ARABESQUE I: CRUISE REPORT

R R S DISCOVERY 210/94
25 AUGUST - 5 OCTOBER 1994
MUSCAT to ARABIAN SEA to
N W INDIAN OCEAN to MUSCAT

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GREAT BRITAIN

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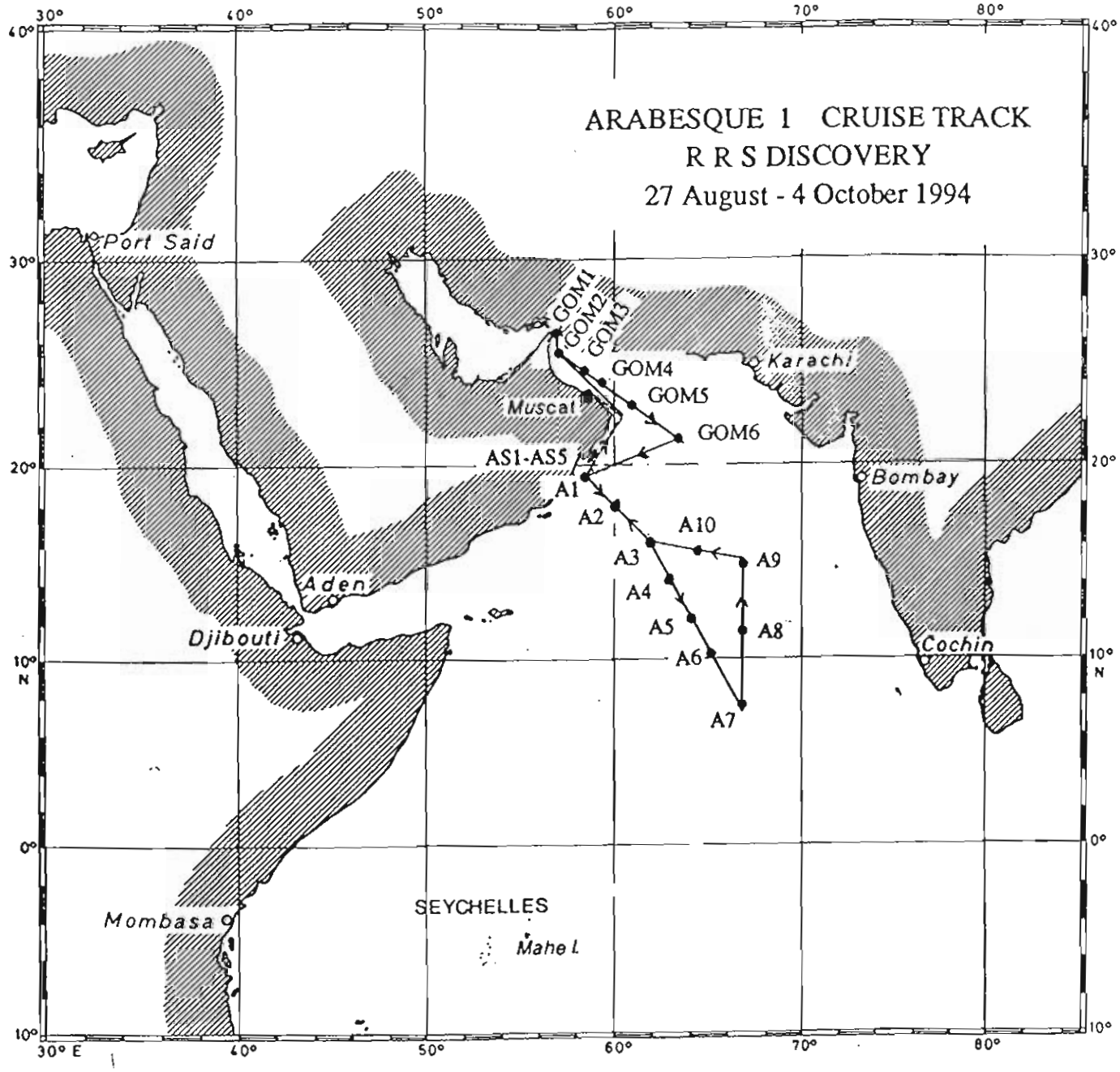
Figure 1: Cruise track and Positions of the ARABESQUE 1 Expedition on board R R S DISCOVERY in the Arabaian Sea; 27 August - 4 October, 1994



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1 OBJECTIVES

The detailed scientific objectives of ARABESQUE cruises are: :

To quantify the seasonal influence of the Monsoon winds in the Arabian Sea on:

(1) upwelling of nutrients and resultant production and fate of phytoplankton, in terms of size-fractionated, new and regenerated production.

(2) vertical and on-shelf gradients of heterotophic, methanogenic and denitrifying bacteria .

(3) distribution of chemotaxonomic pigments with links to optical properties of seawater.

(4) Dissolved Inorganic and Organic Carbon cycle

(5) Air-sea exchange of Sulphur and Nitrogen biogases including dimethyl sulphide, methylated amines, and methane.

(6) Sedimentation rates and fate of organic matter through the oxygen depleted zone.

(7) calibrate satellite data on ocean colour so as to map the biogeochemistry of the northwestern Indian Ocean.

Two cruises (ARABESQUE 1 & II) are planned in August and December 1994 to contrast the effect of the South West monsoons versus the intermonsoon period. This report deals with ARABESQUE 1 expedition held between 27 August and 4 October 1994. These two cruises represent the UK contribution to Arabian Sea JGOFS.

2 SUMMARY OF ACHIEVEMENTS

The ARABESQUE I Expedition departed from Muscat on 27 August and initially we investigated the biogeochemistry of the Gulf of Oman and the outflow of Arabian Gulf waters into the Arabian Sea. Six stationS were occupied from the Straits of Hormuz to the Murray Ridge and repeated CTD/rosette bottle casts were completed for micro-nutrients (NO_3, NO_2, PO_4, Si), nano-nutrients (NO_3, NO_2, NH_4), dissolved organic carbon, SF_6, ammonia and methylamines, TCO_2, pCO_2, N_2O, DMS, DMSO, MDSP, oxygen, pigments by HPLC, flow cytometry, microzooplankton, bacterial counts. Underway biogeochemistry measurements and tows of the undulating oceanographic recorder (UOR) instrumented with an array of optical and oceanographic sensors were also completed between all stations.

The upwelling of nutrient rich waters off the Omani Shelf was mapped by a 100 nm on-slope section of 5 stations (AS 1- AS 5, 2500 m - 50 m) into Masira Bay. The open ocean gradients in nutrient concentrations, biogeochemical fluxes and production were

mapped over a 900 nm SE vertical section from Oman to the central oligotrophic gyre of the N W Indian Ocean.

Diurnal time series studies lasting 3-5 days were carried out at ARABESQUE Reference upwelling St A1, the US JGOFS Arabian Sea Ref St A3, and the 'Oligotrophic ' St A7 which we had previously occupied (St Index 3) during the Darwin cruise in 1986. The time series studies included repeated bioptical and CTD bottle casts in the upper 200 m for biogeochemical parameters listed above, as well as daily primary production rigs in which bottles containing ^{14}C, ^{15}N and other tracers were deployed at 6-10 depths from dawn to dusk. Net and gross phytoplankton production measurements were made with precision ΔO_2, ΔTCO_2. Sediment traps and stand alone *in situ* pumps (SAPS) were deployed to sample the sedimenting and suspended particulate organic matter down to 4000m originating from the intensive blooms. Radiochemical techniques based on ^{210}Pb and ^{234}Th disequilbria were deployed to track the flux and residence time of these particles.

The following phenomena and processes have been investigated:

Inflow of Persian Gulf water tracked isopycnally and from SF_6 distributions
Evaluation of the Oxygen TCO_2, DOC inventory
Budget and speciation of nano and micronutrients
Mapping denitrification and methane fluxes, air sea exchange of NH_3 & methylamines
Size-fractionated, new and regenerated phytoplankton production & light-dependence
Flow cytometric profiling of the picoeukaryots, cyanobacteria, prochlorophytes
Vertical distribution and stoichiometery of dissolved organic carbon and nitrogen
Chlorophyll and carotenoid chemotaxonomy and fluxes
Bacterial production Photochemical production of CO
Profiling and fluxes of DMS, DMSO, and DMSP
Sedimentation fluxes from langrangian drifitng traps.
Particle residence times from scavenging of ^{210}Pb and ^{234}Th by suspended particles
Bioptical province mapping using UOR and pigment distributions

More Detailed accounts of the progress achieved by ARABESQUE scientists are presented in the last section the Cruise Report.

3 PERSONNEL

TABLE 1

SCIENTIST	INVESTIGATION	INSTITUTE
Prof R Fauzi C MANTOURA	Principal Scientist, Organic C & N	P M L
Dr Ray BARLOW	Pigments HPLC, optics	P M L
Mr Ian BELLAN	Undulat.Oceanographic Rec., optics	P M L
Dr Peter H BURKILL	Flow cytometry, microzooplankton	P M L
Ms Jo DIXON	O_2 Winkler titrations	PML/UoP
Ms Elaine EDWARDS	Microplankton & video microscopy	P M L
Mr Tim FILEMAN	Traps & Stand Alone Pumps (SAPs)	P M L
Mr Stuart GIBB	Ammonia & methylamines	P M L
Ms Angela HATTON	Dimethylsulphide, DMSO, DMSP	U E A
Mr Brian IRWIN	^{14}C-Production - light relationships	B I O
Ms Susan KNOX	pCO_2 & TCO_2 biogeochemistry	P M L
Dr Cliff LAW	SF_6 and CO profiles	P M L
Mr Axel MILLER	HTCO-DOC & -DON profiles	P M L
Prof Nicholas J P OWENS	New & regener. production (^{15}N)	U N C
Mr Alan POMROY	Bacterial production & numbers	P M L
Mr Andrew REES	Macro-nutrient chemistry	P M L
Dr Carol ROBINSON	TCO_2, production & respiration	U W B
Dr Graham SAVIDGE	^{14}C size-fractionated production	Q U B
Mr James SMITH	^{234}Th & ^{210}Pb geochronology	U Edinb
Ms Claire STELFOX	Microzooplankton grazing,	P M L
Mr Malcolm S-WOODWARD	Nano-nutrient chemistry	P M L
Dr Chuck TREES	Ocean Optics	S D S U
Dr Robert UPSTILL-GODDARD	Nitrous oxide & methane profiles	U N C
Mr Nasser AL RUMHI	Omani Observer & Engineer	R O N
Mr Howie ANDERSON	Computing Services	R V S
Mr David DUNSTER	Deck Engineering and Winching	R V S
Mr Stirling JORDAN	Deck Engineering and Winching	R V S
Mr Bill MILLER	CTD & Sensors	R V S
Mr Keith AVERY	Captain	R V S
Mr Derek NODEN	Chief Officer	R V S
Mr Syd SYKES	2nd Officer	R V S
Mr Paul BURRIDGE	3rd Officer	R V S

PML: Plymouth Marine Laboratory, Prospect Place, PLYMOUTH PL 1 3 DH, UK.
UoP: University of Plymouth, Department of Environmental Sciences, Drake Circus, PLYMOUTH PL3 8AA, UK.
RVS: Research Vessel Base, Barry, South Glamorgan, CF6 6UZ, UK.
UNC: University of Newcastle, Department of Marine Sciences, Newcastle, NE 1 7 RU, UK.
UCNW: University of Wales Bangor, School of Ocean Sciences, Menai Bridge, Gwynedd, Wales, LL59 5EY, UK
SDSU: San Diego State University, Centre for Hydroptic and Remote Sensing, 6505 Alabarado Rd Suite 206, 92120 California, USA.
QUB: Queens University Belfast, School of Biology and Biochemistry, Marine Biology Station, Portaferry, County Down, Northern Ireland BT 22 1 PF, UK.
BIO: Bedford Institute of Oceanography, Dartmouth, Nova Scotia, B2Y 4A2, Canada
U Edinb: University of Edinburgh, Department of Geology and Geophysics, West Mains Road, Edinburgh, EH9 3JW, SCOTLAND.
UEA: University of East Anglia, School of Environmental Sciences, Norwich NR 4 7TJ, UK.

4 BIOGEOCHEMICAL PARAMETERS & PROCESS INVESTIGATED

The cruise consisted of four distinct types of operations:

(1) **Underway measurements** between stations : time, longitude, latitude, salinity, temperature, fluorescence, transmissometer, bottom depth, solar irradiation, micronutrients all continuous or semi continuous mode; Discrete samples were also taken for microbial biomass, pigments, POC/N particulate absorbtion.

(2) **Profiling Stations** with 1 or 2 Biogeochemical CTD casts & deck incubations lasting < 12 hours. A 'shallow ' and 'deep' casts were undertaken to cover the whole of deep (> 200 m) stations. The parameters measured on these Biogeochemical casts include follow the 'Level 1' protocols of JGOFS and include :

Time, depth, salinity, temperature, potential temperature, density (σ_p), fluorescence, transmission, oxygen electrode, oxygen Winkler, micronutrients (NO_3, NO_2, NH_4, PO_4, Si, Urea) and nano-nutrients (NO_2, NO_3, NH_4), Dimethylsulphide, DMSO, DMSP, Methylamines, pCO_2, TCO_2, N_2O, CH_4, SF_6, CO, DOC, HPLC-pigments, analytical flow cytometry. Seawater samples were also preserved in lugols iodine for microbial biomass and numbers.

Where possible, predawn casts were also carried out for simulated *in situ* incubations on deck.

(3) **Production Stations** to include all operations listed in Profiling Stations plus a a set of pre-dawn casts at 9 - 12 depths for addition of tracers and redeployment of primary production bottle rig from dawn to dusk. these were carried out St A1, A3, A5, A7 and A9. Parameters measured include Pigments HPLC, nutrients, and phytoplankton assimilation of ^{14}C-HCO_3, $^{15}NO_3$, $^{15}NH_4$, and bacterial assimilation of ^3H-thymidine and ^3H-leucine. Community photosynthesis and respiration were also measured using ΔTCO_2 on light and dark bottles. In parallel to the ***in situ*** incubations, are deck incubation with ^{14}C-HCO_3 in a 'photosynthetron' to derive the growth-light relationships for primary production. Following rig recovery at dusk, bottles were dark incubated on board and processed 24 hours after commencement of production experiments. Microbial grazing experiments were also carried out on 1 or 2 depths on the same production rig.

Vertical profiling for ^{210}Pb scavenging is also carried out at each 'production' stations.

(4) **Trap Stations** consist of 3 to 4 day deployment of drifting sediment trap just below the surface mixed layer and/or the chlorophyll maximum at stations A1, A3,and A7. On arrival, the trap is immediately deployed and sedimenting particulates are collected daily into poisoned sample cups for detrmination of vertical fluxes.

Following trap deployment, twin biogeochemistry CTD casts are completed followed by daily deploymenst and recoveries of primary production rigs. The *in*

situ pumping of deep particulates is also carried out in SAPS profiles from the surface to 3500 m depth.

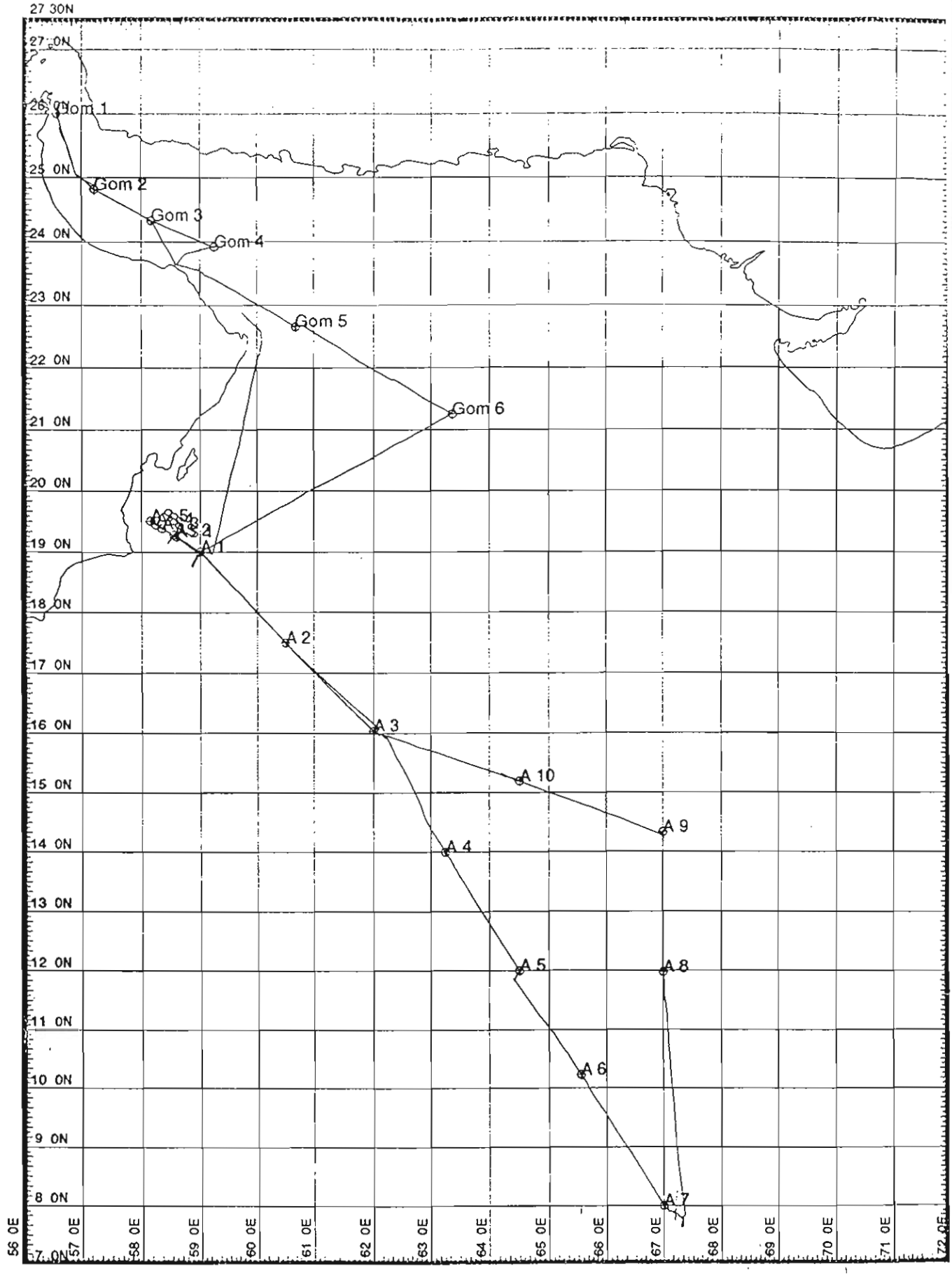
5 STATION AND DATA FORMAT

The Gulf of Oman stations positions are shown in Table 2. .They are designated GOM 1 to GOM 6 and mostly correspond to ones previously occupied on Charles Darwin CD/16 in 1986.

The Arabian Sea stations are designated A1 to A10 and their correspondence to other program stations are also shown Table 2.

Every cast and over the side opration is given an 'OPERATION NUMBER' consisting of station number followed by the operation number. *e.g.* GOM 6-7 meaning station GOM 6 and operation number 7 *etc*..

SPREADSHEETS: to facilitate the integration of individual scientists' data obtaianed from bottle casts, BODC and RVS will prepare LOTUS 123 or EXCELL Spread sheets for the CTD/s/F/O2/Tr data corresponding to each bottle . All the data has been properly calibrated down loaded from the level C system . Diskette spreadsheets will be distributed to all scientists on board. The entire data stream on the level C will of course be reprocessed by the BODC (Bidston) who in due course wil produce CD-ROM of ARABESQUE cruises.



MERCATOR PROJECTION

GRID NO. 1

— Track plotted from

SCALE 1 TO 7600000 (NATURAL SCALE AT LAT. 15)

INTERNATIONAL SPHEROID PROJECTED AT LATITUDE 15

Discovery 210 Cruise Track

6 STATION POSITIONS AND CHART

The station positions and the cruise track are shown inTable 2 and Figure 2 respectively. Actual postion for each cast are documented in the Daily Scientific log (Section 7) and the CTD bottle spreadsheets to be provided by BODC.

TABLE 2
ARABESQUE 1 Station Positions

Station	Lat °N	Long °E	Location	Other inform	Depth (m)
GOM 1	025°59.8'	056°35.0'	Straits of Hormuz		112
GOM 2	024°49.3'	057°13.2'	G of Oman	CD 16 St 11	1255
GOM 3	024°20.0'	58°10.4'	G of Oman	CD 16 St 10	2853
GOM 4	23°55.0'	059°15.0'	G of Oman	CD 16 St 9	3328
GOM 5	022°39.4'	060°40.7'	G of Oman	CD 16 St 8	3173
GOM 6	021°15.5'	063°21.3'	G of Oman	CD 16 St 7	3325
AS 1	019°15.0'	058°35.4'	Oman Slope		2549
AS 2	019°16.5'	058°32.2'	Oman Slope		1206
AS 3	019°23.3'	058°20.6'	Oman Slope		484
AS 4	019°27.0'	058°14.6'	Oman Slope		200
AS 5	019°30.3'	058°09.1'	Shelf Masira Bay		50
A 1	019°00.0'	059°00.0'	N Arabian Sea	ARABESQUE Ref St	3397
A 2	017°30.0'	060°30.0'	N Arabian Sea		3914
A 3	016°02.2'	062°00.0'	N Arabian Sea	US-JGOFS long Time series	3927
A 4	014°00.0'	063°15.1'	N Arabian Sea		4040
A 5	012°00.0'	064°29.9'	C Arabian Sea		4211
A 6	010°14.0'	065°32.7'	C Arabian Sea		4386
A 7	008°00.0'	067°00.0'	C Arabian Sea	CD 16 St 3	4705
A 8	011°58.6'	067°00.0'	C Arabian Sea	CD 16 St 4	4207
A 9	014°20.0'	067°00.0'	C Arabian Sea	CD 16 St 5	3975
A 10	015°11.4'	064°30.2'	N Arabian Sea		3856

7 DAILY LOG OF SCIENTIFIC ACTIVITIES

All times are logged below in local ship time (Z+4h; *i.e.* GMT +4h)

SUNDAY 21 AUGUST

Air flight of ARABESQUE 1 scientists from London Heathrow to Muscat. Transfer to NOVOTEL Ruwi, Muscat.

MONDAY 22 AUGUST

Acclimation in Muscat, awaiting the return of Discovery 209

TUESDAY 23 AUGUST

Unload and transfer on board equipment, reagents, gear from two 40 foot containers on board Discovery. Return to Shore.

WEDNESDAY 24 AUGUST

Transfer ARABESQUE 1 scientists on aboard. Commence upacking and comissioning of equipment.

THURSDAY 25 AUGUST

Commission equipment, containers, CTD, winches for UOR & optics, gas lines, supply, non toxic seawater system, etc...Delivery of gas cylinders delayed by unschedule refit of container vessel. Secured local source of O_2 and on board H_2 for short term usage. Temperatures in Air conditioned General Purpose Laboratory for radiochemical were found to be soaring to 39 °C. Assessed as unsuitable for work at sea.

FRIDAY 26 AUGUST

Completed the shipboard commissioning of equipment. Survey of A/C Container by Omani A/C engineers identified the need for additional A/C.Delayed departure to Saturday. Visit by HM Ambassador R Muir and ADC to coordinate reception.

SATURDAY 27 AUGUST

Completed installation of A/C

1830 Discovery departed Muscat for Shakedown Station

2035 Arrive at Shakedown Station (23°49.0' N, 058°45.0' E; 2500m)

2201 Shakedown CTD cast No 'S' o/b down to 483 m
2319 i/b. Proceed toSt GOM 4

SUNDAY 28 AUGUST

0210 Arrive St GOM 4 (23°55.2' N, 59°13.4'E; 3328m)

0232 GOM 4/1 CTD biogeochemistry cast 0-300 m fired bottle # 1-12 at following depths : 5, 15,19, 40, 50, 75, 100, 160, 174, 216, 301 m. SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2, pCO_2 , micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass. i/b 0343

0458 GOM 4/2 CTD Production cast 0-50 m. i/b 0538

0626 GOM 4/3 CTD Production cast 0-50 m. i/b 0646
Deck Production incubations

0718 GOM 4/4 CTD Radiochemistry cast 0-500 m i/b 0812

0923 GOM 4/6 CTD Deep Biogeochemistry 0-3323m . 12 Bottles fired. O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass. i/b 1232

1412 depart Station GOM 4 to GOM 2, towing the UOR. with underway measurements passed over St GOM3 at 2100.r

MONDAY 29 AUGUST

0337 Recover UOR. i/b 0402

0420 Arrive Station GOM 2 (24°49.33'N, 57°13.2'E, 1255 m)

0430 GOM 2/1 CTD Productivity cast 0-40 m i/b 0459

0544 GOM 2/2 CTD Productivity cast 0-35 m i/b 0605
Deck Production incubations

0628 GOM 2/3 CTD Biogeochemistry deep cast 12 bottles fired.
SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass. i/b 0832

0903 GOM 2/4 Apstein net

0955 GOM 2/5 CTD Cast biogeochemistry cast aborted due to bottle missfire.

1044 GOM 2/6 stern cast for PML sensors optics

1146 GOM 2/7 CTD Biogeochemistry cast 12 bottles to 149 m .SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass i/o1217

1232 GOM 2/8 Stern deployment of MER optics

1318 GOM 2/9 CTD optics cast down top 50 m. i/b1341

1356 Depart St GOM 2 for St GOM 1, towing UOR.

2244 recover UOR

2334 Arrive at Station GOM 1 Straits of Hormuz (26°01.0' N, 056°35.0' E, 112 m)

TUESDAY 30 AUGUST

0008 GOM1/1 Zooplankton netting

0335 GOM1/2 CTD Production Cast 0-40 m i/b 0356

0412 GOM1/3 CTD Production cast 0-40 m i/b 0426

0445 GOM 1/4 CTD Production cast 0-10 m i/b 0452
Deck Production incubations
GOM 1/5 cancelled cast

0735 GOM 1/6 CTD Biogeochemistry cast 12 bottles to 87 m .SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths),TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass. i/b 0804

0905 GOM 1/7 CTD optics cast 0-40 m. 6 depths

1000 GOM 1/8 Stern cast of PML optics

1034 GOM 1/9 Stern cast of MER optics

1112 GOM 1/10 CTD SF6 cast

1146 Depart St GOM 1 for St GOM 3 towing UOR.

1424 UOR in board because ships speed was 8 kts, too slow for undulation

WEDNESDAY 31 AUGUST

0543 Arrive at Station GOM 3 (24°20.0' N, 58°10.4' E, 2853 m)

0735 GOM 3/1 CTD Biogeochemistry cast 12 bottles to 2848 m SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths),TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass

1029 Depart Station GOM 3 for Muscat anchorage towign UOR

1600 arrive at Port Sultan Qaboos; transfer of H_2 & O_2 cylinders.

1800 Depart Port Sultan Qaboos for GOM 5.

THURSDAY 1 SEPTEMBER

0431 Arrive Primary Production Station GOM 5A (22°54.8' N 60°07.9' E, 3146m)

0435 GOM 5A-1 CTD Production cast 0-50 m
Deck incubations
resume passage to St GOM 5

0800 Arrive Station GOM 5 (22°39.4'N 60°40.6'E, 3174 m)

0823 GOM 5/1 CTD Biogeochemistry cast 12 bottles to 3175m .SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths),TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass. i/b 1100

1110 GOM 5/2 Stern optics cast PML sensors

1149 GOM 5/3 Apstein net

1211 GOM 5/4 CTD Biogeochemistry cast 12 bottles to 200 m .SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths),TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass. i/b 1246

1302 GOM 5/5 Stern MER optics cast .

1350 GOM 5/6 CTD optics cast upper 40 m.

1644 Depart St GOM 5 for station GOM 6, towing the UOR

FRIDAY 2 SEPTEMBER

0349 Arrive at station GOM 6A UOR in board.

0404 GOM 6A/1 CTD production cast 0-30 m

0454 GOM 6A/2 CTD production cast 0-30 m
Deck incubations

0509 Depart for station GOM6 towing the UOR

1208 Recover UOR

1220 GOM 6/1 CTD Biogeochemistry cast 12 bottles to 300m .SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths),TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass

1334 GOM 6/2 Stern cast of the MER optics system; i/b 1359

1403 GOM 6/3 Stern cast of the PML optics systems i/b 1414

1425 GOM 6/4 CTD cast optics cast to 40 m i/b 1449

1508 GOM 6/5 Apstein Netting i/b 1519

1555 GOM 6/6 Deep CTD Biogeochemistry cast 12 bottles to 250-3298 m .SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths),TCO_2, pCO_2, micro-, nano- nutrients, DOC, methylamines, Pigments, AFC, microbiomass i/b1837

1934 GOM 6/7 Radiochemistry CTD to 500m. duplicate bottles fired at 500, 350, 250, 100, 75 m for ^{210}Pb. i/b 2036

2056 GOM 6/8 Radiochemistry CTD to 0-50m. duplicate bottles fired at 50, 30, 10, 5 m for ^{210}Pb. i/b 2113

2125 Depart GOM 6 for Reference Station ARABESQUE A1. Towing UOR.

SATURDAY 3 SEPTEMBER

0349 UOR i/b

0415 GOM 6B/1 CTD production cast 0-60 m
Deck incubation for primary production

0452 Resumed passage to A1 towing UOR

1644 haul in UOR for repairs to fairings

1906 Redeploy UOR

SUNDAY 4 SEPTEMBER

0426 UOR i/b

0504 A 1/1 CTD production cast to 41 m i/b 0533

0549 A 1/2 CTD production cast to 65 m i/b 0613

0618 A 1/3 Deploy primary production rig astern

0720 A1/4 Deploy Sediment trap to 100m with 3 daily collection cups set to start a 0600 5/9/94 and terminate 0600 8/9/94.

1018 A1/5 CTD optics cast i/b1105

1128 A1/6 Apstein netting to 50 m i/b 1208

1214 A1/7 Zooplankton net

1234 A1/8 .CTD Biogeochemistry cast to 300 m 12 bottles fired for SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano- nutrients, DOC, methylamines, Pigments, AFC, microbiomass i/b1321

1331 A1/9 stern PML optics cast i/b 1343

1347 A1/10 Stern MER optics cast i/b 1409

1507 A1/11 Deep CTD Biogeochemistsry cast 12 bottles 200-3387 m .SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano- nutrients, DOC, methylamines, Pigments, AFC, microbiomass i/b1745

1853 A1/12 Production Rig recovered and i/b

1959 Trap buoy found caught on PES FISH line on port-side.Haul in Pes & Trap Buoy, untangled, attached Strobe Light redeploy.

MONDAY 5 SEPTEMBER

0022 Zooplankton net WP 2 , twin cast to 100m

0304 A1/13 CTD Production cast 0-10m i/b 0325

0354 A1/14 CTD Production cast 5- 32 m i/b 0406

0426 A1/15 CTD Production cast 0-41 m, i/b 0439

0633 A1/16 Production rigs away.

1025 A1/17 Deep Radiochemical cast 250 - 3385 m i/b 1324

1348 A1/18 Stern deployment of MEL optics systems i/b 1409

1447 A1/19 Apstein cast to 50 m

1516 A1/20 CTD optics cast

1813 Production rig recoverd

1851 A1/21 SAPS pumping in upper water column 5, 10, 25, 50 m
SAPS i/b 2055

TUESDAY 6 SEPTEMBER

0447 A1/23 CTD Production cast to 40 m i/b 0506

0535 A1/24 CTD Production cast to 40 m i/b 0553

0611 A1/25 Deploy Primary Production rig

0637 A1/26 Deploy 4 SAPS to the 100, 200, 300, 500.m depths. i/b
SAPS i/b 11012

1124 A1/27 Stern deployment of MER optics, i/b 1151

1157 A1/28 Stern deployment of PML optis , i/b 1209

1223 A1/29 Apstein Netting to 50 m i/b 1231

1246 A1/30 CTD biogeochemistry 0-200 m cast .SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano- nutrients, DOC, methylamines, Pigments, AFC, microbiomass i/b1319

1445 A1/31 CTD optics cast down to 40 m depth i/b 1505

1627 A1/32 CTD Radionuclide cast upper 500 m i/b 1721

1810 Recovery of production rig

1944 A1/33 Deploy SAPS to depths of 600, 1520, 1600,2000m

WEDNESDAY 7 SEPTEMBER

0440 Final SAPS in board

0517 A1/34 CTD production cast to 41 m

0613 A1/35 CTD Production cast to 40 m

0644 A1/36 Production rig deployed

0700 A1/37 CTD time series (t0) at 5, 35, 50 m

0742 A1/38 30 l Goflow off Kevlar i/b 0757

0809 A1/39 CTD time series (t1) at 5, 35, 50 m

0914 A1/40 CTD N2O.CH4 cast jointly with Time series t(2) 1600 m, i/b1050

1112 A1/41 Apstein netting

1159 A1/42 CTD time series (t3)

1303 A1/43 Stern MER optics cast

1342 A1/44 Stern PML optics cast

1459 A1/45 CTD time series aborted t (4) electrical malfunction of CTD wire

1945 A 1/45 CTD trial deployment upper 50 m used for radio nuclide samples hove to by trap

THURSDAY 8 SEPTEMBER

0727 Recover Sediment Trap . In board at 0746 stram baack to original A1 position

1007 A 1/46 Trial CTD cast down to 100 m to check electrical terminations. Used for POC/N pigments studies.

0811 Deploy repaired PES fish echo sounding the Oman slope into Masira Bay.
Depart for Station AS1

1406 At St AS1 (19°15.0'N, 58°35.4'E, 2500m depth)

1415 AS 1/1 CTD Biogeochemistry cast upper 200 m. SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths), TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass i/b 1517

1532 AS 1/2 stern MER optics cast

1607 AS 1/3 stern PML optics cast

1627 AS 1/4 CTD optics cast down to 40 m

AS 4|5.

1707 Deep CTD Biogeochemistry cast to 2474 m 12 bottles fired. SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths), TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, pigments, AFC, i/b 1918

1918 departed for St AS2

1958 At St AS 2 (19°16.5'N, 58°32.2'E; 1200m)
hove to

FRIDAY 9 SEPTEMBER

0436 AS 2/1 CTD production cast 40 m

0528 AS 2/2 CTD production cast 31 m

0634 AS 2/3 CTD biogeochemistry cast to 1200 m SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths), TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass

0808 AS 2/4 Apstein net.
depart for AS 3

0936 At St AS 3 (19°23.6'E, 058°20.5'E, 500 m)

1016 AS 3/1 Stern PML optics cast

1036 AS 3/2 Stern MER optics cas

1115 AS 2/3 CTD optics cast to 35 m

1149 AS 3/4 CTD biogeochemistry cast to 474 m depth SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths), TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass i/b 1256

1313 AS 3/5 Apstein net to 50 m

1319 depart for Station AS 4

1438 At St AS 4: (19°27.0' N, 58°14.6' E, 200 m)

1438 AS 4/1 Stern PML optics cast

1456 AS 4/2 Stern MER optics cast

1535 AS 4/3 CTD Radionuclide cast to 150 m

1628 AS 4/4 CTD biogeochemistry cast to 145 m SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths), TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass

1656 departed for AS 5

1800 At St AS 5. (19°30.3'N, 58°09.1' E, 50m)

1808 AS 5/1 CTD Biogeochemistry cast to 6 depths. SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths), TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass

hove to vernight at AS 5

SATURDAY 10 SEPTEMBER

0432 AS 5/2 CTD production cast to 25 m

0504 AS 5/3 CTD production cast 25 m

0818 AS 5/4 optics cast

0836 depart St AS 5 for station AS2
deployed UOR for 50 undulations, start underway measurements

1146 UOR recovered, reset and redeployed for 100 m undulations
resumed passage to A 2.

SUNDAY 11 SEPTEMBER

0327 Recover UOR

0357 at Station A 2 (17°30' N, 60°30.0' E, 3914 m)

0502 A 2/1 CTD production cast to 40 m
Deck incubations

0601 A 2/2 CTD Deep (207-3929 m) Biogeochemitsry cast : SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths), TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, Pigments, AFC, microbiomass

0904 A 2/3 twin Apstein net to 50 m

1053 A 2/4 CTD Shallow Biogeochemistry cast 0-207 m SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths), TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1300 Depart A 2 for A 3, deploying UOR resumimng underway measurements.

MONDAY 12 SEPTEMBER

0058 Arrive at Station A3 (16°06'N, 62°00'E, chart depth 3900m)
UOR inboard

0135 A3/1 CTD profile for trap.

0214 Deployed Sediment Trap at 120 m o/b 0238

0315 A3/2 Goflo cast

0333 A3/3 CTD Production cast to 26 m

0407 A3/4 CTD Production cast to 33 m

0435 A3/5 CTD Production cast to 34 m

0507 A3/6 CTD Production cast to 100 m

0549 A3/7 Goflo cast

0600 A3/8 Goflo cast

0622 A3/10 Deploy production rig

1055 A3/11 Stern optics cast using PML sensors

1119 A3/12 Stern optics cast MER sensors

1254 A3/13 CTD optics sampling down to 99m

1403 A3/15 Apstein net

1412 A3/16 Zooplankton cast (Red colonial jelly like material found)

1503 A3/17 CTD Radiochemistry cast 2 bottles at each of 6 depths down to 500 m

1803 Recovered Production Rig

1943 A3/18 Deployed SAPS to 500 m; i/b 2317

2338 A3/19 Apstein net

TUESDAY 13 SEPTEMBER

0435 A3/20 CTD production rig down to 60 m

0608 A3/21 Deployed production rig

0633 A3/22 CTD Radiochemical cast sampling 2 bottles at 6 depths between 1000 m and 3931 m; i/b 0931

1006 A3/23 CTD Shallow Biogeochemistry cast 0-300 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1100 A3/24 Stern cast PML optics

1118 A3/25 Stern cast MER optics

1235 A3/26 CTD Optics cast down to 38 m

1305 A3/27 Apstein cast

1328 A3/28 CTD Dee Biogeochemistry cast 132-3931 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass. i/b 1634

1743 Recover Production rig

1829 A3/29 SAPS & pinger cast ; 4 SAPS pums down to

WEDNESDAY 14 SEPTEMBER

0309 SAPs all inboard

0345 A3/30 CTD Productivity cast to 40 m

0410 A3/31 Goflo bottle cast

0423 A3/32 CTD Productivity cast to 60 m

0447 A3/33 Goflo cast

0454 A3/34 Goflo cast

0504 A3/35 CTD Productivity 7 Time series #1 cast to 9 m

0622 A3/36 Productivity rig deployed

0730 A3/37 CTD Time series # 2 , 3 depths

0819 A3/38 CTD time series #3 + denitrification cast down to 1000m

1042 A3/39 Apstein nets

1128 A3/40 CTD time series # 4

1303 A3/41 CTD Shallow Biogeochemistry cast 0-300m SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1400 A3/42 Stern optics cast PML sensors

1420 A3/43 Stern optics casts MER sensors

1527 A3/44 CTD optics + time series # 5 to 40 m depth

1727 A3/45 CTD Radi0chemistry + time series #6. to 50 m depth

1813 Recover Production rig

1905 A3/46 SAPS pumps overboard down to depths of 200 m

THURSDAY 15 SEPTEMBER

0448 A3/47 CTD Production cast tp 60 m

0530 A3/48 CTD Production cast to 14 m

0605 A3/49 Deploy production rig

1000 A3/50 Stern optics cast PML sensors

1024 A3/51 Stern optics cast MER sensors

1121 A3/52 CTD optics cast down to 101 m

1203 A3/53 SAPS deployment to a depth of . i/b 1450

1559 Recovered Sediment Trap

1619 A3/55 Apstein net

1742 Recovered Production Rig

1754 Depart St A3 for A4, deploying UOR. commence underway measurements

FRIDAY 16 SEPTEMBER

0542 Recover UOR,

0640 At station A4 (14°00' N, 63°15.1' E, 4040 m)

0715 A4/1 CTD Shallow Biogeochemistry ABORTED

0803 A4/2 CTD Shallow Biogeochemistry cast 0-250 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, methylamines, pigments, AFC, microbiomass

0943 A4/3 CTD Deep Biogeochemistry cast 249-4051m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1247 Depart ST A4, deploy UOR commence underway measurements

SATURDAY 17 SEPTEMBER

0200 Recover UOR

0241 at St A5

0318 A5/1 CTD Production cast to 44 m

0348 A5/2 Goflo cast

0359 A5/3 CTD Production cast to 101 m

0428 A5/4 Goflo cast

0436 A5/5 Goflo cast

0446 A5/6 CTD Production cast to 25 m

0606 A5/7 Production rig deployed

0758 A5/8 CTD Shallow Biogeochemistry cast 0-301 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

0946 A5/9 CTD Deep Biogeochemistry cast 301-4210 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1312 A5/10 Stern optics cast PML sensors

1331 A5/11 Stern optics cast MER sensors

1405 A5/12 CTD optics cast to 40 m

1442 A5/13 Apstein net

1500 A5/14 CTD Radiochemistry cast 2 bottles at six depths to 500 m

1615 A5/15 CTD Radiochemistry cast 2 bottles at 4 depths to 50 m

1745 Production Rig recovered

1802 Depart St A5 for A6, twoing UOR and commeced underway measurements

SUNDAY 18 SEPTEMBER

0439 Recover UOR

0459 At St A6 (10°14.0' N, 65°32.7' E; 4386 m)

0511 A6/1 CTD Production cast to 60 m

0650 A6/2 CTD Shallow Biogeochemistry cast 0-198 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

0811 A6/3 CTD Deep Biogeochemistry cast 200-4406 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1143 A6/4 Apstein net

1200 Depart St A6 for A7, deploy UOR, and underway measurements.

MONDAY 19 SEPTEMBER

0200 Recover UOR

0230 At Station A7 (008°00.0' N, 067°00.0' E; 4605 m)

0242 A7/1 CTD profile for trap

0338 A7/2 Deployed sediment trap , single cup, three days

0439 A7/3 CTD Producton cast to 100m

0551 A7/4 Deploy productivity rig

0616 A7/5 CTD Shallow Biogeochemistry cast 0-301 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

0821 A7/6 CTDDeep Biogeochemistry cast 300-4628 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1216 A7/7 Apstein net

1232 A7/8 Apstein net

1253 A7/9 Zooplankton net

1315 A7/10 Zooplankton net

1352 A7/11 Stern optics cast using MER sensors

1418 A7/12 Stern optics cast using PML sensors

1541 A7/14 Radiochemistry cast , two bottle at each of six depths to 500m

1757 Recovered Production rig

1858 A7/15 commence deploying SAPS to mid depths:
recovered i/b 2231

2335 A7/16 Apstein net

2356 A7/17 Zooplankton

TUESDAY 20 SEPTEMBER

0226 A7/18 CTD Production cast to 151 m

0258 A7/19 Goflo cast

0312 A7/20 CTD Production cast to 76 m

0335 A7/21 Goflo cast

0343 A7/22 Goflo cast

0355 A7/23 Production cast to 11 m

0538 A7/24 Production rig deployed

0821 A7/25 CTD Radiochemical Deep six bottles 1000-4637 m

1239 A7/26 CTD High resolution Shallow Biogeochemistry cast 0-181 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1326 A7/27 Stern optics cast PML sensors

1345 A7/28 Stern optics cast MER sensors

1425 A7/29 CTD Optics cast to 60 m

1507 A7/30 CTD high resolution Biogeochemistry cast 0-100 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , miero-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1751 Recovery of Production Rig

1820 A7/31 Commence deployment of SAPS
recovery complete 0325

WEDNESDAY 21 SEPTEMBER

0409 A7/32 Production cast to 75 m

0450 A7/33 Goflo cast

0501 A7/34 Goflo cast

0546 A7/35 Production rig deployed

0555 A7/36 CTD Time series #1 at 5, 10, 15 m

0800 A7/37 CTD Time series # 2 + Radiochemistry cast to 50 m

0906 A7/38 CTD time series #3 and nitirification cast to 1000m

1102 A7/39 two Zooplankton casts

1137 A7/40 Apstein net

1200 A7/41 CTD High resolution Shallow Biogeochemistry & time series # 4 cast 0-100m SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1237 A7/42 Stern optics PML sensors

1301 A7/43 Stern optics MER optics

1421 A7/44 CTD proflie with PML sensors on rosette

1439 A7/45 CTD optics bottle + time series # 5 cast 120 m

1615 A7/46 CTD time series #6

1730 Reover Production rig

1744 A7/47 CTD time series #7

1854 A7/48 commence SAPS deployment to m; completed by 2040.

THURSDAY 22 SEPTEMBER

0432 A7/49 Productcion cast to 75 m

0551 A7/50 Deploy Production Rig

0916 A7/51 Deploy Zodiak for sampling airsea interface simulataneously as A7/52

0934 A7/52 High resolution shallow Biogeochemistry cast 0-161 m SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1034 Zodiak recovered

1104 A7/53 Zooplankton net

1124 A7/54 Apstein net

1345 Recovered Sediment Trap

1404 Test tow of New UOR body

1727 Recovered Production rig
Commence Rest and Recreation period
depart St A7 for A8

FRIDAY 23 SEPTEMBER

Rest & Recreation in passage to A8

SATURDAY 24 SEPTEMBER

0342 At St A8 (11°58.6' N, 67°00' E, 4207 m)

0514 A8/1 CTD Production cast to 75 m Deck incubation

0623 A8/2 CTD Deep Biogeochemistry cast 300-4204 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1006 A8/3 Apstein net

1115 A8/4 CTD optics cast to 50 m

1204 A8/5 CTD Shallow Biogeochemistry cast 0-300 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1302 A8/6 Stern optics cast PML sensors

1315 A8/7 Stern optics cast MER sensors

1340 Depart ST A 8 for St A9 towing the UOR

SUNDAY 25 SEPTEMBER 1994

0232 Recovered UOR

0301 At St A9 (14°20.0' N, 67° 00' E; 3975 m)

0303 A9/1 CTD Production cast to 150 m

0335 A9/2 Goflo cast

0349 A9/3 CTD Production cast to 63 m

0409 A9/4 Goflo cast

0425 A9/5 Goflo cast

0437 A9/6 CTD Production cast to 10 m

0552 A9/7 Production rig deployed

0608 A9/8 CTD High Resolution Midepth Biogeochemistry cast 140-402 m SF_6, CO,O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

0756 A9/9 CTD Radiochemistry & denitrification cast two bottles at six depths down to 500 m

0932 A9/10 CTD Radiochemistry cast & denitrification cast to 50 m

1031 A9/11 CTD optics cast to 40 m depth

1109 A9/12 Stern optics cast PML sensors

1138 A9/13 Stern optics cast MER sensors

1240 A9/14 CTD High Resolution Shallow Biogeochemistry cast 0-140 m SF_6, CO, O_2, N_2O/CH_4 ,, DMS, (scl depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1355 A9/15 Apstein net

1412 A9/16 Zooplankton net

1429 A9/17 Zooplankton net

1605 A9/18 CTD profiling (no bottles)

1755 Reovered Primary production rig

1804 A9/19 CTD profiling (no bottles)

2357 A9/20 Zooplankton net

MONDAY 26 SEPTEMBER

0455 A9/21 CTD Production cast 75 m Deck incubation

0522 A9/22 CTD Deep Biogeochemistry cast 360-4001 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

0948 Surface CTD unscheduled (C Law)

0957 Departed St A9 for A10 twoing UOR

TUESDAY 27 SEPTEMBER

0036 Recover UOR

0200 At Station A10 (15°10.7' N, 64° 30.7E; 3856)

0427 A10/1 CTD Production cast to 40 m Deck Incubation

0516 A10/2 CTD production cast to 10 m for TCO2 incubation

0541 A10/3 CTD Deep Biogeochemistry cast 300-3852 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass. 0832 i/b

1026 A10/4 Stern optics cast using PML sensors

1046 A10/5 Stern optics cast using MER sensors

1121 A10/6 CTD optics cast down to 23 m

1212 A10/7 CTD Shallow Biogeochemistry cast 4-330 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass i/b 1251

1320 Depart Station A10 for A3, towing UOR

WEDNESDAY 28 SEPTEMBER

0247 UOR inboard

0256 A3/56 CTD Production cast to 152 m

0342 A3/57 Goflo CTD cast

0357 A3/58 CTD Production cast to 42 m

0424 A3/59 Goflo bottle cast

0431 A3/60 Goflo bottle cast

0439 A3/61 CTD Production cast to 12 depth

0602 A3/62 Production rig deployed

0623 A3/63 CTD Deep Biogeochemistry cast 232-3935 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass; i/b 0931

1046 A3/64 Stern Optics cast using PML sensors

1106 A3/65 Stern optics cast using MER sensors

1139 A3/66 CTD optics cast to 21 m

1257 A3/67 CTD Shallow Biogeochemistry cast 5-199 m SF_6, CO, O_2, N_2O/CH_4 , DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1340 A3/68 Apstein netting

1409 A3/69 Zooplankton netting

1733 Recover Productivity rig

1812 Depart St A3 towin UOR towards A2

THURSDAY 29 SEPTEMBER

0430 Recover UOR

0540 A2/5 Production cast ; aborted CTD cable failure

0958 A2/6 Stern optics cast PML sensors

1016 A2/7 Stern optics cast MER sensors

1052 A2/9 Apstein netting

1220 A2/10 CTD Shallow Biogeochemistry cast 3-300 m SF_6, CO, O_2, N_2O/CH_4 DMS, (sel depths),TCO_2 , pCO_2 , micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomas

1324 Depart St A2 for A1 towing UOR

FRIDAY 30 SEPTEMBER

0103 Recover UOR

0231 A1/47 CTD Production cast to 35 m

0308 A1/48 Goflo bottle cast

0311 A1/49 CTD Procudtion cast to 21 m

0342 A1/50 Goflo bottle cast

0349 A1/51 Goflo bottle cast

0400 A1/52 CTD Production cast to8m

0519 A1/53 Production rig deployed

0545 A1/55 CTD Deep Biogeochemistry cast 149-3395 m SF_6, CO, O_2, N_2O/CH_4, DMS, (sel depths),TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass; i/b 0827

0934 A1/55 Apstein netting

1022 A1/56 Stem optics cast using PML sensors

1041 A1/57 Stem optics cast using MER sensors

1126 A1/58 CTD optics cast to 22 m

1258 A1/59 CTD Shallow Biogeochemistry cast 5-150 m SF_6, CO, O_2, N_2O/CH_4 DMS, (sel depths),TCO_2, pCO_2, micro-, nano-nutrients, DOC, methylamines, pigments, AFC, microbiomass

1813 Recover Productivity Rig

Proceed overnight to Shelf station AS5

SATURDAY 1 OCTOBER

0735 Deploy UOR undulating to 40 m then adust later to 85 m

1321 UOR inboard at St A1

1409 A1/60 Goflo bottle cast

1414 A1/61 Zooplankton net

1437 A1/62 Zooplankton net

END OF SCIENTIFIC SAMPLING FOR ARABESQUE 1

Hove at St A1; processing sample backlog and completing data reports

TUESDAY 3 OCTOBER

1000 returned to Mina Qaboos, Muscat tuesday 1000

Unloaded and stored equipment ashore for ARABESQUE 2

8 INDIVIDUAL SCIENTIFIC REPORTS

Biogeochemistry

7.1	Micro- and Nanonutrients.	M Woodward and A Rees
7.2	Discrete Oxygen.	J Dixon
7.3	Spatial Distribution of methylamines andammonia	S W Gibb
7.4	Biogoenic Sulphur Compounds	A Hutton
7.5	Dissolved Organic Carbon and Nitrogen	A E Miller
7.6	Sicreet pCO_2 and TCO_2	S Knox
7.7	CO and SF_6 traces	C Law
7.8	N_2O and Methane profiles	R U-Goddard & N Owens

Microbiology

7.9	14C production, size, light, deck & *in situ*	G Savage, A Pomroy, B Irwin,
7.10	Net & Gross production	C Robinson, J Dickson
7.11	Assimilation of nitrogen by phytoplankton	N J P Owens
7.12	Flow cytometric analyses of phytoplankton &grazing	P H Burkill
7.13	Chlorophyll and carotenoid pigments	R Barlow
7.14	Bacterial numbers and heterotrophy	A Pomroy
7.15	Microzooplankton community	C Stelfox
7.16	Microzooplankton herbivory	E Edwards

Particle fluxes & optics

7.17	Goechronology & particle Residence times	J Smith
7.18	Vertical fluxes from Sediemnt Traps and SAPS	T Fileman
7.19	Undulting Oceanographic Recorder operations	I Belland & C Trees
7.20	Bio-optical variablility	C Trees

9 ACKNOWLEDGEMENTS

I would like to thank the Captain, Capt K Avery, his officers and crew for an excellent support and scientific service at sea. The catering staff laid on an excellent reception on board for welcoming the Omani VIP's and HM's Ambassador. We are grateful for the professional support regarding winching and computer and sensor systems for the CTD. The Research Vessel Base provided the logisitical life line for this expedition. We would like tothank NERC, MOD, PRIME and our overseas colleagues for their contributions to the science and funding this exhilirating and successful cruise.

CRUISE REPORT. RRS DISCOVERY CRUISE 210.
INDIAN OCEAN: ARABESQUE I.
27th AUGUST - 4th OCTOBER 1994.

MICRO AND NANO NUTRIENT SPECIES

MALCOLM WOODWARD and ANDY REES.
PLYMOUTH MARINE LABORATORY.

OBJECTIVES

To investigate the nutrient regimes of the oceanic upwelling area off the coast of Oman, in the Arabian Sea, during the south west monsoon season.
To investigate spatial and temporal variations within the coastal region, and to follow an offshore transect towards the offshore deep ocean oligotrophic area.
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, Ammonia and Urea. A new semi-continuous fluorescence analytical technique was employed for ammonia, capable of nanomolar detection levels, due to ammonia being undetectable for most samples by the colorimetric system. Where the water was oligotrophic a nanomolar chemiluminescent analysis sytem for nitrate and nitrite was employed.
All analysis methodologies and detailed in 'Nutrient Analysis Techniques', June 1994, (EMS Woodward).
Analyses were carried out for CTD profiles, and for underway continous transects.

SAMPLES ANALYSED

Discrete Nutrients were analysed for the following CTD stations:

SHAKEDOWN 12 depths: 5-445 m	A3/21, Shallow, 12 depths, 5-300m
GOM - 4 Shallow, 12 depths: 5-301 m	A3/28, Deep, 12 depths, 132-3931m
GOM - 4, Production: 10 depths: 3-40m	A3/30, Production14/9, 10 depths, 0-60m
GOM - 4, Deep,12 depths: 220 - 3323m	A3/41, Shallow, 12 depths, 4-300m
GOM - 2, Production: 10 depths, 0-40m	A3/48, Production15/9, 10 depths, 0-60m
GOM - 2, Deep. 12 depths, 100-1246m	A3/53, 8 depths, 0-70m
GOM - 2, Shallow, 12 depths, 5-149m	A4/1, Shallow, 12 depths, 3-250m
GOM - 1, Production, 10depths, 3-40m	A4/2, Deep, 12 depths, 249-4051m
GOM - 1, 12 depths, 0-87m	A5, Production, 10 depths, 5-100m
GOM - 3, 12 depths, 7-2848m	A5/8, Shallow, 12 depths, 5-301m
GOM - 5A Production, 10 depths, 3-41m	A5/9, Deep, 12 depths, 301-4210m
GOM - 5, Deep, 12 depths, 100-3175m	A6/2, Shallow, 12 depths, 3-198m
GOM - 5, Shallow, 12depths, 3-83m	A6/3, Deep, 12 depths, 200-4406m
GOM - 6A, Production, 10 depths, 0-30m	A7/3, Production, 10 depths, 0-100m
GOM - 6, Shallow, 12 depths, 10-300m	A7/5, Shallow, 12 depths, 10-301m
GOM -6, Deep, 250-3298m	A7/ ,Deep, 12 depths, 300-4628m
GOM - 6B, Production, 10 depths, 3-58m	A7/ , Production20/9, 10 depths, 3-76m
A1/1, Production, 10 depths, 4-41m	A7/26, High Resolut, 12 depths, 5-181m
AI/8, Shallow, 12 depths, 4-299m	A7/32, Production21/9, 10 depths, 0-75m

A1/11, Deep, 12 depths, 200-3387m	A7/ , High Res.21/9, 12 depths, 5-100m
A1/ , Production(5/9), 10 depths, 1-40m	A7/ , Production22/9, 10 depths, 0-75m
A1/20, 8 Depths, 4-101m	A8/1, Production, 10 depths, 0-75m
A1/23, Production, 10 depths, 0-40m	A8/2, Deep, 12 depths, 300-4204m
A1/34,Production, 10 depths, 1-40m	A8/ , Shallow, 12 depths, 4-300m
A1/42, 12 depths, 4-299m	A9/1, Production, 10 depths, 0-75m
AS1/1, Shallow, 12 depths, 3-219m	A9/8, Mid depth, 12 depths, 140-402m
AS1/5, Deep, 12 depths, 201-2474m	A9/14, Shallow, 12 depths, 3-140m
AS2/1, Production, 10 depths, 4-40m	A9/21, Production26/9, 10 depths, 0-75m
AS2/3, 12 depths, 11-1200m	A9/22, Deep, 12 depths, 360-3980m
AS3/4, 12 depths, 3-474m	A10/1, Production, 10 depths, 1-40m
AS4/2, 12depths, 5-145m	A10/3, Deep, 12 depths, 300-3852m
AS5/1, 6 depths, 5-42m	A10/7, Shallow, 12 depths, 4-300m
AS5/ .Production(10/9), 10 depths, 1-25m	A3/56, Production, 10 depths, 1-50m
A2/1, Production, 10 depths, 0-40m	A3/ , Deep, 12 depths, 232-3935m
A2/2, 12 depths, 207-3929m	A3/67, Shallow, 12 depths, 5-199m
A2/3, 12 depths, 5-208m	A2/10, Shallow, 12 depths, 3-300m
A3/ , Production, 9 depths, 0-33m	A1/47, Production, 10 depths, 1-35m
A3/10, 10 depths, 3.5-99m	A1/54, Deep, 12 depths, 149-3394
A3/18, Production13/9, 10 depths, 0-60m	A1/55, Shallow, 12 depths, 1-150m

Continuous underway analysis was carried out over the following periods:

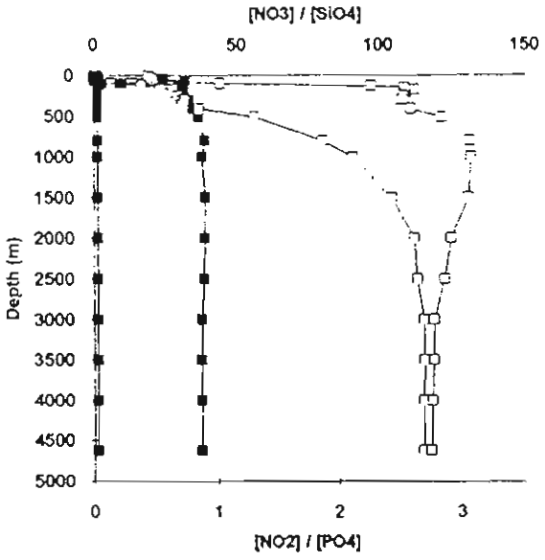
Start date/time	End date/time	Between stations
28/08 - 1311	29/08 - 0015	GOM4 - GOM2
30/08 - 1032	31/08 - 0350	GOM1 - GOM3
02/09 - 1745	03/09 - 0000	GOM6 - GOM6B
03/09 - 0223	03/09 - 2313	GOM6B - A1
10/09 - 0352	10/09 - 2343	AS5 - A2
15/09 - 1342	16/09 - 0230	A3 - A4
17/09 - 1307	18/09 - 0030	A5 - A6

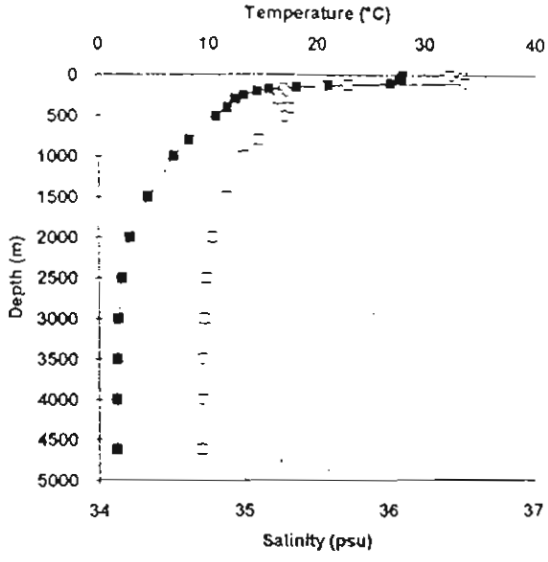
RESULTS

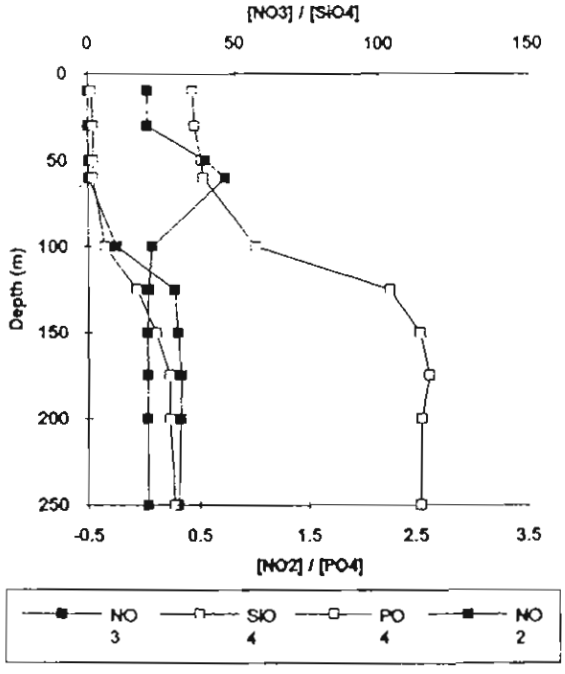
The initial conception for this first Arabesque cruise was that there would be the highly nutrient enriched coastal region off the coast of Oman, extending off shelf but that fairly soon the deeper waters of 4000m would provide the more stable water columns and that analysing along the offshore transect the surface nitrate and phosphate would become deplete as we surveyed into oligotrophic waters. The initial upwelling region at station A1was as expected with nutrient rich upwelled water and surface nitrate concentrations of 4.5umoles, and phosphate of 0.75 umoles, however, as we surveyed along the transect offshore the surface nitrate and phosphate stayed high well offshore. The concentrations only started to fall markedly beyond A3, and that only when beyond station A6 did the surface nitrate really become depleted to the 20 nanomolar levels exhibited at A7 (see diagram). The station at A7 was not classically oligotrophic as the phosphate concentration at the surface was still as high as 0.45 umoles, probably indicating that the area is only becoming oligotrophic following the south west monsoon season. Silicate concentrations at A7 show a classical profiile with high bottom water concentrations of 115 umoles, reducing up through the water column to surface levels of

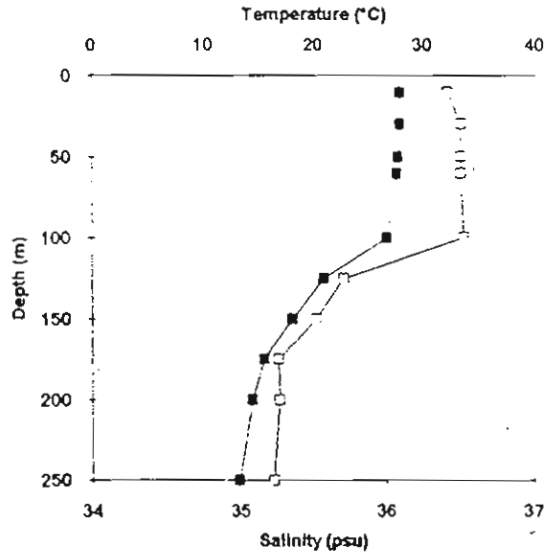
1.16umoles. There was a nitrite maximum at the thermocline, due to nitrification or nitrate reduction processes, at A7 and at most other stations At A7 there was no ammonia maximum, but at other stations, eg A2 there was a large ammonia peak in the water column above the nitrite maximum, correlated to the fluorescence maximum, but its biological or chemical origins are not known as yet. The high nutrient concentrations out into this area of the Arabian Sea demonstrate the large effect that the upwelling area off the Omani coast has upon the whole sea area. It is to be expected that when we return for Arabesque 2, that the monsoonal upwelling effect will have subsided and the offshore area will be classically nutrient deplete in the surface mixed waters.

The survey of the Gulf of Oman exhibited warm nutrient deplete surface water of 20-30 nanomoles of nitrate and phosphate of 0.17umoles, with a very sharp nutricline with nitrate increasing 0.67 to 7.3 umoles within 3 meters at the GOM1 station at the Straits of Hormuz. There was a mid water nitrate maximum of 11umoles at 50 umoles then bottom waters of 6umoles. The transect south east through GOM2 to GOM4 should similar profiles with nitrate deplete surface waters, a sharp thermocline and nitricline, and bottom waters of 38-38umoles. However at GOM5 we had entered the influence of the coastal upwelling area and the nitrate increased to 0.27umoles and phosphate to 0.45umoles. The further transect from GOM6 to A1 through the upwelling exhibited the great variation of the nutrient regime within this area as the nutrients varied along with the salinity, temperature and fluorescence.









Arabesque I. Station 7 - all nutrient concentrations in µmol/L

CRUISE REPORT. RRS DISCOVERY 210

Indian Ocean ARABESQUE 1

27th August - 4th October 1994

Discrete Oxygen Analysis

Joanna Dixon

Plymouth Marine Laboratory

OBJECTIVES

1) To implement the high precision Micro-Winkler method for determination of dissolved oxygen, mapping the vertical and on shelf distribution as a function of monsoonal forcing.

2) To intercalibrate oxygen data analysed by Micro-Winkler technique with that observed from CTD oxygen electrode.

OVERALL PROGRESS

The analysis of discrete oxygen concentrations have been sucessfully completed for all the following ARABESQUE 1 stations; GOM1-6, AS1-5 and A1-9 (for details see Table 1). The method employed was one based on the Winkler titration as first proposed by Winkler (1888). The technique is based on the following principle : The physically dissolved oxygen in a measured amount of seawater is chemically bound by adding Manganese (11) Hydroxide in a strongly akaline medium (1 ml of both Manganous Sulphate and alkaline sodium iodide ions are added to the sample). The Manganese (Mn) (11) is oxidised to Mn(111). i.e. A heterogeneous reaction occurs whereby the precipated Mn(11) Hydroxide reacts with the dissolved oxygen effectively trapping all the bio-gas in the bottle once stoppered and shaken. Due to the instability of Mn(11) in an alkaline medium, the hydroxide is oxidised easily and the reaction is quantitative in the analytical sense. The sample is then acidified with sulphuric acid. The precipitate dissolves and Mn(11) ions are liberated, which in an acidic media oxidises the previously added iodide ions to iodine whereupon the following disproportionation reaction occurs:

$I_2 + I^- \longleftrightarrow I_3^-$

The iodine is then determined by titration with sodium thiosulphate. It is therefore necessary to know the concentration of thiosulphate precisely in order to be able to back calculate the amount of dissolved oxygen in the seawater sample. This is achieved by titration of the thiosulphate solution with potassium iodate which is a recognised primary analytical standard. Three concentrations of thiosulphate were required due to the vast ranges in dissolved oxygen concentration encountered in the water column throughout the Arabian Sea i.e. from hypoxic to saturated conditions. These were re-standardised approximately once a week to account for any potential changes due to evaporation etc. However in practice these were found to be very marginal.

Oxygen concentrations have been tabulated in umol l-1 and presented along with % saturation, apparant oxygen utilisation (AOU), in-situ temperature and salinity, to be lodged at Bidston. The calculated wide range of AOU's encountered in the Arabian Sea are to be correlated with dissolved organic carbon (DOC) analysed by Axel Miller utilising the High Temperature Catalytic Oxidation system (HTCO).

A sucessful intercalibration exercise was completed between discrete oxygen concentration as analysed by micro-winkler titration and CTD oxygen electrode, yielding the following calibration equation:

$O2(uM) = 124.9\ (CTD\ mV) + 0.71$ (R2=0.996)*

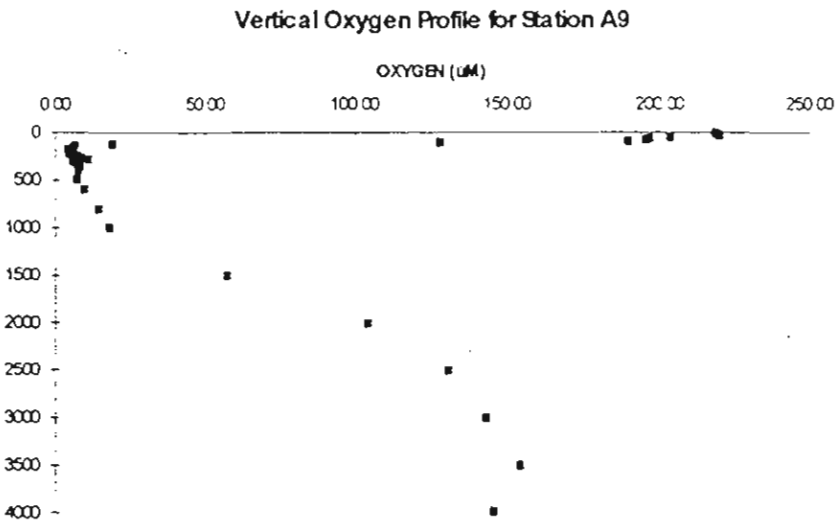
* This equation is only an approximation and should not be used to quote absolute values.

PRELIMINARY RESULTS

The initial cruise track took us up into the Gulf of Oman where typical surface oxygen concentrations were supersaturated (194 - 196 umol l-1). The Straits of Hormuz representing the most northern end member of the track demonstrated no apparant hypoxic layer but similiar surface ranges in oxygen concentration. However, by station GOM2 (24^0N, 57^0E) typical O_2 values of <10% saturation were observed to start at between 250-300m and extend virtually down to the sea bed. The deeper waters of GOM6 (21^0N, 63^0E) showed a broad layer of no apparant dissolved oxygen between 75 and 1500m, with deep water recovery to near 35% saturation (131uM) at a depth of 3900m. The linear stretch of the track from station A1 (19^0N, 60^0E) to A7 (8^0N, 67^0E) showed a gradual thinning of the hypoxic layer i.e. Oxycline deepened from 60m at A1 to 100m at A7 with coresponding decrease in vertical extent. Having occupied the most southerly of our stations we turned North from A7 and headed up towards A9 (14^0N, 67^0E) which we anticipated to be important in terms of denitrification rates. Here the oxycline commenced at 100m and continued down the water column to 1500m with subsequent

recovery (See Figure 1). Surface waters showed pronounced supersaturation values of up to 108% in the top 30m with deep water regeneration of up to 40% (145 uM) saturation at 3900m.

Figure 1



When oxygen concentrations are less than 10% of the saturation value the Winkler method used is imprecise where likely atmospheric contamination can be a serious problem. Therefore, limiting the lower detection value to approximately 20uM (i.e. 10% satutration).

TABLE 1

OXYGEN DATA ARABESQUE 1

The following table summarises all stations sampled for discrete oxygen analysis by Micro-Winkler Titration.

DATE	STATION	CAST#	POSITION		DESCRIPTION
			LAT	LONG	
26/8/94	SHAKEDOWN	1			
30/8/94	GOM 1-6	16	26 00	56 35	Straits of Hormuz
	GOM 1-10	18			Repeat Cast
29/8/94	GOM 2-3	9	24 82	57 22	Deep Cast
	GOM 2-7	11			Shallow
31/8/94	GOM 3-1	19	24 33	58 16	Deep
27/8/94	GOM 4-1	2	23 55	59 18	Shallow
	GOM 4-5	6			Deep
1/9/94	GOM 5-1	21	26 58	60 67	Deep
	GOM 5-4	22	22 67	60 71	Shallow
2/9/94	GOM 6-1	26	21 16	63 21	Shallow
	GOM 6-6	28			Deep
8/9/94	AS1-1	55	19 25	58 59	Shelf Stations
	AS1-5	57			
9/9/94	AS2-3	60	19 28	58 54	
	AS3-4	62	19 39	58 34	
	AS4-4	64	19 46	58 24	
	AS5-1	65	19 51	58 51	
4/9/94	A1-8	35	18 98	59 98	Shallow
	A1-11	36			Deep
6/9/94	A1-30	44	18 93	58 94	Shallow
7/9/94	A1-42	52			Shallow
11/9/94	A2-2	70	17 79	60 21	Deep
	A2-4	71			Shallow
13/9/94	A3-23	81	15 99	62 11	Shallow
	A3-28	83			Deep
14/9/94	A3-41	90	15 92	62 19	Shallow
16/9/94	A4-2	97	14 00	63 25	Shallow
	A4-3	98			Deep
17/9/94	A5-8	102	11 55	64 27	Shallow
	A5-9	103			Deep
18/9/94	A6-2	108	10 20	65 56	Shallow
	A6-3	109			Deep
19/9/94	A7-5	112	7 98	67 02	Shallow
	A7-6	113			Deep
20/9/94	A7-30	122	7 89	67 18	High Resolution/Shallow
24/9/94	A8-2	134	12 02	66 99	Deep
	A8-5	136			Shallow
25/9/94	A9-8	140	14 33	67 00	High Resolution/Mid-depth
	A9-14	144			High Resolution/Shallow
	A9-22	148			Deep
27/9/94	A10-3	151	15 20	64 51	Deep
	A10-7	153			Shallow
28/9/94	A3-63	157	16 12	62 00	Deep
	A3-67	159			Shallow

29/9/94	A2-10	163	17 24	60 36	Shallow
30/9/94	A1-54	167	18 97	59 02	Deep
	A!-55	169			Shallow

TABLE 2

IN SITU RIG STATIONS (Oxygen Respiration, Gross & Net Production)

DATE	STATION	CASTS #	POSITION		RIG#
			LAT	LONG	
5/9/94	A1	37-39	19 00	58 58	1
13/9/94	A3	73-76	16 03	61 99	2
14/9/94	A3	84-86	15 96	62 18	3
18/9/94	A5	99-101	11 99	64 49	4
20/9/94	A7	116-118	7 90	67 09	5
25/9/94	A9	137-139	14 33	67 00	6
28/9/94	A3	154-156	16 06	62 02	7
30/9/94	A1	164-166	19 00	59 00	8

'SPATIAL DISTRIBUTION OF METHYLAMINES AND AMMONIA IN THE N.W. INDIAN OCEAN'

(R.R.S. Discovery 210: *ARABESQUE* LEG 1; 27Aug - 4 Oct 1994)

Stuart W. Gibb (PML / UEA)

INTRODUCTION

Nitrogen is a biologically essential element in the marine environment, 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).

CORE OBJECTIVE

To characterise the spatial distribution of the MA and ammonia in the contrasting oceanographic regimes and overlying atmospheric phases of the N.W. Indian Ocean during the S.W. Monsoon. To interpret the results of these studies within the framework of the biogeochemical cycle of nitrogen with reference to other measured biogeochemical determinants.

TECHNIQUES

An appreciation of the understanding of the marine distribution and biogeochemical cycling of the MA's has largely been restricted through the absence of a sensitive and selective analytical technique capable of their individual quantification at theconcentrations (nM-μM) typically found in natural waters. Durng Arabesque Leg 1, MA and ammonia were determined by Flow Injection Extraction-Ion Chromatography (FIE-IC). This novel and new 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. 2-4nM; co. of variation 2-6% at 20nM for MA's)

Atmospheric (gaseous and particulate) samples were collected and trapped through use of a tandem filter sampling system and analysed by FIE-IC.

ARABESQUE 1 - Preliminary Overview

CTD profiles sampled (Selected depths from the following casts)				**On-way samples**	**Atmospheric samples**
Arabian Sea		*Gulf of Oman*	*Coastal transect*		
				~35 analyses	2 x wet deposition
A1-20 / 30 / 55	A7-5 / 41	GOM5-4	AS1-1	along AS1-A7	
A1-55	A8-5	GOM6-1	AS2-3	transect	5 sets of gaseous
A2-4 / 16	A9-8/14/22	GOM1-6	AS3-4		samples + blanks
A3-4 / 67	A3- 10 / 67	GOM3-1	AS5-1		
A4	A10-7				5 sets of particulate
A5-8					samples + blanks

MA's, like ammonia were observed to be relatively ubiquitous in the upper water column in upwelling, mesotrophic and more oligotrophic regions alike, but subject to considerable spatial variability. Concentrations of ammonia generally exceeded those of the methylamines by 1-2 orders of magnitude in both aqueous and atmospheric phases (particulate and gaseous). Of the MA's, MMA was generally most abundant, whilst TMA was observed in relatively trace quantities (<5nM). Spatial distribution appeared to be influenced primarily by biological factors with thermodynamic conditions exerting little effect.

Highest concentrations of MA's were observed in the shallow coastal waters of the AS1-5 transect (*Fig. 1*) whilst the Arabian Sea was characterised by total MA concentrations of generally < 20nM. In depth profiles, highest concentrations were often found in the region of the chlorophyll maximum (*Fig. 2*) although vertical structure declined with transgression into more oligotrophic conditions. Below the sub surface maximum DMA was found occasionally to be the dominant MA (*Fig. 2*).

All MA's were detected in both gaseous and particulate atmospheric samples, however at concentrations <5% of those of ammonia. Ammonia meanwhile was observed to partition strongly in favour of the particulate phase (gaseous / particulate concentrations <0.2)

Fig. 1. Depth profile of MA concentrations at AS5 (9 Sep GMT 04.00, LAT 19.275N LON 58.536E Tot. Depth 49m)

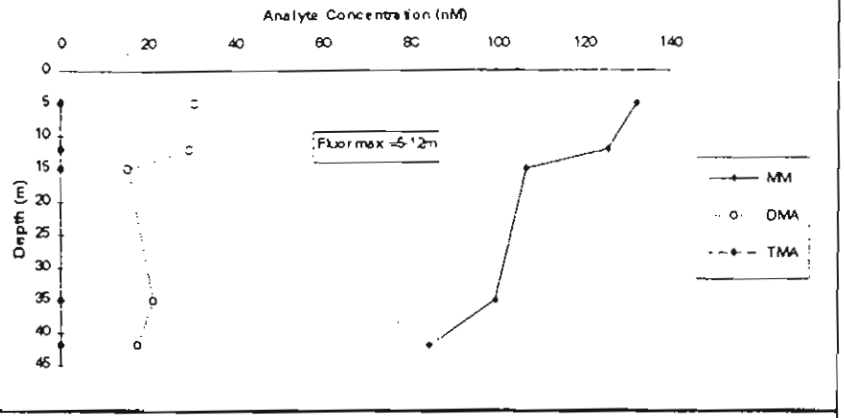
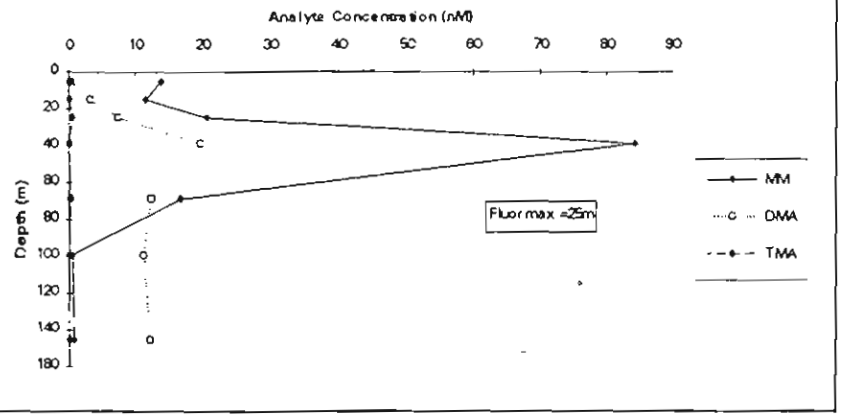


Fig. 2. Depth profile of MA concentrations at AS3 (28 Sep GMT 05.30, LAT 16.069N LON 62.024E, Tot. depth =2942m)



FUTURE WORK

* Full data work up.
* Chlorophyll and carotenoid pigment correlation studies to elucidate the chemotaxonomic production of MA's.
* Elucidation of spatial relationship between MA concentrations and their sulphur cycle analogue DMS and its phytogenic precursor DMSP.
* Calculation of the direction and magnitude of interfacial air-sea exchange fluxes of ammonia and the MA's from data collected simultaneously from surface seawater and atmospheric measurements.

Arabesque 1

27th August - 4th October 1994
Angela Hatton

Objectives - The measurement of biogenic sulphur compounds in the north east Indian ocean

Dimethylsulphide (DMS) is a biogenic sulphur compound generated from the breakdown of dimethylsulphoniopropionate (DMSP), a osmoregularitory compound of phytoplankton. DMS is a volatile compound which passes readily over the air sea interface into the atmosphere. Once in the atmosphere it forms the bases for cloud condensation nuclei, contributing to the acidity of rain water and acting as a potential feedback mechanism in counteracting global warming. DMS can also be converted to dimethylsulphoxide (DMSO) due to photo-oxidation or bacterial transformations, and as such, may act as a possible sink for DMS. Until recently there has not been a reliable method for the measurement of DMSO and so our understand of the production of DMS has not been complete.
The objectives of the cruise was to measure the concentrations of DMS, DMSP and DMSO through the water column, which could then be used to determine the significance of DMSO.
The other objective of the cruise was to compare levels of DMS with those of methylamines and phytoplankton pigments. Methylamines are the produced from the breakdown of quarternary amines, such as glycine betaine, in the same way that DMS is produced from the breakdown of DMSP. Glycine betaine also acts as a osmoregularitory compound in phytoplankton and the methylamines pass over the air-sea interface contributing to the alkalinity of rainwater. Therefore DMS and methylamines may contribute to the pH balance of rainwater. This cruise will be the first time that the two compounds have been measured simultaneously and these results will then be compared to pigment data also obtained on the cruise

Methodology

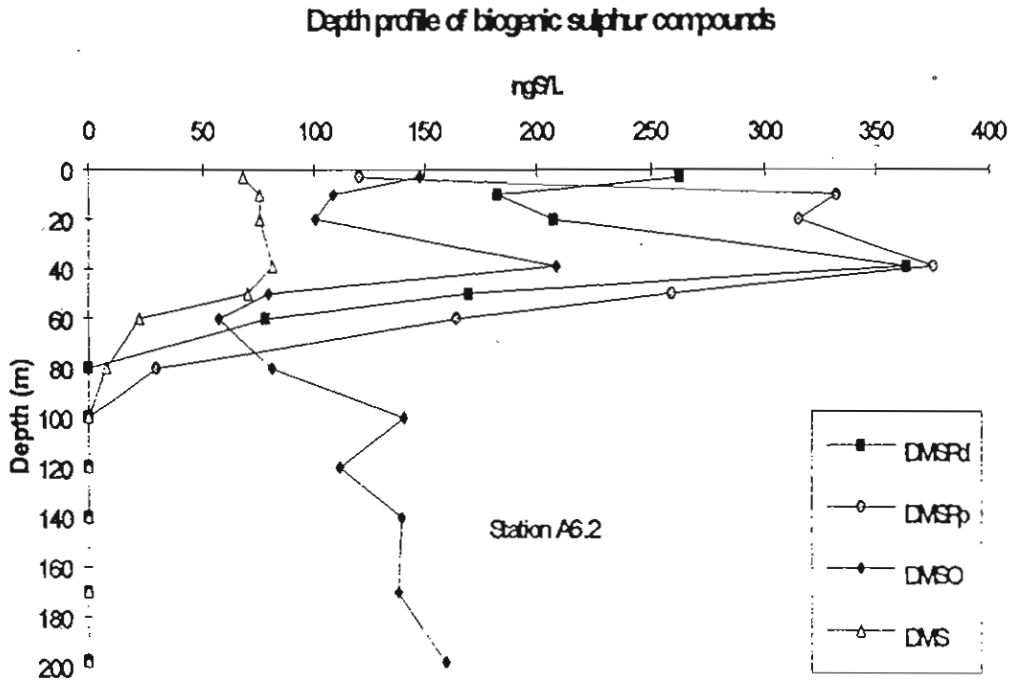
DMS was measured using a gas chromatograph fitted with a flame photometric detector, after pre-concentration in a cryotrap. DMSP was broken down to DMS by overnight incubation with 10M sodium hydroxide and then measured as a DMS sample. DMSO was converted to DMS using the enzyme DMSO reductase purified from the bacterium *Rhodobacter capsulatus* and subsequently measured as a DMS sample.
Measurements of DMS, DMSO, DMSP dissolved and DMSP particulate were carried out on all samples.

Samples analysed

CTD profiles		Onway measurements	Time series Experiment
Arabian sea	Gulf of Oman		
A1/8, A1/30, AS2/3	GOM2/7, GOM3/1	From AS5 to A3	7/9/94 - 0700 to 1230 hr
AS3/4, AS5/1, A3/21	GOM5/2, GOM6/1	10/9-11/9/94	14/9/94 - 0530 to 1930 hr
A3/28, A4/2, A5/8		20 samples	21/9/94 - 0600 to 1745 hr
A6/2, A7/5, A8/5			
A9/8, A9/14, A9/22			
A10/7, A3/67, A2/10			
A1/55.			

Results

Preliminary results indicate that DMS and DMSP (particulate and dissolved) are predominantly in the top 100m of the water column. However DMSO concentrations appear to remain high throughout the water column. Fig 1 gives an example of a depth profile found at station A6.
Concentrations of DMSPp and DMSPd appear to be higher in the eutrophic areas than those in the oligotrophic areas although proper analysis of the data is still required. A number of time series experiments were carried out, but the significance of these is yet to be established. Any correlation between DMS, methylamines and phytoplankton pigments is also yet to be established.



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RRS DISCOVERY 210 - North West Indian Ocean
27th August - 4th October, 1994

CRUISE REPORT

Axel E J Miller

DETERMINATION OF DISSOLVED ORGANIC CARBON & NITROGEN

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 the global biogeochemical cycling, historical and contemporary uncertainties in the 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 dissolved organic carbon (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°), 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 facilitates high precision measurements to be made against the noisy background of ocean-going research platforms.

Recent purchase of a nitrogen-specific chemiluminescence detector provides an opportunity for our first measurenments 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

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.

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 (Jo Dixon / UCNW).

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

Preliminary investigation of the relationship between photochemical decomposition of DOC and production CO (Cliff Law, PML) in oceanic surface waters.

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 greater than ±5%, largely above ±2% for some during some studies. The analytical blank, resulting from the TOC5000 was quantified at around 10-15μ C. Blank-corrected DOC concentrations ranged from around 80μM C in coastal surface waters, approaching the Strait of Hormuz (Stations GOM6-GOM1),

to above 120μM C at lower latitudes. Deeper waters showed DOC concentrations fluctuating between approximately 40-50μ C. An 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 isolation of DON concentrations, but the vertical distribution suggests oceanographic consistency. For example, at Station A3, TDN values increase from the surface (13μm n) down to around 600m (36μM N), but remain fairly constant below this depth.

Incubation experiments, looking at photochemical production of CO (Cliff Law, PML), in conjunction with DOC cosumption, have provided the first complementary data sets from the same waters. As a result of the high precision (<2%) for HTCO-DOC determinations, small (μM C) incremental changes were detected at 3 hour intervals over the course of a 12 hour incubation.

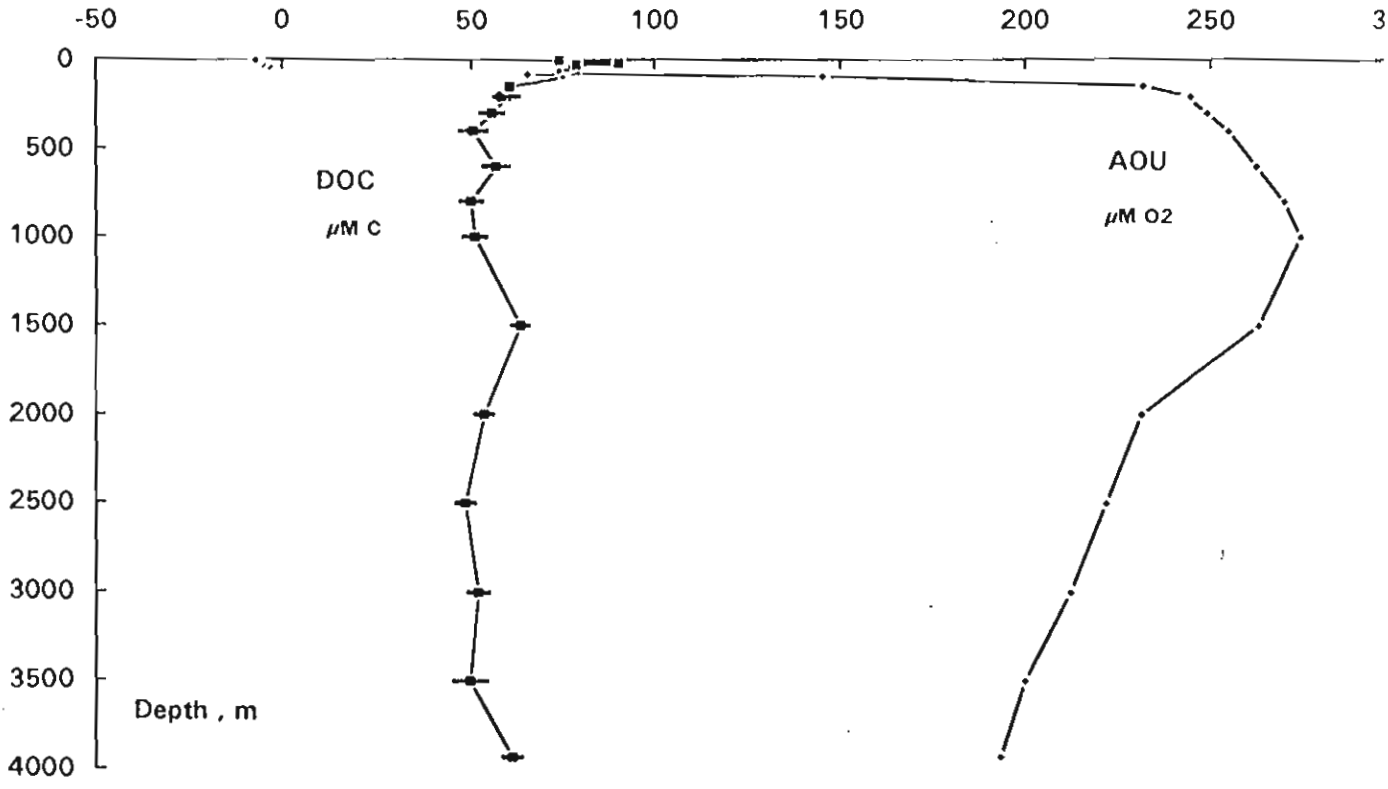
Stations sampled for HTCO-DOC measurements

Station	Cast no.	Depth Range , m	Additional Work	Date
GOM1	6	0 - 90		08 30
GOM2	3	100 - 1250		08 29
	7	0 - 150		
GOM3	1	0 - 2850		08 31
GOM4	1	0 - 300		08 28
GOM5	1	100 - 3175		09.01
	4	0 - 200		
GOM6	1	0 - 300		09 02
	6	250 - 3300		
AS1	1	0 - 210		09 08
	5	210 - 2475		
AS2	3	0 - 1200		09 08
AS3	4	0 - 475		09 09
AS4	4	0 - 145		09 09
AS5	1	0 - 50		09 09
A1	8	0 - 300		09.04
	11	200 - 3390		
A2	2	210 - 3930		09/11
	4	0 - 210		
A3	23	0 - 300	TDN	09/13
	28	130 - 3930		
	35	5	Light incubation	09/14
	35-45	5 , 15	Time series	
	41	0 - 300	Unfiltered cast	
A5	8	0 - 300		09/17
	9	300 - 4210		
A6	2	0 - 200		09/18
	3	200 - 4400		
A7	5	0 - 300		09/19
	6	300 -4630		
	26	100 - 180		09/20
	30	0 - 100		
A8	2	300 - 4204		09/24
	5	0 - 300		
A9	8	140 - 400	TDN	09/25
	14	0 - 140	Light / dark incubations	
	22	360 - 3980	Anoxic calibration	09/26
A3	63	230 - 3935	Deep water photo-oxidation incubation	09/28
	67	0 - 200		
A1	54	150 - 3395	Deep water photo-oxidation incubation	09/30
	55	0 - 150		

Figure 1 Vertical profiles of HTCO-DOC and AOU at A3, the US JGOFS Time Series Station, 16°N, 62°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.

LA2AOURP.XLC

XL3



D210 CRUISE REPORT
SUSAN KNOX

Discrete pCO2 and TCO2 analysis

Three analysis systems were brought to sea to monitor pCO2 and TCO2 in discrete water samples and pCO2 continuously in sea surface waters and marine air. The aim was to map the vertical and on shelf distribution of pCO2 as a function of monsoonal forcing and to take a close look at the detailed structure of the oceanic carbonate system in the water column by calculation of pH and total alkalinity from TCO2 and pCO2 data obtained from CTD casts.
The automated CO2 (pCO2) Analysis system designed and made at Plymouth Marine Laboratory for use on ships of opportunity, was plumbed into the non toxic supply. The instrument incorporates an equilibrator, a Li- Cor Model 6262 CO2/H2O infra red gas analyser and a GPS system. The instrument is designed to run with minimal maintenance and any failure results in automatic shutdown. Subsequent access to a diagnostic file pin points the fault. The system ran successfully for 24 hours in the Gulf of Oman before shutting down. Attempts to access the diagnostic file failed and eventually the cause of failure was traced to the Li-Cor module. No spare was available.
To measure TCO2 a working coulometer is necessary. My aged Model 5010 failed to survive the journey to Muscat and after attempts to boost the lamp voltage and internal settings governing the coulometric titration it was apparent that the photodetector had failed and TCO2 analysis had to be abandoned.
Two systems down and one to go!
Discrete pCO2 is measured by equilibration of samples, poisoned with mercuric chloride, at a constant temperature of 25C followed by gas chromatography with a flame ionisation detector. An ingenious valve system, developed at PML, enabled two samples to be analysed in tandem thus doubling sample throughput. Several bugs and leaks in the system had to be ironed out before reliable data was obtained but in all 36 casts were analysed covering the whole of the survey area.
A wide range of temperatures was encountered in the vertical casts ranging from 28C at the surface of the Arabian Sea down to 1.66C in oceanic bottom water. pCO2 varies strongly with temperature and a precise knowledge of the temperature dependancy is important when pCO2 is measured at a temperature different from the *in situ* temperature. Takahashi and collaborators found that an exponential function described this dependancy well independant of salinity and water composition:-

$$pCO2_T = pCO2_{TM} \cdot \exp(0.0423(T-TM))$$

where TM = temperature at which pCO2 measured
and T = *in situ* temperature

This correction has been applied but the data is still in its preliminary form and on return to PML will be recalculated using corrected thermosalinograph data and a running standard to take account of pressure changes.
The profile depicted shows a pattern common to all the stations in the Arabian Basin. Maximum pCO2 levels occurred around 1000m, just below the oxygen depleted zone. At the surface the differences were in the levels of pCO2 in the top 70 - 100m.

Station A7 showed the most significant undersaturation wheras Station A3 is virtually at equilibrium . The shelf stations from AS1 to AS5 show increasing supersaturation at the surface.

ARABESQUE REFERENCE STATION A3 28 SEPT 94

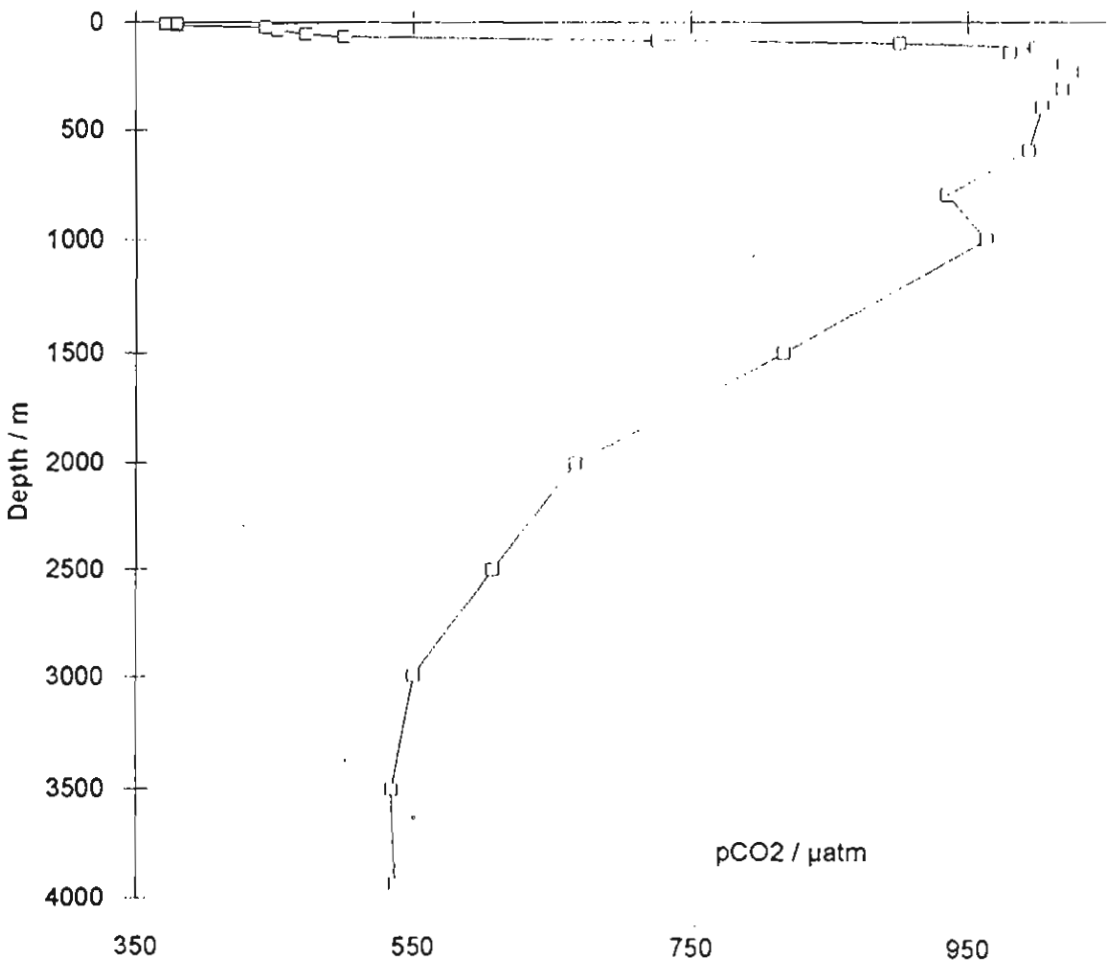


TABLE CASTS WORKED FOR DISCRETE PCO2			
SUSAN KNOX			
GOM1/6	A3/21	A7/52	A1/55
GOM6/1	A3/28	A8/2	
A1/8	A3/35	A8/5	
A1/11	A3/41	A9/8	
A1/30	A4/2	A9/14	
A1/42	A4/3	A9/22	
AS1/5	A5/8	A10/3	
AS2/3	A6/2	A10/7	
AS3/4	A6/3	A3/63	
AS5/1	A7/5	A3/67	
A2/2	A7/6	A2/10	
A2/4	A7/30	A1/54	

Dissolved Gases in the Arabian Sea

Cliff Law,
Plymouth Marine Laboratory,Prospect Place, West Hoe,Plymouth, Devon, UK.

1. Carbon Monoxide (CO) in the upper water column.

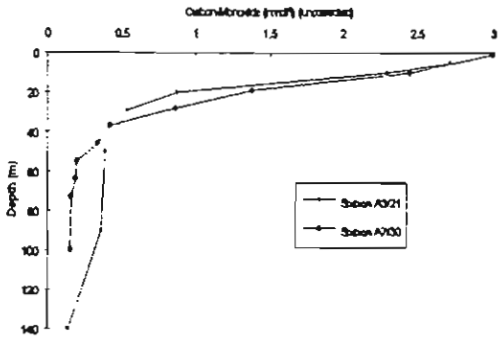
Background: Carbon monoxide is an atmospheric trace gas which influences carbon dioxide and ozone concentrations and the residence time of methane, and therefore plays a secondary role in global warming. CO is produced in the water column photochemically by the action of ultra-violet light on DOC, and so the study of CO dynamics in the ocean provides an insight into the fate of the organic carbon pool. Microbial oxidation by nitrifying and methane-oxidizing bacteria, and loss to the atmosphere represent the major sinks.

Aims:
a) To measure CO concentrations in the upper water column and obtain an areal atmospheric flux.
b) To determine rates of photochemical production of CO by deckboard incubations.
c) To determine rates of CO oxidation by deckboard incubations.
d) To determine the influence of light, wind speed and DOC concentration on CO in a) and b)

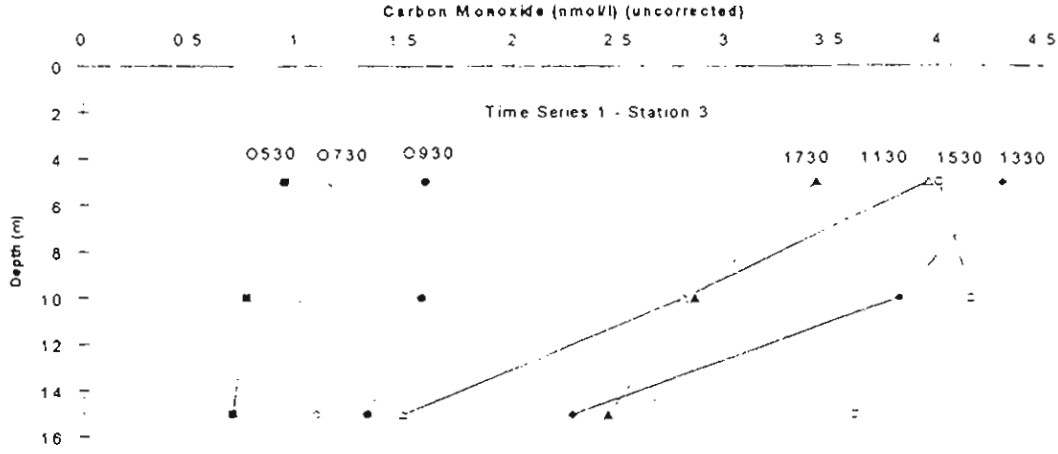
Instrumentation: This consisted of a vacuum-sparge system for extracting the dissolved gas, cryogenic trapping using liquid nitrogen, catalytic reduction of CO to CH_4 and detection by a gas chromatograph equiped with a Flame Ionisation Detector. The system had not previously been used for CO analysis and worked successfully after initial alterations.

Results:

Water and ambient air samples were obtained at 16 stations with the former exhibiting a typical photoproduction profile with maximum concentrations at the surface declining through the photic layer to background levels at around 70-100m (see Fig.1). This represents the first collection of CO data in the Indian Ocean and suggests that concentrations are not significantly different to that reported for other open ocean studies. Any areal variability observed along the cruise track was a function of light intensity and therefore time of day that the profile was obtained.



The influence of light is highlighted by two time series profiles in which concentrations in the upper 15 metres were determined every two hours (see Fig. 2). CO increased as the sun rose, particularly when u.v. light penetration was maximal around midday, after which concentrations fell as the surface waters ventilated to the atmosphere. Rates of CO photoproduction were determined in deckboard incubations of surface water in silica tubes in conjunction with DOC measurements (Axel Miller).


Carbon Monoxide (nmol/l) (uncorrected)
0
0 5
1
1 5
2
2 5
3
3 5
4
4 5
Time Series 1 - Station 3
0530
0730
0930
1730
1130
1530
1330
Depth (m)
0
2
4
6
8
10
12
14
16

2. Sulphur Hexafluoride (SF_6) in the Water Column

Background

Sulphur hexafluoride is a man-made gas which has been accumulating in the atmosphere since the early 1970's. Despite the low atmospheric concentrations (approx 3 parts per trillion) and low solubility the gas can be measured in the upper-mid water column as a result of will equilibration with the atmosphere. Upon sinking the water will retain a SF_6 signature and so, with a documented atmospheric chronology, SF_6 can be used as a transient tracer in the ocean, providing information on the age and rate of movement of a water body.

Aims:

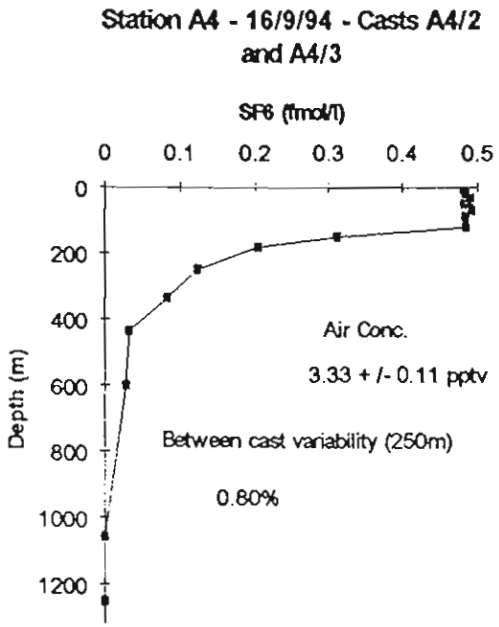
To determine SF_6 concentration in the water column with a view to estimating the residence time of the low oxygen region.

Instrumentation

This consisted of a vacuum-sparge system for extracting the dissolved gas with cryogenic trapping using liquid nitrogen and detection by a gas chromatograph equiped with an Electron Capture Detector. This system was developed for the use of SF_6 as an applied tracer. Apart from initial contamination problems the system functioned well throughout the cruise, with high reproducibility even at concentrations < 0.1 fmol/l.

Results

The SF_6 data set obtained on DI210 represents the first ever attempt to use SF_6 as a transient tracer in the ocean. The air measurements obtained will be added to the database from which the atmospheric history has been derived, to improve the accuracy of the water column dating. An "end-member" profile was obtained at GOM1 showing high concentrations throughout indicating recent contact with the atmosphere. Profiles were obtained at a further 15 stations, and generally exhibited a surface mixed layer in equilibrium with the atmosphere, with concentrations declining at around 60-80m (see Fig. 3). SF_6 was detectable at 500-600m throughout most of the Arabian Sea suggesting that a large proportion of the oxygen deplete zone is less than 20 years, old in agreement with previous measurements using Freons.



3. Nitrous oxide

Background

The water column of the Arabian Sea exhibits regions of N_2O supersaturation and undersaturation as a result of the microbial processes nitrification and denitrification.

Aims

To collect samples for $^{15}N\text{-}N_2O$ analysis to identify the processes influencing N_2O.

Results

415 samples were collected at 11 stations. Double isotope measurements for N_2O will be performed by Static Mass Spectrometry by Prof. C. Pillinger and Dr. G. Roberts of the Geological Science Deptartment of the Open University.

Date	Cast No.	SF_6 Profile	CO Profile	CO -Time Series(TS) /Incub (DI)	N_2O Sam.
30/8/94	GOM1/10	X			
31/8/94	GOM3/1	X			
1/9/94	GOM5/2	X			
	GOM5/4	X			
2/9/94	GOM6/1	X			X
	GOM6/6	X			X
4/9/94	A1/8	X			X
5/9/94	A1/11	X			X
6/9/94	A1/30	X	X		
8/9/94	AS/1	X	X		X
	AS1/5	X	X		X
9/9/94	AS2/3		X		
	AS3/4		X		
	AS4/4		X		X
	AS5/1		X		
11/9/94	A2/2	X	X		X
	A2/4	X			X
13/9/94	A3/21	X	X		X
	A3/28	X			X
14/9/94	A3/35,A3/37			TS1	
	A3/38,A3/39			DI1	
	A3/41,A3/44				
	A3/45				
16/9/94	A4/2	X	X		X
	A4/3	X			X
17/9/94	A5/8	X	X	DI2	X
	A5/9	X			X
18/9/94	A6/2	X	X		
	A6/3	X			
19/9/94	A7/5	X	X	DI3	
	A7/6	X			
20/9/94	A7/30		X		
21/9/94	A7/26,A7/30			TS2	
	A7/36,A7/37			DI4	
	A7/38,A741				
	A7/45,A7/46				
	A7/48				
24/9/94	A8/2	X			X
	A8/5	X	X		X
25/9/94	A9/8	X	X	DI5	X
	A9/14	X	X		X
26/9/94	A9/22	X		DI6	X
27/9/94	A10/3	X			X
	A10/7	X	X		X
28/9/94	A3/63	X		DI7	
	A3/67	X	X		
29/9/94	A2/10	X	X		
30/9/94	A1/54	X			X
30/9/94	A1/55	X	X		X

Nitrous oxide and methane in vertical hydrocasts

R. C. Upstill-Goddard and N.J.P. Owens
University of Newcastle-Upon- Tyne

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 41 vertical hydrocasts were successfully analysed, covering each of 18 oceanographic stations in detail (see Table). Selected stations were each occupied on two separate occasions in order to contrast changes in biological productivity over the course of the monsoon. In all some 934 individual dissolved gas analyses were made. In addition, N_20 and CH_4 were determined in over 400 samples of ambient air from the same locations. These data 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, as shown in the accompanying figure, which shows data from station A8. This is similar to the situation found in the majority of open ocean waters north of 70° 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 CH_4 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. Preliminary calculations confirm typical ΔN_2O values ~ 40-50 nM in these waters (see Fig). These elevated deep water N_2O concentrations were also reflected in the coastal upwelling zones.

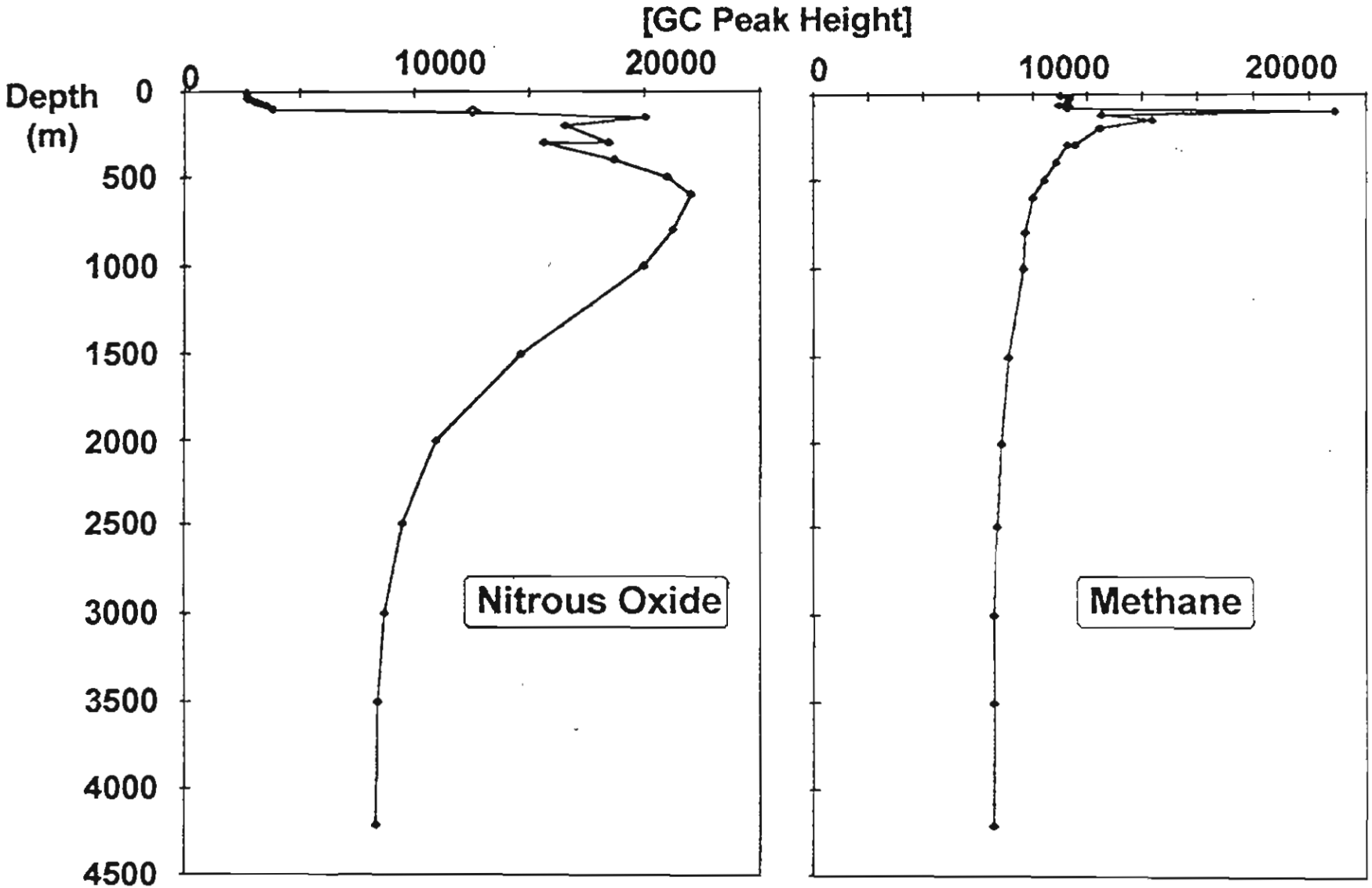
Overall, these data should aid in the refinement of our present estimates of the production fluxes of N_2O in the ODZ, and help to improve calculations of the ventilation fluxes of N_2O and CH_4 to the atmosphere.

Discovery210 : Summary of CTD stations processed for N_20 and CH_4

DATE	STATION No.	SHALLOW CTD	DEEP CTD *
29.08.94	GOM-2	G2/04	
30.08.94	GOM-1		G1/06
02.09.94	GOM-6	G6/01	
02.09.94	GOM-6		G6/06
04.09.94	A1	A1/08	A1/12
06.09.94	A1	A1/30	
07.09.94	A1		A1/40
08.09.94	AS1	AS1/01	AS1/05
09.09.94	AS2		AS2/03
09.09.94	AS3		AS3/04
09.09.94	AS4		AS4/04
09.09.94	AS5		AS5/01
11.09.94	A2		A2/02
11.09.94	A2	A2/03	
13.09.94	A3	A3/21	A3/28
14.09.94	A3		A3/38
16.09.94	A4	A4/02	A4/03
17.09.94	A5	A5/08	A5/09
18.09.94	A6	A6/02	A6/03
19.09.94	A7	A7/05	A7/06
20.09.94	A7	A7/30	
21.09.94	A7		A7/38
24.09.94	A8	A8/05	A8/02
25.09.94	A9	A9/08	
25.09.94	A9	A9/13	
26.09.94	A9		A9/22
27.09.94	A10	A10/07	A10/03
28.09.94	A3	A3/67	A3/63
29.09.94	A2	A2/10	
30.09.94	A1	A1/55	A1/54

* "Deep CTD" refers to all casts covering the whole water column, irrespective of the water depth.

Vertical profiles of nitrous oxide and methane concentration
Station A8



R.C. Upstill-Goddard & N.J.P. Owens, University of Newcastle upon Tyne. 1/10/94

14C PRIMARY PRODUCTION

The primary objective of the 14C primary production component of the ARABESQUE Programme was to estimate both the total and size fractionated primary production at selected stations in the various hydrographic regimes of the north-west Indian Ocean during and immediately following the south-west monsoon season. Secondary objectives of the project were to measure the corresponding total and size-fractionated chlorophyll *a* concentrations and to take samples for the determination of POC and PON concentrations and absorption spectra in additionto making a limited number of estimates of DO14C excretion by phytoplankton. Two approaches were used to estimate production: (a) samples were either incubated *in situ* or "on deck" in a simulated light incubator or (b) were incubated under a range of irradiances in an artificial light incubator to establish the determining photosynthetic parameters, thus allowing the subsequent modelling of production rates. A total of 5148 samples was incubated, resulting in the processing of 8184 individual 14 C determinations. Details of the experimental programme are summarised in Table xx.

Assistance was also given with five time series and five *in situ* production experiments carried out by Dr Carol Robinson to compare production estimates using the TCO2 and 14C approaches.

(a) *In Situ* and "On Deck" Experiments

Following a shakedown station (GOM 2) on 29 August, estimates of 14C primary production were made either from *in situ* or "on deck" incubations on a further 28 days during the cruise as the programme allowed. "On deck" incubations were carried out primarily when the ship was on passage mode. At each station, samples were taken from ten depths between the surface and the 1% light depth before dawn and incubated under the appropiate conditions from dawn to dusk before being placed in the dark on deck overnight prior to filtering the following morning. Six comparisons were carried out between parallel *in situ* and "on deck" incubations; reasonable correspondence of the column production was recorded from five of the experiments, although there was tendency for greater surface photoinhibition in the "on deck" samples.

In general terms a broad correspondence was apparent between the distributions of size-fractionated chlorophyll concentrations and primary production throughout the cruise with certain clear spatial trends being evident in the relative distributions of the three size fractions. At the most northerly stations (GOM 6, A1, AS2, AS5. A2) considerable temporal and spatial variability was apparent in the chlorophyll and production values with the maximum values recorded during the cruise (7.6 mg m-3 and 3193 mgC m-2 d-1) being observed at GOM6. The variability is assumed to reflect the mesoscale variability associated with the inshore upwelling processes. The high chlorophyll and productivity values were essentially contributed to by increases in the >18um fraction (Table. x), consistent with substantial diatom growth as indicated by HPLC measurements. The depth of the mixed layer of up to 100m suggests a high phytoplankton biomass at these stations.

In contrast, at the most southerly stations in the oligotophic water (A6, A7, A8, A9) chlorophyll *a* and production values were consistently low in the surface layer with chlorophyll concentrations of the order of 0.25 mg m-3 increasing to 0.75 mg m-3 in the subsurface chlorophyll maximum. At these stations the >18um fraction contributed <5% of the chlorophyll stock with the <2um fraction forming the maximum contribution (Table.x). Between the northerly and southerly zones, that is in the region primarily influenced by the offshore upwelling processes during the early part of the cruise (A3, A5, A10) chlorophyll concentrations throughout the mixed layer were generally in the range 1.0 - 1.5 mg m-3 with no evidence of a SSCM. At these stations all three size fractions made an approximately equal contribution to the chlorophyll and production values (Table.x). Thus this zone appears to be a transition region in which a co-existence of the populations characteristic of the extremities of the area is able to occur. This balance of production and chlorophyll between the three size-fractions was also apparent at

stations A1 and A3 on the return leg, although total chlorophyll concentrations were higher than observed in the transition zone earlier in the cruise. The even size distribution of of the phytoplankton in this region of the Indian Ocean appears to be a response to finite new nutrient concentrations and a relatively shallow mixed layer.

Data from the DO14C excretion experiments remain to be analysed, although in general very low rates of net excretion were indicated across the region. This may reflect the high bacterial growth rates resulting from the high temperatures and hence the rapid uptake of phytoplankton produced DOM by the bacterial populations. A series of four 14C time course uptake experiments was carried out at stations in the oligotrophic and mesotrophic regions to further investigate the carbon interrelationships of the plankton populations: data from these experiments remains to be analysed.

(b) Photosynthesis: Irradiance Experiments

Water samples for photosynthesis: irradiance experiments were collected from two depths at all of the stations sampled. For the samples collected in the early morning, the chosen depths were selected from the depths from which samples were taken for the *in situ* or "on deck" productivity profiles. Samples collected around midday were usually taken from a depth of 10m and the fluorescence maximum. A total of 110 experiments was completed.

In addition, at each sampled depth, water was filtered for the analysis of the particulate organic carbon and nitrogen content and also for the determination of the absorption spectra. All samples will be analysed at the Bedford Institute of Oceanography on completion of the cruise.

TABLE 1

Chlorophyll *a* concentration (uncalibrated data) of the > 18, 2-18 and 0.2-2 μm plankton size-fractions observed in the surface 10 m at station A1 on 4 and 5 September, station A3 on 13 September, station A7 on 20 September and station A1 on the return leg on 30 September 1994. Concentrations averaged from samples collected in the top 10m and expressed as mg chl *a* m^{-3}.

Station	Date	Hydrographic regime	Size-fraction > 18 μm	Chl *a* 2-18 μm	Concentration 0.2-2 μm
A1	4.9.94	Coastal upwelling	2.61	0.74	0.74
A1	5.9.94	Coastal upwelling	0.28	0.72	0.62
A3	13.9.94	Mesotrophic/transitional	0.41	0.33	0.36
A7	20.9.94	Oligotrophic	0.09	0.17	0.69
A1	30.9.94	Transitional	0.74	0.68	0.36

TABLE 2

Listing of ^{14}C primary production experiments carried out during ARABESQUE Cruise I (Discovery Cruise 210), 28 August - 30 September 1994. (F denotes samples taken from SSCM fluorescence maximum.

Date	Station #	Est 1% LD(m)	^{14}C incubation procedure In situ	On deck	Time ser	Do ^{14}C	P:I sample depth
28.8.94	GOM 4/2						10,23 (F)
29.8.94	GOM 2/1	40		*			10,36 (F)
	GOM 2/9						10,39 (F)
30.8.94	GOM 1/3	40		*			10,30 (F)
	GOM 1/7						10,29 (F)
31.8.94	GOM 3						Surface
	GOM 3						Surface
1.9.94	GOM 5A/1	40		*			10,22 (F)
	GOM 5/6						10,26 (F)
2.9.94	GOM 6A/1	30		*			10,20
	GOM 6/4						10,20
3.9.94	GOM 6B/1	60		*			10,40
4.9.94	A1/1	40	*	*			10,40
	A1/5						10,40
5.9.94	A1/13-15	40	*				10,40
	A1/20						10,35
6.9.94	A1/23	40	*			*	10,40
	A1/31						10,20 (F)
7.9.94	A1/33-34	40	*				10,40
8.9.94	A51/4						10,30 (F)
9.9.94	A52/1	40		*			10,30
	A53/3						10,25
10.9.94	A55/2-3	25		*			10,20
	A55/4						10,15
11.9.94	A2/1	40		*			10,40
12.9.94	A3/3-5	40	*			*	10,26
	A3/10						10,25 (F)
13.9.94	A3/20	60	*	*			10,40
	A3/25						10,39
14.9.94	A3/30-32	60	*	*			14,40
	A3/44						10,30 (F)
15.9.94	A3/48	60	*			*	10,40
	A3/53						10,30 (F)
16.9.94	A4/1						Surface
							Surface
17.9.94	A5/1	100	*				13,43
	A5/12						10,30 (F)
18.9.94	A6/1	60		*			8,60 (F)
19.9.94	A7/3	100	*			*	13,45 (F)
	A7/1						10,60 (F)
20.9.94	A7/18	75	*	*			10,50
	A7/29						10,60 (F)
21.9.94	A7/32	75	*	*			10,57 (F)

Date	Station #	Est 1% LD(m)	In situ	^{14}C incubation procedure On deck	Time ser	Do ^{14}C	P:I sample depth
24.9.94	A8/1	75		*	*		11,50 (F)
	A8/4						10,50 (F)
25.9.94	A9/I	75	*		*		10,50 (F)
	A9/11						10,40 (F)
26.9.94	A9/21	75		*			10,50 (F)
27.9.94	A10/1	40		*		*	10,23 (F)
	A10/6						10,23 (F)
28.9.94	A3/56	40	*		*		10,33
	A3/66						10,20 (F)
29.9.94	A2/9						10,23 (F)
30.9.94	A1/47	35	*	*	*		8,23
	A1/58						10,22

Net and gross plankton production along ecological gradients in the Arabian Sea

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AIM

The aim of the present study was to examine the relationship between ^{14}C determined carbon fixation rates and TCO_2 and O_2 determined rates of gross and net community production across the extreme ecological gradients found in the Arabian Sea.

METHODS

Total dissolved inorganic carbon was measured by coulometric titration, dissolved oxygen by automated Winkler titration. Rates of gross and net community production and respiration were estimated from changes in TCO_2 and O_2 following traditional light / dark bottle *in situ* incubations. Concomitant estimates of plankton fixation of $Na_2H^{14}CO_3$ were undertaken by Dr. Graham Savidge. In order to assess whether the ^{14}C technique approximated to gross or net community production as measured by changes in TCO_2 , a number of on-deck time series incubations were also completed.

Discrete samples from 36 CTD vertical profiles were analysed .

SAMPLES COLLECTED

In situ rigs

1 05/09/1994 station A1 cast 37 surface, 5m, 10m, 17m, 26m, 40m
2 12/09/1994 station A3 cast 73 surface, 5m, 10m, 26m
3 14/09/1994 station A3 cast 84 surface, 8m, 14m, 26m, 40m, 60m
4 17/09/1994 station A5 cast 99 surface, 13m, 24m, 43m, 66m, 100m
5 20/09/1994 station A7 cast 116 surface, 10m, 18m, 32m, 50m, 75m
6 25/09/1994 station A9 cast 137 surface, 10m, 18m, 32m, 50m, 75m
7 28/09/1994 station A3 cast 154 surface, 7m, 12m, 22m, 33m, 50m
8 30/09/1994 station A1 cast 164 surface, 5m, 8m, 15m, 23m, 35m

On deck time series comparisons

1 02/09/1994 cast 25 7m
2 04/09/1994 cast 33 10m
3 07/09/1994 cast 48 10m
4 10/09/1994 cast 66 6m.
5 27/09/1994 cast 149 10m

TCO_2 depth profiles

27/08/1994 GOM 4-1 0-300m
28/08/1994 GOM 4-5 200-3323m
29/08/1994 GOM 2-3 100-1200m
29/08/1994 GOM 2-4 5-150m
30/08/1994 GOM 1-10 0-80m
31/08/1994 GOM 3-1 5-2848m
01/09/1994 GOM 5-1 100-3000m
01/09/1994 GOM 5-4 3-200m
02/09/1994 GOM 6-1 10-300m
02/09/1994 GOM 6-6 250-3298m
04/09/1994 A1- 4-300m
04/09/1994 A1-11 200-3387m
07/09/1994 A1-42 4-300m
08/09/1994 cast 55 AS1 3-200m
08/09/1994 cast 57 AS1-5 200-2500m
09/09/1994 cast 60 AS2-3 10-1200m
09/09/1994 cast 62 AS3-4 4-500m
09/09/1994 cast 64 5-145m
09/09/1994 cast 65 AS4-4 5-42m
11/09/1994 cast 70 A2-2 200-3990m
11/09/1994 cast 71 A2-4 5-200m
13/09/1994 cast 81 A3-21 5-300m
13/09/1994 cast 83 A3- 132-3990m
16/09/1994 cast 97 A4- 3-250m
17/09/1994 cast 102 A5-8 5-300m
17/09/1994 cast 103 A5-9 300-4300m
18/09/1994 cast 108 A6-2 3-200m
19/09/1994 cast 112 A7-5 10-300m
19/09/1994 cast 113 A7- 300-4000m
20/09/1994 cast 122 A7- 4-100m
24/09/1994 cast 134 A8- 300-4000m
24/09/1994 cast 136 A8- 5-300m
25/09/1994 cast 140 A9-8 140-400m
25/09/1994 cast 144 A9-14 3-140m
26/09/1994 cast 148 A9-22 350-4000m
28/09/1994 cast 159 A3-67 5-200m

RESULTS

Surface rates of gross production varied from 17 µmol C/dm^3.24h at the eutrophic station A1 on 30/09/1994 to 2 µmol C/dm^3.24h at the most blue water station A7 on 20/09/1994. Community respiration was always a major component of the gross production rates, varying from 13 to 6 µmol C/dm^3.24h at the surface at A1 and A7 respectively. The TCO_2 gross and net production comparison with ^{14}C uptake awaits analysis of the ^{14}C samples. Full interpretation of the O_2 and TCO_2 production profiles will be possible once data such as light and chlorophyll is available.

All discrete and production TCO_2 data should be in final form and lodged with BODC by Jan 1st 1995.

ACKNOWLEDGEMENTS

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Assimilation of nitrogen by phytoplankton.

N.J.P. Owens
University of Newcastle

The quantities and forms of nitrogen assimilated by the phytoplankton are fundamental in determining the biogeochemistry of any sea area. The northwestern Indian Ocean offers an ideal opportunity to examine one of the largest potential ranges of rates of nitrogen assimilation; from high rates supported predominantly by nitrate (large 'new production') to low rates supported by recycled nitrogen (low 'new production').

Objectives:

1. To measure the rates of nitrogen assimilation in all regions of the Arabesque cruise area during the immediate post SW monsoon period. This cruise to be part of a more complete investigation to include the presumed oligotrophic inter-monsoon period during December.
2. To make the measurements concurrently with a wide range of production, pigment and detailed optical measurements in order ultimately to develop algorithms suitable for the conversion of remotely sensed data to estimates of new and regenerated production.

Experiments carried out:

Deck and *in* situ incubations of samples covering the photic depth were made on 11 stations [Table 1]. Four separate additions of 15N nitrogen were incubated at each of six depths. Nitrogen was added as follows. 1 x 5umole nitrate; 1 x 0.1umole nitrate; 1 x 0.1umole ammonium; 1 x 0.1umole urea. Samples were incubated for a total of 24hours. Filters were stored frozen for subsequent mass-spectrometric analysis at Newcastle. Fitrate was also retained frozen for subsequent analysis of isotope dilution for subsequent estimation of rates of ammonium regeneration and nitrification (see below).

No results are currently available, however, a large range of biomass and nutrient concentrations were encountered thus the overall aim has been achieved. Two stations were re-examined following a period of apparent intense growth which will provide useful support information.

Table 1. Station list for 15N incubations.

Station	Date	Type
GOM-4	31/8/94	Deck
GOM-6	2/9/94	Deck
A1	5/9/94	In situ
AS-5	10/9/94	Deck
A3	12/9/94	In situ
A3	14/9/94	In situ
A5	17/9/94	In situ
A7	20/9/94	In situ
A9	24/9/94	In situ
A3	28/9/94	In situ
A1	30/9/94	In situ

In addition to the main incubations, a series of 16 incubations were carried out in a light gradient box of 24 light intensities. These were short incubations with a high

nitrate addition to normalise for nutrient effects. These incubations were carried out concurrently with various 14C PvI incubations.

Nitrification and Denitrification:

These are two fundamentally important, microbially mediated, biogeochemical processes. It is thought that the balance of these processes is responsible for the globally important high levels of nitrous oxide found in the region. 15N isotope dilution experiments were carried out at stations A1, A3, A7 and A9 to determine the rates of nitrification and denitrification. Samples were targeted at depths exhibiting sharp oxygen gradients. Samples were stored frozen and await mass-spectrometric analysis at Newcastle. In addition, samples from a number of phytoplankton assimilation incubations were retained which could provide further information on nitrification in the photic zone. These samples will be processed using a new method for the analysis of 15N nitrate, but it is not known whether this will be sufficiently sensitive to detect the rates of nitrification at the levels of ammonium addition required for the assimilation experiments.

Flow Cytometric Analysis of Phytoplankton and their herbivorous interaction with Microzooplankton.

Peter Burkill (Plymouth Marine Lab)

Objectives

1) To characterise and quantify phytoplankton populations in the Oman Basin and Arabian Sea.

2) To quantify the herbivorous interactions between microzooplankton and phytoplankton in the Arabian Sea.

Approach & Methods

1) Flow cytometric protocols based on cellular light scatter and fluorescence were developed and used to characterise and quantify total phytoplankton concentrationand those of individual taxa (prochlorophytes, cyanobacteria, picoeukaryotes) in samples obtained from water bottles on CTD profiles.

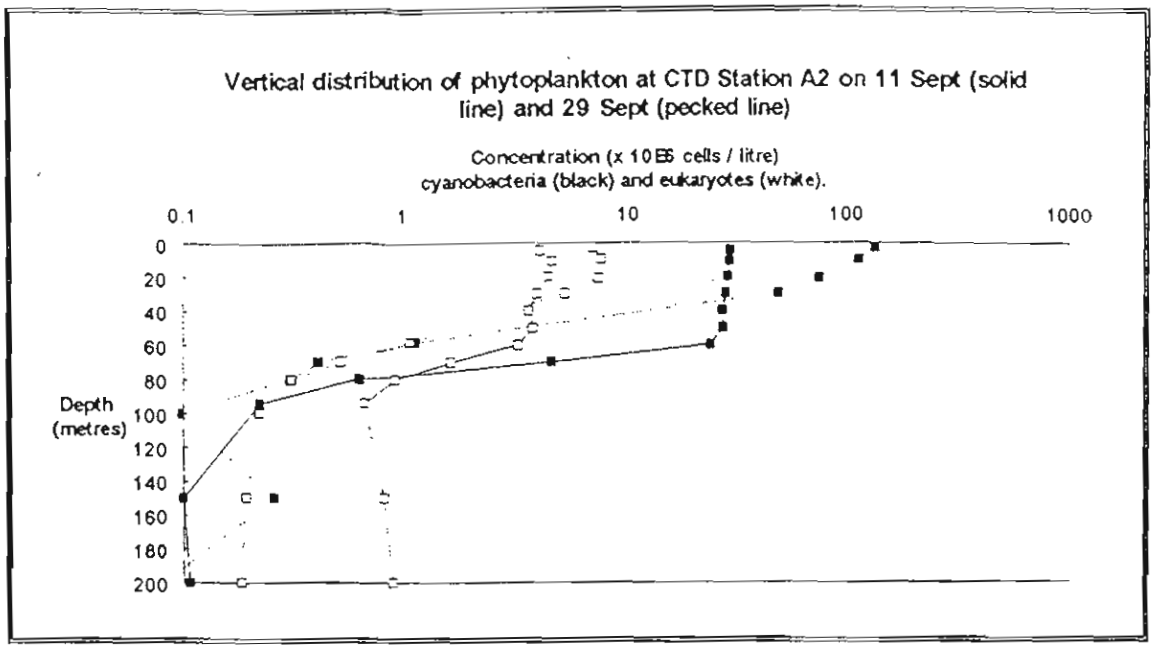
2) Microzoplankton grazing dilution experiments (set-up by Elaine Edwards using JGOFS protocols) were sampled over a time-course of 0, 12 & 24 hours. Flow cytometric protocols, described above, to quantify different taxa (prochlorophytes, cyanobacteria, picoeukaryotes) of the phytoplankton, were used in order to compute growth rates and grazing induced mortality rates of individual phytoplankton taxa. Experiments were run in parallel with those of Elaine Edwards on grazing on total phytoplankton, and of Claire Stelfox on FLA uptake to identify principal microzooplankton grazers.

Results

The DRA funded Becton Dickinson FACSort cytometer behaved impeccably and proved a joy to use. Sensitivity was adequate to determine cellular light scatter and fluorescences from prochlorophytes (0.6 μm in size and ca 1 fg chlor-a) in surface waters. A total of 1051 samples were analysed from 35 vertical profiles and 12 grazing and other experiments, as outlined in Table 1.

Cyanobacteria (*Synechococcus* spp.) were abundant ($>10^6$ cells litre^{-1}) in the surface mixed layer throughout the Gulf of Oman and the Arabian Sea. Populations reached 450 x 10^6 cells litre^{-1} in the upwelling water and dominated the phytoplankton numerically throughout most of the region. Prochlorophytes (*Prochlorococcus* spp.) were restricted to the oligotrophic waters at the SE end (A4 onwards) of our main transect where they were more abundant than the cyanobacteria. Prochlorophytes were entirely absent from the upwelling waters. Picoeukaryotes were found throughout the region. Their cytometric signatures often suggested a disperse population, although a distinct population at a depth of 120-140 metres was observed frequently. This population may contain chlo-c since their chlorophyll fluorescence spectra crossed over into the phycoerythrin channel. Phytoplankton populations were found to be growing fast during the period of the cruise. Analyses carried out at station 2 (Fig 1) showed that the cyanobacteria had increased by 800% and eukaryotes by 300% in surface waters over an 18 day time period.

Fig 1: Vertical profiles of phytoplankton on 11th and 29th September revealed rapid growth in surface waters.



Microzooplankton grazing experiments on autotrophic picoplankton revealed:
a) microzooplankton herbivory was vigorous at all stations with specific rates in the range of 0.1 to 1.0 day-1.
b) growth rates of cyanobacteria, eukaryotes and prochlorophytes was generally higher than that of their mortality from grazing;
c) rates generally decreased with reduced ambient nutrient content.

The overall picture obtained during the waning SW monsoon period, was one of intense microbial activity. It will be interesting to see how this process has developed when we return in November.

Table 1: Flow Cytometric Analyses carried out on cruise D210. VP: vertical profiles with depth range (metres) of samples analysed. GRA: Microzooplankton grazing experiments with time course measurements (T) in hours. INC: Incubation on board. INSIT: incubation in situ.

Date	*Station*	*Analysis*	*Date*	*Station*	*Analysis*
27-Aug-94	Shakedown	VP;10	17-Sep-94	A5	GRA5;T0,T12INC,T12INSIT
	GOM4	VP;5-100		A5/8	VP;5-301
29-Aug-94	GOM2/7	VP;5-150	18-Sep-94	A5	GRA5;T24INC;T24INSIT
30-Aug-94	GOM1/6	VP;1-87		A6/2	VP;3-198
31-Aug-94	GOM3/1	VP;7-2848	19-Sep-94	A7/5	VP;10-301
01-Sep-94	GOM5/4	VP;3-200	20-Sep-94	A7	GRA6;T0,T6INC,T12INC
02-Sep-94	GOM6/1	VP;10-300		A7/26	VP;100-180
04-Sep-94	A1/8	VP;4-300		A7/30	VP;1-100
05-Sep-94	A1	GRA1;T0	21-Sep-94	A7	GRA6;T24INC,T24INSIT
	A1	GRA1;T12		A7	GRA7;T0
06-Sep-94	A1	GRA1;T24INCUB		A7/40	VP;5-100
		GRA1;T24INSITU	22-Sep-94	A7	GRA7;T24INC
	A1/30	VP;2-200		A7/52	VP;5-161

07-Sep-94	A1	GRA2;T0;T3;T7;T10;T14	23-Sep-94	A8/5	VP,4-300
	A1/?	VP;0600;0800;1000	25-Sep-94	A9	GRA8;T0
	A1/42	VP;4-299		A9/8	VP;140-402
08-Sep-94	A1	GRA2;T24		A9/14	VP;3-140
	AS1/1	VP;3-219	26-Sep-94	A9	GRA8;T24INC,T24INSIT
09-Sep-94	AS2/3	VP;11-250	27-Sep-94	A10/7	VP;5-300
	AS3/4	VP;3-50	28-Sep-94	A3	GRA9;T0,T12INC,T12IN SIT
	AS4/4	VP;5-80		A3	DOC EXPT T0DAY
	AS5/1	VP;5-35		A3/67	VP;3-199
11-Sep-94	A2/4	VP;5-208	29-Sep-94	A3	GRA9;T24INC,T24INSIT
12-Sep-94	A3	GRA3;T0,T2,T4,T6,T8,T1 0,T12,T14		A3	DOC EXP T1DAY
13-Sep-94	A3	GRA3;T24INC,T24INSIT		A2/10	VP;3-300
	A3/21	VP;5-300	30-Sep-94	A1	GRA10;T0,T12INC,T12I NSIT
14-Sep-94	A3	GRA4;T0, T12INC,T12INSIT		A1/54	VP;200-300
		SIZE & PHYCOE ANALYSES		A3	DOC EXPT T2DAYS
	A3/41	VP;4-300		A1/55	VP;5-150
15-Sep-94	A3	GRA4;T24INC;T24INSIT	01-Oct-94	A1	GRA10;T24INC,T24INSI T
16-Sep-94	A4/1	VP;3-250		A3	DOC EXPT T3 DAYS

Acknowledgements: Thanks to Fauzi for PSing such a productive cruise, Claire and Elaine for skilled assistance and Jane Fonda, and all the ARABESQUE guys and gals for making it happen in such a fun way.

DISTRIBUTION OF CHLOROPHYLL AND CAROTENOID PIGMENTS IN THE ARABIAN SEA

RAY BARLOW PLYMOUTH MARINE LABORATORY

OBJECTIVES

1) To track the varying concentrations of chlorophyll and carotenoid pigments in the Arabian Sea at the end of the SW 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) Conduct an *in situ* pilot experiment of ^{14}C uptake into pigments to determine the specific turnover rates of pigments and hence specific growth rates of various phytoplankton classes.

SAMPLING AND METHODS

Samples (1-2l) were drawn from all shallow biogeochemistry CTD casts, filtered onto GFF filters, and immediately stored frozen in liquid nitrogen until analysis. Pigments were extracted into 90% acetone and an aliquot injected onto a C-8 reverse phase column for high pressure liquid chromatographic separation and quantitation of some 20 chlorophyll and carotenoid pigments using both absorbance (440nm) and fluorescence (Ex 405nm; Em 670nm) detection. Details of the CTD sampling are presented in Table 1. Other subsamples were taken from pooled water samples used for primary production studies, filtered, frozen and analysed as above (see 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* while the trap, SAP and underway samples were stored frozen for analysis at PML. At the final occupied station (A1) an *in situ* pilot experiment was conducted to determine the uptake of ^{14}C into various pigments. Seawater (2.7l) from 6 depths were each spiked with 250 μCuries ^{14}C, incubated for 24h, and the phytoplankton filtered onto GFF filters which were stored frozen for later analysis at the PML.

PRELIMINARY RESULTS

A range of chlorophylls and carotenoids were detected in the Arabian Sea, including chlorophylls *a*, *b*, c_1c_2, c_3, divinyl chlorophyll *a*, peridinin, butanoyloxyfucoxanthin, fucoxanthin, hexanoyloxyfucoxanthin, diadinoxanthin, alloxanthin, zeaxanthin and α

and β-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 (1200 ng/l at AS5) and steadily decreased at each station along the south easterly cruise track into oligotrophic waters. Fig. 1 illustrates the decline in surface chlorophyll *a* concentrations (upper 5m) and it may be noted that the chloropyll *a* levels at station A7 were as low as 56 ng/l. Fucoxanthin was the most dominant accessory pigment in the inshore region (700- 800 ng/l), indicating that diatoms accounted for a large proportion of the chlorophyll biomass. Chlorophyll *a* (1608 ng/l) and fucoxanthin (690 ng/l) were also the most prominent pigments at station A1 on our first day of occupation, but their concentrations decreased considerably over the next 3 days as we drifted into other water masses by following the sediment trap, and hexanoyloxyfucoxanthin and zeaxanthin were then the more significant accessory pigments. Similar observations were also noted for stations A2, A3 and A4. Hexanoyloxyfucoxanthin and zeaxanthin were again the important accessory pigments at stations A5, A6 and A7, while the detection of divinyl chlorophyll *a* at these stations indicated the prescence of prochlorophytes. Divinyl chlorophyll *a* levels near the surface were very low at A5 (4-10 ng/l) compared to chlorophyll *a* concentrations of 250-380 ng/l, but increased to 25-31 ng/l at A6 and A7 whereas chlorophyll *a* had decreased considerably to 56 ng/l at A7. Hexanoyloxyfucoxanthin concentrations were 133 ng/l at A6 and 55 ng/l of zeaxanthin were measured at A7, indicating the significance of prymnesiophytes and cyanobacteria, respectively, at these two stations. On the return leg, chlorophyll *a* levels were found to be 520 ng/l at A3 and 676 ng/l at A1, which were comparable to the concentrations measured previously.

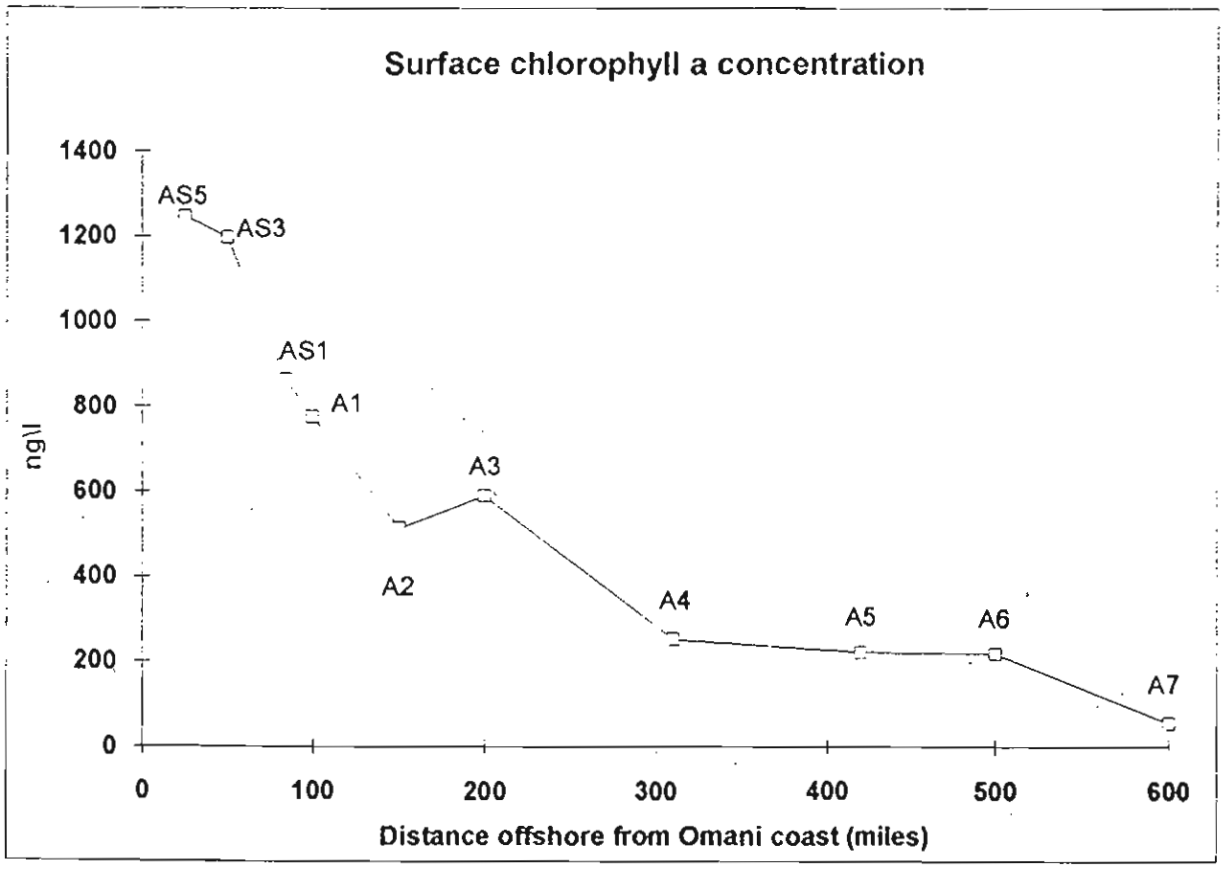
TABLE 1. SAMPLING FOR PIGMENTS

SHALLOW CTD CASTS

DATE	*STATION*	*DEPTHS SAMPLED*
28 /8/94	GOM4	12 to 300m
29/8/94	GOM2	12 to 150m
30/8/94	GOM1	12 to 90m
31/8/94	GOM3	7 to 250m
1/9/94	GOM5	12 to 200m
2/9/94	GOM6	12 to 300m
4/9/94	A1	12 to 300m
5/9/94	A1	8 to 100m
6/9/94	A1	12 to 200m
7/9/94	A1	12 to 300m
8/9/94	A1	7 to 100m
8/9/94	AS1	7 to 100m
9/9/94	AS2	7 to 100m
9/9/94	AS3	7 to 100m
9/9/94	AS5	6 to40m
11/9/94	A2	12 to 210m
12/9/94	A3	10 to 100m
13/9/94	A3	12 to 300m
14/9/94	A3	12 to 300m
16/9/94	A4	12 to 250m
17/9/94	A5	12 to 300m
18/9/94	A6	12 to 200m
19/9/94	A7	12 to 300m
20/9/94	A7	14 to 140m
21/9/94	A7	13 to 120m
22/9/94	A7	13 to 160m
24/9/94	A8	12 to 300m
25/9/94	A9	18 to 240m
27/9/94	A10	12 to 300m
28/9/94	A3	12 to 200m
29/9/94	A2	12 to 300m
30/9/94	A1	12 to 150m

PRODUCTION CTD CASTS

DATE	*STATION*	*DEPTHS SAMPLED*
5/9/94	A1	6 to 40m
6/9/94	A1	6 to 40m
7/9/94	A1	6 to 40m
12/9/94	A3	4 to 25m
14/9/94	A3	6 to 60m
20/9/94	A7	6 to 75m
25 /9/94	A9	6 to 75m
28 /9/94	A3	6 to 50m
30/9/94	A1	6 to 35m


Surface chlorophyll a concentration
1400
1200
1000
800
600
400
200
0
ng/l
AS5
AS3
AS1
A1
A2
A3
A4
A5
A6
A7
0
100
200
300
400
500
600
Distance offshore from Omani coast (miles)

Samples for bacterial numbers and heterotrophic activity

Date	Station	Depths sampled (metres)										
30/8/94	GOM3/1	1	5	10	14	17	23	26	30	33	40	
1/9/94	GOM5A	1	5	10	14	17	23	26	30	33	40	
2/9/94	GOM6A	1	4	7	11	13	17	20	23	25	30	
3/9/94	GOM6B	1	8	14	21	26	35	40	46	50	60	
4/9/04	A1/1	1	5	10	14	17	23	26	30	33	40	
5/9/94	A1/13	1	5	10	14	17	23	26	30	33	40	
6/9/94	A1/23	1	5	10	14	17	23	26	30	33	40	
7/9/94	A1/34	1	5	10	14	17	23	26	30	33	40	
7/9/94	A1/40	4	45	50	100	200	400	800	1000	1200	1300	1500
9/9/94	AS2/1	1	5	10	14	17	23	26	30	33	40	
10/9/94	AS5/3	1	3	6	9	11	15	17	19	21	25	
11/9/94	A2/1	1	5	10	14	17	23	26	30	33	40	
12/9/94	A3/4	1	5	10	14		23	26	30	33		
13/9/94	A3/18	1	8	14	21	26	35	40	46	50	60	
14/9/94	A3/30	5	10	15	45	50	100	200	400	800	1000	
15/9/94	A3/48	1	8	14	21	26	35	40	46	50	60	
17/9/94	A5/1	1	13	24	35	43	58	65	76	82	100	
18/9/94	A6/1	1	8	14	21	26	35	40	46	50	60	
19/9/94	A7/3	1	13	24	35	43	58	65	76	82	100	
20/9/94	A7/18	1	10	18	26	32	44	50	57	62	75	
21/9/94	A7/38	5	10	15	45	50	100	200	400	800	1000	
22/9/94	A7/49	1	10	18	26	32	44	50	57	62	75	
24/9/94	A8/1	1	10	18	26	32	44	50	57	62	75	
25/9/94	A9/1	1	10	18	26	32	44	50	57	62	75	
27/9/94	A10/1	1	5	10	14	17	23	26	30	33	40	
28/9/94	A1/47	1	5	8	12	15	21	23	27	29	35	

MICROZOOPLANKTON COMMUNITY STRUCTURE

Claire Stelfox (Plymouth Marine Lab/Southampon Uni)

Objective: To assess the microzooplankton community structure across the eutrophic/oligotrophic gradient in the Arabian Sea.

Specific Aims:

1. To quantify the concentration and species composition of microzooplankton (phagotrophic organisms <200µm in length) in the surface mixed layer of the Arabian Sea.
2. Determine microzooplankton standing stocks.
3. Assess qualitatively the main grazers of phytoplankton 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 ananlysed by inverted/fluorescent microscopy at the 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. Approximately 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.

Table 1. Dominant microzooplankton and phytoplankton cells as identified from Apstein hauls

Station	**Date**	**Dominant species**
GOM2	29.8.94	*Rhabdonella sp., Eutintinnus sp., Protoperidinium spp.*, Acantharians, Radiolarians, *Rhizosolenia spp.*
GOM5	1.9.94	*Dictyocysta elegans, Codonellopsis sp., Ceratium spp., Protoperidinium spp., Dinophysis sp.*, Acantharians, Radiolarians, *Rhizosolenia spp., Chetoceros spp., Trichodesmium sp.*, large ciliate sp
GOM6	2.9.94	*Dictyocysta elegans, Codonellopsis sp.,Eutintinnus sp., Leegaardiella sp., Gyrodinium spp., Protoperidinium spp., Dinophysis sp.*, Acantharians, Radiolarians, Foraminiferan., *Rhizosolenia spp., Nitzschia spp., Phaeocystis sp., Navicula spp.*
A1	4.9.94	*Codonellopsis sp., Rhabdonella sp., Dadayiella sp., Tiarina sp., Protoperidinium spp., Podolampas sp.*, Acantharians, Radiolarians, Foraminiferan, *Rhizosolenia spp., Nitzschia spp., Navicula spp., Ceratium spp.*

A1	5.9.94	*Amphorides sp., Codonellopsis sp., Dadayiello sp., Ascampbelliella sp., Tiarina sp., Protoperidinium spp., Dinophysis sp., Cochlodinium sp.*, Acantharians, Radiolarians, Foraminiferan, *Cerotium spp., Prorocentrum sp., Trichadesmium sp., Rhizosolenia spp., Chetoceros spp.*
A1	6.9.94	*Codonellopsis spp., Ascampbelliella sp., Acanthostomella sp.,Dictyocysta elegans, Strobilidium sp., Euplotes sp., Protoperidinium spp., Ceratium spp., Histoneis sp.*, Acantharians, Radiolarians, Foraminiferan, *Trichodesmium sp., Nitzschia spp., Navicula spp., Chetoceros spp.*
A1	7.9.94	*Codonellopsis sp., Dictyocysta elegans., Amphorides sp., Rhabdonella sp., Strobilidium sp., ciliate sp., Dinophysis spp., Protoperidinium spp., Gyrodinium sp., Cochlodinium sp., Ceratium spp., Histoneis sp., Prorocentrum sp.*, Acantharians, Radiolarians, Foraminiferan, *Trichodesmium sp., Rhizosolenia spp., Chetoceros spp., Phaeocystis sp.*
AS2	9.9.94	*Codonellopsis spp., Dictyocysta elegans, Ascampbelliella sp., Rhabdonello spp., Strombidium sp., Euplotes sp., Dinophysis spp., Protoperidinium spp., Gymnodinium spp., Gyrodinium spp., Dissodinium sp.*, Acantharians, Radiolarians, Foraminiferan, *Histoneis sp., Thalassiosira sp., Rhizosolenia spp., Chetoceros spp., Eucampia sp., Navicula spp., Nitzschia spp.*
AS3	9.9.94	*Codonellopsis sp., Ascampbelliella sp., Dictyocysta elegans, Rhabdonella spp., Amphorides sp., Parundella sp., Salpingella sp.,Protoperidinium spp., Gymnodinium spp.,Ceratium spp., Silica flagellate*, Acantharian, Radiolarian, Foraminiferan, *Trichodesmium sp., Rhizosolenia spp., Chetoceros spp., Cosinodiscus sp., Eucampia sp., Navicula spp., Nitzschia sp.*
A2	11.9.94	*Codonellopsis sp., Rhabdonella spp., Gymnodinium sp., Protoperidinium spp., Ceratium spp., Prorocentrum sp.*, Acantharians, Radiolarians, Foraminiferan, *Pterosperma sp., Rhizosolenia spp., Chetoceros spp., Thalissiosira sp., Cosinodiscus sp., Nitzschia spp., Pyrophacus sp.*
A2	12.9.94	*Amphorides sp., Ascampbelliella sp., Eutintinnus sp., Codonellopsis sp., Dadayiella sp., Euplotes sp., Dinophysys sp., Podolampas sp., Protoperidinium spp., Gymnodinium spp., Prorocentrum sp., Ceratium spp., Histoneis sp.*, Acantharians, Radiolarians, Foraminiferan, *Rhizosolenia spp., Navicula spp., Phaeocystis sp., Chetoceros spp., Cosinodiscus sp.*

A3	13.9.94	*Dadayiella sp., Codonellopsis sp., Dinophysis sp., Protoperidinium spp., Gymnodinium spp., Erythropsis sp., Ceratium spp.*, Acantharians, Radiolarians, Foraminiferan, *Rhizosolenia spp., Navicula spp., Phaeocystis sp., Chetoceros spp., Cosinodiscus sp., Nitzschia sp.*
A3	14.9.94	*Dadayiella sp., Codonellopsis sp., Dinophysis sp., Protoperidinium spp., Gymnodinium spp., Dinophysis sp., Podolampas sp., Erythropsis sp., Ceratium spp., Histoneis sp.*, Acantharians, Radiolarians, Foraminiferan. *Silica flagellate, Rhizosolenia spp., Navicula spp., Phaeocystis sp., Chetoceros spp., Cosinodiscus sp., Nitzschia sp.*
A3	15.9.94	*Dadayiella sp., Codonellopsis sp., Parundella sp., Dinophysis sp., Protoperidinium spp., Gymnodinium spp., Dinophysis sp., Podolampas sp., Erythropsis sp., Ceratium spp., Histoneis sp.*, Acantharians, Radiolarians, Foraminiferan, *Silica flagellate, Rhizosolenia spp., Navicula spp., Phaeocystis sp., Chetoceros spp., Cosinodiscus sp., Nitzschia sp.*
A5	17.9.94	*Ascampbelliella sp., Proplectella sp., Rhabdonella sp., Amphorides sp., Podolampas sp., Protoperidinium sp., Gonyaulax sp., Prorocentrum sp., Erythropsis sp., Cochlodinium sp., Torodinium sp., Dinophysis sp.*, Acantharians, Radiolarians, Foraminiferan, *Rhizosolenia spp., Cosinodiscus sp., Phaeocystis sp.*
A6	18.9.94	*Proplectella sp., Rhabdonella sp., Codonellopsis sp., Podolampas sp., Dinophysis spp., Gonyaulax sp., Ceratium spp., Histoneis sp.*, Acantharians, Radiolarians, Foraminiferan, *Rhizosolenia spp., Pterosperma sp., Chetoceros spp., Phaeocystis sp.*
A7	19.9.94	*Codonellopsis sp., Rhabdonella sp.,Parundella sp., Proplectella sp., Cochlodinium sp., Gymnodinium sp., Oxytoxum sp., Phalachroma sp.*, Acantharians, Radiolarians, Foraminiferan, Silica flagellate, *Rhizosolenia spp., Nitzschia sp., Phaeocystis sp.*
A7	21.9.94	*Codonellopsis sp., Rhabdonella sp.,Parundella sp., Proplectella sp., Cochlodinium sp., Gymnodinium sp., Oxytoxum sp., Gonyaulax sp., Dinophysis sp.,Phalachroma sp.*, Acantharians, Radiolarians, Foraminiferan, Silica flagellate, *Rhizosolenia spp., Nitzschia sp., Phaeocystis sp.*

A7	22 9.94	*Climacocylis sp., Codonellopsis sp., Rhabdonella sp.,Parundella sp., Proplectella sp., Salpingella sp., Cochlodinium sp., Gymnodinium sp., Oxytoxum sp., Gonyaulax sp., Dinophysis sp.,Prorocentrum sp.,* Acantharians, Radiolarians, Foraminiferan, Silica flagellate, *Rhizosolenia spp., Nitzschia sp., Phaeocystis sp.*
A8	24.8.94	*Amphorides sp., Dadayiella sp., Rhabdonella sp., Proplectella sp., Leegaardiella sp., Tiarina sp., Gyrodinium spp., Gymnodinium spp., Cochlodinium spp., Protoperidinium spp., Gonyaulax sp., Erythropsis sp., Histoneis sp.,* Acantharinas, Radiolarians, Foraminiferan, *Rhizosolenia sp., Navicula spp., Nitzschia spp.*
A9	25.9.94	*Dadayiella sp., Dinophysis sp., Gymnodinium sp., Ceratium sp., Protoperidinium sp.,* Acantharian, Radiolarian, Foraminiferan, *Nitzschia sp., Rhizosolenia sp.*
A3	28.9.94	*Proplectella spp., Xystonella sp., Rhabdonella sp., Parundella sp., Codonellopsis sp., Eutintinnus sp., Dadayiella sp., Amphorides sp., Protoperidinium spp., Gymnodinium spp., Pronoctiluca sp., Gyrodinium spp., Dinophysis spp., Prorocentrum sp.,* Acantharians, Radiolarians, Foraminiferan, *Rhizosolenia spp., Pterosperma sp., Pyrophacus sp., Cosinodiscus sp., Nitzschia sp.*
A2	29.9.94	*Xystonella sp., Rhabdonella sp., Salpingella sp., Proplectella sp., Leegaardiella sp., Peritromus sp., Protoperidinium spp., Gyrodinium spp., Erythropsis sp., Gonyaulax sp., Dissodinium sp., Ceratium spp.,* Acantharians, Radiolarains, Foraminiferan, *Rhizosolenia spp., Navicula spp., Nitzschia spp., Eucampia sp.*
A1	30.9.94	*Dictyocysta sp., Codonellopsis sp., Tiarina sp., Tontonia sp., Strombidium sp., Protoperidinium spp., Podolampas sp., Gyrodinium spp., Gymnodinium spp., Gonyaulax sp., Torodinium sp., Prorocentrum sp., Dinophysis sp.* Acantharians, Radiolarians, Foraminiferan, *Rhizosolenia spp., Chetoceros sp., Navicula sp., Dactyliosolan sp.*

Cyanobacteria

10 mls of water collected from the biogeochemical CTD was filtered onto 0.2μm nucleopore filters and cyanobacteria were enumerated by fluorescent microscopy. Cell concentrations were highest in the Gulf of Oman reaching 200,000 cyanobacteria per ml. These microscopic counts have been compared to the flow cytometer counts - see Peter Burkill's report.

Phytoplankton

1.9.94	GOM5	Apstein 50m
	GOM5#4	Lugol's 3-101m
		Phytoplankton 3-101m
		Cyanobacteria 3-101m
		Glutaraldehyde 3-101m
		underway phytoplankton sampling
2.9.94	GOM6	Apstein 50m
	GOM6#1	Lugol's 10-101m
		Phytoplankton 10-101m
		Cyanobacteria 10-101m
		Glutaraldehyde 10-101m
		underway phytoplankton sampling
3.9.94.	GOM6-A1	underway sampling
4.9.94	A1	Apstein 50m
		Phytoplankton 4-299m
5.9.94	A1	FLA#1 10m
		Apstein 100m
6.9.94	A1	Apstein 40m
	A1#30	Lugol's 3-150m
		Phytoplankton 3-200m
		Cyanobacteria 3-55m
		Glutaraldehyde 3-55m
		Formaldehyde 3-55m
		Bouins 3-30m
7.9.94	A1	FLA#2 10m
		Apstein 50m
	A1#42	Lugol's 4-101m
		Phytoplankton 4-201m
		Cyanobacteria 4-51m
		Glutaraldehyde 4-51m
8.9.94	AS1#1	Lugols 3-99m
		Phytoplankton 3-99m
		Cyanobacteria 3-99m
		Glutaraldehyde 3-99m
9.9.94	AS2	Apstein 50m
		Lugol's 11-100m
		Phytoplankton 11-100m
		Glutaraldehyde 11-100m
		Cyanobacteria 11-100m
	AS3#5	Apstein 50m
		Lugol's 3-141m
		Phytoplankton 3-141m
		Cyanobacteria 3-101m
		Glutaraldehyde 3-101m
	AS5#1	Lugol's 5-42m
		Phytoplankton 5-42m
		Cyanobacteria 5-42m
		Glutaraldehyde 5-42m
10.9.94	AS5-A2	underway phytoplankton sampling
11.9.94	A2	Apstein 50m
	A2#4	Lugol's 5-150m
		Phytoplankton 5-208m
		Cyanobacteria 5-94m
		Glutaraldehyde 5-94m
		Formaldehyde 5-50m
		Bouins 5-20m

100mls of water from upper 300m 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.

Fluorescently Labelled Algae (FLA) Experiment

To assess which individual microzooplankton species graze on different size classes of phytoplankton the tracer method of labelling algae with the fluorescent dye 5-(4.6-dichlorotriazin-2-yl) aminofluorescein (DTAF) was used, following the protocol of Rublee & Gallegos (1989) and Sherr *et al* (1991). Eight FLA cultures. of sizes 1-30μm. were added to 4 litres of seawater (collected from the pre-
dawn**********
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****
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****
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**********m[illegible]iferan, Silica flagellate, Rhizosolenia spp., Nitzschia sp., Phaeocystis
sp.[illegible]

Table 2. Sampling Procedure

DATE	STATION	SAMPLING EVENT
28.8.94	GOM4#1	Lugol's 5-100m
		Phytoplankton 5-100m
		Cyanobacteria 5-100m
		Glutaraldehyde 5-50m
		underway phytoplankton sampling
29.8.94	GOM2	Apstein 50m
	GOM2#7	Lugol's 5-100m
		Phytoplankton 5-101m
		Cyanobacteria 5-101m
		Glutaraldehyde 5-101m
		underway phytoplankton sampling
30.8.94	GOM1#6	Lugol's 5-87m
		Phytoplankton 5-87m
		Cyanobacteria 5-87m
		Glutaraldehyde 5-87m
		underway phytoplankton sampling
31.8.94	GOM3#1	Lugol's 7-174m
		Phytoplankton 7-174m
		Cyanobacteria 7-174m
		Glutaraldehyde 7-80m
		underway phytoplankton sampling

12.9.94	A2	FLA#3 10m
		Apstein 50m
		Phytoplankton 4-99m
13.9.94	A3#23	Lugol's 5-141m
		Phytoplankton 5-300m
		Cyanobacteria 5-110m
		Glutaraldehyde 5-110m
		Formaldehyde 5-50m
		Bouins 5-50m
		Apstein 50m
14.9.94	A3	FLA#4 10m
	A3#41	Lugol's 4-150m
		Phytoplankton 4-150m
		Cyanobacteria 4-99m
		Glutaraldehyde 4-99m
15.9.94	A3#53	Phytoplankton 0-100m
		Apstein 50m
16.9.94	A4#2	Lugol's 3-121m
		Phytoplankton 3-250m
		Cyanobacteria 3-90m
		Glutaraldehyde 3-90m
		Formaldehyde 3-50m
		Bouins 10-50m
17.9.94	A5#8	FLA #5 10m
		Lugols 5-150m
		Phytoplankton 5-301m
		Cyanobacteria 5-101m
		Glutaraldehyde 5-101m
		Formaldehyde 5-60m
		Bouins 5-60m
		Apstein 50m
18.9.94	A6#2	Lugols 3-100m
		Phytoplankton 3-120m
		Cyanobacteria 3-100
		Glutaraldehyde 3-100m
		Apstein 50m
19.9.94	A7#5	Lugol's 10-150m
		Phytoplankton 10-301m
		Glutaraldehyde 10-100m
		Formaldehyde 10-50m
		Bouins 10-50m
		Apstein 50m&100m
20.9.94	A7	Apstein 100m
		FLA#6 30m
	A7#26/30	Lugol's 1-140m
		Phytoplankton 1-160m
		Glutaraldehyde 1-100m
21.9.94	A7	FLA#7 30m
		Apstein 100m
22.9.94	A7#52	Lugols 5-130m
		Phytoplankton 5-161m
		Glutaraldehyde 5-101m
		Apstein 100m
24.9.94	A8#5	Lugol's 4-120m
		Phytoplankton 4-300m
		Glutaraldehyde 4-100m
		Apstein 100m

25.9.94	A9	FLA#8 20m
	A9#14	Lugol's 3-120m
		Phytoplankton 3-140m
		Glutaraldehyde 3-100m
		Formaldehyde 3-50m
		Bouins 10-50m
27.9.94	A10#7	Lugol's 5-140m
		Phytoplankton 5-300m
		Glutaraldehyde 5-100m
28.9.94	A3	FLA#9 20m
		Apstein 100m
	A3#67	Lugol's 5-120m
		Phytoplankton 5-199m
		Glutaraldehyde 5-99m
		Formaldehyde 5-55m
		Bouins 10-55m
29.9.94	A2	Apstein 100m
	A2#10	Lugol's 3-101m
		Phytoplankton 3-300m
		Glutaraldehyde 3-101m
30.9.94	A1	FLA#10 10m
		Apstein 100m
	A1#55	Lugol's 5-100m
		Phytoplankton5-150m
		Glutaraldehyde 5-100m
		Formaldehyde 10-49m
		Bouins 10-30m

Microzooplankton Herbivory
Elaine Edwards (Plymouth Marine Lab)

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

Methods
Grazing
Microzooplankton grazing dilution experiments were carried out at 5 station along the cruise track. 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 sreened using a 200µm 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, whenever possible *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 P.H.Burkill cruise report).

Copepod predation experiment
To estimate the predation of copepods on protozoa one experiment was carried out where a 200µm screened microzooplankton population was incubated for 24 hours in the presence and absence of copepods. Copepods were collected using a WP-2 net and were added to 2 litre polycarbonate bottles containing the microzooplankton population. Copepod concentrations reanged from 10 to 30 individuals per bottle. Sub-samples were taken at T0 and T24 for determination of chlorophyll and prey numbers.

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 30-60mls were fixed in 0.3% glutaraldehyde, stained with DAPI and Proflavin and filtered onto 0.8µm black polycarbonate filters. Filters were mounted onto microscope slides and stored frozen for subsequent analysis. Some analysis has been carried out but it is envisaged that the majority will be analysed back in the laboratory.

Results
All grazing experiment chlorophyll samples have been analysed. Preliminary results show microzooplankton to be grazing between 10% (station A1) and 43% (station A7) of the phytoplankton population per day. Growth rates of phytoplankton was found to be high in all experiments. Further analysis on the structure of the micrograzer community will be carried out in the lab.

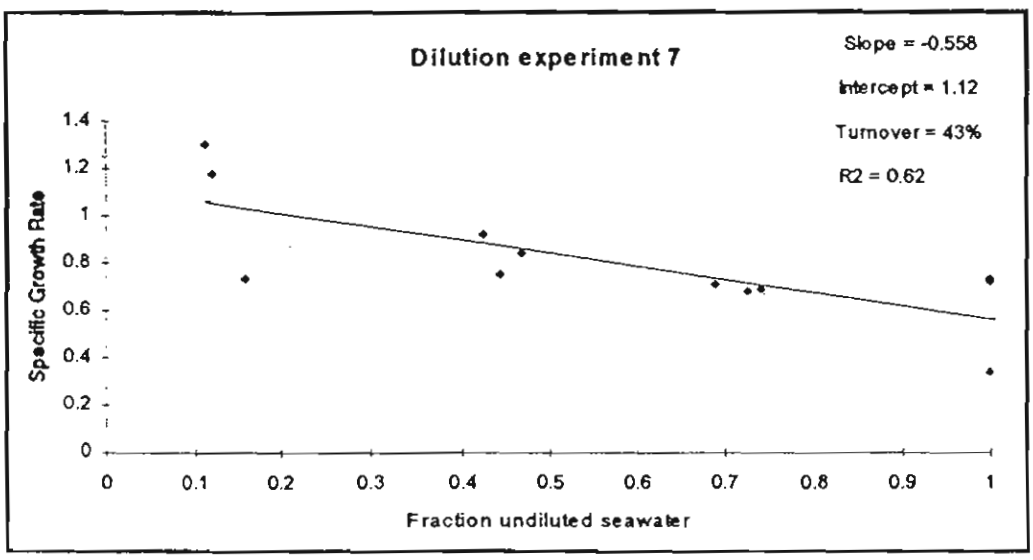

Figure 1: Dilution experiment plot showing results of experiment carried out at station A7. The specific growth rate of the dilutions can be plotted against the fraction of undiluted seawater to give a negative linear correlation. The slope of the regression represents the grazing rate and the y intercept 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. All net hauls, using a WP-2 net, were carried out to a depth of 100m. Samples were size fractioned through a 2000, 1000, 500, & 200µm mesh, sub-samples were filtered onto GF/C filters for C & N analysis, and the bulk sample fixed in buffered formalin.

References:

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

Special thanks to NickO for organising the rigs "you did a wonderful job, don't you feel good!" and Bill for the Go-flos (they were't so bad after all!).

Table 1: Microzooplankton grazing experiments carried out on cruise D210

EXPT No.	DATE	STATION	DEPTH	INCUBATION	ANALYSIS
1	5/9/94	A1	10m	In situ & lab	0.2µm
2	7/9/94	A1	10m	Lab	0.2, 2 & 18µm
3	12/9/94	A3	10m	In situ & lab	0.2, 2µm
4	14/9/94	A3	10m	In situ	0.2µm & HPLC
5	17/9/94	A5	10m	In situ & lab	0.2, 2µm
6	20/9/94	A7	30m	In situ & lab	0.2µm
7	21/9/94	A7	30m	Lab	0.2µm
8	25/9/94	A9	20m	In situ & lab	0.2, 2µm
9	27/9/94	A3	20m	In situ & lab	0.2µm
10	30/9/94	A1	20m	In situ & lab	0.2, 2µm

Table 2: Mesozooplankton biomass sampling

DATE	STATION	TIME
30/8/94	GOM1	0000
4/9/94	A1	1200
5/9/94	A1	0000
12/9/94	A3	1400
13/9/94	A3	0000
19/9/94	A7	1200
20/9/94	A7	0000
21/9/94	A7	1200
25/9/94	A9	1200
26/9/94	A9	0000
28/9/94	A3	1200
1/10/94	A1	1400

Geochronology and Particle Residence Times

Jim Smith
University of Edinburgh

$^{210}Po/^{210}Pb$

Twenty litre samples have been collected from ten depths surface, 10, 30, 50, 75, 100, 150, 250, 350, and 500m) using dedicated CTD casts. The samples have then been processed to remove the particulates by filtration and the dissolved by scavangeing and reprecipitation . These samples will be processed upon their return to The Grant Institute, Edinburgh University.

^{234}Th

Samples collected by the SAPs both particulate and disolved have been counted on a shipboard spectroscopy system useing a high purity, 38% efficient, germanium detector connected to a cryogenic cold head assembly (EG&G Ortec Electricool system) . Counting will continue at Edinburgh University.

DATE	STATION	210Po/210Pb Samples	234Th Samples
28/8/94	GOM4	10 depths samples	
2/9/94	GOM6	10 depths samples	
5/9/94-7/9/94	A1	15 depths samples	9 depths sampled
9/9/94	AS4	6 depths samples	
12/9/94-14/94	A3	15 depths sampled	10 depths sampled
17/9/94	A5	10 depths samples	
19/9/94-21/9/94	A7	15 depths samples	8 depth sampled
25/9/94	A9	10 depths samples	

Vertical Fluxes of Sedimenting Particulate Organic Carbon and Nitrogen
ARABESQUE 1 - RRS Discovery 210
Tim Fileman

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 collect a vertical profile using the SAPs for Dan Repeta at Wood's Hole for HPLC Pigments.

Analyses

SAPs filters:

a) POC/PON	Tim Fileman/PML
b) Chlorophylls and Carotenoid pigments (HPLC)	Ray Barlow/PML
c) Fatty Acids (lipid biomarkers) (GC and GC/MS)	Tim Fileman/PML
d) Normal and highly branched aliphatic hydrocarbon biomarkers (GC and GC/MS)	Dave Cook/UoP
e) Dissolved and particulate radionuclides (^{234}Th)	Jim Smith/UoE
f) DMSP	Angela Hatton/UEA
g) Carbon and nitrogen isotopes	Nick Owens/UoN

Sediment Trap material:

a) POC/PON	Tim Fileman/PML
b) Chlorophylls and Carotenoid pigments (HPLC)	Ray Barlow/PML
c) Carbon and nitrogen isotopes	Nick Owens/UoN
d) Particulate silica	Fileman & Woodward/PML

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

Sampling Methods

Stand Alone Pumps:

SAPs are completely self contained large volume *in-situ* pumping systems capable of operation down to depths of 5500 metres. They allow very large volumes (1000 - 2000 litres) of water to be sampled for a range of determinands. Power is provided by rechargable 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 293mm diameter filter and dissolved radionuclides are stripped from the filtered water using Manganese Dioxide coated in-line cartridges. The 293mm glass fibre filters are quantitatively subsampled for a range of analyses and the remainder filter is analysed for radionuclides and kept for future reference.

Sediment Traps:

Sediment traps are 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 - 120 metres) at each of the three stations. The trap rig was allowed to drift freely for up to four days. Only one trap was used to try to minimise any tipping of the trap rig caused by differences in current velocities with depth. Collection times were set to coincide with productivity measurements. See Table 1 below for trap deployment data.

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 1: Sediment trap data - ARABESQUE 1(RRS Discovery 210)

Station #	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)
A1	100	04/09/94	7:40	08/09/94	7:27	18 59.4	58 59.7	18 45.3	58 51.6	16.0	208.7	0.17	1	05/09/94	6:00	24
	100												2	06/09/94	6:00	24
	100												3	07/09/94	6:00	24
A3	120	12/09/94	2:38	15/09/94	15:59	16 01.5	62 00.2	15 55.3	62 13.6	14.3	115.6	0.17	4	12/09/94	6:00	24
	120												5	13/09/94	6:00	24
	120												6	14/09/94	6:00	24
A7	120	19/09/94	3:38	22/09/94	13:45	07 59.7	67 00.2	07 47.8	67 19.7	22.7	121.5	0.28	7	19/09/94	6:00	72

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

Table 2: Stand Alone Pumps data - ARABESQUE 1 (RRS Discovery 210)

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	Comments
A1	05/09/94	14 48	A1/21	18 56 2	58 58 0	5	541 9	23 96	3 33	361 47	
						10	534 9	23.65	3 29	356 80	filter nipped - no breakthrough
						25	509.0	22.50	3 13	339 53	
						50	383.6	16.96	2 36	255 88	filter nipped - no breakthrough
	06/09/94	2 31	A1/26	18 56 3	58 55 8	100	1227 6	54.27	7 55	8*8 86	
						200	968 6	42 82	5.96	646 10	
						300	869 5	38 44	5 35	580 00	
						500	510 1	22 55	3 14	340 26	
	06/09/94	15 53	A1/33	18 54 0	58 55 6	600	1917 9	84 79	11 80	1279 32	volume too high - filter not sealed ?
						1520	1272.4	56 25	7.83	848 75	
						1600	500 3	22 12	3 08	333 72	
						2000	345 0	15 25	2 12	230 13	
A3	14/09/94	15 02	A3/46	15 55 3	62 11.3	11	630 6	27 88	3 88	420 84	
						17	742 8	32 84	4 57	495 48	
	13/09/94	14 26	A3/29	15 58 2	62 08 5	60	969 4	42 86	5 97	646 63	
	12/09/94	15.37	A3/18	15 59.3	62 04.4	100	1214.9	53.71	7.48	810.39	
						200	1194.3	52.80	7.35	796.65	
						300	844 8	37 35	5 20	563 52	
						500	956 2	42 27	5.88	637 83	
	14/09/94	15 02	A3/46	15 55.3	62 11.3	1000	1082.5	47.86	6.66	722 08	
						1500	1061 9	46 95	6 53	708.33	
	13/09/94	14:26	A3/29	15 58.2	62 08 5	2500	1023.3	45.24	6 30	682.59	filter nipped - no breakthrough
						3500	897.2	39 67	5 52	598.47	
	15/09/94	7.55	A3/53	15 55.5	62 13.2	10	655.8		4.04	627 55	
						50	402.5		2.48	385 16	
						100	1294.5		7 97	1238.74	
	13/09/94	14 26	A3/29	15 58.2	62 08.5	500	755.2		4.65	722.87	
A7	21/09/94	14.48	A7/31	07 52.8	67 10.5	10	372.1	16.45	2.29	248 21	
						25	506 5	22.39	3.12	337.86	
						50	647.9	28.64	3.99	432.18	
						75	706.3	31.23	4.35	471.13	
	19/09/94	14:52	A7/15	07 55.7	67 04.2	100	996 3	44.05	6.13	664.58	
						200	1109.6	49.06	6 83	740.15	
						300	1103.1	48.77	6 79	735 82	
						500	1097 0	46 50	6 75	731 75	
	20/09/94	14 18	A7/48	07 48.8	67 17 1	1000	685.1	30.29	4 22	456 99	
						2000	926.5	40 96	5 70	618 02	filter nipped - no breakthrough
						2600	591 9	26 17	3 64	394.82	

Notes

1. Filtration areas (cm2) 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. total 11 x 22mm punches	41.8
g. total 6 x 59mm punches	163.8
h. residual (whole filter less f and g above)	411.9

2. Samples for Wood's Hole from Station A3

Sample	Date	Time (Z)	Depth	Volume (l)
1	15/09/94	7.55	10	627.55
2	15/09/94	7:55	50	385.16
3	15/09/94	7:55	100	1238.74
4	13/09/94	14:26	500	722.87
5	13/09/94	14:26	2500	682.59

a. volumes are for the remainder filter given to Wood's hole

b. subsamples taken from filters are:

i) sample 5 has had a full set of subsamples taken, see report for details (11 x 22mm & 6 x 59mm punches)

ii) samples 1, 2, 3 & 4 have had 7 x 22mm punches removed for POC/PON and pigments.

REPORT ON UOR OPERATIONS
RRS Discovery 28 August - 1 October 1994

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and

C. Trees
San Diego State University

2 October 1994

This is a report on the work carried out by I.Bellan and C. Trees on behalf of PML and SDSU whilst aboard RRS Discovery during the ARABESQUE 1 cruise of the Gulf of Oman and Arabian Sea.

1 UOR BACKGROUND

Understanding the global distribution of marine phytoplankton (microscopic plants living in the top hundred metres or so of water) has assumed new importance over the last few decades. Recent research has shown that large-scale atmospheric pollution, principally from coal and gas-fired power stations and from traffic exhaust fumes, may be able to significantly alter global climate. The burning of coal, oil and gas generates carbon dioxide which then builds up in the atmosphere. This increase in concentration tends to give a gradual warming of the earth by reducing the loss of heat to space - the "greenhouse effect". If this increase of carbon dioxide were to continue, the climate control of the earth could eventually break down completely with possible catastrophic consequences.

Marine phytoplankton play a major part in controlling the climate firstly by using carbon dioxide for growth and secondly by producing chemicals which allow clouds to develop which then shade the earth. The effect of an increased concentration of carbon dioxide in the atmosphere on phytoplankton is not currently known. Increased carbon dioxide in the atmosphere may cause phytoplankton to remove more carbon dioxide from the air which would then stabilize the levels. On the other hand, higher carbon dioxide levels in the air may reduce the amount removed by the phytoplankton; this would give still higher concentrations of carbon dioxide in the air and the normal climate pattern will be more likely to break down. Because of this role in climate control, there is a currently much research into marine phytoplankton and, in particular, on ways to measure their global abundance.

The concentration of phytoplankton in open water determines its colour - the more plankton, the more green the water; the less plankton, the more blue the water. This makes it possible to calculate the concentration of plankton in the surface few metres of water from measurements of its colour. Working on this idea, a US satellite carrying the "Sea viewing Wide Field of View Sensor" (SeaWiFS) is due for launch in early 1995. The satellite will measure ocean colour over the whole world every two days and this data will then be used to estimate surface phytoplankton concentrations. The relationship between the concentration of phytoplankton in the surface few metres and that which is too deep to be observed by the satellite directly still needs to be worked out. The UOR collects data to look at both of these steps; firstly for ways to convert ocean colour measurements from satellite to actual concentrations of phytoplankton in the surface few metres and secondly to compare the amount of plankton on the surface with the amount beneath.

The UOR is designed to undulate between two metres and about eighty metres of depth every six minutes or every two kilometres or so. The vehicle is towed approximately 350 metres behind the ship at speeds up to twelve knots and controls its depth by moving a diving plane. The depth it can achieve depends on the speed of the ship, the length of wire, type of wire (faired or unfaired,

different weights) and the programming of the computer which controls the angle of the diving plane. The UOR carries sensors to record its depth, pitch and roll and sensors to give water structure (temperature, conductivity and hence salinity), chlorophyll concentration (and hence phytoplankton concentration), water clarity (by a transmissometer) and the directional intensity of light at a number of visible wavelengths (colours) corresponding to those which are observable from space. The data is currently recorded in the body and dumped to computer when the UOR is retrieved - this allows it to be used on ships of opportunity (such as ferries and merchant shipping) where there is no conductor-cored cable available. Different models which give real-time data up the cable also exist. Data is taken every four seconds which gives the UOR a maximum towing time of about fifteen hours.

2 UOR OPERATIONS

The tows completed onboard RRS Discovery are given on the Operations sheet. 25 tows to collect bio-optical data were carried out successfully , covering a towed distance of approximately 4400 kilometres. The undulating window was set between 2 and 92 metres with a towing speed of 11 knots with 250 metres of plain Kevlar 8 mm cable and 350 metres of 8 mm steel towing cables. The UOR performed well throughout the cruise although in the Gulf of Oman high sea temperatures caused slow ships speed . Further south into the Arabian sea with a drop in temperature to 26-27 c 11 knots was maintained The cruise track and days allocated for towing were chosen to provide long track data between stations and give as much coverage of different provinces as possible. We covered 2 nominal provinces - the Gulf of Oman area, and the Arabian sea The actual variety of oceanography between these nominal provinces remains to be seen once the data is analyzed. Chlorophyll concentrations were very varied and as the UOR data set shows choosing stations positions becomes a lottery.

A second set of light sensors were deployed as a vertical profile to 200m depths around midday followed by SDSU ,s M.E.R. light sensor array with a 7 channel Satlantic deck cell mounted on a high position on the Quarterdeck to measure ambient light . The position was relatively shadow free with a clear hemispherical view of the sky and may allow research to be carried out on the transmission of light through the water surface. Both UOR and vertical profile sensor packages were lowered with the CTD and can be used as a basic check on the calibration of the UOR fluorometer depth, conductivity DO and transmissometer.

Tests were also completed on new equipment developed at PML. 1 tow was carried out to test new towed body, the new PML Servo which is programmed to provide a smoother undulation pattern. The new towed body (Stealth) provides user friendly access and programing methods. The haired Kevlar towing cable introduced very high towing loads so operations were continued using 250m plain Kevlar outboard and 350m x 8 mm steel inboard. Some results were very encouraging, especially on the new PML Servo, but more effective ways of using the haired Kevlar wire need to be found.

3 OPERABILITY

The deployment and recovery of the UOR, which was carried out at about 4 knots, was efficient and effective. The new sheave being a vast improvement. The UOR suffers the same problems of snagging on drift nets and lines as any towed vehicle and normal procedures for avoidance of floats or buoys should be followed.

Overall, RRS Discovery has proved a good base from which to operate the UOR and useful work has been achieved in terms of collecting data for bio-optical research and testing equipment. We are grateful to the Captain and all the crew of RRS Discovery for their professionalism and kind hospitality.

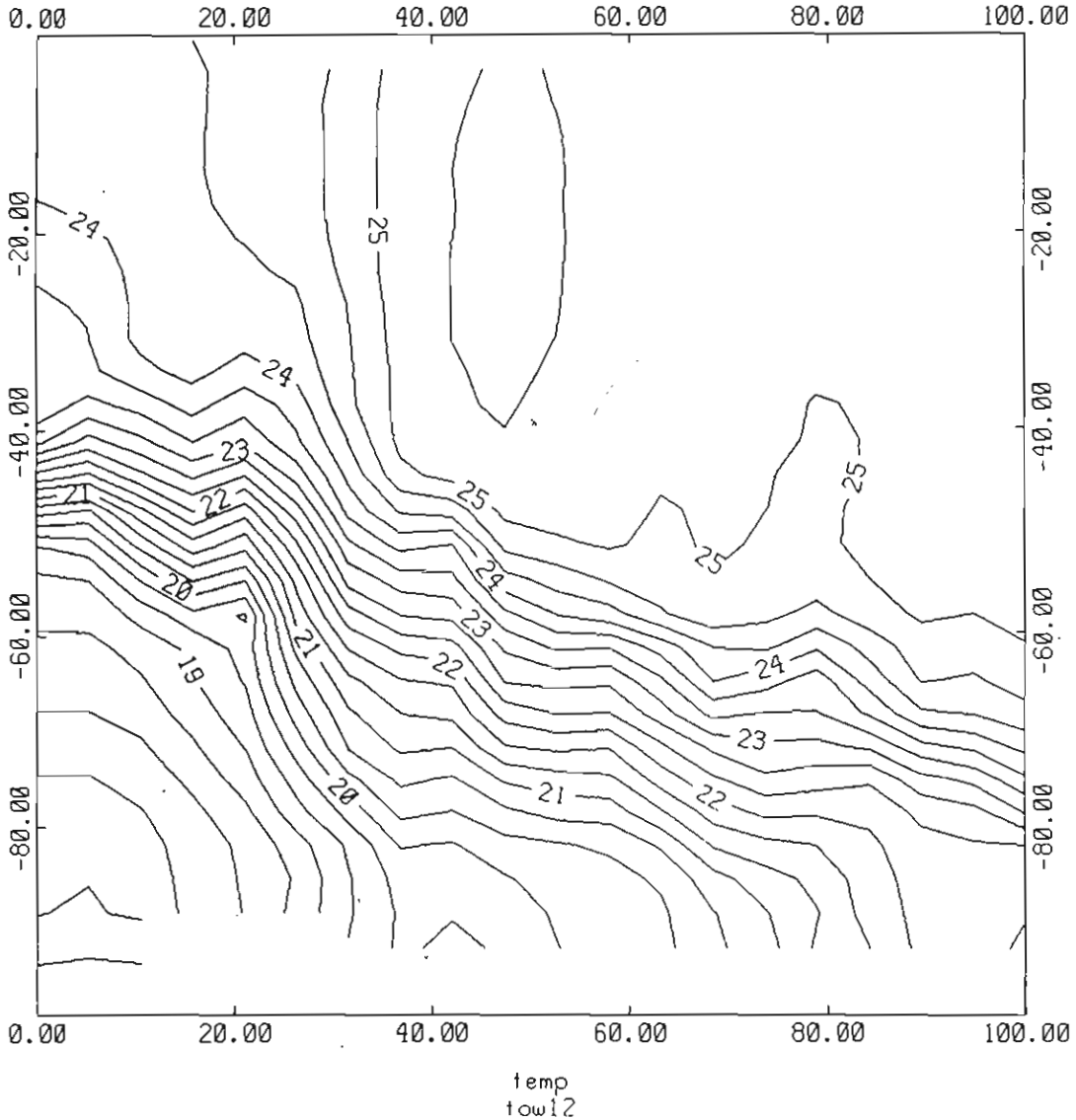
Arabesque 1 UOR Tows

TOW No.	DATE	TIME G.M.T.	SPD (kts)	TOW TIME. (h m.)	LAT(N)	LONG (E)	DEPTH RANGE (m)	NO. OF UNDS	TOW DIST (km)	COMMENTS	DATA RATE CAL FILE
d99401	28 8 94	10:13	8	13 51	23 55.53	59 11.56	5\85	68		ships speed slow	4 secs
g4-g2	29 8 94	00:03			24 48.96	57 13.38			203	eng overheating	d99432m3
d99402	29 8 94	09:58	9	9 05	24 52.85	57 12.95	2\72	38		very hot with	4 secs
g2-g1		19:03			26 01.63	56 34.59			151	thin cloud	d99432m3
d99403	30 8 94	07:44	7	2 40	26 00.58	56 34.40	50\80	37		UOR hit seabed	4 secs
g1-g3		10:44			25 42.89	56 38.58			35	at 87m	d99432m3
d99404	31 8 94	07:05	7.5	4 11	2415.11	58 13.26	20\100	19		250m kevlar aided	4 secs
g3-		11:16			23 46.19	58 30.66			62	unds at slow speed	d99432m3
d99405	1 9 94	12:44	10	11 05	22 41.01	60 47.80	12\95	58		required less wire	4 secs
to g5		23:49			21 48.24	62 20.67			195		d99432m3
d99406	2 9 94	01:19	10	6 50	21 48.50	62 2197	11\89	38		cond over ranging	4 secs
gom5-6a		08:09			21 15.73	63 21.13			127	top 10m	d99432m3
d99407	2 9 94	17:30	8	6 19	21 15.30	63 21.19	10\90	31		cond reduced to	4 secs
6a-gom6		23:49			20 48.39	62 29.91			99	9mm dia	d99432m3
d99408	3 9 94	00:52	9.5	12 05	20 48.39	62 28.60	9\90	19		kevlar jumped block	4 secs
gom6-6b		12:57			19 53.98	60 44.22	5\86	49	212	prop blade broken	d99432m3
d99409	3 9 94	15:10	10	9 16	19 43.98	60 24 64	22\92	42		towed on 500m of	4 secs
gom6b-a1	4 9 94	00:26			19 01.52	59 03.58			170	steel,no kevlar	d99432m3
d99410	10 9 94	04:39	10	2 09	19 29.90	58 09.50	1\42	34		towing of shelf	4 secs
as5-as4		06:48			19 19.80	58 27.10			40	50 plain kev +100 stee	d99432m3
d99411	10 9 94	07:12	11	8 31	19 17.85	58 29.70	30\87	47		crank arm fouling	4 secs
as4-a1		15:43			18 21.53	59 39.14			173	body,poor und	d99432m3
d99412	10 9 94	16:29	10.5	6 58	18 21.08	59 39.12	5\88	37		small fish in uor	4 secs
a1-a2		23:27			17 30.84	60 27.90			135		d99432m3
d99413	11 9 94	09:02	11	11 56	17 30.77	60 28.76	4\87	65		stn a2-a3	4 secs
a2-a3		20:58			15 59.69	61 59.27			244	cloud & sun	d99432m3
d99414	15 9 94	13:54	11	12 16	15 54.83	62 14.41	3\86	70		overnight a3-a4	4 secs
a3-a4	16 9 94	02:10			13 57.96	63 16.68			250	sws leaking.noisy data	d99432m3
d99415	16 9 94	08:51	11.5	13 09	14 00.63	63 17.41	4\85	74		ja5 bats.low at end	4 secs
a4-a5		22:00			11 56.99	64 31.38			288	DO sensor pos cause	d99432m3
d99416	17 9 94	14:06	11	10 54	11 51.82	64 23.96	4\84	62		overnight tow	4 secs
a5-a6	18 9 94	01:00			10 13.93	65 32.75			228		d99432m3
d99417	18 9 94	08:01	11	14 17	10 10.61	65 34.50		75		hot & sunny	4 secs
a6-a7		22:18			08 02.09	66 59.28	7\88		290	greenflash sunset	d99432m3
d99418	22 9 94	10:03	10.5	2 29	07 47.54	67 19.83	2\55	14		stealth???	4 secs
a7-a7		12:32			07 37.69	67 19.33	15\80		48		d99432
					07 48.99	67 19.69	20\88				
d99419	24 9 94	09:40	11	12 53	12 00.49	66 59.26	5\87	69		sensor cyl.bats.failed	4 secs
a8-a9		22:33			14 17.22	67 00.36			262	final 3hrs.	d99432m3
d99420	26 9 94	06:03	11	14 33	14 17.51	66 57.17	5\84	80		sensor changed to ja5	4 secs
a9-a10		20:37			15 13.03	64 27.44			296		d99452m3
d99421	27 9 94	09:00	11	13 47	15 13.85	64 26.10	3\83	79		puffer fish in uor	4 secs
a10-a3		22:51			16 02.04	61 59.86			281		d99452m3
d99422	28 9 94	13:59	11	10 52	16 04.15	62 06.28	4\84	63		overnight tow	4 secs
a3-a2	29 9 94	00:51			17 24.33	60 36.18			221		d99452m3
d99423	29 9 94	09:10	11	11 54	17 29.61	60 30.32	3\84	68		through a1	4 secs
a2-a1		21:04			19 01.77	58 58.57			242		d99452m3
d99424	1 10 94	03:29	11	1 08	19 30.76	58 08.75	2\45	17xikm		shallow tow	4 secs
as5-as4		04:47			19 45.52	58 19.16			23	leaving shelf (40m)	d99452m3
d99425	1 10 94	04:54	11	4 48	19 24.57	58 18.90	4\84	25		return to a1	4 secs
as4-a1		09:22			18 59.18	59 02.56			91	bright sun	d99452m3

ARABESQUE 1 OPTIC VERTICAL PROFILE

V P No	DATE	G M T	TIME	LAT (N)	LONG (E)	DEPTH	COMMENT	DATA RATE
STATION			mins			metres		CAL FILE
1	29 8 94	06 46		24 51 31	57 12 69	200	off stern	1 secs
		07 01	15					d99454m2
2	30 8 94	06 03				200	off stern	1 secs
		06 31	28					d99454m2
3	1 9 94	07 11		22 40 29	60 42 15	200	off stern	1 secs
		07 28	17					d99454m2
4	2 9 94	10:02		21 16.92	63 21.65	200	cloudy,off stern	1 secs
		10:14	12				light card loose	d99454m2
5	4 9 94	09:32		18 59.49	58 59.88	200	off stern	1 secs
		09:44	12				par/683	d99454m2.con
6	5 9 94	11:16		18 56.35	58 58.57	200	profile with ctd	1 secs
a1/20 cast41		11:46	30				cloudy par/683	d99454m2
7	6 9 94	07:56		18 56.02	58 56.29	200	off stern	1 secs
		08:09	13				no "b"light	d99454m2
8	7 9 94	09:38		18 50.06	58 52.37	200	off stern	1 secs
		09:50	12					d99454m2
9	8 9 94	12:05		19 14.51	58 35.15	200	off stern	1 secs
a1		12:18	13				sun,high thin clou	d99454m2
10	9 9 94	06:17		19 23.32	58 20.54	200	off stern	1 secs
as2		06:33	16				cloudy	d99454m2
11	9 9 94	10:38		19 27.07	58 14.59	200	off stern	1 secs
		10:54	16				sun	d99434m2
12	12 9 94	07:04		16 00.24	62 03.15	200	stern DO over rng	1 secs
		07:16	12				light readings ?	d99454m2
13	13 9 94	07:02		15 58.68	62 05.65	200	off stern	1 secs
a3/19		07:16	14					d99454m2
14	14 9 94	09:59		15 55.04	62 11.36	200	off stern	1 secs
		10:15	16				up cast best	d99454m2
15	15 9 94	06:04		15 55.67	62 12.76	200	off stern	1 secs
		06:19	15				clear sun	d99454m2
16	17 9 94	09:12		11 52.09	64 25.75	200	off stern	1 secs
		09:28	16					d99434m2
17	17 9 94	10:05		11 52.09	64 25.75	200	with ctd	1 secs
a5		10:33	28				calibrate ja3	d99434m2
18	19 9 94	09:55		07 57.31	67 03.10	200	off stern with ME	1 secs
		10:19	24				cond topped	d99454m2
19	19 9 94	10:38		07 57.44	67 02.79	200	with ctd	1 secs
		11:21	43				calibrate ja5	d99454m2
20	20 9 94	09:27		07 53.57	67 10.16	200	off stern	1 secs
		09:42	15				sun	d99454m2
21	21 9 94	08:39		07 49.46	67 15.44	200	off stern	1 secs
		08:58	19				poor wire angle	d99454m2
22	21 9 94	10:18				1	ctd light cal	1 secs
		10:30	12					d99432/par
23	21 9 94	10:13		07 48.90	67 15.56	200	calibrate ja3/par	1 secs
a7/45		11:21	42				ctd 128	d99432/par
24	24 9 94	08:38		12 00.71	66 59.17	200	off stern	1 secs
		09:12	14				sun	d99454m2
25	25 9 94	07:09		14 19.63	66 59.33	250	off stern ,sun	1 secs
		07:35	26				surrounded by fish	d99454m2

26	27 9 94	06:26		15 12.80	64 28.80	200	off stern	1 secs
		06:44	18					d99454m2
27	28 9 94	06:46		16 04.43	62 01.70	200	off stern	1 secs
a3		07:01	15					d99454m2
28	29 9 94	05:56		17 29.68	60 30.22	200	off stern	1 secs
		06:15	19					d99454m2
29	30 9 94	06:20		18 58.22	59 01.66	200	off stern	1 secs
a1		06:39	19				sun	d99454m2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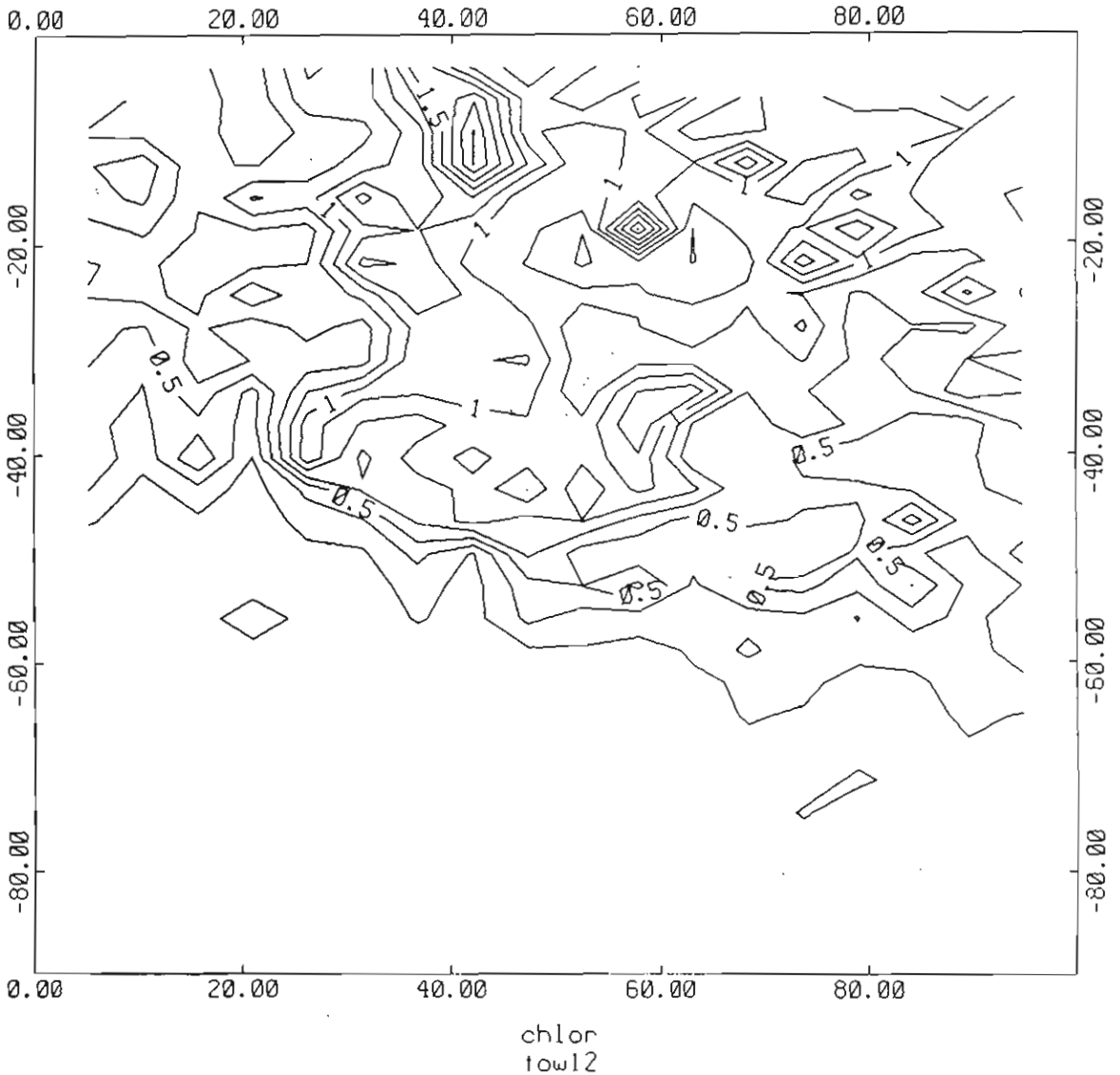
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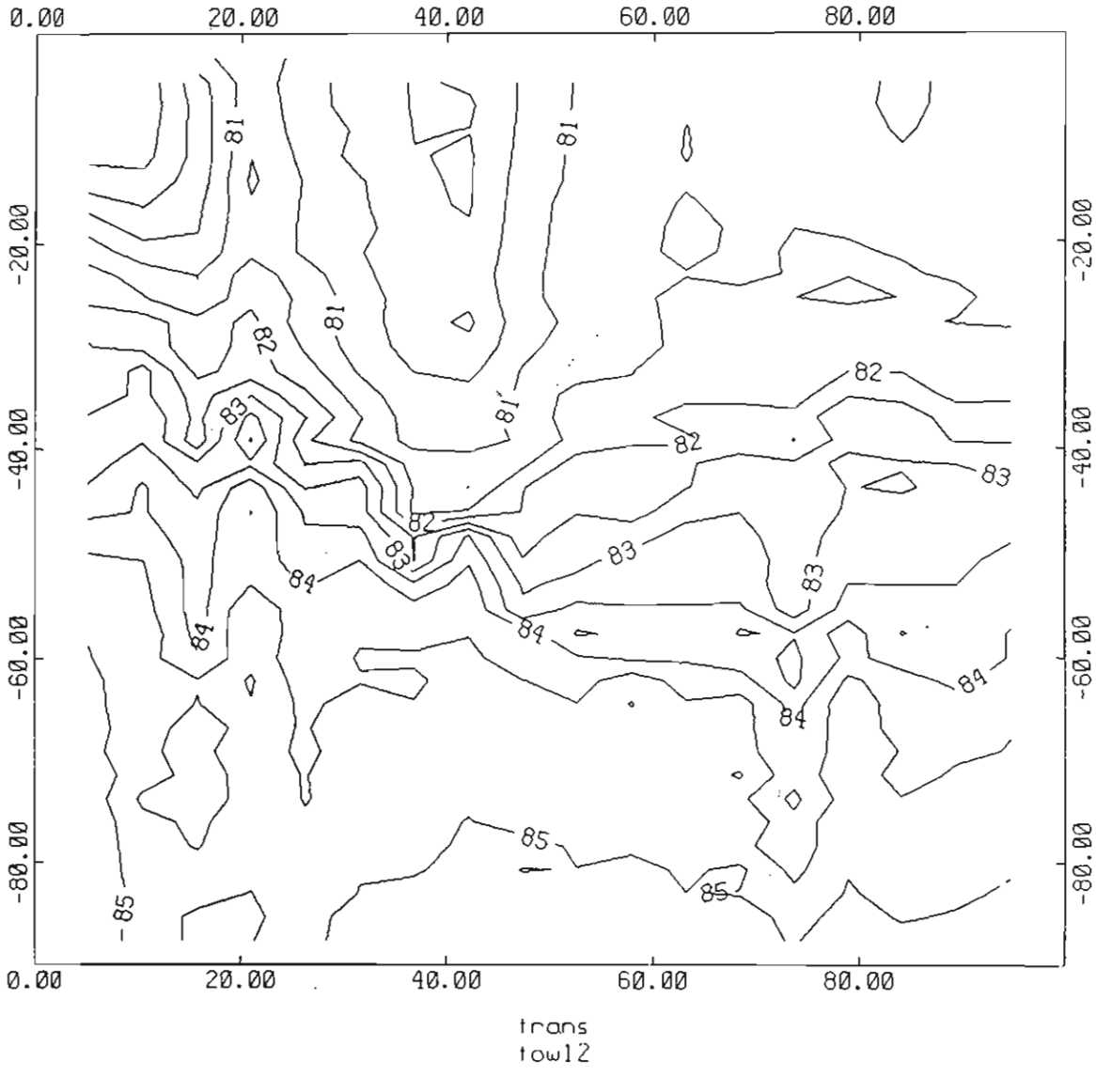
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84
85
trans
tow12

BIO-OPTICAL VARIABILITY IN THE ARABIAN SEA DURING ARABESQUE CRUISES

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ABSTRACT The focus of this program is to consistently characterize bio-optical properties in the Arabian Sea under the U.S. JGOFS Arabian Sea Program. During the first cruise a bio-optical profiling system was deployed and discrete water samples were collected for phytoplankton pigment, total particulate absorption and dissolved organic material absorption analyses. In addition, an aliquot of acetone extracted pigment sample was analyzed using the standard fluorometric method, so that comparisons could be made with HPLC derived chlorophyll a concentrations. Algorithms will be developed relating spectral reflectances to in-water bio-optical and biogeochemical properties. The various cruise regions will be divided into 'bio-optical provinces' within each of which a single set of regression models will be developed to relate the vertical distribution of irradiance attenuation and normalized fluorescence to remote sensing diffuse attenuation coefficient [K(490)]. These models will then provide a way for extrapolating near surface ocean color measurements vertically for estimating integrated phytoplankton biomass and productivity.

TECHNICAL OBJECTIVES Our working hypothesis is that over relatively large spatial and temporal scales, the vertical profiles of bio-optical properties are constant or at least predictable. This approach requires that enough measurements of bio-optical variability be made from ships and other platforms to determine those scales statistically.

The objectives of the proposed work were to:

1. To determine the concentration and distribution of the various phytoplankton pigments using high-performance liquid chromatography (HPLC). In addition chl a and phaeopigment concentrations will also be determined by the standard fluorometric method, providing a direct link to past CZCS pigment algorithms and assist in CZCS and SeaWiFS derived products comparisons.
2. To characterize the inherent optical properties in the water column by measuring the beam transmission using a Sea Tech Transmissometer and to analyze discrete samples for total particulate absorption and dissolved organic absorption.
3. To characterize the apparent optical properties in the water column by measuring spectral irradiance and radiance using a Biospherical Instruments Multichannel Environmental Radiometer (MER). From these data, vertical profiles (200 m) of diffuse attenuation coefficients and remote sensing reflectances will be calculated.
4. To establish locally derived, in-water algorithms relating reflectance spectra to beam attenuation, particulate absorption and concentrations of phytoplankton pigments, through intercomparisons with in situ measurements.
5. To describe the vertical distribution of photoadaptive properties in the water column by measuring vertical profiles of natural (NF) and stimulated (SF) fluorescence and examining relationships between NF and SF as a function of diffuse optical depth. Regression models will be developed to relate profiles of irradiance attenuation and SF to remotely sensed diffuse attenuation coefficients [K(490)].

BACKGROUND Water column reflectance or ocean color has been shown by several authors to be related to the ratio of backscattering to absorption (Gordon and Morel, 1983). For open ocean areas which are considered Case-I waters, scattering and absorption by marine phytoplankton dominate the optical properties (including spectral reflectance). This is the basis for the highly successful CZCS algorithms relating ratios of water leaving radiance at 2 wavelengths to phytoplankton pigment (Clark, 1981; Gordon et al., 1983) and to diffuse attenuation coefficient K(490) (Austin and Petzold, 1981). Coastal areas (Case-II waters) exhibit less well behaved relationships because dissolved organic material and inorganic particles contribute significantly to light attenuation.

With the development and validation of satellite ocean color sensors, improvements have been made in estimating phytoplankton pigment concentrations over large areas synoptically, thus reducing some of the errors associated with areal production estimates. Unfortunately, this coverage is limited to the near surface layers, requiring models to estimate the vertical distribution of pigment biomass and to convert these profiles to primary productivity. Recent publications indicate that improvements can be made in estimating the vertical distribution and primary productivity by understanding how the photoadaptive state of phytoplankton change in response to incident spectral irradiance and its attenuation with depth.

Bio-Optical Provinces A 'bio-optical province' is a region wherein ocean bio-optical properties are relatively similar over a geographic and temporal extent, and where these properties differ significantly from those in adjacent provinces. Climatologies of optical, biological and physical properties (including satellite data) are first used to divide the oceans into hypothetical first-guess provinces. In situ bio-optical data from within each province are then analyzed to determine whether there are statistically significant differences (within and between provinces in different seasons) for the defined variables.

The utility of 'bio-optical provinces' was first demonstrated for the Northeast Pacific Ocean by Mueller and Lange (1989). They found that within each defined province (California Current System, N.E. Central Pacific gyre, Subarctic Front and Alaskan gyre) in a given two-month period, a family of regression equations accurately predicted vertical profiles of irradiance attenuation and normalized chl a fluorescence from the remotely sensed diffuse attenuation coefficient, K(490). For predicting the vertical distribution of chl a fluorescence, a conceptual model was developed based on a log-linear photoadaptive profile of fluorescence as a function of diffuse optical depth. At least in the Northeast Pacific Ocean, these 'bio-optical provinces' were related to well known features of the regional ocean circulation.

MEASUREMENTS Measurements were made of downwelling irradiance (411, 442, 453, 490, 509, 529, 555, 589, 632, 655, & 671 nm), upwelling irradiance (411, 442, 490, 509, 555, 529, 633 & 671 nm), and upwelling radiance (411, 442, 490, 509, 532, 556, 671 nm) using a Biospherical Instruments Inc. MER 1032. The channels of the MER include all SeaWiFS visible wavelength bands. The MER is an optical data acquisition system, which also measures water pressure (depth) and temperature. This data is merged with data from a seven channel (411, 442, 490, 509, 555, 590 & 665 nm), deck cell to correct for changes in the incident spectral irradiance at the surface during the profiling period. Included on the MER, and interfaced with the data acquisition system, is a scalar PAR sensor, a sensitivity enhanced upwelled radiance sensor at 680 nm (natural fluorescence), a Sea Tech fluorometer (stimulated fluorescence) and a Sea Tech Transmissometer (beam attenuation coefficient, c(660); 25 cm pathlength). Twenty five optical casts were made during the cruise.

Discrete Sampling Samples were collected from the early morning productivity stations and from the stations around noon which were designated as Optical CTD's. The depths sampled were usually in the upper 50m and always include the Pvsl depths. Underway samples were collected at the beginning of the cruise from the non-toxic system, but were found to be contaminated by detrital type particles. Continued sampling was abandoned.

Pigments -- Phytoplankton pigment composition will be measured by both HPLC and standard fluorometric methods. Samples were collected on a 25 mm GF/F filters using a positive pressure filtration system and frozen in liquid nitrogen. Samples will be analyzed back at CHORS/SDSU using a Thermo-Separation HPLC system. In addition 100 microliter samples from Dr. Ray Barlow's HPLC samples were also analyzed on a shipboard Turner Designs fluorometer. Over 200 measurements were made for comparison between the two techniques.

Particulate Absorption -- Samples were collected in 1.0 liter polycarbonate bottles. The bottles were filled to the top, representing a know volume (1.155 liters). Samples were filtered through 24 mm diameter GF/F (nominal pore size of 0.7 micrometer) glass fiber filters at a low vacuum pressure (6-10 inches mercury) and then stored in plastic petri dishes for analysis later. Each filtration funnel has a specific filter clearance diameter that is recorded with each sample.

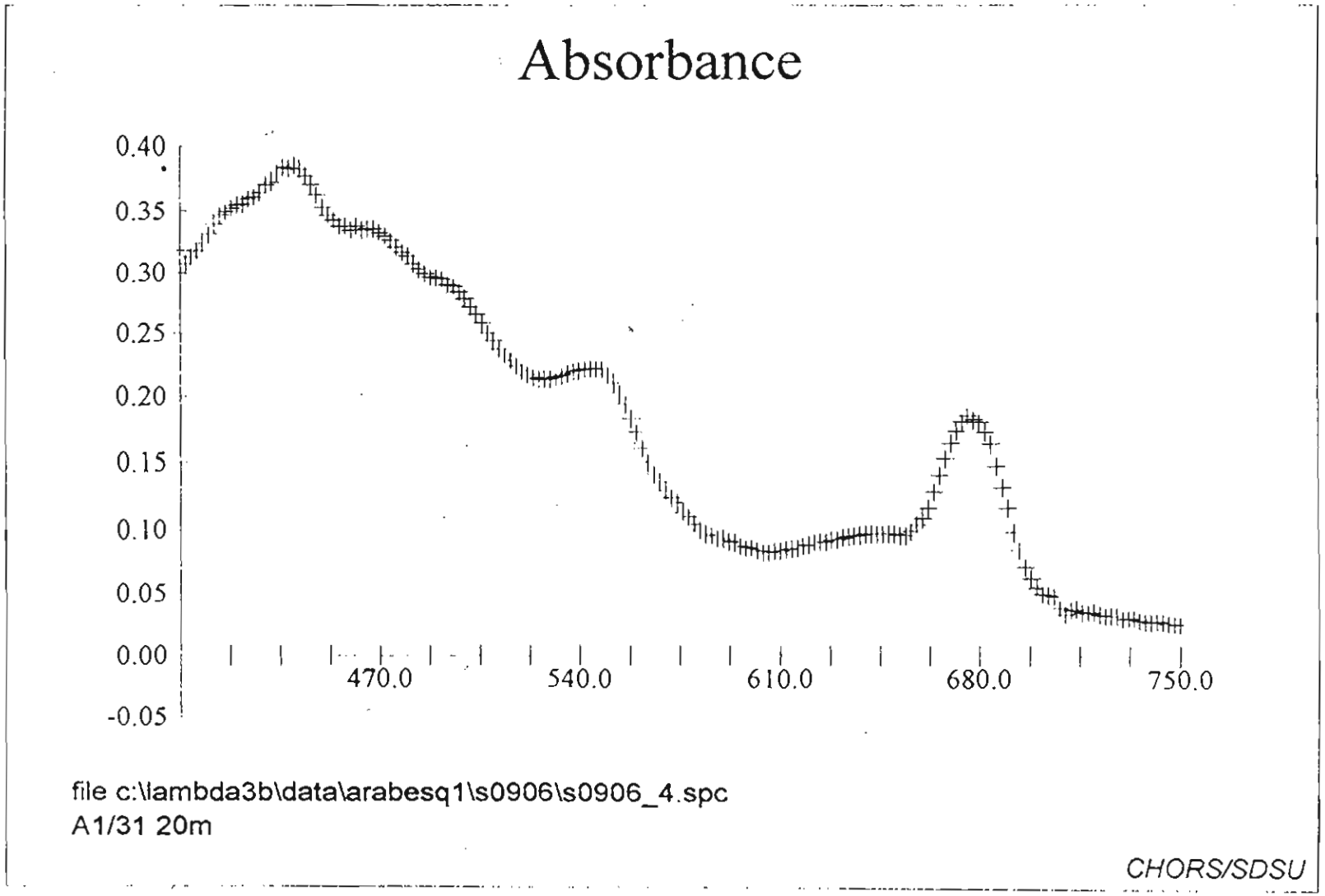
A Perkin-Elmer Lambda 3B was used to make the spectral absorption measurements from 400-750 nm. A wetted GF/F glass fiber filter was used a blank. To determine the contribution to absorption by detrital material a methanol extraction method was used. After the

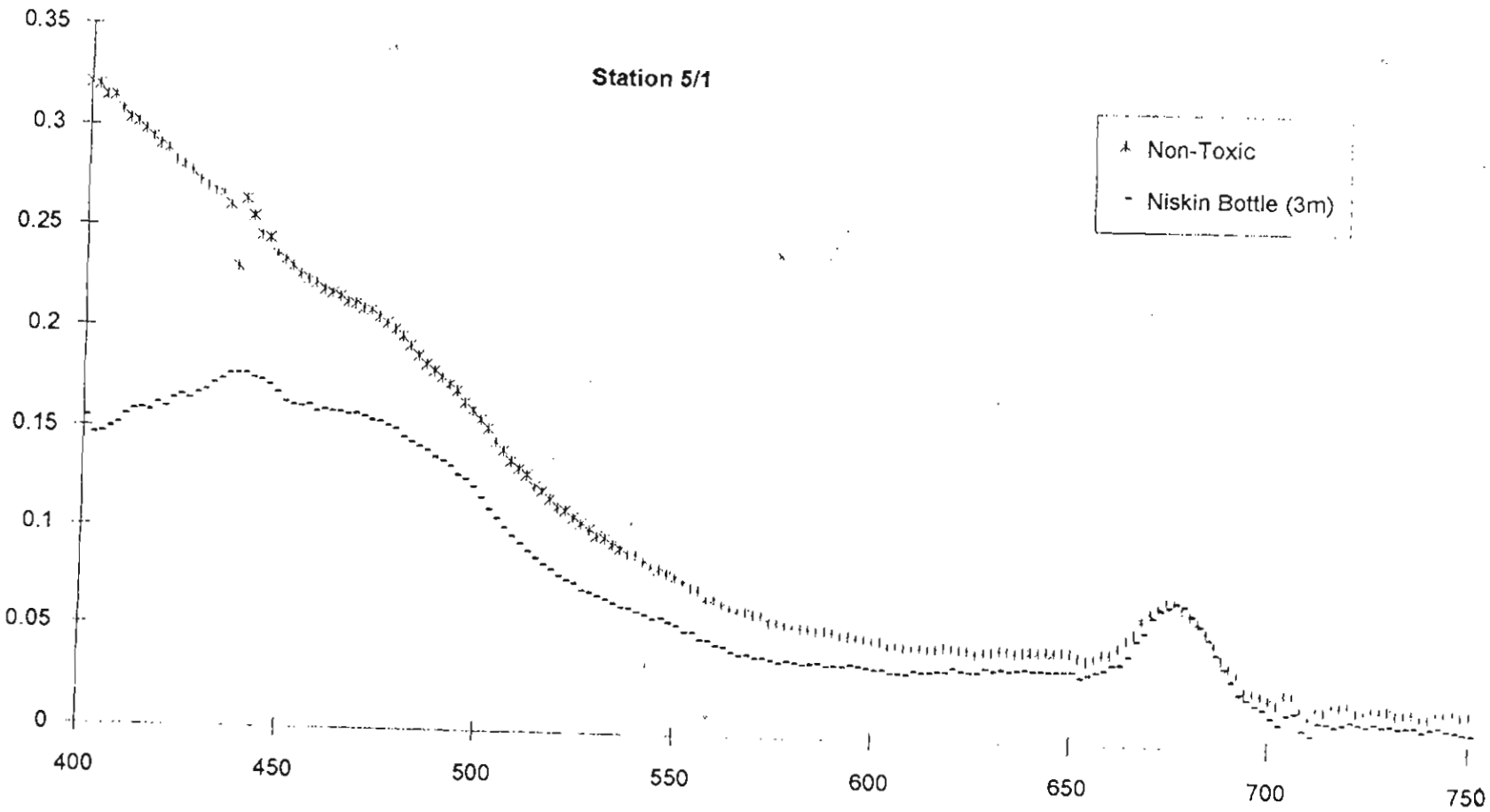
measurement of the particulate absorption, the filters were placed back on the filtration system and hot methanol is drawn through the filters. Additional methanol (about 5 ml) is then added to each filter and left to soak for 30 minutes. The vacuum is applied and the filters were then rinsed with small volumes of filtered seawater. Measurement of the absorption of these filters was the same as the original samples. By differencing the particulate absorption with the detrital absorption an estimate of the absorption by phytoplankton pigments was determined.

Dissolved Organic Material Absorption -- Samples were collected in 150 ml polycarbonate bottles. Each bottle was rinsed with the sample before filling. The samples were then filtered through 0.22 micrometer Millipore Sterivex-GS cartridge filters directly into the 10 cm quartz cells. Prior to sample filtration, the cartridges were washed with 100 ml of MilliQ water to remove any particulate residue. The samples were then stored in the dark at room temperature until spectrophotometric analysis. Concentrations were so low during the cruise that this analysis was not continued throughout the cruise.

Below is list of the stations that samples were collected and optical profiles made.

STATION #	DATE	HPLC	PART ABS	DOM ABS	OPTICS
Shake-Down	27 Aug	0	3	3	xxx
GOM2	29 Aug	10	10	3	xxx
GOM1	30 Aug	9	9	0	xxx
GOM5	1 Sep	9	9	0	xxx
GOM6A	2 Sep	4	4	0	
GOM6	2 Sep	4	4	0	xxx
GOM6B	3 Sep	4	4	0	
AS1	4 Sep	7	7	3	xxx
AS1	5 Sep	10	10	3	xxx
AS1	6 Sep	9	9	0	xxx
AS1	7 Sep	0	0	0	xxx
AS1	8 Sep	5	5	0	xxx
AS3	9 Sep	9	9	0	xxx xxx
AS2	11 Sep	5	5	0	
AS3	12 Sep	9	9	0	xxx
AS3	13 Sep	9	9	0	xxx
AS3	14 Sep	9	9	0	xxx
AS3	15 Sep	9	9	0	xxx
AS5	17 Sep	9	9	0	xxx
AS6	18 Sep	5	5	0	
AS7	19 Sep	5	5	0	xxx
AS7	20 Sep	9	9	0	xxx
AS9	21 Sep	5	5	0	xxx
AS8	24 Sep	9	9	0	xxx
AS9	25 Sep	9	9	0	xxx
AS9	26 Sep	4	4	0	
AS10	27 Sep	8	8	0	xxx
AS3	28 Sep	8	8	0	xxx
AS2	29 Sep	4	4	0	xxx
AS1	30 Sep	9	9	0	xxx


Absorbance
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
-0.05
470.0
540.0
610.0
680.0
750.0
file c:\lambda3b\data\arabesq1\s0906\s0906_4.spc
A1/31 20m
CHORS/SDSU


Station 5/1
Non-Toxic
Niskin Bottle (3m)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
400
450
500
550
600
650
700
750