m
27.11.94	AS3	Apstein 50m
		Lugol's 7-102m
		Phytoplankton 7-102m
		Glutaraldehyde 7-102m
	AS5	Lugol's 5-40m
		Phytoplankton 5-40m
		Glutaraldehyde 5-40m
28.11.94	AS5 - A2	Underway phytoplankton sampling
29.11.94	A2	Apstein 50m
		Lugol's 6-100m
		Phytoplankton 6-199m
		Glutaraldehyde 11-100m
	A2 - A3	Underway phytoplankton sampling
30.11.94	A3	FLA#3 20m
		Lugol's 6-92m
		Phytoplankton 6-199m
		Glutaraldehyde 6-92m
1.12.94	A3	Apstein 50m
		Fine resolution CTD
		Phytoplankton 11-80m
2.12.94	A3	FLA#4 10m
		Lugol's 7-102m
		Phytoplankton 7-199m
		Glutaraldehyde 7-102m
4.12.94	A3	FLA#5 30m
		Lugol's 11-96m
		Phytoplankton 11-198m
		Glutaraldehyde 11-96m
5.12.94	Intercalibration with T. Thompson	Phytoplankton 10-60m
6.12.94	A3	Lugol's 6-101m
		Phytoplankton 6-200m
		Glutaraldehyde 6-101m
7.12.94	A4/2	Lugol's 7-101m
		Phytoplankton 7-200m
		Glutaraldehyde 7-101m
		Underway phytoplankton sampling
8.12.94	A5	FLA#6 10m
		Apstein 50m
		Lugol's 7-100m
		Phytoplankton 7-100m
		Glutaraldehyde 7-100m
	A5 -A6	Underway phytoplankton sampling

9.12.94	A6	Lugol's 8-102m
		Phytoplankton 8-102m
		Glutaraldehyde 8-102m
10.12.94	A7	Lugol's 12-102m
		Phytoplankton 12-102m
		Glutaraldehyde 8-102m
11.12.94	A7	High resolution CTD
		Phytoplankton 46-111m
12.12.94	A7	FLA#8 10m
		Lugol's 12-101m
		Phytoplankton 12-101m
		Glutaraldehyde 12-101m
		Apstein 50m
		Apstein 50m
14.12.94	A8	Lugol's 12-101m
		Phytoplankton 12-200m
		Glutaraldehyde 12-101m
15.12.94	A9	Lugol's 12-111m
		Phytoplankton 12-200m
		Glutaraldehyde 12-111m
		Apstein 50m

7.17: MICROZOOPLANKTON HERBIVORY

Elaine Edwards

(Plymouth Marine Laboratory, UK)

OBJECTIVE

To quantify microzooplankton herbivory in the northern Arabian Sea using the dilution technique of Landry & Hassett (1982).

METHODS

a) Grazing. Microzooplankton grazing dilution experiments were carried out at 5 stations along the cruise track as shown in Table 1

Expt No.	Date	Station	Depth	Analysis
1	22/11/94	A1	10m	0.2 μm
2	24/11/94	A1	20m	0.2 μm
3	30/11/94	A3	20m	0.2, 2 μm
4	2/12/94	A3	10m	0.2 μm
5	4/12/94	A3	30m	0.2 μm & ^{14}C
6	8/12/94	A5	10m	0.2 μm
7	10/12/94	A7	10m	0.2, 2 μm
8	12/12/94	A7	10m	0.2 μm
9	15/12/94	A9	10m	0.2 μm & ^{14}C

Table 1: Microzooplankton grazing experiments carried out on cruise D212

Water was collected pre-dawn using 30 litre Go-flo water bottles on a Kevlar line. Each experiment was set up following the JGOFS microzooplankton grazing protocol. Water was screened using a 200 μm mesh to remove mesozooplankton predators Serial dilutions of 100, 70 40 & 10% were made up in 2 litre polycarbonate bottles. These were incubated for a period of 24 hours, *in situ* ,and in a Gallenkamp lab incubator. Sub-samples were taken from each bottle at T0 & T24 hours for chlorophyll analysis, community structure analysis (lugols & glutaraldehyde) and for flow cytometry (see G.Tarran cruise report).

b) Impact of microzooplankton herbivory on interpretation of ^{14}C primary production. Conventional phytoplankton ^{14}C assimilation rates would be expected to underestimate true primary production rates due to microzooplankton grazing activity. The degree to which they underestimate true production rates would

depend on the magnitude of microzooplankton grazing. To test the hypothesis that microzooplankton grazing influences the cell specific & chlorophyll-specific assimilation rates of phytoplankton experiments were run in parallel on microzooplankton grazing and ^{14}C assimilation rates under different degrees of grazing pressure. Phytoplankton ^{14}C assimilation determined by A.Pomroy.

c) Nanozooplankton community. Samples were collected for the determination of standing stocks of heterotrophic nanoplankton. See cruise report by Claire Stelfox for sampling details. Water was collected form the CTD rosette sampler. Sub samples of between 30-60 mls were fixed in 0.3% glutaraldehyde, stained with DAPI and Proflavin and filtered onto 0.8 μm black polycarbonate filters. Filters were mounted onto microscope slides and stored frozen for subsequent analysis back in the laboratory.

RESULTS

All grazing experiment chlorophyll samples have been analysed and data worked up. Results show microzooplankton to be grazing between 11% (station A7) and 49% (station A3 & A1) of the phytoplankton population per day. Growth rates of phytoplankton were found to be high in all experiments. Further analysis on the structure of the micrograzer community will be carried out in the lab.

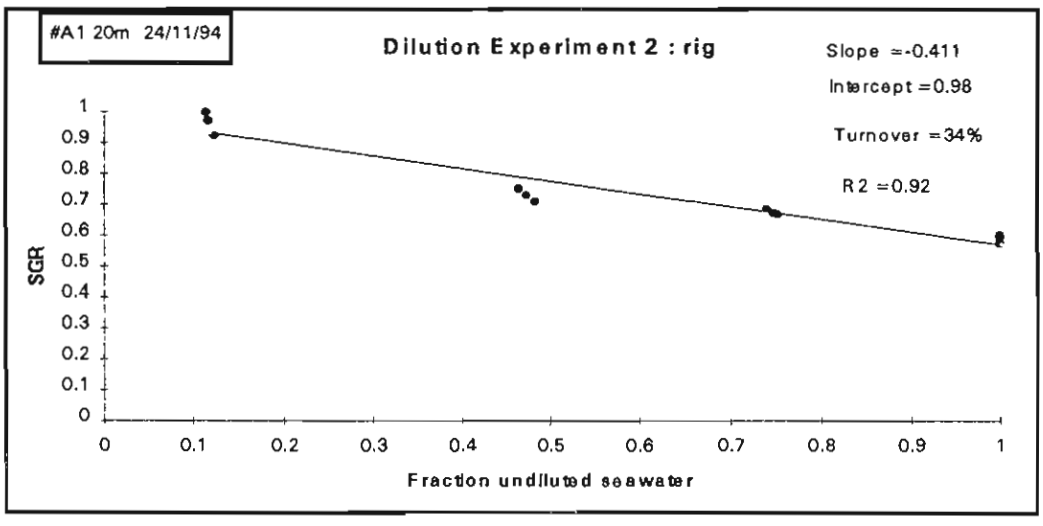

Figure 1: Dilution experiment plot showing results of experiment carried out at station A1. The specific growth rate of the dilutions can be plotted against the fraction of undiluted seawater to give a negative linear correlation. The slope of the regression represents the grazing rate and the y intercept gives the phytoplankton growth rate in the absence of grazers.

MESOZOOPLANKTON SAMPLE COLLECTION

Samples were collected for the determination of mesozooplankton biomass, details shown in Table 2.

DATE	STATION	TIME
22/11/94	A1	0000
22/11/94	A1	1100
30/11/94	A3	2330
1/12/94	A3	1245
12/12/94	A7	1215
12/12/94	A7	2315

Table 2: Mesozooplankton biomass sampling

All net hauls, using a WP-2 net, were carried out to a depth of 100 m. Samples were size fractioned through a 2000, 1000, 500, & 200 μm mesh, sub-samples were filtered onto GF/C filters for C & N analysis, and the bulk sample fixed in buffered formalin. Analysis will be carried out by R.P.Harris (PML).

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Landry M.R. & Hassett,R.P. (1982) Estimating the grazing impact of marine microzooplankton. *Mar. Biol.* **67:** 283-288.

7.18: BACTERIVORY AND AMMONIA REMINERALISATION BY NANO- AND MICROZOOPLANKTON

T. Weisse
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OBJECTIVES

The goal of this study was to measure bacterivory and the potential for ammonia nutrient regeneration by natural nano- and microzooplankton (< 100 µm) in the euphotic zone of the Arabian Sea. Taken together with the independently measured bacterial production rates (A. Pomroy) the assessment of bacterial grazing loss rates will lead to an improved understanding of the bacterial dynamics in the northwestern Indian Ocean.

METHODS

Rates of bacterivory and ammonia regeneration by nano- and microzooplankton were measured on 26 occasions at 19 stations. Water samples were collected by CTD rosette or individual GoFlow bottles from various depth across the euphotic zone. Water from up to 10 discrete depths was mixed immediately after sampling to obtain one integrated sample of the euphotic zone. Samples usually were taken before dawn. The routine experiments begun 1.5 to 2 h after sampling. Three to five 300 ml samples of the mixed water were poured into clean 500-ml volume polycarbonate Erlenmeyer bottles and incubated in the laboratory at approximately the ambient temperatures for one h in the dark. To remove larger predators, the mixed water samples were prefiltered through a 100-µm mesh screen prior to the experiments.

Bacterivory was measured by two independent approaches: (1) as the uptake of ^{3}H-Leucine labelled bacteria (ULB) and (2) as loss of bacterial cell numbers (LBC) during the incubation period. For ULB measurements, bacteria were labelled by L-(4,5-^{3}H)Leucine of high specific activity (171 Ci/mmol) for 12 to 25 h. After labelling, bacteria were heat killed for 1 h at a temperature of 70-80 ^{o}C. In order to harvest the labelled bacteria and remove the excess label, bacteria were then filtered

onto 0.2 μm pore size 47 mm diameter Nuclepore membranes and resuspended in sterile filtered sea water. The bacterial suspension was added to the experimental bottles in a ratio of 1:4 to 1:6 to the mixed water samples. To prevent bacteria that were present in the experimental water at their natural concentrations from the uptake of any free ^{3}H-leucine during the experiments, a mixture of bacterial antibiotics (Penicillin/Streptomycin, final concentration 100 units ml^{-1}/100 mg ml^{-1}) was added 10 minutes prior to the start of the experiments. Experiments were run in duplicate or triplicate. Another bottle was fixed with buffered glutaradehyde (1% final concentration) and served as a control. Samples for the measurement of radioactivity (3 x 20 ml of each bottle) and microbial cell numbers (10 ml, glutaradehyde-fixed) were taken at the beginning and at the end of the experiments. The protocol to measure the uptake of L-(4,5-^{3}H)leucine-labeled bacteria largely followed Kirchman (1993). Samples were killed by adding 2 ml cold TCA (50%) to 20 ml sample water and rinsed 4 times with 2 ml aliquots of 5% ice cold TCA after sequential filtering on 8, 1, and 0.2 μm Nuclepore filters. Filters were stored dry in 5 ml scintillation vials. Filters were prepared for radioassay by adding 2.5 ml of OptiPhase 'HisSafe'scintillation cocktail 24 h after filtering. Radioactivity was measured aboard ship in a LKB 1219 Rack-Beta scintillation counter. Uptake of the labelled bacteria (ULB) was measured separately in three size fractions, 0.2-1 μm (bacterial fraction), 1-8 μm (flagellates), and 8-100 μm (microzooplankton). For LBC estimates, cell numbers of bacteria and heterotrophic flagellates were measured by means of epifluorescense microscopy in the glutaraldehyde-fixed samples. The decline in bacterial cell numbers during the period of incubation was used as an independent measurement of total bacterial loss rates.

In addition to the routine 1 h incubation period, time course experiments in which bacterivory was followed over 4 h were conducted at 3 stations (GOM 2/A, A1, A7). The diel variation of bacterivory was studied at stations A3 and A7. Table 1 gives an overview of the various experiments, experimental conditions, and parameters measured.

Table 1. Summary of bacterivory and nutrient remineralisation experiments (Temp.=Experimental temperature, Time=Time at the beginning of experiments, ULB=Uptake of 3H-labeled bacteria, LBC=Loss of bacterial cell numbers, Nutr. rem.=Nutrient remineralisation experiments)

		Depth						
Exp.#	Station	Min	Max	Temp.	Time	ULB	LBC	Nutr. rem.
1	GOM 2/A	1	60	27.3	6.24	X	X	
2	GOM 4/A	1	60	27.5	5.52	X		
3	GOM 5/A	1	60	27.4	7.08	X		
4	GOM 5/B	1	60	26.8	7.29	X		
5	A1/6	11	37	27.1	6.37	X	X	
6	A1/35	13	35	27.4	13.29	X		X
7	A1/39	10	35	27	17.18	X		
8	A1/40	10	35	27.1	7.32	X	X	X
9	AS3/1	1	45	26.9	8.42	X		X
10	AS5/3	1	32	26.8	12.26	X	X	
11	A2/1	1	50	26.6	8.15	X		X
12	A3/4	1	60	26.6	11.09	X		
13	A3/23-1	10	10	26.7	6.2	X	X	X
14	A3/23-2	10	10	27.8	12.24	X	X	
15	A3/23-3	10	10	26.9	18.29	X	X	
16	A3/23-4	10	10	26.9	0.21	X	X	
17	A3/46	1	80	26.7	7.11	X	X	X
18	A 4/1	1	80	26.6	7.54	X	X	X
19	A6/A	1	70	27.4	7.36	X	X	X
20	A7/2	28	80	27.8	7.32	X	X	X
21	A 7/22-1	10	10	27.8	6.14	X		X
22	A 7/22-2	10	10	27.8	12.09	X	X	
23	A 7/22-3	10	10	28.4	17.37	X		X
24	A 7/22-4	10	10	27.4	23.40	X		
25	A 7/22-5	10	10	28.2	07.17	X		
26	A9/2	1	100	26.6	7.21	X	X	X

Ammonia regeneration rates were measured in the same experiments on 12 occasions (Tab. 1) in collaboration with Malcolm Woodward, PML, who analysed ammonia concentrations by the fluorescence method (Jones 1991) that allows for the detection of nanomolar levels. Two further experimental series were run with filtered seawater and deionised water to calibrate for the effect of externally mediated changes of ammonia due to the experimental handling. Triplicate subsamples of 10 ml each were taken from each experimental bottle at the beginning and end of the experiments. In those experiments where ammonia regeneration rates were measured simultaneously with bacterivory, one or two additional bottles that did not receive the labelled bacterial suspension served as controls.

RESULTS

Uptake of labelled bacteria was high and relatively constant in the Gulf of Oman. The flagellate fraction removed an average of 2.7 % of the total bacterial biomass per h, the larger microzooplankton an additional 1.2-1.9 % per h (Fig.1).

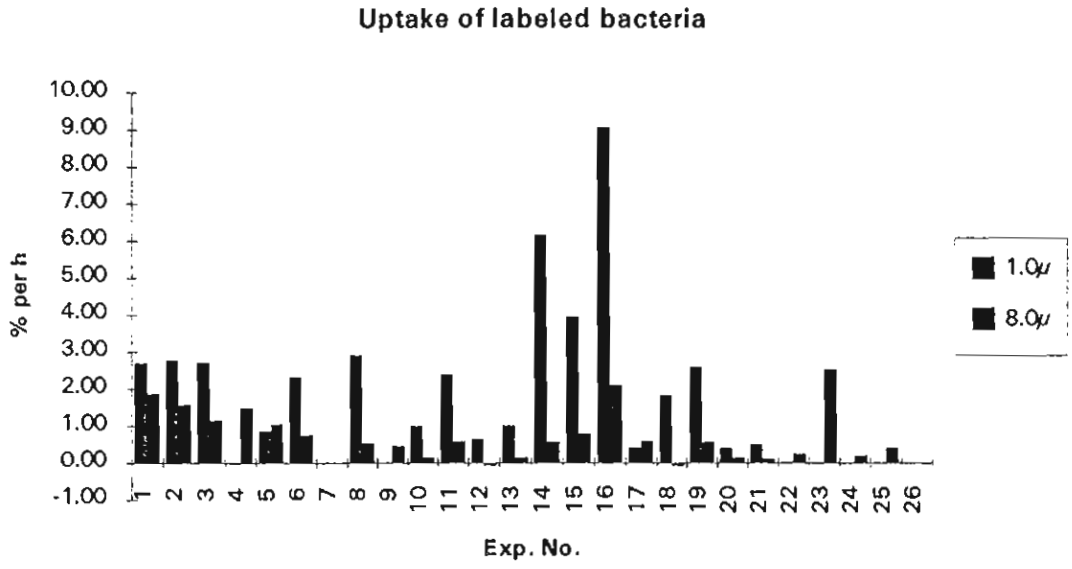


Fig. 1. Uptake of 3H-labeled bacteria by two size fractions of microzooplankton

Total bacterivory was lower and more variable along the transect from the coast of Oman towards the central Arabian Sea. Most offshore stations yielded total loss rates below 2 % per h during the routine experiments in the early morning hours. Drastically higher rates were found at night at station A3 and, to a lesser extent, at station A7. It is apparent that at both of these stations the relative share of the larger fraction (>8 µm) of total bacterivory increased over the day. When only the morning experiments are compared, the bacterivory of the larger fraction was higher both in absolute and in relative terms along the Omani coast as compared to the central Arabian Sea. The combined uptake of the 1-8 µm and the 8-100 µm fraction was approximately equivalent to the concurrent loss rate occurring in the bacterial (0.2 µm) fraction. Both measurement were within reasonable agreement to the independent measurement of total bacterial cell loss rates. In conclusion, this study suggests that grazing pressure on free-living bacteria is high in coastal waters of the northwest Indian Ocean during the end of the Intermonsoon period. The lower values measured

in the central part of the Arabian Sea would still require relatively high bacterial production rates if bacterial production and loss processes were in balance.

Measurements of ammonia remineralisation showed a similar trend as bacterivory along the transect from the coast of Oman towards the central Arabian Sea. Highest rates were measured at stations AS5 to A2. Results have to be corrected for the increase in ammonia in experimental bottles that was induced by the handling of the bottles during subsampling. Preliminary results indicate, however, that bacterivory and the linked and/or subsequent release of ammonia by microzooplankton is a process that might contribute substantially to the nitrogen demand of phytoplankton in the euphotic zone of the Arabian Sea.

References

Jones, R.D. (1991). An improved fluorescence method for the determination of nanomolar concentrations of ammonium in natural waters. *Limnol. Oceanogr.* 36: 814-819.

Kirchman, D.L. (1993). Leucine incorporation as a measure of biomass production by heterotrophic bacteria. In: *Handbook of Methods in Aquatic Microbial Ecology*, Kemp, P.F. et al. (eds.), Lewis Publ., Boca Raton, pp. 509-513.

7.19: VERTICAL FLUXES OF SEDIMENTING POC/N

Tim Fileman

(Plymouth Marine Laboratory, UK)

OBJECTIVES

1. To track the vertical gradient in the export of carbon and nitrogen.
2. To characterise the exported carbon using pigment, lipid and hydrocarbon biomarkers.
3. To compare flux measurements obtained using sediment traps and large volume *in-situ* pumping systems (Stand Alone Pumps - SAPs).
4. To compare seasonal changes in character and fluxes of sedimenting organic matter.

ANALYSES

Samples were collected on SAPs filters as follows:

Constituent	Person
POC/PON	Tim Fileman (PML)
Chlorophylls and Carotenoid pigments (HPLC)	Ray Barlow (PML)
Fatty Acids (lipid biomarkers) (GC and GC/MS)	Tim Fileman (PML)
Normal and highly branched aliphatic hydrocarbon biomarkers (GC and GC/MS)	Dave Cook (UoP)
Dissolved and particulate radionuclides (^{234}Th)	Graham Shimmield (UoE)

Sediment Trap material was also collected as follows:

Constituent	Person
POC/PON	Tim Fileman (PML)
Chlorophylls and Carotenoid pigments (HPLC)	Ray Barlow (PML)
Particulate silica	Fileman & Woodward (PML)
Dissolved and particulate radionuclides (^{234}Th)	Graham Shimmield (UoE)

With the exception of some of the radionuclide analysis, carried out on board DISCOVERY, all the above analytical measurements will be carried out at respective laboratories.

SAMPLING METHODS

Stand Alone Pumps (SAPs): SAPs are completely self contained large volume *in-situ* pumping systems capable of operation down to depths of 5,500 metres. They allow large volumes (1000 - 2000 litres) of water to be sampled for a range of determinands. Power is provided by rechargeable lead/acid paste batteries and controlled by a

sophisticated timer/control circuit. Pump and delay times can be set and then activated by magnet from outside the pressure housing. The motor inside the pressure housing drives a pump using a magnetic coupling through a titanium plate. A flow meter allows the volume of water pumped to be measured. Particulates are collected on a 293 mm diameter filter and dissolved radionuclides are stripped from the filtered water using Manganese Dioxide coated in-line cartridges. The 293 mm glass fibre filters are quantitatively sub sampled for a range of analyses and the remainder filter is analysed for radionuclides and kept for future reference.

Sediment Traps: Sediment traps were used to collect sedimenting particles from the water column. On ARABESQUE traps are being used to estimate the vertical export of organic carbon and nitrogen down from the surface waters to the deep ocean. The basis of the trap is a large collection funnel with a collection area of $0.5m^2$. At the base of the funnel is a motor driven carousel which can place collection cups under the funnel. The computer controlled carousel can be programmed to allow any combination of collection times with up to 21 cups. The traps can be deployed at any depth down to 6000 metres for periods of up to a year. However, for ARABESQUE short term deployments of three or four days were used.

CRUISE DATA

Three stations (A1, A3 & A7) were sampled using the sediment trap and the SAPs.

A single trap was placed just below the fluorescence and particulate maxima (100 metres) at stations A1 and A3. The trap rig was allowed to drift freely for up to five days. Collection times were set to coincide with productivity measurements, where possible. At station A7 traps were deployed at 60 metres, just below the mixed layer, and 260 metres at the base of the thermocline. See Table 1 below for trap deployment data.

Table 1: Sediment trap data - ARABESQUE 2 (RRS Discovery 212)

Station #	Trap Depth (m)	Date o/b	Time o/b	Date i/b	Time i/b	Lat o/b (N)	Lon o/b (E)	Lat i/b (N)	Lon i/b (E)	Drift (nm)	Direction overall	Speed (knts)	Cup #	Date open	Time open	Exposure (hrs)	Comment
A1	100	21/11/94	18:05	25/11/94	10:02	19 00.41	58 59.29	18 43.96	57 56.11	62.1	254.7°	0.71	1	22/11/94	06:00	24	
													2	23/11/94	06:00	24	
													3	24/11/94	06:00	24	
A3	100	30/11/94	03:57	05/12/94	06:44	16 02.86	61 59.41	17 33.30	61 33.16	93.5	344.0°	0.76	1	30/11/94	06:00	120	no sample
A7	60	10/12/94	07:33	13/12/94	00:10	07 59.15	66 59.46	08 04.21	66 54.13	7.3	313.6°	0.11	1	10/12/94	09:00	62	no sample
	260												1	10/12/94	09:00	62	

Notes:
1. times local
2. trap collection area 0.5 sq m
3. samples quantitatively divided into 4
4. swimmers hand picked prior to splitting

Four SAPs were used. Each SAP was fitted with a 293mm ashed GF/F filter and two radionuclide scavenger cartridges. A depth profile was taken at each station (12 depths). See Table 2 below for SAP deployment data and sample data.

Table 2: Stand Alone Pumps data - ARABESQUE 2 (RRS Discovery 212)

Station	Date	Time o/b (Z)	Cast #	Lat (N)	Lon (E)	Depth (m)	Total Vol (l)	Sub-sample volumes (l) 1 x 59mm	1 x 22mm	Residual
A1	23/11/94	15:05	A1/26	18 57.36	58 23.99	5	151.6	6.70	0.93	102.06
						10	507.7	22.45	3.12	341.78
						25	513.2	22.69	3.16	345.49
						50	645.5	28.54	3.97	434.55
	21/11/94	15:57	A1/3	19 00.27	58 58.15	100	1228.1	54.29	7.56	826.75
						200	889.8	39.34	5.48	599.01
						300	991.4	43.83	6.10	667.41
						500	609.5	26.95	3.75	410.31
	22/11/94	14:42	A1/17	18 59.62	58 41.95	600	1167.8	51.63	7.19	786.16
						1600	778.9	34.44	4.79	524.35
						2000	809.3	35.78	4.98	544.82
						3000	1041.3	46.04	6.41	701.00
A3	04/12/94	13:42	A3/41	17 24.09	61 32.17	5	589.4	26.06	3.63	396.78
						10	547.3	24.20	3.37	368.44
						25	600.1	26.53	3.69	403.99
						50	669.2	29.59	4.12	450.50
	30/11/94	08:37	A3/9	16 08.92	61 54.14	100	1175.9	51.99	7.24	791.61
						200	922.5	40.78	5.68	621.03
						300	807.9	35.72	4.97	543.88
						500	1239.1	54.78	7.63	834.16
	01/12/94	13:55	A3/22	16 30.23	61 44.37	1018	815.1	36.04	5.02	548.72
						1459	701.2	31.00	4.32	472.05
						2518	1185.9	52.43	7.30	798.35
						3459	1227.2	54.26	7.55	826.15
A7	12/12/94	14:19	A7/33	08 03.57	66 53.97	5	646.2	28.57	3.98	435.02
						10	550.9	24.36	3.39	370.86
						25	587.3	25.96	3.61	395.37
						50	695.8	30.76	4.28	468.41
	11/12/94	14:55	A7/21	07 59.81	66 55.38	100	1394.6	61.66	8.58	938.84
						200	664.0	29.36	4.09	447.00
						300	927.4	41.00	5.71	624.32
						500	993.4	43.92	6.11	668.76
	10/12/94	14:31	A7/13	07 59.61	66 58.24	1000	372.3	16.46	2.29	250.63
						2000	1219.5	53.91	7.50	820.97
						3000	1052.3	46.52	6.48	708.41
						4000	737.9	32.62	4.54	496.75

Notes:

1. Filtration areas (cm^2) for 293mm diameter SAPs filter.

a. total area of filter	674.3
b. unused filter area	56.8
c. filtration area used	617.5
d. area 59mm diameter punch	27.3
e. area 22mm diameter punch	3.8
f. area total 10 x 22mm punches	38
g. area total 6 x 59mm punches	163.8
h. residual (whole filter less f and g above)	415.7
i. residual as a proportion of whole filter (%)	67

7.20: Natural Radionuclides as Tracers of Vertical Particle Flux and Water Mass Residence Time

Graham Shimmield

(University of Edinburgh, UK)

OBJECTIVES:

Several isotopes of the natural U-decay series offer considerable potential for quantifying chemical budgets (fluxes of particulate and dissolved material) with spatial and temporal resolution appropriate to other biogeochemical measurements. Essentially, the uniform distribution with salinity of uranium (as the uranyl carbonate species) allows the source function for "particle-reactive" daughters to be well constrained. By measuring both the dissolved and particulate activity of selected isotopes, and calculating the departure from equilibrium (activity ratio of unity), an estimate of radionuclide flux and residence time may be made using a simple, two-dimensional box-model approach. By measuring radionuclide:organic carbon/nitrogen ratios in sinking and suspended particulate material it is possible to derive quantitative fluxes of biogenic materials. In recent years there has been some effort to develop analytical and interpretational methods to overcome the necessary steady-state assumptions inherent in this approach. During the two Arabesque cruises identical procedures, stations and sample depths were used to allow not only the snapshot radionuclide budget to be measured, but also the exciting possibility of calculation of budgets between monsoon and inter-monsoonal conditions. If this approach is successful then this work will provide some of the first data on non-steady state radionuclide budgets for the Arabian Sea.

The nuclides measured in this study were ^{234}Th, ^{210}Pb and ^{210}Po allowing the disequilibrium behaviour between ^{238}U:^{234}Th and ^{210}Pb:^{210}Po to be exploited. ^{234}Th is extremely particle-reactive, being effectively removed from the upper ocean mixed layer by biogenic processes. At sub-thermocline depths activity ratios of unity are often observed. The 24 day half-life of ^{234}Th allows estimates of vertical removal flux

appropriate to biogeochemical processes operating on the monthly to seasonal timescales. Both ^{210}Pb and ^{210}Po are involved in biogeochemical cycling, although ^{210}Po is effectively assimilated into marine organisms and concentrated up the food chain. With half-lives of 22.3 years and 138 days these isotopes offer potential for estimation of seasonal to decadal flux variations. Another important aim of the Arabesque radionuclide study is to compare and contrast the differences in ^{234}Th and ^{210}Po scavenging between productive and oligotrophic conditions.

METHODOLOGY:

Due to the nature of marine radiochemistry, most of the available shipboard time is taken up with sample processing in preparation for shore-based analysis. However, considerations of cruise length and the isotopic half-life of ^{234}Th, required that shipboard analysis for this isotope be carried out. This was performed using a high purity, germanium, gamma-ray spectrometer cooled using an electrical cryogenic system. The detector was shielded from cosmic rays and stray background radiation by a commercial lead shield assembly, but without a Cu-Cd liner. Both particulate and dissolved samples on standard geometry filter papers (see below for method) were counted at 8-12 hour intervals at sea. For ^{210}Pb and ^{210}Pb 20 litre water samples were processed for particulate (>0.45μm) and dissolved phases, the latter by chemical extraction and precipitation on filter papers. ^{210}Po will be analysed on return to Edinburgh by alpha-particle spectrometry; ^{210}Pb by ingrowth and re-plating ~10 months later. A full data set will be available approximately 14 months post cruise.

^{234}Th

Samples for ^{234}Th analysis were collected using stand-alone pumps (SAPs; see Fileman, this cruise report) for dissolved and particulate phases. Following filtering through 293mm diameter GF/F glass fibre filters for particulate material, the filtrate was passed over two in-line MnO_2-coated cartridges to remove the dissolved nuclides. This MnO_2 was chemically stripped with conc. HCl and 40% hydoxylammonium chloride and repreciptated with ferric chloride and concentrated

ammonia onto 150mm GF/D filters prior to counting. Only half the samples collected have been analysed on the shipboard system; the remainder will be completed in Edinburgh. Weekly electrical interference on the gamma spectroscopy system proved to be of considerable inconvenience resulting in 36 hours of down-time per week. The cause could not be traced.

^{210}Pb/^{210}Po

Using 20 litre samples from double CTD rosette Go-Flos many detailed profiles were collected. Particulate material was collected on 0.45 μm Asypor filters; dissolved isotopes using Co-APDC co-precipitation techniques and subsequent filtering. All analyses will be carried out in the Edinburgh laboratory.

Additional samples from the sediment traps (see report by Fileman) were also collected and counted for ^{234}Th and will be analysed for ^{210}Pb/^{210}Po.

Underway samples:

On this cruise underway samples were taken from the non-toxic water supply in order to examine disequilibrium within surface waters along the primary transect normal to the Oman margin. At approximately 2 hourly intervals 20 litres of seawater was collected for ^{210}Pb/^{210}Po between stations AS6 and A3. In order to obtain sufficient water for the ^{234}Th analysis a filter subsystem was constructed using the same filters and cartridges as the SAPs. This was connected to the non-toxic supply and filtered seawater over approximately 3-hourly periods providing an integration of surface water activity.

Table 1: 234Th Underway samples:

DATE	TIME	LAT	LONG	#
28/11/94	05:05	19 27.4	58 14.8'	
	07:10	19 16.0'	58 33.1'	1
28/11/94	08:05	19 12.7'	58 38.4'	
	11:07	19 03.2'	58 54.4'	2
28/11/94	11:27	19 01.5'	58 57.2'	
	14:37	18 39.7'	59 20.3'	3

28/11/94	14:55	18 37.5'	59 22.5'	
	17:25	18 20.6'	59 39.7'	4
28/11/94	17:50	18 17.6'	59 42.8'	
	20:50	17 55.7'	60 4.4'	5
28/11/94	21:05	17 53.8'	60 06.4'	
29/11/94	00:05	17 34.3'	60 25.8'	6
29/11/94	10:20	17 23.2'	60 37.3'	
	13:20	17 00.3'	61 00.7'	7
29/11/94	13:35	16 58.2'	61 02.7'	
	15:05	16 33.4'	61 27.7'	8

Table 2: 210Pb/210Po underway samples:

DATE	TIME(Z)	LAT	LONG	#
28/11/94	04:00	19 30.3'	58 09.2	1
28/11/94	06:00	19 22.9'	58 21.9'	2
28/11/94	07:00	19 16.5'	58 32.4'	3
28/11/94	10:00	19 09.6'	58 44.3'	4
28/11/94	12:00	18 58.1'	59 02.2'	5
28/11/94	14:00	18 44.4'	59 15.7'	6
28/11/94	16:00	18 30.3'	59 29.9'	7
28/11/94	18:05	18 15.4'	59 44.9'	8
28/11/94	20:00	18 01.9'	59 57.9'	9
28/11/94	22:00	17 46.6'	60 13.6'	10
29/11/94	00:00	17 34.5'	60 25.6'	11
29/11/94	10:00	17 24.9'	60 35.6'	12
29/11/94	12:00	17 10.5'	60 50.3'	13
29/11/94	14:05	16 55.4'	61 05.7'	14
29/11/94	16:00	16 41.7'	61 19.6'	15

Table 3: Profiles of $^{210}Pb/^{210}Po$ in 20 litre samples were taken from the following stations and depths:

DATE	STATION	LAT	LONG	0m	10m	30m	50m	75m	100m	150m	250m	350m	500m	1000m	1500m	2000m	2500m	3000m	others
19/11/94	GOM4	23 56.2'	59 11.6'	*	*	*	*	*	*	*	*	*	*						42m
23/11/94	A1	19 01.0'	58 42.0'	*	*	*	*	*	*	*	*	*	*	*	*	*	*		3100m
27/11/94	AS4	19 27.0'	58 14.6'	*	*	*	*	*											220m
01/12/94	A3	16 23.6'	61 46.7'	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	3823m
07/12/94	A4	13 59.9'	63 14.9'	5	10	20	40	60	200										
08/12/94	A5	11 59.6'	64 28.8'	*	*	*	*	*	*	*	*	*	*						
10/12/94	A7	7 58.2'	66 58.0'	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	4574m
15/12/94	A9	14 17.6'	66 58.1'	*	*	*	*		*		*		*						

Table 4: Profiles of ^{234}Th in SAP samples, particulate and dissolved

DATE	STATION	LAT	LONG	Depths													
21-23/11/94	A1	18 59.6'	58 41.9'	5	10	25	50	100	200	300	500	600	1600	2000		3000	
30-4/12/94	A3	16 30.2'	61 44.4'	5	10	25	50	100	200	300	500	1018	1459		2518	3459	
10-12/12/94	A7	7 59.8'	66 55.4'	5	10	25	50	100	200	300	500						

7.21: COMPUTING

Paul Duncan

(Research Vessel Services, UK)

General comments.

1. The ABC system performed very well during the cruise. The Level B system did not crash, so no data were lost.
2. Both Discovery1 and 2 crashed 2 or 3 times each. These crashes were related to use of the internal PC floppy drive.
3. A few of the MK II level A's were reporting "Master clock jumps" at various times. This is a known problem which does not affect data acquisition, but is annoying. All that is required is to reset the offending Level A's when this happens.
4. The Nicolet Zeta A0 drum plotter was not working when I came on the ship but Simon Watts and I replaced the pen carriage assembly. Part of a spring which returns the solenoid which pushes the pen down had snapped off and was jamming the solenoid. Later during the cruise the 8 pen pen holder started to fall apart, and was repaired using parts from a four pen holder. A new pen holder will be with the ship by its next scientific cruise. This plotter was used for producing track plots with station positions, track plots showing UOR tows, CTD profiles and profiles of underway variables against time.
5. The Tektronix 4693RGB Wax Transfer Screen Dump Plotter worked although it jammed on every plot. Sometimes it was just a case of opening and closing the front panel, in other cases it was necessary to go inside and remove offending pieces of paper. Over fifty UOR contour plots were produced using this plotter during the cruise. I believe this equipment is to be replaced with a Hewlett Packard Deskjet 1200C/PS before the next scientific cruise.
6. Every 24 hours the entire data set was backed up onto Exabyte (8mm video tape). This format will also be used in the exchange of data with the RV Thomas G. Thompson in Muscat.

The following hardware was used in support of the scientific operations.

Discovery1 (Level C)

Sun SPARCstation IPC

Hard Disks:

200Mb Internal

2800Mb HAMCOM External

Floppy disk: 3.5" 1.44Mb/720K PC or UNIX format.

Tape Units:

150Mb Sun Quarter Inch Cartridge (QIC) drive

Resolv Exabyte 8mm drive

Sun CD-ROM drive.

Discovery2

Sun SPARCstation IPC

Hard Disks:

200Mb Internal

311Mb External

1340Mb External

Floppy disk: 3.5" 1.44Mb/720K PC or UNIX format.

Tape Unit:

150Mb Sun Quarter Inch Cartridge (QIC) drive

Discovery3

Sun SPARCstation 1

Hard Disks:

317Mb External

317Mb External

Floppy disk: 3.5" 1.44Mb/720K PC or UNIX format.

Discovery4

Sun SPARCstation 1

Hard Disks:

317Mb External

No floppy disk.

Total Hard disk space on network: 5.8Gb

Output Devices (permanently on ship)

NEC Pinwriter P5 (Wide carriage dot matrix printer) Hewlett-Packard Laserjet III with Turboscript Postscript cartridge Tektronix 4693RGB Wax Transfer Screen Dump Plotter

Nicolet-Zeta A0 Drum plotter

Level B - Custom built fault-tolerant data logger, comprising: Philips PG2111 Single board computer featuring:

68030 25Mhz CPU with 68882 Floating-point Co-processor 4Mb RAM

1Mb ROM

4 Serial ports

1 Parallel port

SCSI port

Mirrored 150Mb SCSI Hard disks

150Mb Viper QIC tape drives x 2

Radstone PME-SIO4 Intelligent Serial Cards x 2 featuring:

68020 12.5Mhz CPU

1Mb RAM

128K ROM

8 x 68681 DUART giving a total of 16 serial ports per card. Thus up to thirty-two Level A's can be connected to a single Level B.

Level A computers.

There were three types of Level A used during cruise 207.

Mk 1 Level A based on an RVS designed board utilising an Intel 8085 processor. MX1107 Magnavox MX1107 transit satellite navigator

NUTRI2 Nutrients Analyser

Mk II Level A based on the Syntel CP-68 board using a Motorola 68000 processor. GYRO_RVS Ships gyro

GPS_TRIM Trimble GPS Surveyor

LOG_CHF Chernikeeff log

SIM500	Simrad EA-500 Hydrographic Echosounder
GPS_ASH	Ashtek Differential GPS Receiver
PC Based Level A's	
SURFLOG	Thermosalinograph, fluorometer, transmissometer
METLOGGR	Wind speed/direction, wet/dry temperature, barometric pressure, long wave radiation, port/starboard light sensors.
WINCH	Seametrix winch monitoring system.
MK II CTD Level A based on a Level B processor board	
RVS_CTDF	IOS 17byte CTD

7.22: CTD SYSTEM

John Wynar

(RVS Barry, UK)

The CTD system gave few problems, the ones that did occur being easily dealt with i.e. replacing an intermittent connector on the fluorometer. The CTD termination was re-made four times during the cruise, usually because the outer armouring of the CTD cable itself was un-ravelling.

With regards to the remaining instrumentation, the ADCP occasionally crashed, but came back on line after reconfiguring the work file. Also, the echo sounder printer failed but was replaced with a spare.

In general, the on-board scientific instrumentation worked satisfactorily with little downtime.

CTD calibration files are held by PSO, BODC and myself.

7.23: MECHANICAL ENGINEERING

Jeff Jones & Chris Rymer

(RVS Barry, UK)

GENERAL INTRODUCTION

Cruise 212 was a concentrated water sampling and CTD cruise which used various methods of sampling equipment, both when on station and when underway. In all 121 CTD casts were made.

CTD: The CTD was used in the normal way using the stbd gantry. The CTD itself worked well but we suffered a loss of 6 niskin bottles from the rosette. After this loss which happened early on in the cruise the CTD casts were carried out without any further mishaps. It became necessary to reterminate the wire on 3 occasions as the wire is showing signs of fatigue, this is more prominent at the end 100m, but the rest of the wire is far from perfect. The wire dims is down 0.1mm on its lowest tolerance.

TOWING THE UOR: This was done over the stern of the ship ,and was deployed using the R.V.S. seasor winch. The winch performed satisfactorily, but using a winch rated to 400kgs swl for loads of up to 750kgs whilst towing, a anchor chain had to be used on the cable. It must be said that on deployment and recovery the loads were not exceeding 400kgs, Although recovering the UOR at 4knts this winch was, at a time at its maximum capacity. The U.O.R.was also deployed using the stbd stern crane. On consultation with the PML technician, using the stbd side crane was the method preferred, as was used on the previous cruise. However the crane did rock from side to side and the gantry in my opinion would have been a better choice.

LIGHT METER AND OPTICS: These were deployed over the stern using both stern cranes and the R.V.S. Ossel winch. These all worked well and there were no problems.

S.A.P.S.: The saps were deployed through the stbd gantry using the RVS SAP winch. Although there is not much room, with the wire leading across the deck, this worked well and there were no problems.

APSTEIN NETS: These were also deployed through the stbd gantry and no problems encountered.

SEDIMENT TRAPS: These were deployed through the stbd gantry using the saps winch and the small gantry winches. No problems encountered with this equipment.

GO - FLOWS: The Go - Flows were deployed through the stbd gantry using the kevlar rope off the aft gantry winch. Although we managed to loose one messenger there were no problems encountered.

10T SYSTEM. This worked well and provided a trouble free service. The 20t system was not used. 10t and 20t outboard compensators not used. A problem with motor 1 on the 37kw power pack hindered the first half of the winch operations. This problem with the thermal overload was rectified by disconnecting the sensor from the plc. This was done by removing wire id 22105. This was to prove success and all other winch operations were unhampered. Slight adjustments were made to the i\b compensator oil pressure. 10t haulers were clamping on to wire after 15mins or so and were found to be rubbing on ctd cable. Each time the haulers were jacked off by starting the power pack.

SEAMETRIX SYSTEM: No problems encountered.

STERN CRANES: These provided a trouble free service.

MIDSHIPS HYD POWER PACK: On start up of this system, we blew two fuses in the main contactor on the three phase. After the fuses were replaced, there were no further problems.

AFT HYD POWER PACK: No problems encountered.

STERN GANTRY: No problems encountered.

P.E.S. WINCH: No problems encountered.

TRANSDUCERS: As in port, the removal of the chernikeif log was hampered by a leaking hull valve. As a result the log space was not interfered with on cruise 212.

NON TOXIC SUPPLY: Minor problem with hanger deck hoses.

GAS DISTRIBUTION AND ALARM: Not used.

LABS AND WINCH CONTROL CAB:Winch control cab: fwd wiper u\s. Could still use some sun blinds.

SEISMIC COMPRESSORS: Not used.

ITEMS TO BE REPAIRED\REPLACED: EOS Camera on 10t system was replaced with the one off the super aramid drum. Camera should be returned for repair.

SPARES USED: Mid power pack fuse - E31 Legrand AM 63A

REFIT NOTES AND OBSERVATIONS: Ventilation from and to the winch room inadequate with the ambient temp rising above 40°C. No enviro-clean available for cleaning down operations. Chief Engineer stopped us from cleaning down the winch room with water as their water\oil separator is u\s.

8: ACKNOWLEDGEMENTS

The success of ARABESQUE depended not just on the capability, enthusiasm and dedication of the scientists and technicians who sailed, but also on many other people and organisations in the background. All these have ensured that the many wheels, that make up the complex operation of ARABESQUE, turned in the right way at the right time.

It is a pleasure to thank Captain Geoff Long, Officers and Crew on RRS DISCOVERY for their full support on board DISCOVERY. Not only did they give us full scientific rein onboard, they also helped us to make the cruise enjoyable also.

ARABESQUE owes much to JGOFS Indian Ocean Planning Committee (Chair: Prof Dr Bernt Zeitzschel) for providing a framework and context for fruitful international collaborations. Thus ARABESQUE blossomed with the participation of scientists from 5 nations on cruises. In Oman itself, we were helped in so many ways by Dr Thabit Al Abdessalaam (Director of Marine Science & Fisheries Centre, Muscat) and by Prof Craig Kensler, Dr Barry Jupp and their colleagues at Sultan Qaboos University, Muscat. Their practical help was literally invaluable in so many ways.

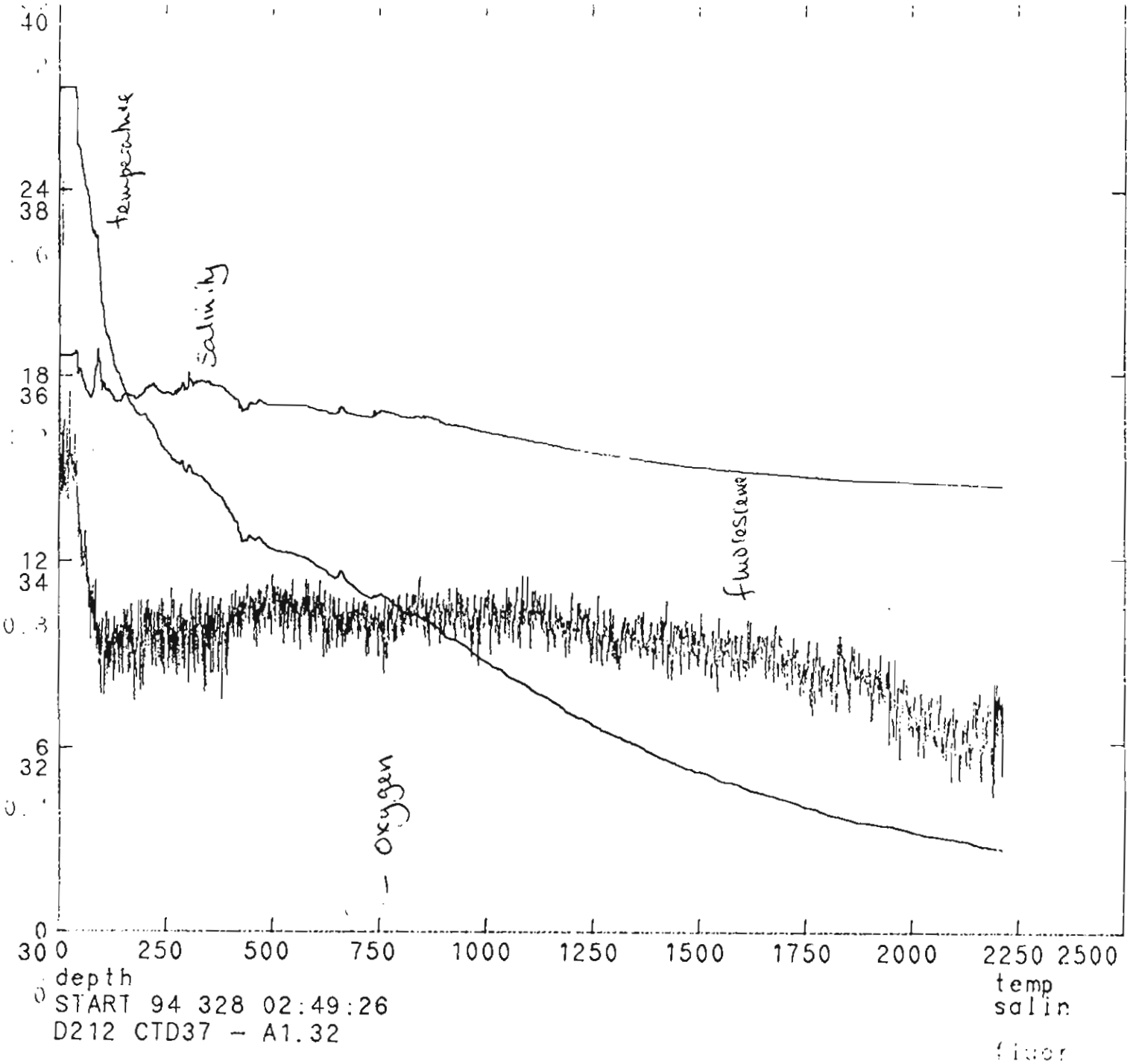
We also thank Prof Dr Bernt Zeitzschel for the loan of two sediment traps from Institut fuer Meereskunde, Kiel. This was done in the true spirit of international collaboration within JGOFS.

ARABESQUE would never have sailed without extensive financial support. This was provided by NERC, the Defence Research Agency, PRIME CRP and Amersham International. Their funds allowed us to do our science, and for this we thank them.

Throughout the complex procedures of getting ARABESQUE to become 'a-goer', Dr Brian Bayne (Director, PML) supported us to the full and it is pleasure to thank him and other colleagues at PML for their commitment to our programme.

Peter Burkill, Chief Scientist ARABESQUE
Plymouth Marine Laboratory, May 1995

Station A1|32



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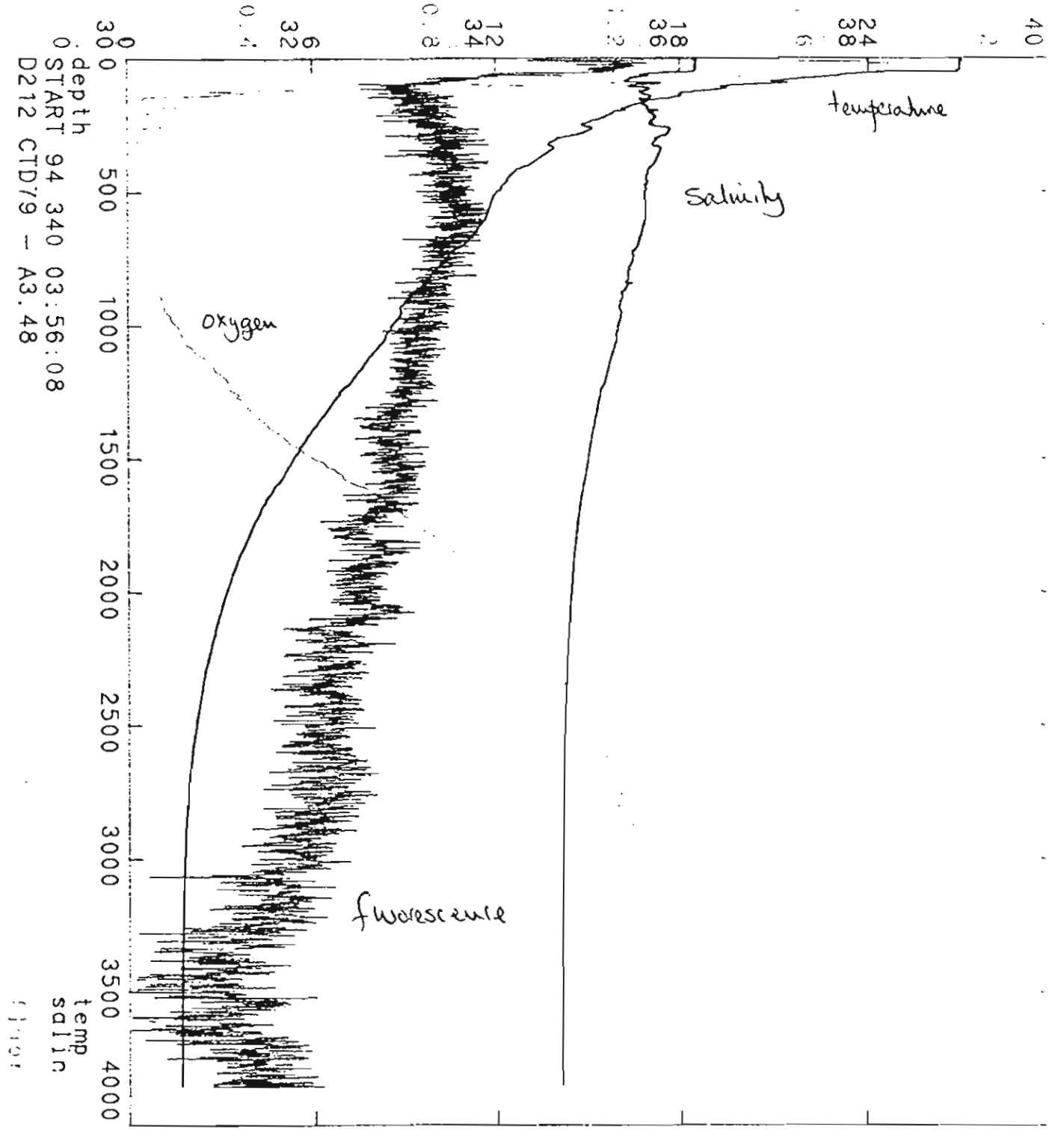
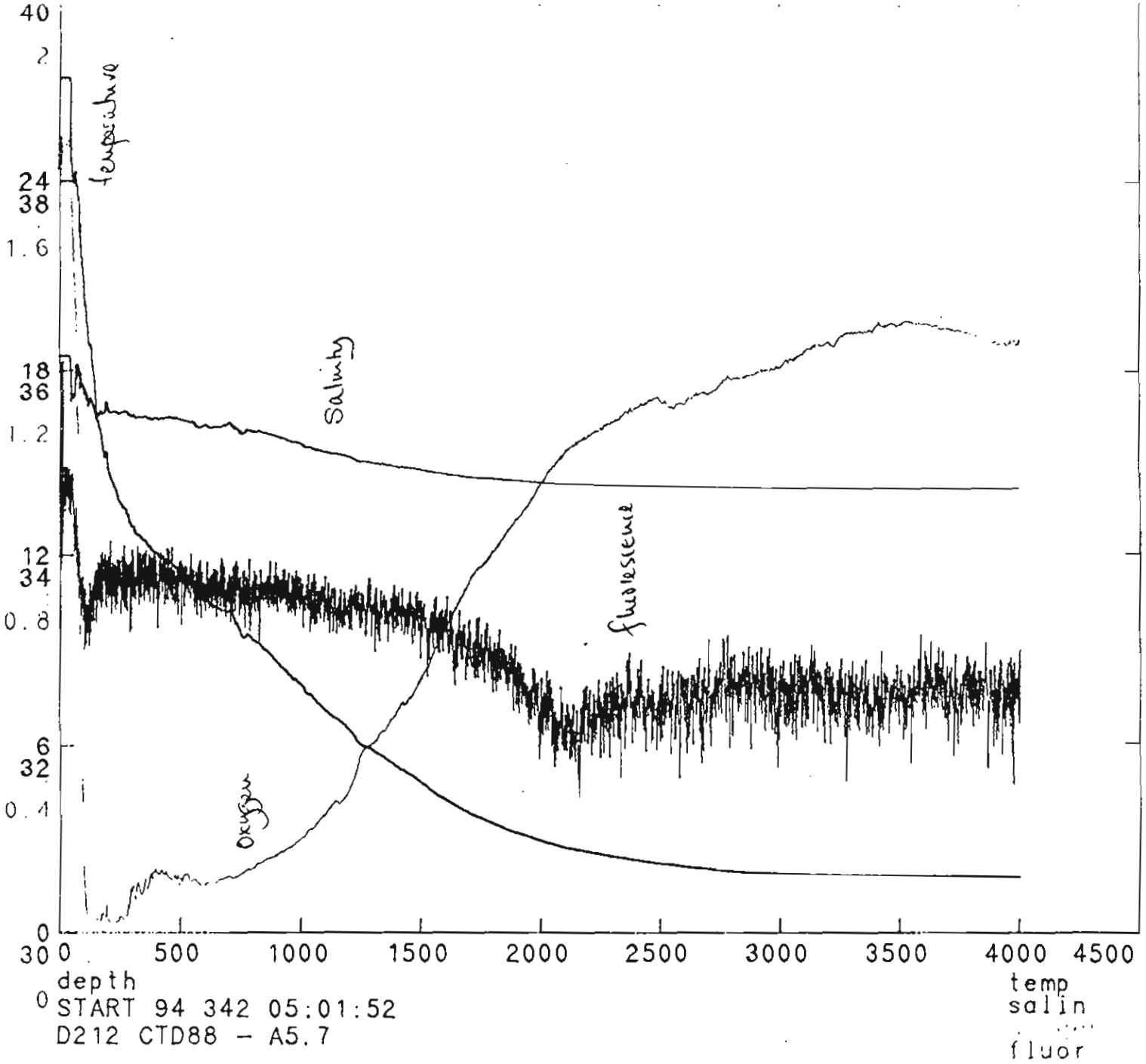


Station A5.7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Salinity
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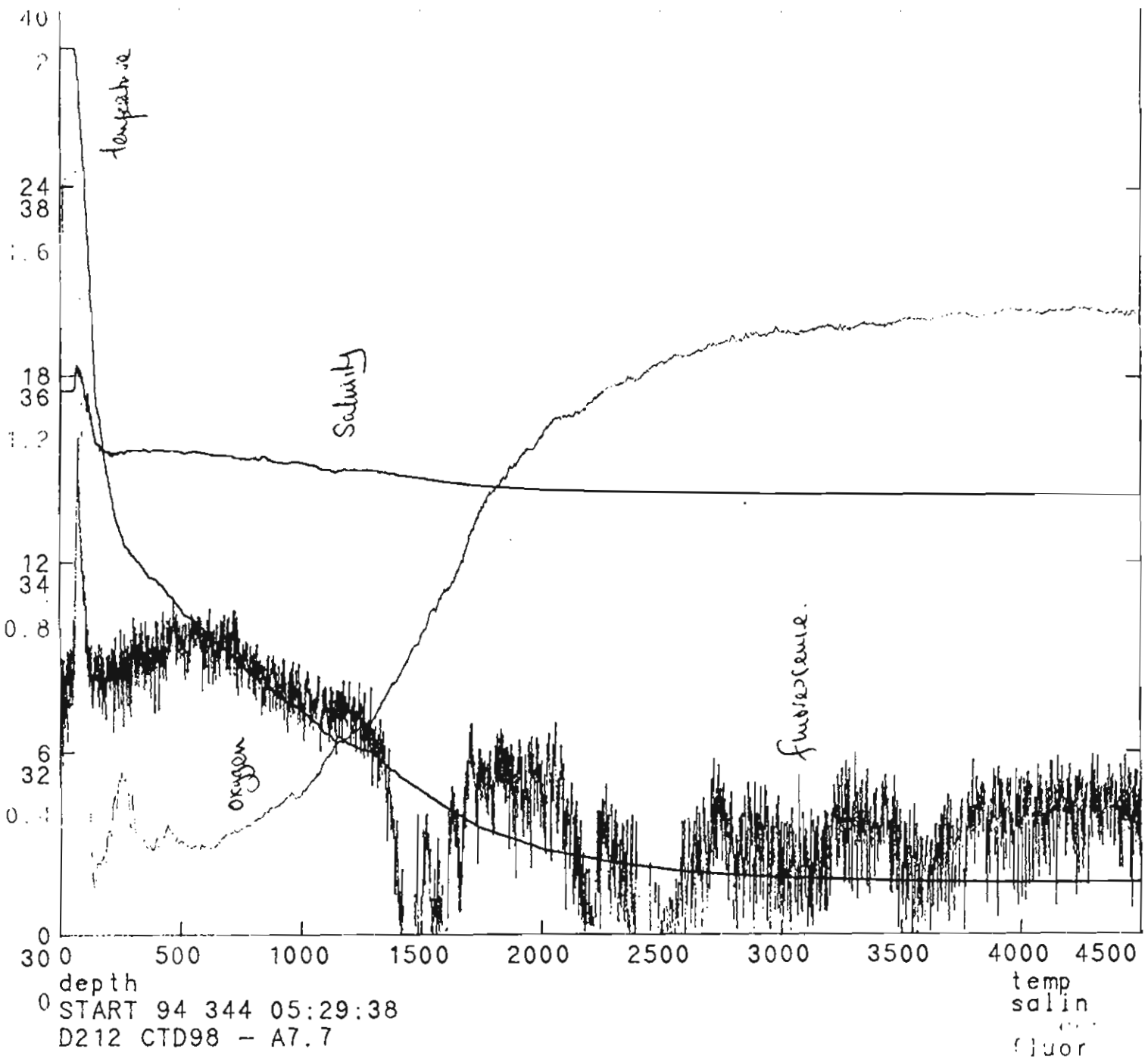
Station A7/7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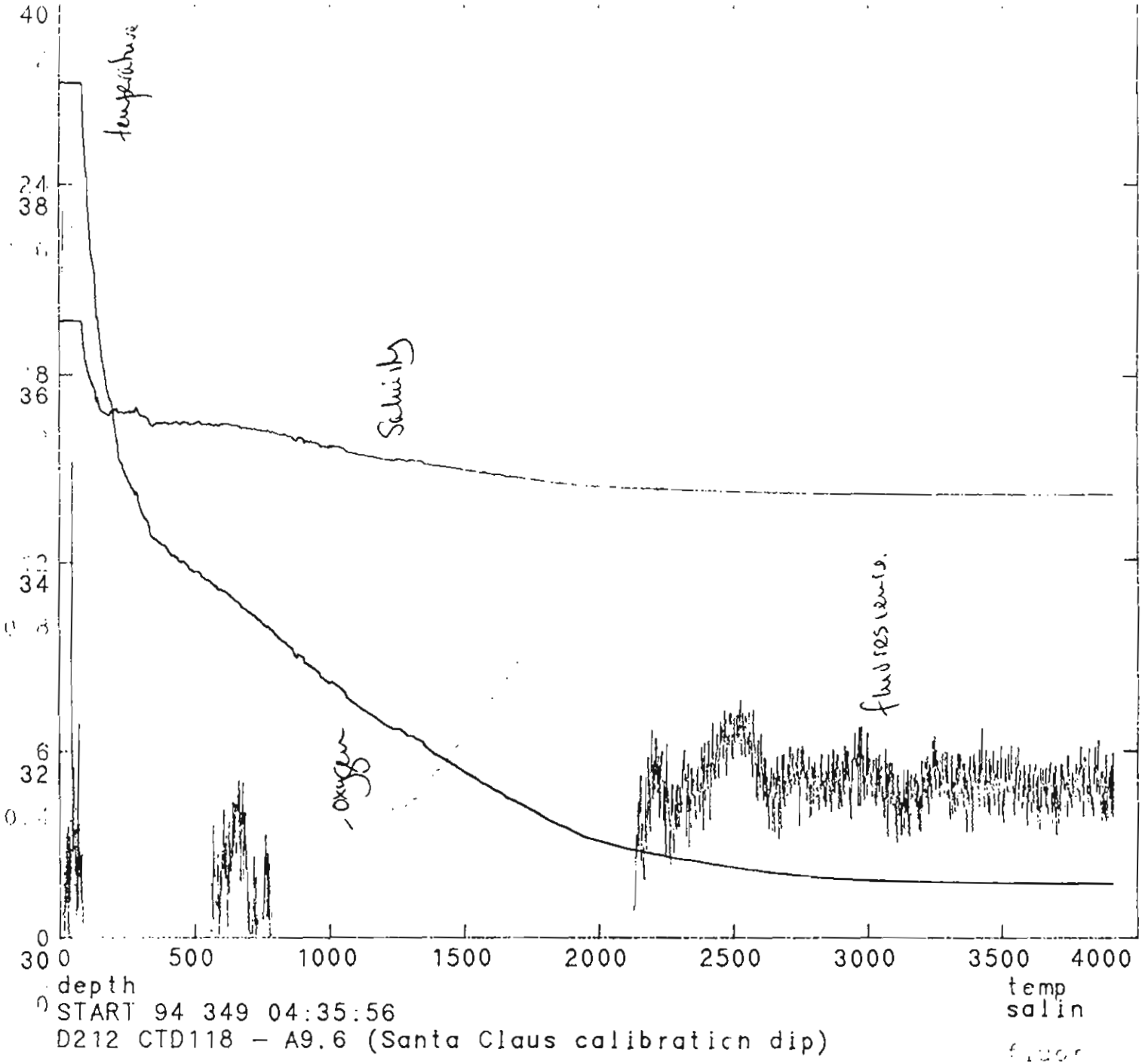
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depth
temp
salin
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