Box 5.

BENTHIC COMMUNITY AND FLUXES IN RELATION TO THE OXYGEN MINIMUM ZONE IN THE ARABIAN SEA

Cruise Report: R.R.S. *Discovery* 211/94
9th October - 11th November 1994

Table 3: Fate of multiple corer samples

Station	12671	12682	12685	12686	12687	12690	12692	12693	12694	12695	12698	12699	12700	12704	12705	12706	12708	12711	12713	12715	12718	12720	12722	12723	12725	12728	12729	12732
Use																												
Nematode studies	1	2	3	1	4	1	1	-	-	3	1	-	-	1	-	1	1	-	-	-	-	-	-	2	3	-	-	-
Meiofauna: formalin	1	2	1	1	1	-	1	1	1	-	-	1	-	-	1	1	-	-	-	-	-	-	-	-	1	1	-	-
Gluteraldehyde	-	-	-	-	1	-	-	-	-	1	-	-	-	1	-	-	1	-	1	-	-	-	-	-	-	-	-	-
Forams: whole core	1	2	2	1	3	1	1	1	1	3	1	1	-	-	1	1	2	1	2	-	2	-	1	2	2	1	-	-
subcore	1	2	2	-	3	1	1	1	1	1	-	1	-	1	1	1	1	1	2	-	1	-	-	2	3	1	-	-
Gluteraldehyde	-	-	-	-	-	-	-	-	-	1	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-
Gromiid study	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	18	4	-	-
0-2cm layer	-	-	9	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Macrofauna: whole core	-	1	8	-	-	-	-	4	4	-	15	6	12	-	6	6	-	-	-	-	-	-	-	-	-	-	-	-
Mudball study	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	1	5	12	-	-	-	-	-	-	-	-
Qualitative (macrofauna, forams)	-	-	-	7	8	-	1	1	1	14	-	1	-	-	-	1	-	-	-	-	2	-	4	2	-	-	6*	-
Incubtation experiment	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	12	-	-	-	-	-	-
Enzyme studies	-	1	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-
Organic chemistry	-	-	1	-	4	1	1	1	1	3	-	-	-	1	-	-	3	-	2	-	2	-	1	2	2	1	-	-
Chemistry (Frozen)	-	-	-	-	2	-	-	-	-	-	1	1	-	1	1	1	-	-	1	-	-	-	-	-	1	-	-	-
Homogenization	-	-	-	-	3	1	1	-	-	2	1	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	-
Pigments	1	2	1	-	2	1	-	-	-	1	-	-	-	-	-	-	3	1	2	-	2	-	1	-	2	-	-	-
Geochemistry	-	4	2	1	3	2	-	-	-	3	-	-	-	-	-	-	1	2	-	-	2	-	-	2	-	2	-	-
Pore water	-	2	1	-	3	1	1	-	-	1	-	-	-	-	-	-	-	1	-	-	1	-	-	2	-	1	-	-
C:N determination	-	2	1	-	3	1	1	-	-	1	-	-	-	-	-	-	3	1	2	-	2	-	1	2	-	1	-	-
eH measurements	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2	-	-	12
Pb210	2	4	4	-	3	2	2	-	-	2	-	-	-	-	-	-	6	2	4	-	4	-	2	4	2	-	-	-
Archive	-	-	1	-	2	-	-	-	-	-	1	-	-	-	-	-	-	-	1	-	1	-	-	1	-	-	-	-
Discarded	-	-	-	-	-	-	-	1	1	1	2	-	-	6	1	-	14	-	1	-	1	-	1	1	-	-	-	-

*Very short disturbed cores

BENTHIC COMMUNITY AND FLUXES IN RELATION TO THE OXYGEN MINIMUM ZONE IN THE ARABIAN SEA

Cruise Report: R.R.S. *Discovery* 211/94
9th October - 11th November 1994
Muscat to Owen Basin and Adjacent Continental Slope off Masirah Island to Muscat

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1. OBJECTIVES

This cruise formed part of a suite of four cruises (cruises 209-212) on R.R.S. *Discovery* during her 1994 Indian Ocean Campaign. The overall objectives of R.R.S. *Discovery* cruise 211 were the following:

1. To test the hypothesis that the Oxygen Minimum Zone (OMZ) has a profound effect on community composition, abundance, diversity, size structure, reproductive mode and lifestyle of benthic biota by a comprehensive sampling strategy across areas where the OMZ impinges on the bottom.

2. To see what role the OMZ, and other related physical gradients, play in determining depth-related changes in the benthic community compared to data sets available from the northern Atlantic.

3. To test whether the upper and lower OMZ boundary is a zone of enhanced biological activity with respect to the benthos in the Arabian Sea.

4. To measure size-related biomass, particulate organic carbon fluxes and total benthic metabolism in the sediment at sites within and below the OMZ in order to examine the roles of different food-web components in the benthos, particularly in the context of carbon, nitrate and sulphate fluxes and the relative importance of aerobic and anaerobic metabolism in the sediment.

5. To investigate the benthic response in terms of biogenic reworking, bioturbation, redox conditions and burial rates along oxygen gradients through the OMZ and in response to seasonal carbon input in relation to benthic fluxes and activity, and to determine how organism interactions affect the recycling and/or burial of organic matter.

2. ACHIEVEMENTS

The cruise provided the opportunity to address all five objectives listed above, although the final scientific outcome will not be known in detail until the samples are processed - a task requiring several months of post-cruise effort.

The cruise track of the Cruise Proposal covered much more of the northern Arabian Sea than was actually achieved on the cruise and this was perhaps the inevitable consequence of the paucity in information of the benthic environment of the area. As it turned out, in order to make an impact on the need to understand the effect of the OMZ on the sediment environment where it impinges on the continental slope, it soon became apparent that we would need to concentrate our energies on just one section of the Oman margin. Hence, the working area turned out to be more tightly constrained than originally anticipated. Although a major purpose of the cruise (see above Objectives) was to examine the changing faunal and biogeochemical response to the impingement of the OMZ on the Oman margin, it had been hoped that comparative sampling might have been possible at JGOFS stations south of the Murray Basin and the Owen Fracture Zone on to the Arabian Basin south of the Indus Cone.

The area of the slope chosen was very much dictated by the bathymetry available from previous work kindly provided by the Institute of Oceanographic Sciences and from soundings made during *Discovery* cruises 209 and 210. Although some swath bathymetry was available from previous American ODP studies in the area to the south west, the area covered was limited and in any case seemed to indicate a very undulating and in parts precipitous, slope. The line finally chosen for the down slope transect lay off the Gulf of Masirah (Figs. 1- 3) between Masirah Island and Ras al Madraka. This lies adjacent to a station (A1) in the Murray Basin worked as part of JGOFS studies by the Plymouth Marine Laboratory during the immediately preceeding cruise and where midwater and some seasonal carbon flux data was available. All the stations where samples were successfully recovered are listed in the summary Table 1.

There was no swath bathymetry on board; however the Simrad system and computer plotting facilities under the direction of Mr Derek Lewis of RVS allowed us to assemble a detailed view of this section of the continental slope (Fig. 3). Although very steep and undulating, happy coincidence provided a spur- or terrace-like feature (see Fig. 4) that provided a fairly gentle slope from the shelf edge into the oxygen minimum zone. This, as it turned out, was very important as our sequential sampling down slope showed up marked changes in conditions, presumably tracked by the very obvious differences in the larger fauna. At depths below about 1,000 m the slope became steeper and more difficult to sample, particularly with bottom towed gear. However, at these greater depths, changes in the physical and biological environment seemed to become more gradual. It therefore seemed less important to sample at such close depth intervals.

Objectives 1-3 (above), in attempting to map the distribution of benthic life through the OMZ, were to test for a previous finding by Dr Lisa Levin of Scripps Institution of Oceanography of zoned benthic distributions on the sides of seamounts emerging into the OMZ in the equatorial eastern Pacific. These were expressed as an intensification of biomass and benthic activity at the OMZ interface with more oxygenated conditions in the water column. Another important part of these objectives was to investigate the benthic response, in terms of benthic fluxes and bioturbation, to the dysaerobic conditions, and to determine how organism interactions (see below) affect the recycling and/or burial of organic matter. A linked aim for the five-week cruise was to determine how organism interactions affect the recycling and/or burial of organic matter in this biogeochemically important area.

Objective 4 was to estimate from measurements of size-related biomass, sediment particulate organic carbon fluxes and total benthic metabolism at sites within and below the OMZ, the roles of different food-web components in the benthos, particularly in the context of N_2O and CH_4 fluxes and the associated importance of aerobic and anaerobic microbial metabolism in the sediment. The goal will be to develop a partitioned food-web model for the sediment community, using inverse methods, that includes a variety of microbial chemoautotrophic and heterotrophic components, and redox mechanisms.

One of the early findings of the John Murray Expedition of 1933-34 on the research ship *Mabahiss,* which still serves as one of the basic sources of zoological information of the Arabian Sea, was quickly confirmed by us within our first few days of arrival. This was the extremely rugged and steep nature of the continental slope along the southern coast of Oman. The vanishingly low concentrations of dissolved oxygen in the water were unknown to the scientists

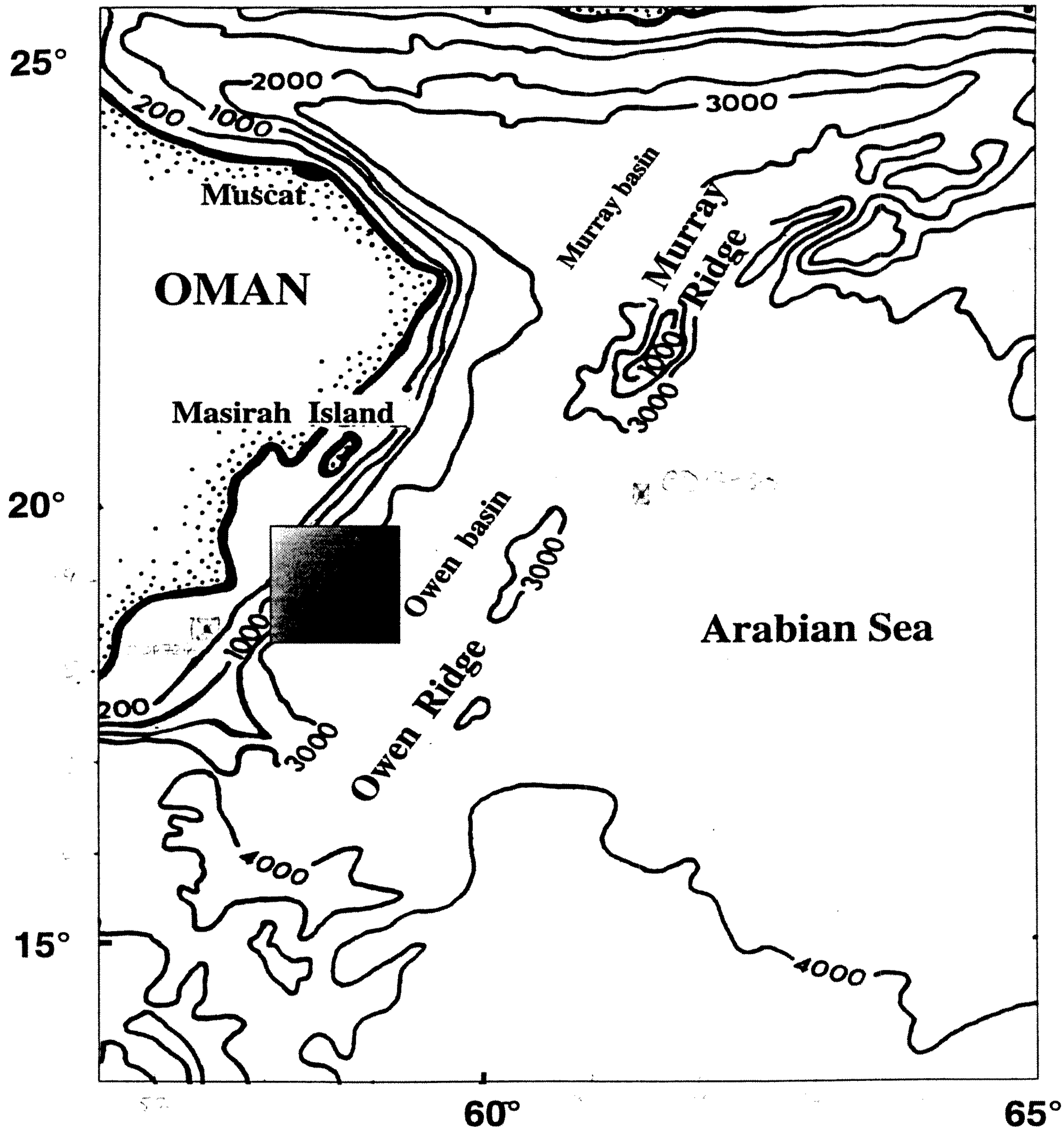

Figure 1: Location map of R.R.S. *Discovery* cruise 211 (Muscat, 8/10/94 - Muscat, 12/11/94). Shaded region highlights main working area.

Table 1 Station List

Station No. Drop	Position N	Position E	Water Depth(m)	Gear	Station No. Drop	Position N	Position E	Water Depth(m)	Gear
12671#1	19 01.01	59 00.24	3380	CTD	12703#1	19 22.34	58 11.42	115	L
12671#3	19 00.03	59 00.57	3393	MC	12704#1	19 18.58	58 15.62	673	MC
12671#4	19 00.29	59 00.22	3392	BC	12705#1	19 16.71	58 25.63	910	MC
12672#2	19 00.00	58 49.05	3334	CTD	12706#1	19 17.25	58 30.41	1010	MC
12673#1	19 03.30	58 44.95	3250	CTD	12707#1	19 11	58 13	~350	AT
12674#1	19 08.16	58 41.66	3209	CTD	12708#1	19 22.12	58 11.50	110	BC
12674#2	19 06.01	58 40.25	200	ZP	12708#2	19 22.36	58 11.47	109	BC
12675#1	19 07.19	58 39.35	3133	CTD	12708#3	19 22.28	58 11.43	106	MC
12677#1	19 12.71	58 26.31	1124	CTD	12708#4	19 22.16	58 11.49	108	BC
12678#1	19 15.36	58 21.78	738	CTD	12708#5	19 22.18	58 11.44	119	MC
12681#1	19 23.25	58 08.31	78	CTD	12708#6	19 22.34	58 11.49	108	BC
12682#1	19 19.09	58 15.65	600	CTD	12708#7	19 22.31	58 11.40	106	MC
12682#2	19 19.05	58 15.61	618	BC	12708#8	19 22.38	58 11.35	104	BC
12682#3	19 18.70	58 15.74	742	MC	12709#1	19 13	58 30	~1200	AT
12682#4	19 18.74	58 15.47	696	BC	12710#1	19 22.14	58 11.40	105	BC
12682#5	19 18.66	58 15.55	685	MC	12710#2	19 22.14	58 11.55	110	BC
12682#7	19 18.77	58 15.55	630	BC	12710#3	19 22.34	58 11.54	108	BC
12683#1	19 32	58 10	~50	TD	12710#4	19 22.33	58 11.50	116	CTD
12685#1	19 18.95	58 15.53	674	BC	12711#1	19 14.31	58 22.93	837	CTD
12685#2	19 18.91	58 15.44	680	MC	12711#2	19 14.21	58 23.11	840	BC
12685#3	19 18.99	58 15.47	622	BC	12711#3	19 14.10	58 22.86	833	MC
12685#4	19 18.70	58 15.45	700	KC	12712#1	19 15	58 31	~1200	ES
12685#5	19 18.98	58 15.26	672	CTD	12713#1	19 14.35	58 23.16	850	BC
12685#6	19 18.88	58 15.46	700	BC	12713#2	19 14.29	58 22.87	823	MC
12685#7	19 18.65	58 15.48	667	MC	12713#3	19 14.13	58 22.84	827	MC
12685#8	19 18.66	58 15.64	690	BC	12713#4	19 14.16	58 23.13	862	BC
12685#9	19 18.68	58 15.58	695	MC	12713#5	19 14.14	58 23.01	854	BC
12685#10	19 18.72	58 15.79	755	BC	12714#1	19 12	58 22	~900	AT
12686#1	19 14.35	58 23.07	840	MC	12715#1	19 13.60	58 22.97	874	BC
12687#1	19 59.51	59 00.76	3372	BC	12715#2	19 13.80	58 22.84	857	MC
12687#2	18 50	59 00	~3300	AT	12716#2	19 17.05	58 30.08	996	BC
12687#3	18 59.96	59 00.45	3348	MC	12717#1	19 21.93	58 15.44	398	L
12687#4	18 59.84	59 00.96	3360	BC	12718#1	19 16.59	58 29.85	983	MC
12687#5	18 59.67	59 00.10	3393	MC	12718#2	19 16.62	58 29.77	992	BC
12687#6	19 01	58 58	~3300	ES	12718#3	19 16.77	58 29.91	981	MC
12687#7	19 00.14	59 00.12	3358	BC	12718#4	19 16.87	58 29.81	982	BC
12687#8	18 59.33	58 59.09	3350	MC	12719#1	19 07	58 39	~3000	AT
12687#9	18 59.77	59 00.49	3392	BC	12720#1	19 20.80	58 14.72	406	MC
12687#10	18 59.42	59 00.92	3397	MC	12721#1	------	------	325-560	ES
12687#11	18 59.43	59 00.03	3332	BC	12722#1	19 16.09	58 29.68	992	BC
12688#1	19 50	58 23	~50	TD	12722#2	19 16.73	58 29.71	972	MC
12689#1	19 49	58 24	~60	TD	12722#3	19 16.24	58 29.48	975	BC
12689#2	19 49.37	58 23.71	70	L	12722#4	19 16.28	58 29.25	963	BC
12690#1	19 22.00	58 15.43	402	MC	12722#5	19 16.69	58 29.65	999	CTD
12690#2	19 21.98	58 15.44	401	BC	12723#1	19 15.39	58 30.01	1292	CTD
12690#3	19 22.00	58 15.46	418	BC	12723#2	19 14.02	58 31.42	1285	BC
12691#1	19 48.84	58 23.50	75	BC	12723#3	19 14.33	58 31.56	1268	MC
12692#1	19 21.83	58 15.42	384	MC	12723#4	19 14.25	58 31.55	1291	BC
12692#4	19 21.97	58 15.59	417	BC	12723#5	19 14.38	58 31.46	1252	MC
12693#1	19 22.05	58 14.12	216	MC	12724#1	------	------	720-813	ES
12694#2	19 22.77	58 12.60	121	MC	12725#1	19 13.82	58 31.44	1296	MC
12695#1	19 21.97	58 15.47	416	CTD	12725#2	19 14.03	58 31.29	1265	BC
12695#2	19 22.07	58 15.43	412	MC	12725#3	19 14.14	58 31.30	1254	MC
12695#3	19 21.82	58 15.38	385	BC	12725#4	19 13.91	58 31.63	1310	BC
12695#4	19 21.92	58 15.49	406	BC	12725#5	19 14.15	58 31.28	1256	MC
12695#5	19 22.02	58 15.55	402	MC	12725#6	19 14.31	58 31.32	1244	BC
12695#7	19 21.83	58 15.42	414	BC	12725#7	19 14.02	58 31.32	1277	CTD
12695#8	19 22.12	58 15.46	412	MC	12726#1	------	------	1000	ES
12696#1	19 11	58 18	~650	AT	12727#1	19 13.15	58 30.59	1284	BC
12698#1	19 21.78	58 15.49	401	BC	12728#1	19 13.38	58 32.90	1617	MC
12698#2	19 21.75	58 15.35	362	MC	12728#2	19 13.38	58 32.87	1639	BC
12698#3	19 21.88	58 15.68	416	MC	12729#1	19 13.98	58 34.03	1778	MC
12698#4	19 21.77	58 15.38	369	BC	12729#2	19 14.30	58 34.90	2260	BC
12698#5	19 21.60	58 15.45	353	BC	12730#1	19 00.72	58 59.41	3400	BC
12699#1	19 21.74	58 16.65	551	MC	12730#2	18 59	59 00	~3400	ES
12700#1	19 21.19	58 15.36	426	BC	12731#1	19 13	58 10	~150	AT
12700#2	19 21.88	58 15.37	380	MC	12732#1	19 13.51	58 14.39	392	MC
12702#1	19 15	56 27	~1000	AT	12733#1	------	------	555-650	ES

Key to Gear Symbols:

MC - Multi-corer; BC - Box-corer; KC - Kasten corer; L - Benthic Lander

AT - Agassiz trawl; TD - Tjarno dredge; ZP - Zooplankton dredge

ES - Epibenthic sled

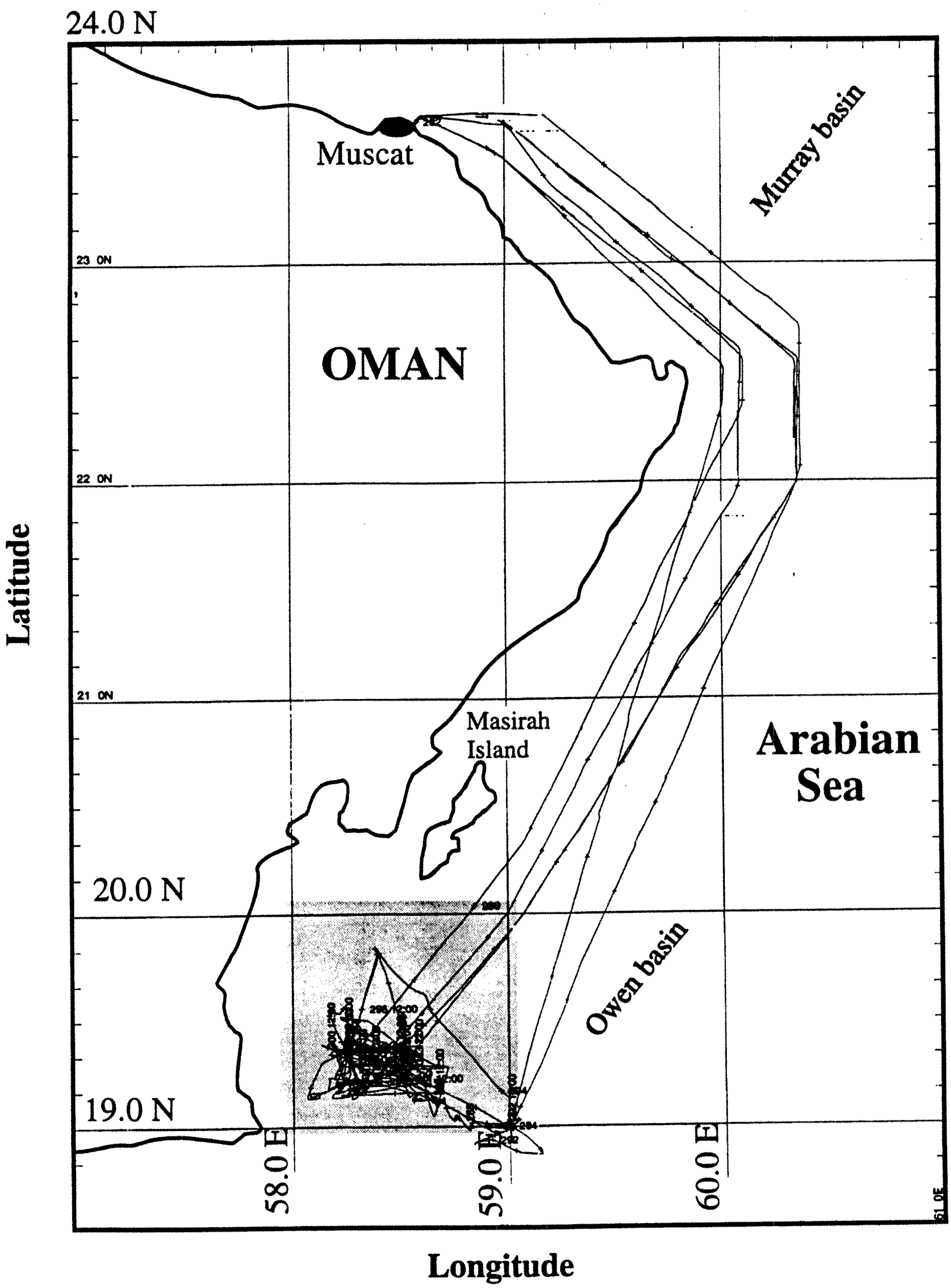

Figure 2: R.R.S. *Discovery* 211 (Muscat 8/10/94-Muscat 12/11/94) Cruise Tract.

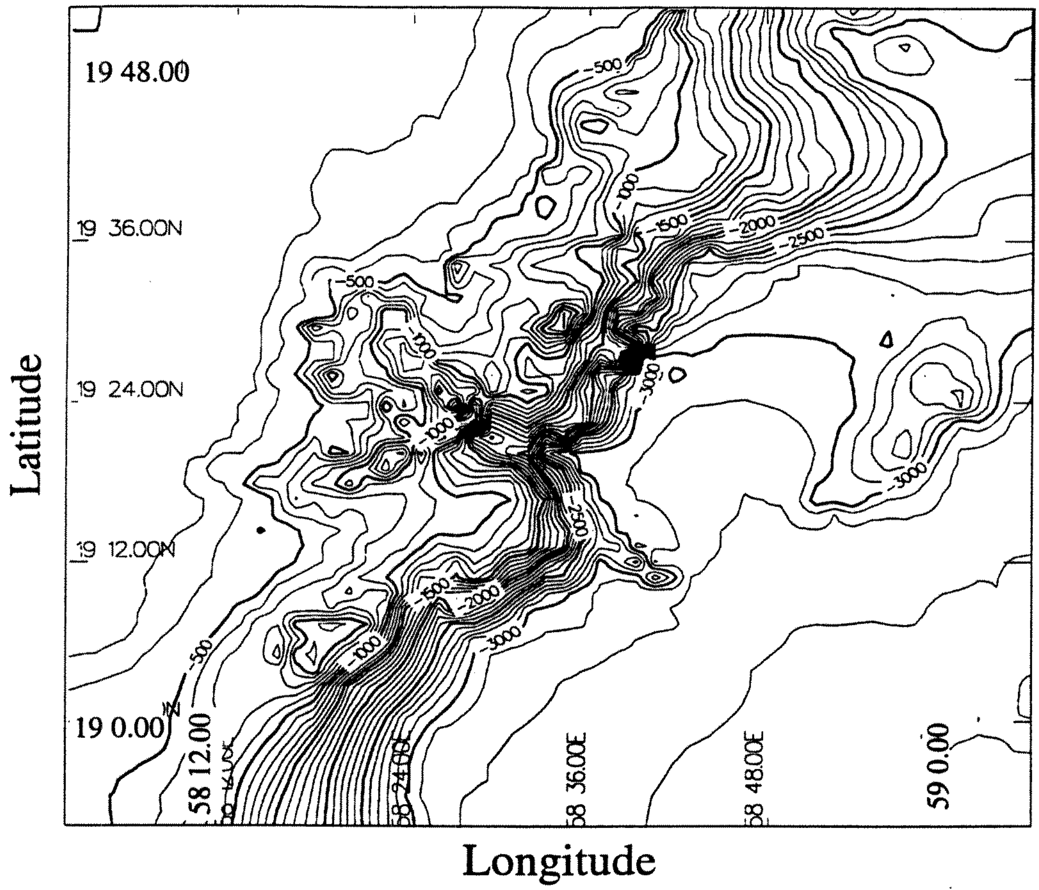

Figure 3: Bathymetric map of the main working area of R.R.S. Discovery cruise 211 (shaded region in fig 1).

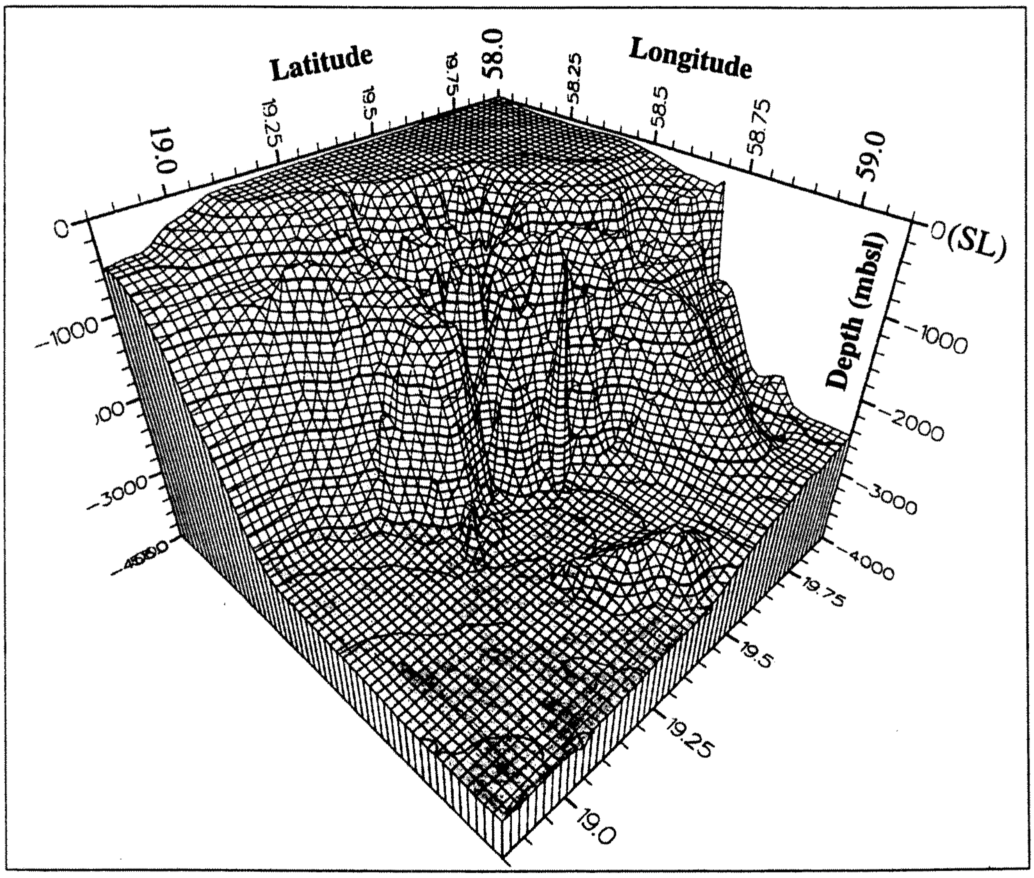

Figure 4: Three dimensional bathymetry of the of the working area (shaded region in fig. 1) during R.R.S. Discovery cruise 211.

on the *Mabahiss*. However, the John Murray Expedition was responsible for discovering the existence of the OMZ as the cruise leader R.B. Seymour Sewell, in his Cruise Scientific Report, describes " ... a zone between the depths of some 100 metres and 1300 metres in which there seems to be a complete absence of life, though above and below there is a varied and in places a rich fauna".. We proved this to be erroneous, although the general finding of a soft, green mud occasionally smelling strongly of H_2S gas certainly was confirmed!

Although we started off working a full suite of sampling gear at a JGOFS position in 3,300 m depth within the Owen Basin between the Murray Ridge and the continental slope, our subsequent efforts were spent carefully working our way down an adjacent area of the slope. From previous bathymetry undertaken during the two earlier *Discovery* cruises immediately before ours, this area was thought to have at least some sediment cover allowing us to sample there. One important aim became the bathymetric mapping of this section of the slope (Fig. 3,4) so that we could better understand its topography in relation to the benthic distributions.

In the work on sampling and in situ measurements on the sea bed, we were very considerably helped by the superb weather (the wind scarcely blew above Force 3, with sunny skies and frequently flat calm seas) and by the attractions of watching flying fish and dolphins jumping from the sea.

Much CTD data, along with measurements of dissolved oxygen and particle scatter was obtained. The oxygen sensor, however was near the range of its sensitivity in the OMZ and the values required calibration by means of Winkler titrations in order to provide definitive measurements. These provided some extraordinarily low values near the bottom, with a measured low of 0.16 ml per litre at about 400 m depth compared with surface water values of around 4 ml /l dissolved O_2. On the basis of these data we were expecting marked changes in both the composition, species richness and body size-related biomass of the benthic fauna in line with trends previously described in the Pacific by Dr Levin. Although diversity certainly did seem much depressed within the OMZ, what we found at the depths of most intense depletion of oxygen therefore came as a complete surprise. In box core samples and the bottom photographs obtained by Brian Bett (IOSDL) with his epibenthic sled, there was evidence for dense populations of both relatively large-sized (in deep-sea terms) bivalve molluscs, including a byssal nest-forming mytilid, *Amygdalum* (?) *politum*, and a spider crab *Encephaloides armstrongi*, were found. This latter species was previously known only from its type locality on the slope on the west side of the Indian subcontinent. The presence of such relatively large-sized fauna seemed contrary to the expectation of an increasing predominance of the community by smaller-sized organisms! We also found that the epi- and infaunal community seemed to show a very rapid rate of change with depth. But perhaps the most surprising discovery of all was of a dense population of up to 30-mm diameter 'jelly' balls attached by fine fibrils to the mud surface at about 1500-1600 m depth where the indications were that, although oxygen was still somewhat depleted, strong currents prevailed over the bottom. These strange organisms were identified by Andy Gooday of IOSDL as most probably allogromiid foraminiferans, but of a species previously completely unknown, and which must represent the largest individual body size yet found in the Foraminifera (see figure on page 34).

The other finding - not completely unexpected - was evidence for well-developed blood pigmentation presumably in order to enhance the abilities of the animals to extract what little oxygen was available from their environment. The other hope was to see if there were any chemosynthetic bacterial symbionts within the tissues of some of the animals living in these highly organic, but oxygen depleted, conditions. The characteristically swollen, fleshy pink, modified gill lamellae of vesicomyid and lucinid bivalves found in the samples by Graham Oliver (National Museum of Wales) were thought to be the sites in the tissues for such symbionts.

One of the tasks for the cruise was to measure directly sea bed fluxes of oxygen which are likely to be affected in interesting ways by the high organic input to the area from the seasonal upwelling and high surface productivity and, of course, by the OMZ itself. This develops partly as a result of the high surface productivity that consumes oxygen in the warm midwater depths below the euphotic zone. These measurements were to have been undertaken in situ using a new benthic lander, BioSTABLE, that had been developed by David Smallman and myself at the Dunstaffnage Marine Laboratory in conjunction with the Proudman Oceanographic Laboratory at Birkenhead. It was developed primarily for new work at the shelf edge off the west of Scotland, and was completed just in time to allow us to take it with us to the Arabian Sea. We did manage two test deployments of BioSTABLE which indicated that the benthic chamber syringe sampling system and video monitoring worked well. But on the third deployment in 400 m we failed to recover it after the acoustic command to come to the surface. This loss cast a slight cloud over the cruise, but the remainder of the work went so well that the cruise was felt by everyone to be a resounding success. Preliminary observations made during and immediately after the cruise, however, enable much to be said regarding the OMZ. In particular, our observations (see also detailed Reports of Participants) made it very apparent that the OMZ did exert an important effect on benthic community composition, abundance and diversity - with very marked changes being obvious in samples separated by just modest changes in depth. With regard to size structure we were surprised to discover dense populations of organisms, such as the spider crab, probably *Encephaloides armstrongi*, that were clearly visible in the unenlarged photosled photographs and therefore justified as megafaunal. This was contrary to our expectation of a shift in body size relations to smaller body size in the more oxygen depleted conditions. Other large sized fauna also occasionally appeared numerous in the samples, such as lucinid and vesicomyid bivalves in which, as mentioned above, chemosynthetic bacterial symbionts were present. This may also explain why, in one 0.25 m^2 box core we found what may turn out to be one of the highest recorded concentrations of animal biomass (642 g ww of lucinid bivalves alone) from non-hydrothermal vent sediments in the deep sea.

Objective 5 was dependent on whether samples could be taken on earlier/later *Discovery*/JGOFS cruises in the area. This was to test whether variability in labile organic particulate flux as a result of monsoon-driven upwelling is reflected in seasonality in the benthic biota, and in particular to investigate the time-scale of the benthic response to seasonal carbon input from the point of view of changes in population abundance, size structure and reproductive status. As it turned out, it was not possible to address this objective because of the lack of opportunities to obtain comparable samples on preceding and subsequent cruises in the area worked. It was not possible to obtain sediment sampling time on either of the two earlier or the following cruise of R.R.S. *Discovery* because of pressure on their already busy programmes. Furthermore, an approach was made to the organiser of the US JGOFS Arabian Sea cruises during 1994/95, however no reply was received.

3. DIARY OF EVENTS

Times logged below are in local ship time i.e. (Z+4hr)

Thursday 6th October

Air travel of scientific party from London to Muscat

Friday 7th October

1100 hrs The scientific party joined R.R.S. *Discovery* and immediately assisted in loading of equipment from the two 40' containers previously shipped to Muscat and the final installation and commissioning of this equipment on board. The absence of the USNEL box corer, an essential piece of our sampling gear from Research Vessel services, Barry (RVS), however, was the subject of emergency communications with RVS. Scientists join vessel at 1100 hrs and assist in loading and final installation of equipment.

Saturday 8th October

Loading and gear installation and commissioning by scientific party continued all day.

Sunday 9th October

0800 hrs Sailing delayed in order to await delivery of air freighted box corer
1415 hrs Consignment delivered to ship
1530 hrs R.R.S. *Discovery* sailed 7.5 hrs late from Port Sultan Qaboos for the first station off the southern coast of Oman

Monday 10th October

Passage to Stn 1 on 19° N, 59° E; passage was delayed north of Ras-al-Had by high sea water temperatures reducing the ship's speed by as much as 40%
0500 hrs *Discovery* rounded Ras-al-Had. During the passage both the box corer and the multicorer were assembled and their correct operation checked.
1718-1752 hrs CTD trials with Niskin bottles to 500 m depth by RVS staff completed successfully

Tuesday 11th October

0200-0515 hrs The first station (Station A1 of *Discovery* cruise 210) in the Owen Basin on 19° N 59° E, depth 3,380 m depth was reached and a full CTD/Niskin water bottle station (T1) was worked from the surface down to 2,500 m depth (bottom depth 3,300 m), bottom temp. 1.70C
0835-1115 hrs Kasten Corer tried but recovered empty
1200-1445 hrs Multicorer. 4 good cores only; voids in sediment column of rest, greenish sediment
1535-1833 hrs Box corer; large sample indicated lead ballast needed to be removed to reduce core penetration
2100-2354 Slow passage to next station using 3.5 Khz profiling system

Wednesday 12th October

0010-0100 hrs Oblique zooplankton net haul for PML/JGOFS
0122-0433 hrs CTD/Niskin stn T2; water samples to 2,500 m; bottom depth 3,250 m
0435-0748 hrs CTD/Niskin. stn T3 Cast failed, no samples obtained
0748-1015 hrs CTD/Niskin T3 again water samples to 3,165 m; bottom depth 3,197m
Slow passage to next Stn
1425-1751 hrs Oblique zooplankton net haul, thence slow passage to next Stn.
1555-1835 CTD/Nisken Stn T
1954-2225 hrs CTD Stn T4 followed by test of CTD transponder. Large colonial salp captured around wire. Surveyed benthic topography; followed by passage to next Stn.6; 1,124 m wire out in 1,140 m bottom depth
2343-0043 hrs CTD Stn T5, aborted owing to very steep topography

Thursday 13th October

0130-0238 hrs CTD Stn T6, 1140 uncorrected m water depth; water bottle samples down to recorded 1124 m water depth
0343-0444 hrs CTD Stn T7, 737 uncorrected water depth; niskin samples down to 700 m water depth
0615-0709 hrs CTD Stn T8, 948 m wire out in bottom depth of 924 uncorr m; thence passage to next Stn
0845-0916 hrs CTD Stn T9, depth approx. 150 m; followed by passage to next Stn
1038-1055 hrs CTD Stn. T10, water depth 70 m; Niskin samples to bottom depth. Thence slow passage to next Stn
1335-1425 hrs CTD stn. T11, water depth 605 uncorrected metres;
1510-1555 hrs Box corer in 592 m bottom depth; soft muddy sample overflowed top of box
1616-1729 hrs Multicorer in 742 m bottom depth; 12 good cores obtained
1846-1940 hrs Box corer in 675 m bottom depth
2112-2210 hrs Multicorer in 662 m bottom depth
2250-2353 hrs Box corer; drop failed owing to non-triggering

Friday 14th October.

0030-0122 hrs Box corer in 630 m bottom depth; good sample obtained
0143-0700 hrs Vessel repositioning
0805-0814 hrs Tjarno dredge in 45-50 m water depth near shelf edge; good haul of coral sand
0920-1054 hrs Tjarno dredge in 45 m depth; bag recovered ripped
1230-1325 hrs Tjarno dredge with bag replaced in 84 m water depth. Recovered sample of slightly finer sand with larger stones and epifauna
1639-1727 hrs Box corer in 610 m depth with column stops set lower to reduce core penetration; good sample obtained
1808-1854 hrs Multicorer in 685 m water depth; 12 good samples
1926-2009 hrs Box corer in 590 m water depth; fuller than previous core, but 10 vegematics usable
2058-2152 hrs Kasten corer with 2 m barrel in 657 m water depth; 1 good core obtained with no obvious varving
1950-2006 hrs CTD Stn. Successful Niskins down to bottom depth (672 m)

Saturday 15th October

0200-0726 hrs Overnight sounding survey grid using Simrad
0823-1025 hrs Box corer in 688 m water depth; good cores
0938-1025 hrs Multicorer in 658 m bottom depth; good cores
1046-1325 hrs Box corer in 690 m bottom depth. During this station a minor fault developed on the traction winch system. This was quickly resolved by the RVS technicians
1535-1632 hrs Multicorer in 693 m bottom depth, recovering a good set of cores
1702-1755 hrs Box corer in 746 m bottom depth, also recovering a good, undisturbed sample
1920-2024 hrs Multicorer in 820 m water depth; more good cores
2040-2200 hrs Bathymetric survey
2200 hrs On passage to Port Sultan Qaboos in order to pick up remainder of scientific party

Sunday 16th October

Passage to Muscat

Monday 17th October

1000 hrs R.R.S. *Discovery* arrives off Port Sultan Qaboos
1100 hrs Boat transfer of scientists. Return passage started on completion

Tuesday 18th October

1941 hrs on Stn 18° 59'N, 59° 00'E
1945-2347 hrs Box corer in 3,384 m water depth. Again further minor problems with scrolling gear on winch system. However, a useful core was obtained

Wednesday 19th October

0200-0940 hrs Agassiz Trawl in 3,356 m bottom depth; 7,500 m trawl wire payed out, obtaining a rich haul of epibenthic megafauna and larger macrofauna. Included large numbers of the bivalve *Limopsis* and the brachiopod *Pelagodiscus*
1134-1420 hrs Multicorer in 3,380 m bottom depth; good cores
1507- 2000 hrs Boxcorer in 3,382 m water depth. Problems with a sheared bolt in the winch system which meant much stripping down and re-assembly by the RVS technicians; but fair core obtained eventually
2044-2336 hrs Multicorer in 3,381 m depth; 12 good cores obtained

Thursday 20th October

0100-0734 hrs IOS Epibenthic PhotoSledge in 3,357-3,371 m depth; torn net and flash system had not worked owing to power packs not having been charged properly
1038-1320 hrs Box corer in 3,380 m depth; but box had overflowed with the soft mud again
1345-1618 hrs Multicorer in 3,372 m depth; 12 excellent cores
1652-1924 hrs Box core in 3,380 m depth; box completely filled but sediment surface intact and relatively undisturbed
1957-2318 hrs Multicorer in 3,385 m depth. Further problems during this station with

the winch system, but eventually 12 good cores were recovered on deck

Friday 21st October

2357-0224 hrs Box corer in 3,380 m depth. Tried a very quick touch down on sediment and recovered a deep, H_2S smelling sample with animals visible in subcores
0300-0920 hrs steam to new position 19° 50'N, 58° 25'E.
0953-1013 hrs Tjarno dredge in 47 m depth; sandy coral sand sediment
1123-1148 hrs Tjarno dredge in slightly deeper water (59 m), recovering a slightly muddier sand
1215 hrs BioSTABLE Lander (with amphipod trap) deployed in water depth of 55 m; glass float and two plastic floats attached to a 50 m stray line for recovery
1300-1600 hrs Steam to new Stn on 19.220N, 58.150 E
1621-1658 hrs Multicorer in 377 m depth, recovering 12 beautiful samples
1727-1805 hrs Box corer in 382 m depth, recovered with overflowing box
1838-1916 hrs Box corer in 382 m depth; touched down very lightly and recovering a very H_2S-smelling sample with a rich fauna in washings
2030 hrs Commenced overnight bathymetric survey

Saturday 22nd October

Continue survey and return to lander position for 1100 hrs
1330-1340 hrs BioSTABLE lander recovered in calm conditions. One release weight had become stuck in guide and not released. Acoustics worked well; syringe sampling system partly worked
1410-1425 hrs Box corer in 63 m depth; poor seating of spade with box; but recovering a sandy sample with many cumaceans
1718-1752 hrs Multicorer in 372 m depth obtaining good cores
1816-1847 hrs Box corer at 384 m again in order to recover a good sample from this very soft sediment. Sample had overflowed box
1921-1948 hrs Box corer in 385 m depth again. Same result
2010-2101 hrs Box corer in 380 m depth. A reasonable sample was recovered by "kissing" the gear onto the bottom
2202-2226 hrs Multicorer in 184 m depth, short but usable cores
2252-0011 hrs Multicorer in 109 m depth; again short but useful cores

Sunday 23rd October

0020-0840 Bathymetric survey
0840-0931 hrs CTD in 400 m bottom depth; Niskins down to 398 m
1039-1115 hrs Multicorer in 382 m depth
1217-1245 hrs Box corer in 365 m depth; box overflowing
1320-1400 hrs Box corer in 394 m depth; box overfowing
1430-1500 hrs Multicorer in 390 m depth; good cores
1540- 1635 hrs Box corer in 441 m depth, sample had washed out owing to lack of seal of spade with bottom edge of box
1701-1737 hrs Box corer in 401 m depth; useful core
1805-1843 hrs Multicorer in 391 m depth; good cores
1845-2220 hrs Shift position
2220-0045 hrs Agassiz trawl in 626-730 m bottom depth; sample recovered early

because of tension spikes on wire. Good sample of spindly spider crab *Encephaloides armstrongi* and some cocoon mussels *Amygdalum politum.*

Monday 24th October

0330-0515 hrs Agassiz trawl in 366- 368 m depth; many basaltic pebbles with blackened sharks teeth and large vertebrae ("death assemblage" haul); also many *Amygdalum politum*
0831-0905 hrs Box corer, 379 m depth; good core retaining overlying water
0940-1012 hrs Multicorer in 346 m depth; good cores
1055-1132 hrs Multicorer in 410 m; good cores
1205-1240 hrs Box corer in 357 m depth; fair core; water drained from non-vegematic area, but vegematic cores usable
1247-1319 hrs Box corer in 341 m depth; fair core as previously
1430-1512 hrs Multicorer in 523 m depth; good cores
1640-1737 hrs Box corer in 414 (+15?) m depth; overflowing so discarded
1819-1900 hrs Multicorer in 368 m depth; cores combined and used for macrofauna
2029-2231 hrs WHOI pattern epibenthic sledge in 700 m depth approx. Good haul of spider crabs Encephaloides armstrongi

Tuesday 25th October

0100-0449 hrs Agassiz trawl in 1,000 m approx; moderate but varied catch
0848 hrs Lander deployed in 103 m depth near the shelf edge
1000-1737 hrs Winch failure
1737-1831 hrs Multicorer in 661 m depth; good cores
2008-2111 hrs Multicorer in 898 m depth; good cores
2235-2337 hrs Multicorer in 990 m depth; good cores
2337-0220 Steam to trawl site

Wednesday 26th October

0220-0443 hrs Agassiz trawl in approx. 400 m depth; very large haul (> 2 tonnes) of mud, small stones and fauna
0443-1108 hrs Steam to Lander site
1118 hrs Lander recovery; one weight had not released again. Good video record; some syringe operations missed
1235-1245 hrs Box corer in 97 m; poor penetration in sandy sediment, but with overlying water intact. Screened catch included large nemerteans
1325-1337 hrs Box corer in 96 m; much as previously
1350-1410 hrs Multicorer in 94.5 m depth
1510-1525 hrs Box corer in 96 m depth; as previously
1555-1607 hrs Multicorer in 95 m; good cores
1650-1703 hrs Box corer in 96 m depth; good cores
1823-1939 hrs Multicorer in 94 m depth; good cores
2000-2014 hrs Box corer in 92 m depth; good, although shallow core
2100-0006 hrs Bathymetric survey

Thursday 27th October

0006-0521 hrs Agassiz trawl in approx. 1,209-1,222 m depth; small but rich catch

0854-0906 hrs Box corer in 94 m depth; good core
1047-1050 hrs Box corer in 98 m depth; good core
1051-1104 hrs Box corer in 96 m depth; failure
1230-1240 hrs Box corer in 96 m depth; good cores although supernatant drained before subcoring
1325-1345 hrs CTD in 96 m depth; successful Niskin samples at bottom depth
1400-1837 hrs Bathymetric survey
1837-1957 hrs CTD in 825 m depth; water samples down to recorded 830 m depth
2034-2136 hrs Box Corer in 840 m depth; good core, subsampled
2152-2253 hrs Multicorer in 833 m depth; good cores

Friday 28th October

0030-0555 hrs WHOI pattern Epibenthic Sledge in approx. 1,211-1,299 m depth; winch tension band problems experienced to winch during this haul; this affected the catch which was largely mud. However, some large allogromiid foraminiferans were recovered
0930-1032 hrs Box corer in 850 m depth; good core
1053-1147 hrs Multicorer in 822 m depth
1225-1325 hrs Multicorer in 827 m depth
1350-1450 hrs Box corer in 842 m depth
1515-1612 hrs Box corer in 842 mm depth
1656-2327 hrs Bathymetric survey

Saturday 29th October

2327-0246 hrs Agassiz trawl in approx. 919-967 m depth; varied catch
0300-0845 hrs Bathymetric survey
0845-1008 hrs Box core in 874 m depth; good core
1025-1125 hrs Multicorer in 856 m depth
1200-1535 hrs Two CTD stations at 820 m depth for bottom water incubations and salinity analysis
1606-1710 hrs Box corer in 996 m depth; shallow core of stiffer, sandier sediment. Many brittle stars on sediment surface
1718 hrs Commenced bathymetric survey track

Sunday 30th October

Bathymetric survey throughout

Monday 31st October

Bathymetric surveying throughout until 0830 hrs
0901 Deployed lander in 400 metres of water thence proceeded to multicorer station nearby
1200-1305 Multicorer in 893 m depth
1335-1448 hrs Box corer in 980 m depth; good core
1520-1623 hrs Multicorer in 981 m depth
1647-1752 hrs Box corer in 975 m depth; good core
1800 hrs Resumed bathymetric survey
2207-0534 hrs Agassiz trawl in approx. 3135-3151 m depth; rich catch, many

echinoderms.

Tuesday 1st November

0600 hrs vessel returned to Lander site
1030 hrs Lander reported released but not sighted at surface
1100-1723 hrs Box Search for lander undertaken in calm seas and very good visibility; nothing found or heard on acoustics
1830 hrs Returned to coring position
1850-1930 hrs Multicorer at 406 m depth
2042-2305 Bathymetric survey.
2305-0510 hrs IOS Epibenthic PhotoSledge in 349-500 m depth; no net fitted

Wednesday 2nd November

Returned to Lander position in order to resume visual search
0655-1054 hrs Acoustics interrogation
1100-1650 hrs Visual search down current for lander without success
1700 hrs Returned to Box core station
1914-2005 hrs Box core in 992 m depth; good core
2057-2158 hrs Multicorer in 972 m depth
2221-2328 hrs Box corer in 975 m depth ; this core recovered some very soft H_2S-smelling soft mud with 17 large-sized lucinid bivalves present

Thursday 3rd November

2358-0102 hrs Box corer in 963 m depth; soft, smelly black mud; one large lucinid present
0135-0242 hrs CTD in 987 m depth; successful Niskins to bottom depth
0635-1337 hrs Dragging for lander without success
1337-1545 hrs steam to new position
1600-1727 hrs CTD in 1,280 m depth; successful Niskin samples to bottom depth
1804-1919 hrs Box corer in 1,285 m depth; good core with fairly undisturbed surface, with flocculent detritus and some large 'jellyball'-like allogromiid foraminiferans up to 3 cm in diameter
1951-2103 hrs Multicorer in 1,268 m depth
2123-2242 hrs Box corer in 1,279 m depth
2303-0014 hrs Multicorer in 1,252 m depth

Friday 4th November

0035-0505 hrs IOS Epibenthic PhotoSledge survey; no net fitted (winch failure between 0402-0420)
On Passage to Port Sultan Qaboos to land two of the Scientific Party.

Saturday 5th November

Passage to Port Sultan Qaboos
1845-2030 hrs Hove to off Port Sultan Qaboos for port clearance prior to landing two scientists.

Sunday 6th November

Return passage to work area

Monday 7th November

0915 hrs Arrive back on station
0927-1044 hrs Multicorer in 1,296 m depth
1140-1252 hrs Box corer in 1,265 m depth
1308-1415 hrs Multicorer in 1,245 m depth
1442-1550 hrs Box corer in 1,309 m depth
1622-1733 hrs Multicorer in 1,280 m depth
1756-1910 hrs Box corer in 1,243 m depth
1942-2053 hrs CTD in 1,285 m depth; Niskin samples to 1,277 m
2100-2233 hrs Bathymetric survey
2233-0529 hrs IOS Epibenthic PhotoSledge in approx. 814-1,214 m depth

Tuesday 8th November

0624-0738 hrs Box corer in 1,284 m depth; no vegematics
0828- 0955 hrs Multicorer in 1,617 m depth
1024-1154 hrs Box corer in 1,626 m depth; good core with several solitary corals and one large 'jellyball' on surface, smoothed sediment surface indicative of high bed flow
1235-1410 hrs Multicorer in 1,778 m depth; good cores
1441-1659 hrs Box corer in 2,260 m depth; good core
1600-2000 hrs Steam for A1 position in Owen Basin
2023-2306 hrs Box corer in 3,400 m depth; good core completing previous suite to make five

Wednesday 9th November

0257-0535 hrs WHOI pattern epibenthic sled in approx. 3,386 m depth; very small catch obtained - gear may have been 'flying'
0540-1046 hrs Steam to new position on slope
1100-1201 hrs Agassiz trawl in approx. 150 m depth
1301-1352 hrs Multicorer in 392 m depth for cores for redox measurements
1447-1550 hrs IOS Epibenthic PhotoSledge in approx. 551-600 m depth; short photographic tow in order to complete suite of photo transects
1612 hrs All scientific equipment secured. Scientific programme completed
On passage to Port Sultan Qaboos.

Thursday 10th November

On passage to Port Sultan Qaboos

Friday 11th November

0700 hrs R.R.S. *Discovery* arrived off Port Sultan Qaboos
0815 Ship berths. Unloading of scientific equipment commenced as soon as the vessel was cleared by the port authorities.

Total distance of cruise: **2061 nm**
Total steaming time: **215.4 hrs**
GAS: **9.57 knots**

Total scientific time: **578.2 hrs** (does not include stoppages)

4. GEAR REPORTS

Box corer

Early in the cruise tests were made to see if it were possible to compare and possibly interchange the 'vegematic' subcores and box kindly loaned by Dr Lisa Levin from the Scripps Institute of Oceanography with those from the RVS 'vegematic' box. Both boxes fitted the RVS stainless box corer, but it turned out that the subcores were sufficiently dissimilar in both length, cross sectional area and fitting to make use of both awkward and statistically undesirable. It was not possible to use the Scripps subcores in the RVS vegematic box, so we decided thereon to use only the Scripps vegematic subcores and box so that there would be no possible confusion on the dimensions of the subcores in subsequent samples. We also found that the Scripps box and subcores were somewhat easier to assemble and fit.

Early on in the cruise, we found it necessary to adjust the lead ballasting of the box corer in order to reduce the penetration into the very soft sediments encountered. As much as possible of the lead billets and lead shot that had been packed into the centre column of the corer were removed. This was found sufficient to prevent the heavy corer from over filling the sample box in the softest sediments encountered within the Owen Basin and on the upper continental slope within the oxygen minimum zone, while trial-and-error determined how much of the ballast needed to be replaced on the firmer sediment encountered below about 1,000 m on the lower continental slope.

Two rows of five, aluminum 'vegematic' subcores were fitted along one side of the box, with two plexiglas slab cores secured along their inner margin. The latter were very successfully used by Mr Dan Hoover (Hawaii) to obtain sediment slabs for X-radiography, processing the images on board. The remaining sediment obtained in the box was used for a variety of purposes. Most was subcored for geotechnical, granulometric and bioturbation study by Dr P. Meadows (Glasgow University), with other cores being taken by Mr Chris Young (University of Newcastle-upon-Tyne) for studies on denitrification. A bottom-triggered 35-mm camera system with built in flash (Mr D. Hoover, Univ. Hawaii) was strapped to one of the corer frame legs and used for nearly all deployments sufficient to provide between 3 and 9 photographs at each replicated station in addition to non-replicated ones. The colour film exposed was developed on board and yielded good pre bottom-impact images of the sediment surface.

Multicorer

The IOSDL multicorer which was used worked remarkably well. The gear was able to yield a full set of the 12 twelve cores reliably, drop after drop. The easily adjusted ballasting of this corer was able to cope well with the differing fluidity of the sediments encountered. The same simple bottom-triggered 35 mm camera system used with the box corer was used with the multicorer drops. It likewise provided good pre-impact images of the bottom for virtually all the multicorer deployments. For further details of the multicorer deployment see Gooday, A. (p 30)

Kasten Corer

One Kasten core was successfully recovered at station 12671#3 (19° 00.75' N 59° 00.45' E) from 3355 m water depth. This 2 m core was photographed then sampled every 20-30 cm throughout its length for ^{14}C analyses of the sediments which will be used for dating and flux calculations. The remaining sediment was examined for any bioturbation structures before being discarded. The topmost 15 cm of the core was lost in the corer. The sediment from this core was stored in the normal (-10°C) freezer on The R.R.S. *Discovery* and will, it is hoped, be transported back to the UK with the material from a future cruise.

CTD

The CTD performed faultlessly recording temperature, dissolved oxygen, salinity and fluorimetry /transmitometry eight times per second during its downward and return journeys at each drop. Sea water was also successfully recovered using its twelve 10 litre niskin bottle rosette. Calibration of its oxygen probe with dissolved oxygens ($D.O_2$) derived using the Winkler technique, however, indicated that the CTD $D.O_2$ surface water values were around half of those using the chemical method whereas the CTD values from within the OMZ were as much as an order of magnitude lower than the Winkler results (see Patience, A.J., pp 52-62). Thus, any simple linear calibration of the CTD result was not achieved.

IOSDL EPIBENTHIC SLEDGE

The IOSDL epibenthic sledge was deployed on five occasions. The first, at the A1 3300 m stations was a total failure; the camera system failed on deck pre-deployment and the net was torn end to end during the deployment. In contrast the remaining four tows were successful, acoustic telemetry indicated good bottom contact, and in all cases an appropriate quantity of film had run through the camera. Bathymetric coverage appears to be good; 325 - 560 m (12721#1), 555 - 650 m (12733#1), 720 - 813 m (12724#1), and 833 - 1220 m (12726#1). Although the four successful tows did not carry nets, deployment 12733#1 nevertheless caught 100+ spider crabs which were retained by A. Rogers, MBA. In all cases the camera was loaded with Kodak Eastman 5297 colour negative film. Films will be processed on return to the UK, with the intention of making a spare positive print available for inspection by other participants.

The deployment of the various **trawls** is described in the scientific reports (section 7).

5. SCIENTIFIC AND SHIPS PERSONNEL

Scientific Personnel

Name	Institute and Address
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Mr Jeff **Crooks**	**Scripps Instution of Oceanography**, Marine Life Research Group 0218, La Jolla, CA 92093-0218, USA.
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A. **Adams** .... Ch. Engineer
J. **Crosbie** .... 2nd Engineer
J. **Jones** .... 3rd Engineer
A.F. **James** .... 3rd Engineer
M. **Trevaskis** ...... CPO (D)
C. **Vrettos** .... PO (D)
D. **Buffery** S1A
S.C. **Cook** S1A
A. **Maclean** S1A
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Lastly, I wish to acknowledge the enthusiastic cooperation and help received from the scientific participants which has ensured the lasting success of this cruise. In particular, the efforts of Dr D.J.Smallman in organising the complex logistics associated with transport of ourselves and our gear to Muscat, Mr Peter Lamont for his untiring efforts in curating the ever-increasing stock of biological samples, and lastly the great help received from Dr Andrew Patience in preparing this Report.

7. SCIENTIFIC REPORTS

(In alphabetical order of authorship)

Bett, B.J.

A MILLION SPIDER CRABS CAN'T BE WRONG !

(an extract from "Deep Sea Newsletter", No. 23, March 1995)

When working with deep-sea megabenthos it is usually most convenient to quote densities per hectare to avoid too many leading zeros. However, when peak densities start to exceed one million individuals per hectare it is time to revert to smaller units.

Elsewhere in this issue of the newsletter John Gage describes some of the events and findings of R.R.S *Discovery* cruise 211, designed to investigate the influence of an intense oxygen minimum zone on the benthos of the Oman continental margin (NW Indian ocean, Arabian Sea). In John's account he mentions the discovery of dense populations of a small spider crab, probably *Encephaloides armstrongi* (Fig.5a) within the oxygen minimum.

In the context of deep-sea megabenthos, a dense population might be one, or a few, individuals per square metre - but in the case of these crabs, densities exceed 100 individuals per square metre, equivalent to one million per hectare. Preliminary analyses of three photo transects (see Fig. 5b) within the oxygen minimum zone have revealed not only these incredibly high densities but also an intriguing bathymetric distribution (see Fig. 6).

The two shallower tows, covering the depth ranges 570-625 m and 740-815 m, gave similar results: maximum density of about 20 and mean density of about 10 indiv. m^{-2}, and in the combined total of over 200 usable photos spider crabs were absent from only one. The deeper tow, covering the range 830-1230 m, produced completely different results. Almost half of the 140 usable frames contained no spider crabs! yet within a 50 m depth band centred on 985 m, mean density reaches 70 indiv. m^{-2}, and maximum density 137 indiv. m^{-2}. High densities were also recorded towards the deepest point of the tow, with individual counts in excess of 30 indiv. m^{-2}.

Explaining this bathymetric distribution may be more difficult than describing it. It is tempting to speculate that the high density band close to 1000 m reflects a biologically relevant boundary between the intense oxygen minimum above and more oxic conditions below. However, this does not explain the rarity/absence of crabs immediately above and below the high density band nor their return to comparatively high densities at the upper and lower depth ranges surveyed.

This is only a preliminary analysis, and although the densities reported here are unlike to change appreciably, considerably more information can be gleaned from these films. Of particular significance may be the size distribution of the crabs - small individuals predominate in the high density zone whereas at other depths the population consists almost exclusively of large individuals.

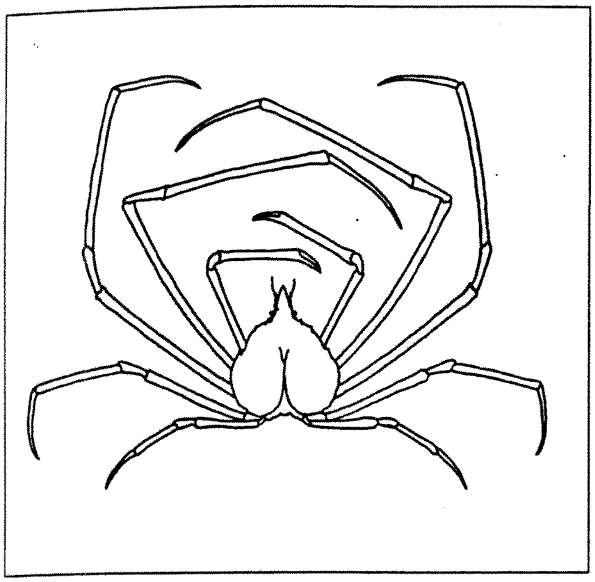

Figure 5a: diagram of the spider crab *Encephaloides armstrongi.*

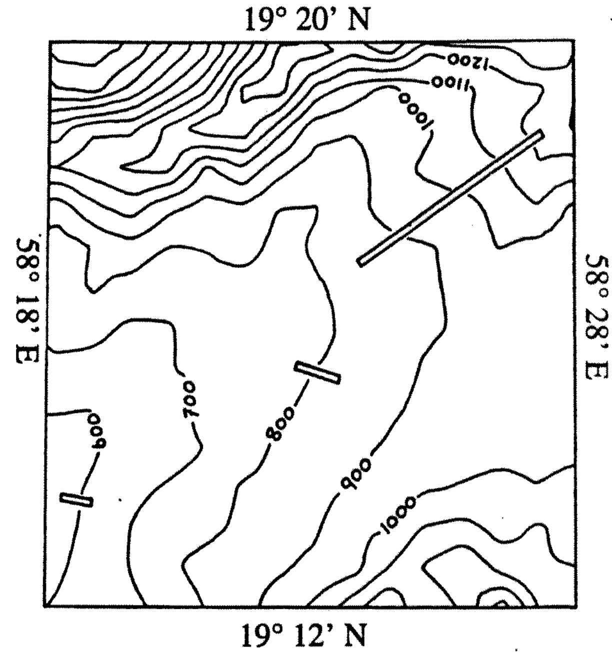

Figure 5b: chart showing the approximate seafloor tracks of three IOSDL epibenthic sledge tows in the Arabian sea, bathymetry is shown in 100 m contours.

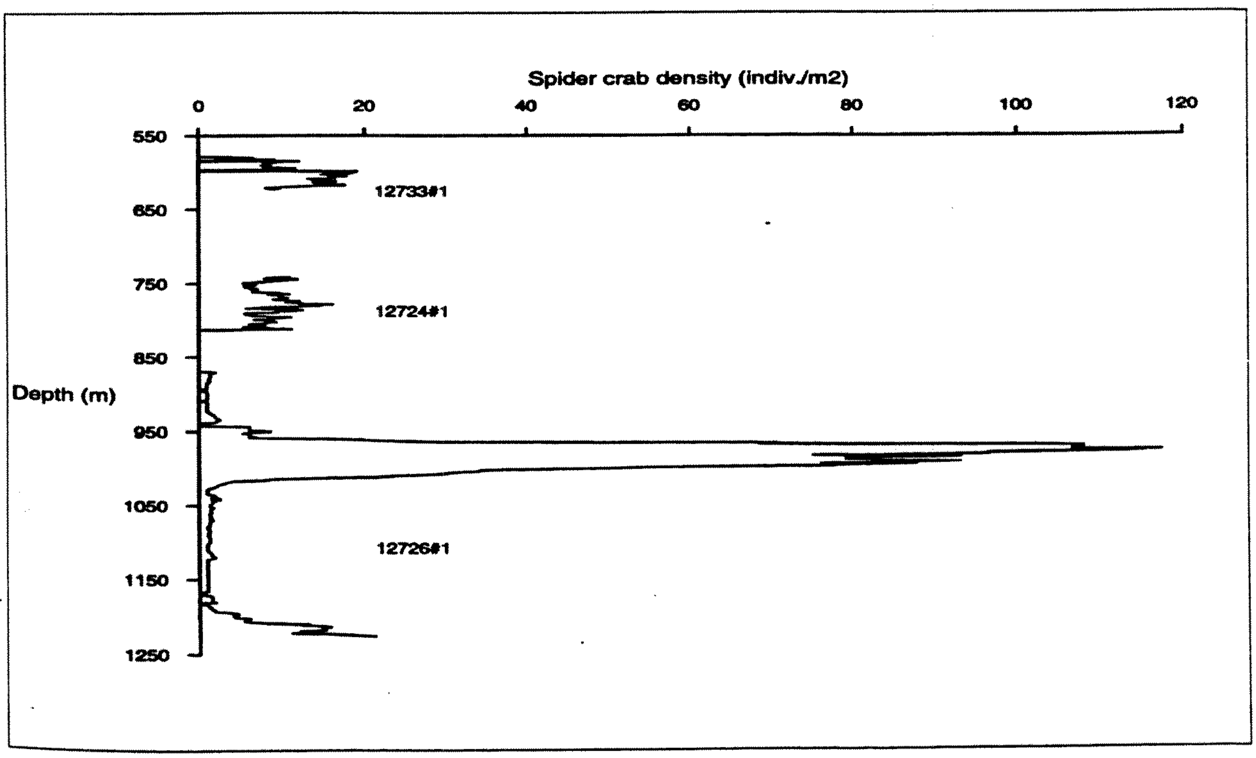

Figure 6: approximate density of *Encephaloides armstrongi*, estimated from IOSDL epibenthic sledge photos taken in the Arabian sea.

Bett, B.J. and A.J. Gooday

MULTICORE OXYGENATION / STAGNATION EXPERIMENT

All twelve cores from drop 12720#1, at the 400 m intensive coring station, were employed in an oxygenation / stagnation experiment. On recovery of the corer a supernatant water sample for oxygen determination (A. Patience, SAMS) was taken from one of the cores at random, all twelve tubes were then removed in the normal way, bungs were then inserted into the tops of each tube and the tubes taken to the constant temperature laboratory (11 °C) within 11 minutes of arrival on deck. Tube numbers, used to identify the individual core positions on the corer head, were used to randomly assign the tubes into three sets: four control, four stagnation, four oxygenation.

The control cores were processed immediately, with supernatant water and eight sediment sections (0-0.5, 0.5-1, 1-2, 2-3, 4-5, 5-10, 10-15 cm) collected from each core.

Oxygenation cores were set up by removing the top bung, taping round the lower bung and marking the supernatant level in each core. In addition a small wooden frame of cocktail sticks was inserted into the sediment surface of each core to act as an emergence panel. Oxygenation cores were all initiated within 17 minutes of the corer arriving on deck.

Stagnation cores were set up by removing the top bung inserting a wooden frame, as above, tightly fitting a new top bung with water sampling taps, silicone sealing round the top bung, and taping round top and bottom bungs. All stagnation cores were prepared within 40 minutes of the corer arriving on deck.

All oxygenation and stagnation cores were then placed in a dark, constant temperature incubator maintained at 11°C. The cores were inspected at least once daily; no water leaks were detected in any core, no air leaks were detected in any of the stagnation cores, evaporative losses from the oxygenation cores were made good by additions of de-ionised water.

The experiment was terminated after approximately eight days of incubation. Supernatant water was withdrawn for the determination of oxygen concentrations (A. Patience, SAMS) some 7 days 21 hours and 31 minutes after the corer first arrived on deck. Stagnation cores were sampled shortly after supernatant withdrawal, between 7 days 22 hours and 51 minutes and 8 days 0 hours and 21 minutes after initiation. The samples collected were as described above for the control cores with the addition of the wooden frame. Oxygenation cores were sampled in the same way, between 8 days 19 hours and 51 minutes and 8 days 20 hours and 14 minutes after initiation.

It is intended that the material collected during the experiment will initially be processed for the analysis of all meiobenthic groups at the higher taxon level, and subsequently for the nematodes and foraminiferans at the specific level.

Campbell, A.C., Squire, G. and P.A.Tyler

ECHINODERMATA

All classes other than Crinoidea were represented in the catches. Sevėn pieces of wood were collected for subsequent investigation of putative Centrocycloidea. Eighty five samples were collected in twenty hauls. Numerically the Ophiuroidea were predominant. Amphiurid brittlestars were well represented in most catches. The shallow water hauls (above 100 m) included forms, inter alia the ophiotrichids *Ophiothela venusta* and *Macrophiothrix hirsuta*, which are common in intertidal situations in Oman. Great numbers of ophiuroids were collected from two mid depth stations (12702/1 at 1050 m and 12714/1 at 967 m) where estimated numbers in the catch were in excess of 15000 for each. Of these an unidentified ophiacanthid was dominant. *Ophiura irrorata* and *Ophiomastus* sp. were characteristic of the deep stations.

The asteroids and echinoids were better represented at the very deep stations with *Nymphaster* sp. relatively abundant at 3400 m, but even so in small numbers. Two echinoids, *Pourtalesia alcocki* (?) and *Brissopsis* sp. were collected around 3000 m, but again in small numbers. The cidaroid echinoid *Prioncidaris bacculosa* occurred in the shallow water station at 45 m. This is common in shallow water all round Oman.

Samples of pedicellariae from *Pourtalesia* were fixed in glutaraldehyde for electron microscopy and all taxonomic material, except holothuroids, was returned to London dried. Gonad samples, fixed in formaldehyde or glutaraldehyde, were taken for histology and egg size analysis.

DATABASE for MEGABENTHIC CATCHES

A database was set up using Paradox. This covered principal station data, oxygen concentrations (where available) and taxonomic data on the catches. Special attention was paid to the manner of preservation and destinations of the catch material. At the end of the cruise there were 370 data sets in the database. After suitable editing at Queen Mary & Westfield College, this will be circulated on disc and as hard copy to all interested parties.

Campbell, A.C., Oliver, G., Rogers, A.D., Squire, G., Tyler, P.A. and C.M. Young

GENERAL MEGABENTHOS

Seventeen samples (8 Agassiz trawls, 5 Tjarno dredges, 2 IOS epibenthic and 2 WHOI-pattern epibenthic sledges) taken over a depth range of 48 to ~3500 m revealed a rich and diverse megafauna down the slope of SW Oman. The fauna, as identified to date, can be seen in the database attached to this report. The provisional results are described in order of increasing depth rather than the chronological order of sampling.

In shallow water (48 and 58 m) above the oxygen minimum zone (Stations 12688#1 and 12689#1) a megafauna containing ophiuroids, ascidians, sponges, bryozoans, pennatulids and a limited number of bivalves occured. The diversity was partly determined by the sandy/shell substratum at this depth and the occurrence of large pieces of rock in the samples.

With increasing depth, and penetration of the upper part of the oxygen minimum zone the Agassiz trawl at 150 m (Station 12731#1) collected a large number of swimming crabs as well as some gastropods, bivalves and some juveniles of the spider crab found at greater depths (see below). A number of fish were also taken.

At 400 m in the centre of the oxygen minimum zone megafauna was more common than had been expected. At Station 12697#1 the fauna was dominated by the bivalve *Amygdalum* (?) *politum*
which inhabits a small nest composed of byssus threads. Also present were at least four species of gastropod, ascidians, a number of spider crabs and a few polychaetes.

At 570 m (Station 12733#1) the IOS epibenthic sledge being used in camera mode trapped over 140 small and medium sized spider crabs in the protective mesh framework.

This spider crab dominated in the Agassiz trawl and WHOI epibenthic sledge taken at ~700 m (Stations 12696#1 and 12707#1). over 1400 spider crabs were recovered and size measurement and sexing revealed a predominance of males. In the Agassiz trawl at this depth 2 individuals of *Amygdalum* were found and in the epibenthic sledge two sipunculids were taken.

At 850 to 900 m (Station 12714#1) the trawl appeared to start on sediment but the tension trace suggested it finished on rocks. The fauna was dominated by a wide variety of fish, bivalve, gastropod, crustacean, ophiuroid and cnidarian species. This rich fauna suggests the area sampled was just in, or more likely, below the oxygen minimum zone.

The next deeper station (12702#1) was an Agassiz trawl from 933 to 1100 m depth. This sample was dominated by an (as yet) unidentified ophiacanthid (17 kg in total weight), *Munidopsis* sp., a red shrimp, *Maia* sp. and dromid crabs, a variety of anemones and pennatulids, fish and numerous individuals of a number of species of mollusc dominated by *Xylophaga* sp., *Natica* sp. and turrids. A box core (Station 12722#3) at 975 m sampled 16 living specimens of the large bivalve *Lucina* sp. plus numerous dead shells. The nature of this bivalve suggests it contains chemosynthetic symbionts.

At the 1200 m sampling station (12709#2) a small sample was taken by the Agassiz trawl containing the holothurians *Ypsilothuria* sp. and *Molpadia* sp. and a small number of crustacea and the bivalve *Propeamussium watsoni.*

Because of the steepness of the slope it was not possible to sample between 1300 m and 3000 m. Although subsequent sampling with the muticorer and box corer suggested sediment cover, echo sounding did not reveal an area large or flat enough to deploy the Agassiz trawl.

At ~3100 m an Agassiz trawl (Station 12719#1) collected a very rich bivalve fauna dominated by protobranchs and *Limopsis tenella*. In addition there was a rich gastropod fauna including a number of aplacophorans. Echinoderms were also well represented particularly the ophiuroid *ophiomastus* sp..

At station Al at 3370 m an Agassiz trawl, IOS epibenthic sledge and a WHOI epibenthic sledge were deployed. The net of the IOS sledge (Station 12687#6) ripped and only a small sample containing the bivalve *Limopsis tenella*, a large *Thyrasira* and some small *Nucula* was retained. The WHOI sledge (Station 12730#2) also collected only a small sample dominated by *Limopsis tenella*. The Agassiz trawl (Station 12687#2) produced a rich fauna typical of the deep sea with a wide variety of echinoderms, molluscs, crustacea, sponges and fish.

Tyler, P.A. and C.M. Young

REPRODUCTIVE STUDIES

A wide variety of samples of megabenthos were taken for gametogenic examination. From the echinoderms sufficient samples of *Ophiacantha* sp., *Ophiomastus* sp., *Ophiura irrorata* and *Ypsilothuria* sp. were collected to allow determination of age at first reproduction, reproductive effort and gametogenic pattern. The same parameters can be determined on the bivalves *Limopsis* sp., *Lucina* sp., *Bentharca* sp. and *Amygdalum* sp. as well as four species of protobranch from the deepest station. From the crustacea it will be possible to use sufficient numbers of *Polycheles* sp., *Munidopsis* sp. and samples of the red shrimp, the large prawn and the spider crab from the oxygen minimum zone.

Debenham, N.J.

NEMATODE STUDIES

A total of twenty-five cores were taken from twenty-five deployments of the multiple corer. The cores were sectioned in 1cm horizons to depth of 5 cm, and then in 5 cm sections to a depth of 20 cm. The samples were then fixed in 5 % formalin and will be returned to IOS until collected by NHM. The nematodes will be extracted using a modified 'Ludox-™' flotation system and counted. The animals will then be mounted onto slides and stored until required for identification. In addition, one core from four replicated sampling stations was taken. The cores were sliced into 1 cm sections to a depth of 5 cm, and then in 5 cm sections to a depth of 15 cm. This material was placed into plastic sample bottles and frozen at -20 °C, and the nematodes will subsequently be used for biochemical analysis by Southampton University.

Gooday, A.

MULTIPLE CORER

The corer was deployed 44 times (in two cases with only ten core tubes) and returned a total of 496 usable cores out of a maximum possible of 524 (Table 2), a success rate of 96.5%. The lengths of cores ranged from <175 mm in sandy sediments at shallow stations (12693, 12694, 12708) to more than 400 mm in the soft muds which occurred in the centre of the oxygen minimum zone (Station 12692). Substantial problems were encountered on only two occasions. At Station 12671#3 the presence of a sandy layer (possibly a turbidite) below about 150 mm resulted in the partial washing out and disturbance of almost half the cores. At Station 12729#1 the corer returned only a few, short disturbed cores, probably because it landed on a slope which may have caused it to drag across the seabed. In addition, at Station 12718#3 three tubes failed to retain cores when their rings became loose and slipped.

The cores were used for a wide variety of purposes (Table 3) including biological (nematodes and other metazoan meiofauna, foraminifera, macrofauna) and chemical (organic chemistry, pigments, geochemistry, pore water chemistry and C:N determinations) studies. In addition, several complete sets of cores were used for special purposes, namely an evaluation of macrofaunal abundance (12700#2), a study of cirratulid mudballs (12715#2), an incubation experiment (12720#1), and sediment eH determinations.

BENTHIC FORAMINIFERA

Samples: An extensive suite of samples was taken in order to document foraminiferal (and xenophyophore) assemblages across the Oman margin. At each of the main stations (94-108 m, 350-410 m, 658-693 m, 822-857 m, 972-990 m, 1252-1296 m, 3372-3392 m depth) four multiple cores (25.5 cm^2 cross-sectional area) were taken from separate deployments and sliced into the following horizontal layers: 0-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, 8-9, 9-10, 10-15, 15-20 cm. Each slice will be sieved on a series of screens down to 63 microns. Four other cores, also from separate deployments, were subcored using a cut-off 20 ml syringe (3.45 cm^2 cross-sectional area). The syringes were placed in a freezer until the sediment was solid enough to be extruded and the subcores then sliced into the following horizontal layers: 0-1, 1-2, 2-3, 3-4, 4-5 cm. These were sieved down to 31 or 15 microns in order to document tiny micro- and nanoforaminifera. At each main station, the 0-1 cm and 2-3 cm layers from one additional core were fixed in 3% glutaraldehyde (0.1M Na cacodylate buffer) for transmission electron microscopy.

In order to fill gaps in the bathymetric coverage, complete cores and syringe subcores were also taken for foraminiferal studies at a series of single-deployment stations (184 m, 540 m, 742 m, 830 m, 900 m 1617 m) and a single subsample was taken, using a multiple-corer tube, from a box core obtained at 2248 m (Station 12729 series 2). In addition, opportunistic observations were made of large foraminifera on the surfaces of box core samples.

Table 2: Multiple corer deployments

Station	Series	Depth	Cores obtained	Core length (mm)
12671	3	3392	7	230-355
12682	3	742	12	125-220
12682	5	662	12	220-355
12685	2	685	12	200-280
12685	7	658	12	230-340
12685	9	693	12	200-325
12686	1	830	12	240-340
12687	3	3382	12	135-305
12687	5	3361	12	220-350
12687	8	3372	12	275-315
12687	10	3385	12	310-330
12690	1	377	12	325-355
12692	1	372	12	300-420
12693	1	184	11	90-170
12694	1	108	11	85-145
12695	2	382	12	325-345
12695	5	390	12	360-390
12695	8	391	10	240-260
12698	2	350	10	330-360
12698	3	410	10	350-380
12699	1	540	12	280-335
12700	2	368	12	145-180
12704	1	680	12	315-500
12705	1	900	12	225-340
12706	1	990	12	235-270
12708	3	945	10	70-145
12708	5	96	12	125-175
12708	7	94	12	110-150
12711	3	833	12	210-320
12713	2	822	12	220-325
12713	3	827	12	240-325
12715	2	857	11	210-320
12718	1	983	12	215-260
12718	3	981	9	230-245
12720	1	406	12	ND
12722	2	972	11	235-260
12723	3	1268	11	190-230
12723	5	1252	12	215-245
12725	1	1296	12	250-255
12725	3	1254	12	180-260
12725	5	1255	12	195-235
12728	1	1617	12	135-220
12729	1	1778	6	<120
12732	1	392	12	ND

Observations: During the cruise, a cursory examination was made of foraminiferal species occurring at the main stations. Most of these observations are based on >300 micron residues of core samples, some concern large species visible on core surfaces, a few are derived from net samples.

(i) 59 m (dredge sample): Large, bush-like astrorhiziids common.

(ii) 108 m: Coarse shelly sand with patches of brown phytodetritus on surface. Large epifaunal foraminifera absent. Foraminifera extremely abundant and diverse in >300 micron fraction with *Uvigerina* dominant. Other foraminifera present include typical shelf taxa (*Elphidium, Ammonia*), nodosariids and a tiny white *Bathysiphon.*

(iii) 184 m: Similar to 108 m sample but with small bolivinids common and *Globobulimina* (with red protoplasm) present for first time.

(iv) 350-391 m: Large epifaunal foraminifera absent. Foraminifera much less abundant and less diverse than at shallower depths; *Globobulimina* predominant (red protoplasm), *Lenticulina iota*, *Saracenaria* sp. and tiny white *Bathysiphon* also present but *Uvigerina* rare. *Cribrostomoides* and small allogromiids occur occasionally.

(v) 658-693 m: Large epifaunal foraminifera absent. *Lenticularia iota* very common, *Globobulimina* (greenish-brown protoplasm) and *Uvigerina* both common, *Hoeglundina elegans* fairly common, occasional tiny *Bathysiphon*, *Cribrostomoides*, *Ehrenbergina trigona* and small allogromiids.

(vi) 746 m: Large agglutinated foraminifera (*Pelosina* sp., bush-like astrorhiziids) present on surface of a box core.

(vii) 822-857 m: *Pelosina* present but less common than at 746 m; *Globobulimina* and *Lenticularia* abundant, *Uvigerina* also present.

(viii) 972-990 m: Large epifaunal foraminifera absent. Sparse, mostly dead but fairly diverse assemblage dominated by *Hyalinea balthica*; *Globobulimina* and *Uvigerina* both present but rare.

(ix) 1252-1296 m: Numerous large epifaunal gromiids in trawls and cores. Smaller foraminifera abundant and quite diverse; dominant species *Hyalinea balthica*, *Bulimina* sp. and several clearly trochospiral calcareous species also present, *Globobulimina* rare.

(x) 1617 m: Abundant large gromiids and fairly common large, flat *Julienella*-like agglutinated species.

(xi) 1778 m (remnants of cores from failed multicorer deployment): Diverse assemblage including *Julienella*-like species, white, sphaerical psammosphaerid, *Discospirina italica*, and xenophyophore fragments.

(xii) 3372-3392 m: Abundant, diverse assemblage dominated by *Rhabdammina* spp. with *Bathysiphon* spp. and *Hyperammina crassatina* also abundant; Komokiaceans and small psamminid xenophyophores fairly common; *Globobulimina* present but rare. Trawl residues consist almost exclusively of large agglutinated foraminifera.

These preliminary observations indicate that foraminiferal assemblages clearly change across the OMZ. For example, *Globobulimina* sp. is common in the centre of the zone while *Uvigerina* spp. is common above and below the centre, possibly reflecting an edge effect; *Pelosina* is also prominent in the lower part of the OMZ. Large gromiids and large agglutinated foraminifera (*Julianella*-like species) are common where bottom water oxygen concentrations begin to return to more normal values between 1250 m and 1600 m. The 3400 m station, situated well below the OMZ, is characterised by a typical bathyal assemblages consisting of large agglutinated foraminifera. These taxa appear well adapted to utilizing the inputs of phyodetritus which are an obvious feature of core surfaces at this station.

Gromiids. A variety of large gromiids (or allogromiids) was present in trawl, box core and multicore samples taken between 1211 m and 1617 m. These protists are characterised by a transparent, single chambered, organic test containing numerous stercomata (waste pellets). Several distinct taxa were recognised. The most common forms had either an elongate or rounded, sack-like test with a single aperture directed downwards into the sediment. Another species, which was less common in the core samples, had a large (up to 3 cm diameter) spherical test dotted with numerous small apertures (Fig. 7). Undisturbed specimens were weakly anchored to the sediment by a mass of detritus-like sediment. These bizarre organisms probably represent a new family of gromiids or allogromiids and deserve detailed study.

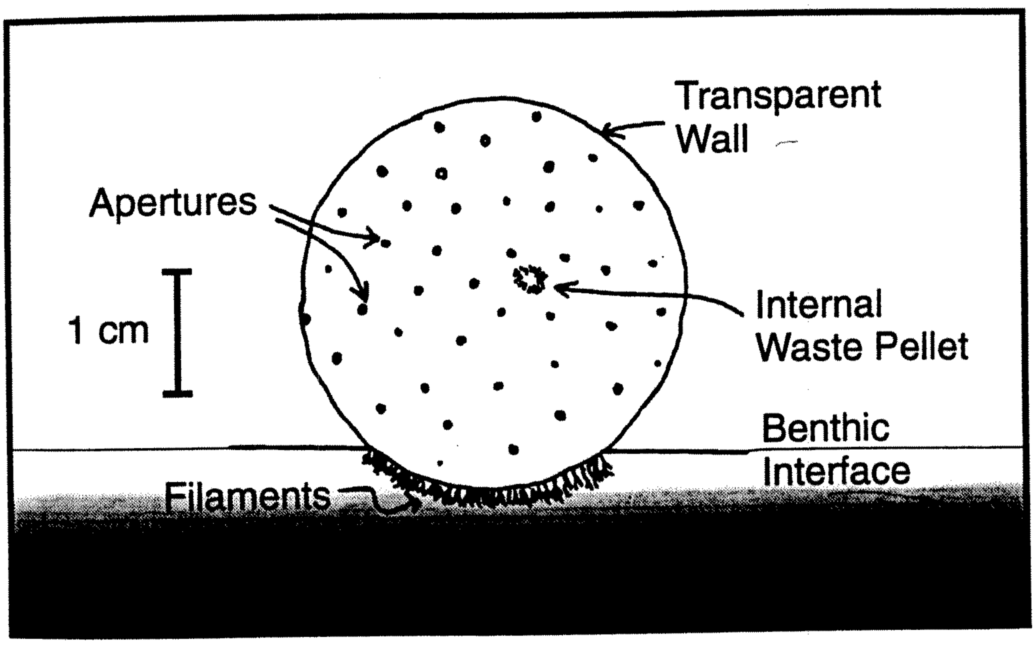

Figure 7. The giant "Jellyball" allogromiid which occurs between 1250 m and 1500 m on the Oman margin.

Levin, L., Crooks, J. and D. Hoover

MACROFAUNAL STUDIES

Samples were collected primarily by 0.25 m^2 boxcore. Five boxcores were collected from each of 8 stations, located roughly at 100 m, 350-420 m, 610-750 m, 820-875 m, 960-990 m, 1250-1310 m, and 3370-3392 m (Table 4). Single boxcores were taken at 1617 m and 2248 m. From each boxcore our group processed 5 vegematic subcores (90.25 cm^2 each) to a depth of 20 cm. Most vegematics were sectioned at the following intervals: 0-1 cm, 1-2 cm, 2-5 cm, 5-10 cm, and 10-20 cm, to examine vertical distribution of infauna. Material from the top 2 cm was preserved unsieved. The remainder was sieved through a 300 micron screen, usually prior to preservation. Several multicore samples were processed as described above from 121 m, 196 m, 365 m, 380 m, 422 m, 551 m, 752 m, and 910 m. Often these were grouped in batches of three.

Planned macrofaunal analyses for specimens >300 microns include documentation of species composition, densities, vertical distributions, animal lifestyles and feeding modes, and possibly biomass and body size distributions.

Cursory observation of a very small number of macrofaunal cores reveals the following patterns.

50-100 m This is a shelly sand site with a high diversity of molluscs, polychaetes, and crustaceans. Dominant forms include cumaceans, bivalves, and spionid and nephtyid polychaetes.

100-200 m. Shelly sand, but finer than above. The macrofauna remain diverse and relatively abundant. Gastropods are abundant as are polychaetes (spionids, lumbrinerids, ampharetids, polynoids, nephtyids).

340-420 m. This site has soupy, organic -rich mud. The fauna is the least diverse of any observed, but with relatively high biomass (mean = 11.6 +/- 4.5 g/m^2) and abundance (14,000 +/- 1,450 individuals/m2). Two polychaete species comprise over 90% of the individuals present, a spionid (*Minuspio* sp.) and a cirratulid (*Aphelachaeta* sp.). Also present are several other polychaetes, nemerteans, shrimp (Natantia) and the mussel, *Amygdalum* sp. The mussel forms a mud cocoon or nest that contains at least 5 polychaete species, 4 of which may not be present in surrounding sediments. A form of sheathed, filamentous bacteria, probably Thioploca, is exceedingly common.

540-600 m Sediments remain soupy and organic rich. The fauna is dominated by a low diversity assemblage of tube-dwelling, surface feeding polychaetes. Two spionids and a cirratulid accounted for 98% of animals observed. A single multicore yielded 51 relatively large polychaetes (4 species), corresponding to a density of > 20,000/m^2.

650-750 m Sediments are slightly firmer with many tube builders present. The system appears to exhibit high densities and low diversity. Dominant are spionid polychaetes and ampeliscid amphipods. Spider crabs appear in the box cores.

820-900 m. Sediments are firmer, but remain organic rich. The primary feature of this site is extensive biogenic sediment structure in the form of cone-shaped mudballs 1 to 2 cm long (2,000 to 3,000 per sq. m). These mudballs are made by a cirratulid polychaete that lives inside *Montecellina* sp.). They extend through the top 10 cm of sediment, but only a few mudballs are occupied below 2 cm. A spionid *(Laubieriellus* sp.), ampharetid polychaetes (possibly *Anabothrus* spp.), paraonid polychaetes (*Allia* sp.), and ampeliscid amphipods are common. Many arborescent foraminifer are also present, sometimes attached to the mudballs. We see higher polychaete diversity and small burrowing shrimp. Also present are lucinid and vesicomyid bivalve.

975-1000 m. Sediments are firmer and notably sandier with *Globigerina* tests present. Diversity continues to rise while densities drop. Ophiuroids are abundant at the sediment surface. Polychaetes include paraonids, sabellarids and maldanids that construct reef-like structures, ampharetids, lumbrinerids, cirratulids, as well as pogonophorans and amphipods. Several cores from this site included abundant Lucina, a bivalve that appears to be symbiont bearing (G. Oliver, person. comm.).

1200-1300 m. Sediments are quite sandy. We see lower densities, higher diversity assemblages that include polychaetes, aplacophorans, pogonophorans, and ophiuroids, but no bivalves or crustaceans. Large spherical protozoans (jelly balls) and sausage-shaped gromids were prevalent in most cores.

3370-3400 m Sediments were fine mud with a distinct phytodetrital 'fluff' layer. This layer was nearly gone on a single core taken 3 weeks later than the first 4, but colour differences remained between the top cm and deeper sediments. This site appears to have a typical deep sea fauna dominated by forams and some xenos (recovered only as fragments so far), with a rich bivalve fauna. Also present are tanaids and aplacophorans as well as *Hyalinoecia* and pectinariid polychaetes.

It is premature to try to relate oxygen levels to fauna pattern, but we anticipate inverse relationships between oxygen level and macrofaunal biomass, and positive relationship between oxygen level and diversity.

PIGMENT and Pb-210 ANALYSES

Samples were collected from multicores for laboratory analysis of chlorophyll a and possibly other plant pigments, and for gamma counting of Pb-210. Our objective is to use Pb-210 and pigments deposited during the most recent monsoon period as a tracer for bioturbation studies. Accordingly, sediments were sampled from different vertical fractions within the core to generate pigment and Pb profiles (Table 5). These will be modeled to estimate depth of mixing and mixing coefficients.

Pigment samples were taken from the following intervals: 0-0.5 cm, 0.5 cm-1.0 cm, 1.0-1.5 cm, 1.5-2.0 cm, 2-3 cm, 3-4 cm, 4-5 cm, 6-7 cm, 8-9 cm, 10-11 cm, 15-16 cm, 20-21 cm. From each of these intervals 2 or 3 2ml samples were removed and frozen at -40°C. These will be analysed at Scripps, probably by HPLC.

Pb-210 samples were collected at 1 cm vertical intervals for the full length of the core. Five intervals from each sample will be selected and analyzed on a gamma counter by Craig Smith at the University of Hawaii.

Approximately 3 multicores from each of the 8 depth stations listed above (see Macrofauna Section) were processed for pigment analyses. Six multicores per depth station (2 multicores combined into a single sample for each of 3 replicate drops) were processed for Pb-210 analyses.

X-RADIOGRAPHS

X-radiographs were made of 1 to 2 sediment slabs (each slab 2.5 cm thick by 10 cm wide, length varies with core penetration, typically 10 - 15 cm) per boxcore, from 3 - 4 box cores at approximately each of the 8 depth stations cited in the macrofaunal discussion. Rectangular plexiglass subcores (dimensions as above) were fixed next to vegematics in each boxcore, or inserted after the core was returned to the ship. X-radiographs were taken immediately and developed shortly thereafter.

Coarse sand cores from ~100 m show little evidence of bioturbation, although occasional ~5 mm diameter burrows penetrate to at least 4 cm, and laminations visible at ~4 - 8 cm show evidence of cross-cutting features, implying bioturbation activity not recorded in the sandy matrix.

Cores from deeper stations contain finer sands, muds and clays, and typically show moderate density increases from the surface downward (except where the trend is interrupted by the appearance of dense clay fragments or layers, presumably the residue of turbidity flows). Bioturbation is visible at these stations to varying degrees as mottling and discrete structures: from 350 to 630 m the sediment fabric consists of blurred background mottling and very fine structures, mostly in the upper few cm, with samples from ~400 m exhibiting almost no evidence of bioturbation. At around 700 m numerous 1 - 2 mm diameter tubes and burrows appear, continuing through a depth of about 850 m, with the 1000 m station showing a change to denser sediment at the sediment-water interface, more rapid consolidation of sediment with depth, and a sediment fabric dominated by a blurred background of fine scale structure, occasional large (~4 mm diameter, to 4 cm depth), convolute maldanid tubes, and possibly large (1.5 - 2 cm), relict horizontal burrows at 6 - 12 cm. By 1200 - 1300 m, extensive networks of vertical tubes reappear and surface sediment appears soupier than at 1000 m. Single radiographs from 1626 and 2248 m show changes from shallower stations but should be interpreted cautiously due to lack of replication: at 1626 m the general fabric is similar to the 1200 - 1300 m radiographs except that numerous 2 - 4 mm tubes are visible in the top 6 cm, occasionally to 12 cm, and there is no evidence of large bioturbation structures at depth. At 2248 m, changes are more dramatic: discrete structures are no longer visible and the sediment fabric is dominated by apparently randomly oriented wisps of high density material. At 3400 m, sediment fabric is dominated by fine, reticulate low density structure in the upper 6 cm with only light mottling below (except occasional large - ~1.5 cm - infilled burrow segments) and abundant 1 - 2 cm foraminiferal tests in the upper few cm.

While interpretation of x-radiographs is subjective, it would appear that stations within the oxygen minimum zone exhibit very little in the way of bioturbation structure, and that bioturbation increases dramatically around the lower boundary, persisting with only minor changes in mode and intensity to at least 1600 m, followed by a general decrease in the scale of mixing. The potentially anomalous observations at the 1000 m station may be associated with the unusually level topography at that depth compared to the other stations sampled.

BOTTOM PHOTOGRAPHS

Bottom photographs were obtained with a single-shot camera mounted on the coring device and triggered by a bottom contact switch. Not all coring drops were rigged for photographs, but sufficient drops were made to provide between 3 and 9 photographs at each replicated station, as well as photographs of non-replicated stations where possible. The camera was rigged with the lens line-of-sight angled 30° off vertical toward the centre of the corer, producing an image of an approximately 1.1 m^2 area of the sea floor immediately beneath the coring head. Film was developed on board using Kodak Ektachrome E-6 kits.

Photographs show sediment surface features, including colour, roughness, and animal traces, as well as animals large enough to be resolved by the film (roughly > 1 cm).

~100 m (6 photos)
Light tan sand covered by patchy layer of darker greenish-brown material (presumably phytodetritus). No identifiable megafauna in photos.

~400 m (4 photos)
Slightly rough, chocolate-brown sediments with scattered bright white points of unknown origin. Occasional light brown patches suggesting deposition of lighter underlying sediments at surface. No identifiable megafauna.

~700 m (3 photos)
Relatively smooth brown sediments, colour slightly lighter/greener than at 400 m. Bright spots similar to 400 m but less abundant. Abundant dark spots (barely visible in photos) may be amphipod tubes which were extremely abundant at this station. No pronounced animal traces or animals visible.

~850 m (6 photos)
Rough sediment surface ("mudballs"), predominantly dark brown with faint lighter mottling and occasional smooth dark circular patches, ~10 - 20 cm diameter. Occasional small red shrimp on surface (~4/m^2).

902 m (1 photo)
Relatively smooth sediments, colour similar to 850 m, faint lighter mottling. First appearance of

megafauna: 9 ophiuroids, a small squat lobster, 7 shrimp cf 850 m, and 13 stalked pennatulids (cf *Umbellula*?)

~1000 m (5 photos)
Sediment colour/texture as at 902 m. Extremely abundant ophiuroids (about 30 - 60/m^2) and shrimp as at 850 m but less abundant (~1/m^2).

1244 - 1310 m (6 photos)
Sediment surface darker than previous entries, abundant lighter mottling in many forms, from abundant small patches to large contiguous areas and discrete circular structures to 20 cm diameter. Very abundant small dark elongate objects, presumably gromiids, occasional small to moderate diameter (< ~2 cm) objects, presumably "jelly balls"

~1620 m (2 photos)
Sediments as above but mottling is small-scale, reticulate only. Light areas associated with very abundant large (~ 2 - 4 cm) blue-grey spheres ("jelly balls"), ~ 20 - 40/m^2. Also visible are abundant small elongate gromiids and occasional ~ 3 cm orange discs (corals per box core results), ~ 4/m^2.

2248 m (1 photo)
Sediments smooth, lighter brown with abundant mottling of distinct to diffuse circular light areas. Six 2 - 4 cm diameter dark spiky subspherical objects (urchins? corals?).

3400 m (8 photos)
Slightly rough-looking darker brown sediments with only occasional small lighter patches. Single crabs in 2 photos, one photo with two large (~ 30 cm diameter) asteroid sitzmark.

These observations have been combined with those by other cruise participants to produce a preliminary summary table (table 6) of sediment composition and structure.

In summary, photos of areas within the oxygen minimum zone show sediments with little evidence of large-scale reworking and no megafauna. Shrimp and visible evidence of infauna ("mudballs") become apparent at ~800 m, followed by abundant megafauna (ophiuroids, pennatulids) in the 900 - 1000 m range. At 1200 - 1600 m, extensive mottling indicates infaunal reworking and fauna is dominated by gromiids and large "jelly ball" foraminifera. By 2250 m, reworking is still evident but forams are no longer visible although 5 unidentified organisms are present, and at 3400 m, there is only minor evidence of sediment reworking and fauna is limited to occasional crabs.

Table 4: Sample Log, (IACB = Vegematics inserted after core is aboard)

Depth	Date	Station #.	Lat. Long.	Sample type	Comments
104	26 Oct.	12708/8	19°22.38 N 58°11.5 E	SBC Veg. 1,3,5,7,9	IACB
105	27 Oct.	12710/1	19°22.14 N 58°11.40 E	SBC 2,4,6,8, 10	IACB; to 13 cm
108	26 Oct.	12708/6	19°22.34 N 58°11.49 E	SBC Veg. 2,4,6,8,10	IACB
121	22 Oct.	12694/1	19°22.19 N 58°12.60 E	MC No. 1,2,4,5	0-2, 2-END
196	22 Oct.	12693/1	19°22.05 N 58°14.2 E	MC No. 8,9,10,11	0-2,2-end
353	24 Oct.	12698/5	19°21.60 N 58°1545 E	SBC Veg. 6,7,8,9,10	rocky; 0-5, 5-20 cm
364	24 Oct.	12698/2	19°21.5 N 58°15.35'E	MC No. 1,2,5 (I);	
				MC No. 6,7,8 (II);	
				MC No. 9,10, 11 (III)	
380	24 Oct.	12700/2	19°21.88 N 58°15.37 N	MC No. 10,11,12 (IV)	No. 1-9 to Gage
391	24 Oct.	12698/1	19°21.78 N 58°15.49 E	SBC Veg. 2,4,6,8,10	veg 6 some spilled in 0-2
394	21 Oct.	12690/3	19°22.00 N 58°15.46 E	SBC Veg. 1,3,5,7,9	bottles labeled as 12689/2
406	23 Oct.	12695/4	19°21.92 N 58°15.49 E	SBC Veg. 2,4,6,8,10	
413	23 Oct.	12695/7	19°21.03 N 58°15.42 E	SBC Veg. 1,3,5,7,9	IACB
422	24 Oct.	12698/3	19°21.88 N 58°15.68 E	MC No. 1,3,4 (I);	
				MC No. 7,8,9 (II)	
551	24 Oct.	12699/1	19°21.74 N 58°16.65 E	MC No. 1,4,7 (I);	
				MC No. 8,9,10 (II)	live counts; MC No II
610	14 Oct.	12685/3	19°18.99 N 58°15.47 E	SBC Veg. 1,3,6,7	9 label is 7
653	14 Oct.	12685/1	19°18.95 N 58°15.53 E	SBC Veg.2,4,6,8,10	
688	15 Oct.	12685/6	19°18.88 N 58°15.46 E	SBC Veg. 2,4,6,8,10	
690*	15 Oct.	12685/8	19°18.66 N 58°15.64 E	SBC Veg 1,3,5,7,9	veg 7 1-2cm, veg 9 1-2cm
742	13 Oct.	12682/3	19°18.7 N 58°15.74 E	MC No. 6	preserved unsieved
746	15 Oct.	12685/10	19°18.72 N 58°15.79 E	SBC Veg. 2,4,6,8,10	to 17 cm
822	27 Oct.	12711/3	19°16.10 N 58°22.86 E	MC No. ?	mudball study
840	27 Oct.	12711/2	19°14.21 N 58°23.11 E	SBC Veg. 1,3,5,7,9	mudballs
850	28 Oct.	12713/1	19°14.35'N 58°23.16 E	SBC Veg. 2,4,6,8,10	0-2 cm....
851	28 Oct.	12713/4	19°14.16 N 58°23.13 E	SBC Veg. 1,3,5,7,9	mudballs
854	28 Oct.	12713/5	19°14.14 N 58°23.01 E	SBC Veg. 2,4,6,8, 10	mudballs (IACB)
874	29 Oct.	12715/1	19°13.60 N 58°22.97 E	SBC Veg. 1,3,5,7,9	0-2 cm ...
910	25 Oct.	12705/1	19°16.71 N 58°25.63 E	MC No.5, 7,9,11	0-5,5-20 cm
963	2 Nov.	12722/4	19°16.28 N 58°29.25 E	SBC Veg. 1,3,5,7,9	
975	31 Oct.	12718/4	19°16.87 N 58°29.81 E	SBC Veg. 2,4,6,8, 10	
975	2 Nov.	12722/3	19°16.24 N 58°29.48 E		*Lucina*; Gage kept wash's
980	31 Oct.	12718/2	19°16.62 N 58°29.77 E	SBC Veg. 1,3,5,7,9	
984	29 Oct.	12716/2	19°17.05 N 48°30.08 E	SBC Veg. 2,4,6,8, 10	to 18 cm
992	2 Nov.	12722/1	19°16.09 N 58°29.68 E	SBC Veg. 1,3,5,7,9	
1243	7 Nov.	12725/6	19°14.30 N 58°31.32 E	SBC Veg. 1,3,5,7,9	sandy
1265	7 Nov.	12725/2	19°14.03 N 58° 31.29 E	SBC Veg. 1,3,5,7,9	frame furrow
1279	3 Nov.	12723/4	19°14.25 N 58°31.44 E	SBC Veg 2,4,6,8,10	
1285	3 Nov.	12723/2	19°14.02 N 58°31.42 E	SBC Veg. 1,3,5,7,9	sand
1309	7 Nov.	12725/4	19°13.91 N 58°31.63 E	SBC Veg. 2,4,6,8,10	
1626	8 Nov.	12728/1	19°13.38 N 58°32.87 E	SBC Veg. 2,4,6,8,10	jellyball
2248	8 Nov.	12729/2	19°14.30 N 58°34.90 E	SBC Veg. 1,3,5,7,9	muddy
3370	8 Nov.	12730/1	19°20.72 N 58°59.41 E	SBC Veg. 1,3,5,7,9	
3392	11 Oct.	12671/4	19°20 N 59° 0.17 E	SBC Veg 1,3,5,9	phytodet; some sorted
3392	20 Oct.	12687/9	18°59.77 N 59°0.49 E	SBC Veg 1,3,5,7,9	overfilled
3394	19 Oct.	12687/4	18°59.84 N 59°0.96 E	SBC Veg. 2,4,6,8,10	phytodet; V6 0-1somelost
3396	18 Oct.	12687/1	18°59.5 N 59° 0.76 E	SBC Veg. 1,3,5,7,9	

Table 5: Pigment Core Log (from Multicores), 2 or 3 2 ml samples taken per vertical fraction at the following intervals: 0-0.5, 0.5-1, 1-1.5, 1.5-2,2-3,3-4,4-5,6-7,8-9,10-11, 15-16, 20-21.

* frozen 12-24 hr after sectioning

DEPTH	DATE	STATION	SAMPLE NO	BOX	VIAL
94	26 Oct.	12708/7	MC No.8	6	16-45
95	26 Oct.	12708/3	MC No. 10	4	37-39
95	26 Oct.	12708/5	MC No. 7	4	67-81
5	1-15				
372	22 Oct.	12692/1	Mc No.4	3	73-75 surface?
390	23 Oct.	12695/5	MCNo. ?	4	1-36
658	15 Oct.	12685/7	MC No. 6	2	27-50
662	13 Oct.	12682/5	MC No.8	1	68-77
2	1-26				
742	13 Oct.	12682/3	MC NO.8	1	35-67
822	28 Oct.	12713/2	MC No. 4	5	70-81
6	1-12				
827	28 Oct.	12713/3	MC No. 1	6	13-36
833	27 Oct.	12711/3	MC No.3	5	46-69
972	2 Nov.	12722/2	MC No. 11	frozen as patties	
981	31 Oct.	12718/3	MC No. 8	6	61-81
7	2,3				
983	31 Oct.	12718/1	MC NO. 5	6	37-60
1252	3 Nov.	12723/5	MC No. 6	frozen as patties	
1296	7 Nov.	12725/1	MC No. 10	7	4-22
bottom frozen as patties					
12??	7 Nov.	12725/5	MC No. 5	frozen as patties	
3376	20 Oct.	12687/8	MC No. 9	3	1-36
"		12687/8	"2	72 Phytodet.	
3380	19 Oct.	*12687/3	MC No. 2	2	51-78*
3385	*21 Oct.	12690/1	MC No. 10	3	37-72
3392	11 Oct.	12671/3	MC No.8	1	1-32
"Phytodetritus 1		33,78-81			

Table 6: summary of sediment composition and structure at varying depths and oxy concentrations.

DEPTH (m)	O_2 (ml/l)	SUBSTRATE	FORAMINIFERA (multicore, boxcore)	METAZOAN MACROFAUNA (boxcore, multicore)	MEGAFAUNA (trawl, sledge, photo)	BIOTURBATION (x-radiograph)
0-100	0.461	Shelly sand	Bush-like astrorhiziids in 47m trawl	Diverse: cumaceans, bivalves, polychaetes (spionids, nephtyids)	Rich bivalves (*Tellina, Corbula*) ophiuroids dominant, echinoids (*Proucidaris*)	Occasional burrows+ shell visible. Homogeneous downcore w/laminations at > 4 cm depth, some crosscutting structures and minor diffuse mottling
100-200		Shelly, fine sand	High diversity assemblage dominated by *Uvigerina* (likes abundant OM) Mix of shelf (Ammonia, Elphidium) and deeper taxa also present(Globobulimina at 200m)	Diverse: gastropods abundant, bivalves, polychaetes (spionid, lumbrinerid, ampharetid, polynoid, nephtyids)	Swimming crabs, bivalves (vesicomyid), gastropods, scaleworms, juv. spider crabs	
340-400	0.315	Fine, soupy mud	Low diversity assemblage dominated by *Globobulimina* (low O2 tolerant), *Uvigerina* rare, No large surface taxa	High density, low diversity assemblage 2 spp. spionid dominate + mussels (*Amygdalum*) with other polychaetes in cocoons. Sheathed bacteria common.	Rich bivalves (*Amygdalum*), ascidians (*Styela*) dominant + other bivalves, crustaceans	clay aggregates, little structure, mottling to 12 cm, boundary at 2 cm
540-600		Fine, soupy mud		Tube-dwelling, surface-feeding assemblage. Low diversity, high density; 2 spionids dominant + cirratulid, cossurid (> 20,000/m2)	Spider crabs	minor mottling < 10 c vertical burrows < 2 c
650-700	0.268	Fine, soupy mud	*Globobulimina* again common, *Uvigerina* more common than at 340-400m No large surface taxa	Tube-building assemblage high density, moderately low diversity spionids & ampeliscid amphipods	Spider crabs dominant, little else	horizontal & vert.tube & burrows < 5cm consolidated clay
700-750	0.414		First appearance of lg. arborescent forams (*Pelosina*). Also, bush-like astrorhizids similar to 47 m species	Tube-builder assemblage high density, moderately low diversity	No sample	Extensive vertical tubes & burrows< 3cm
820-900	0.221	Firmer mud	*Pelosina* less common, astrorhiziids absent *Globobulimina* still common in > 300 micron	Cirratulid mudball dominated, with amphipods, ampharetid polychaetes thalassinid shrimp, Higher diveristy	Rich fish fauna, varied molluscs crustacean, & cnidarian fauna *Umbellela*, ophiuroids at 902 m	Mudballs to 1.5 c extensive small-scalebioturbation >12 cm
975-1000	0.593	Sandy mud	No large surface taxa, forams sparce modly dead but diverse, very flat trochospiral species makes first appearance, Globos rare *Uvigerina* present	Ophiuroid-polychaete dominated Higher diversity, reduced density (paraonids, maldanids, ampharetids, lumbrinerids, sabellarids, cirratulids) *Lucina* beds	Rich ophiuroidea (Ophiocamthidae) > *Munidopsis* > shrimp dominant various bivalves, crustacea, fish	Well mixed + horiz.burrows to 10 cm, Lg. maldanid tubes
1200-1400	0.966	Globigerina sand	Abundant large gromiids (jelly balls+sausages) Smaller forams fairly abundant, diverse, dominant spp. flat trochospiral, *Globobulimina* rare	Low density, polychaetes, pogonophorans gastropod, nematodes, *Stephanocycthus*	Poor: Ophiuroidea (Ophiacanthidae> > shrimp dominant	moderate mix vert. tubes,burrows to 8 cm, more exten.vert.burrows to 4 cm
1600		Muddy sand	Jellyballs	Solitary corals, onphids		
2250				Asteroids, corals		
3370-3400	1.388	Phytodetrital layer over fine mud	Abundant, diverse assemblange dominated by *Rhabdammina* spp. with *Bathysiphon* spp.*Hyperammina* also abundant, Komoki and xenos occur. Globulimina present. Trawl residues almost entirely agglutinating forams	Low density, high diversity: bivalves, aplacophorans, tanaids, cirratulid maldanid & pectinarid polychaetes lg. nemertean	Rich: Bivalves (Limopsis.) *Tenella* + other bivalves, Asteroidea, Crustacea	Moderate mottling to 10 cm, horiz. + vert. struc. throughout

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BIOTURBATION, SEDIMENT GEOCHEMISTRY AND SEDIMENT GEOTECHNICS ACROSS THE OXYGEN MINIMUM ZONE ON THE OMAN CONTINENTAL SLOPE.

1 BACKGROUND

1.1 The research conducted on the cruise forms part of an on-going programme on deep sea environments initiated at Glasgow University in 1982. The aims are to study the role of benthic organisms in determining the geotechnical and geochemical properties of seabed sediments, particularly in relation to sediment fabric, slope stability and early diagenesis. Our ultimate objective is to establish a comparative inventory of the role of biological activity in these processes in the world's oceans.

1.2 R.R.S *Discovery* cruise 211 offered a unique opportunity to expand our knowledge of the sediment / benthos system by conducting comparative studies of the role of biological activity within and on either side of the oxygen minimum zone (OMZ).

2. METHODS

2.1 The research conducted during the cruise consisted of taking sub cores from spade box core samples at 17 stations spaced across the OMZ from a depth of 100 metres to 3500 metres. An additional two multi core stations were taken towards the end of the cruise, making a total of 19 stations in all. This is the largest number of stations that we have been able to work on any cruise to date, and reflects the excellent sea conditions throughout the cruise and the efficiency and versatility of the newly lengthened R.R.S *Discovery*.

Table 7. Stations sampled by spade box corer (SBC) and multi corer (MC). *Discovery* station numbers (DISC. ST.) and equivalent Biosedimentology station numbers (BIOS. ST.) are given.

GEAR	DISC. ST.	BIOS. ST.	Water Depth(m)	LAT. North	LONG. East	DATE
SBC	12671#4	1	3392	19° 0.29'	59° 0.20'	11.10.94
SBC	12682#7	2	630	19° 18.99'	58° 15.80'	14.10.94
SBC	12685#1	3	610	19° 18.97'	58° 15.54'	14.10.94
SBC	12684#6	4	688	19° 18.88'	58° 15.46'	15.10.94
SBC	12687#1	5	3396	18° 59.51'	59° 0.76'	18.10.94
SBC	12687#9	6	3394	18° 59.77'	59° 0.49'	20.10.94
SBC	12695#4	7	406	19° 21.92'	58° 15.49'	23.10.94
SBC	12698#1	8	391	19° 21.78'	58° 15.49'	24.10.94
SBC	12708#6	9	108	19° 22.34'	58° 11.49'	26.10.94
SBC	12710#1	10	105	19° 22.14'	58° 11.40'	27.10.94
SBC	12711#2	11	840	19° 14.21'	58° 23.11'	27.10.94
SBC	12713#4	12	854	19° 14.16'	58° 23.13'	28.10.94
SBC	12716#2	13	1008	19° 17.05'	58° 30.08'	29.10.94
SBC	12718#4	14	987	19° 16.87'	58° 29.81'	31.10.94
SBC	12722#1	15	992	19° 16.09'	58° 29.68'	2.11.94
SBC	12723#2	16	1285	19° 14.02'	58° 31.42'	3.11.94
SBC	12725#2	17	1265	19° 14.03'	58° 31.29'	7.11.94
MC	12725#3	18	1254	19° 14.14'	58° 13.30'	7.11.94
MC	12732#1	19	392	19° 13.51'	58° 14.39'	9.11.94

2.2 Vertical profiles of bioturbation (numbers, distribution and size of animal burrows), of redox conditions (Eh and pH), and of sediment strength (shear strength) were obtained from stations 1 to 17, together with archived cores and bulk samples for later laboratory analysis of geotechnical properties. Two new techniques were also tested successfully at these stations. The first involved the preservation of horizontal slices of sediment from the sub cores for later analysis of burrow shape and abundance. The second, developed jointly with Professor David Muir Wood of the Department of Civil Engineering at Glasgow University, consisted of the first sea trials of a new computerised load cell and probe for detecting micro scale changes in sediment strength in vertical profiles of successive 10 cm lengths of the sedimentary column. Both techniques worked successfully, and we are very positive about the outcome of these developments after they are integrated with the results from our methods perfected on previous cruises. Stations 18 and 19 were multi core stations at which a comparison was attempted between the oxygen tension in the water immediately above the sediment /water interface and the redox state of the sediment at and below the sediment surface.

Plankton samples were collected at stations 1 to 17 by vertical haul of a fine plankton net from 50 m to the surface and by bucket from the ship's side. These, together with samples from the surface of the sediments at the same stations, were preserved for future analysis by Dr M. Stirn, Department of Fisheries and Fisheries Science, Sultan Qaboos University, Muscat, Oman.

3. RESULTS

Our research strategy on the cruise was planned to answer the following questions. A short summary answer is given after each question.

3.1 Are the anoxic conditions in the overlying water within the OMZ reflected in lowered redox conditions within the sedimentary column?
Yes. Sediments within the OMZ had low redox states when compared with sediments outside the OMZ. This was noticed at the sediment surface, and also at deeper depths to 20 cm in some instances.

The results of the redox measurements are briefly summarised as follows (Table 8). Redox decreased into the sediment at all stations sampled, with the lowest values being recorded at water depths of 390 to 690 metres within the OMZ.

Table 8. Range of redox values (Eh) (mV) at the sediment surface, 10 cm and 20 cm for different water depths.

		Depth in sediment (cm)		
Station	**Water Depth (m)**	**0**	**10**	**20**
7, 8	390 - 410	310-330	200-270	50-150
2, 3, 4	610 - 690	320-330	200-270	70-100
11, 12	840 - 860	330-400	260-340	170-190
13, 14, 15	980 - 1010	300-390	260-320	170-240
16, 17	1260 - 1290	420-430	280-290	200-300
5, 6	3390 - 4000	410-430	170-350	250-300

3.2 Is it possible to directly relate the oxygen tension in the overlying water in the OMZ, with the redox conditions in the sediment column?
Yes. A direct comparison was done at stations 18 and 19. These stations were multi core stations at which a comparison was attempted between the oxygen tension in the water immediately above the sediment/water interface and the redox state of the sediment at and below the sediment surface. The results suggested a good correlation.

3.3 What effect does the OMZ have on the shear strength of surficial sediments? Sediments within the OMZ usually have very low shear strengths especially within 5 to 10 cm of the sediment surface (table 9). This has important implications for potential down-slope failure under these conditions.

Table 9. Range of shear strength values (kN/M2) at the sediment surface, 10 cm and 20 cm for different water depths.

		Depth in sediment (cm)		
Station	**Water Depth (m)**	**0**	**10**	**20**
7, 8	390 - 410	0.12-0.68	0.30-0.98	0.50-2.70
2, 3, 4	610 - 690	0.02-0.50	0.25-0.98	0.50-1.50
11, 12	840 - 860	0.10-0.30	1.50-6.13	1.00-2.70
13, 14, 15	980 - 1010	0.20-1.50	2.70-6.13	2.70-6.13
16, 17	1260 - 1290	0.15-0.30	0.98-6.13	2.20-6.13
5, 6	3390 - 4000	0.10-0.25	0.68-1.50	0.98-1.50

3.4 Does the degree and nature of bioturbation change across the OMZ? Yes. Bioturbation was present in sediments obtained from all stations, burrows being most abundant within 10 cm of the sediment surface (Table 10). It was highest towards the lower diffuse boundary of the OMZ at water depths of 840 to 1010 metres. There was also some indication of fewer types of burrows within the OMZ than outside it.

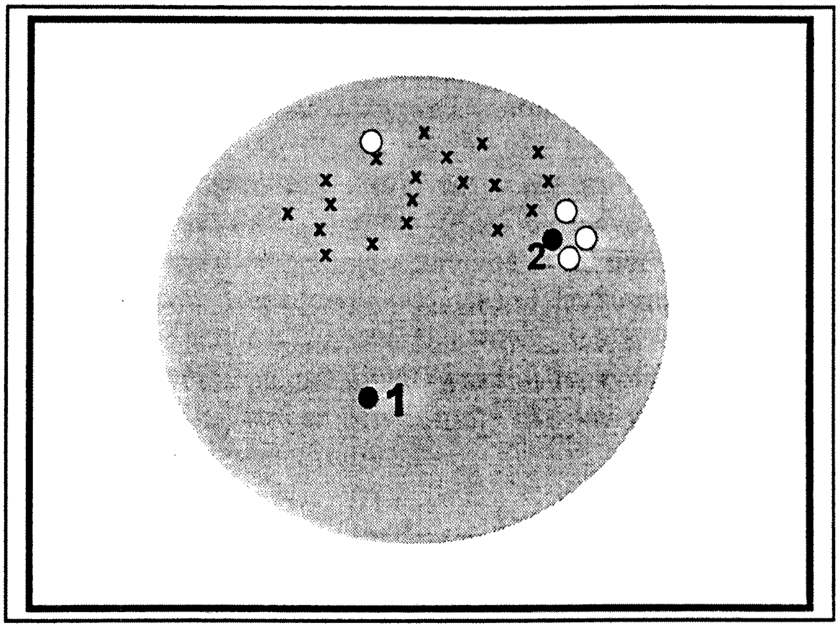
Table 10. Range of bioturbation (numbers of burrows/M2) at the sediment surface, 10 cm and 20 cm for different water depths.

		Depth in sediment (cm)		
Station	**Water Depth (m)**	**0**	**10**	**20**
7, 8	390 - 410	390-1170	260-650	0-910
2, 3, 4	610 - 690	520-4550	0-130	0
11, 12	840 - 860	2800-5590	520-1300	0
13, 14, 15	980 - 1010	910-5970	0-910	0-260
16, 17	1260 - 1290	390-2470	0	0
5, 6	3390 - 4000	260-1300	0-130	0

3.5 Is it possible to estimate the effect that bioturbation within the OMZ will have in determining the redox state and the shear strength of sediment in the zone?
Yes. Bioturbation often produces a significant amount of vertical mixing, which in turn is likely to lead to the redox profiles being more uniform in the surficial sediment layers. Shear strength was on occasion very variable, however initial results with the load cell showed clear differences

between the shear strength of sediment close to large burrows and at some distance from them horizontally (figure 8, 9). The shear strength in the top 2 cm of the sedimentary column at station 7 was more variable and lower near the burrows than in the main body of the sediment. These effects and their interactions, however, will need detailed laboratory analysis before definitive conclusions can be drawn.

Figure 8. Schematic diagram illustrating the surface of a 10 cm internal diameter sub core taken from a spade box core at station 7. Note positions of penetrometer probe: 1, probe inserted into main body of sediment; 2, probe inserted close to three large burrows.



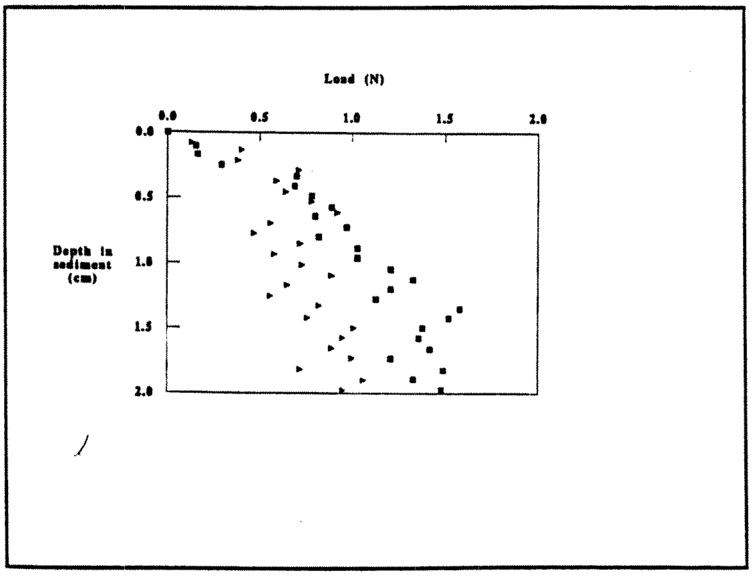


Figure 9. Graph showing the increase in load as the penetrometer probe was progressively inserted into the sediment for 2 cm at the two positions shown in figure 1. Squares: position 1 in main body of sediment; triangles: position 2, close to three large burrows.

3.6 Can the results from the new computerised load cell be related to conventional estimates of shear strength in the sedimentary column?
Yes. Initial results from the cruise suggest a good correlation, although this will require a full statistical analysis.

4. DISCUSSION

The results of the cruise are in the process of being analysed, and so our discussion is limited to those points that we feel need comment at this stage. These centre on unexpected phenomena noted in or at the surface of sediments within the OMZ compared to sediments elsewhere.

4.1 The sedimentary column within the OMZ was on occasion extremely heterogeneous, with layers of anoxic semi-fluid sediment lying above much harder more aerobic clay/sand strata. The anoxic sediment, which was always bioturbated, sometimes contained small nodules of gravel size. Bioturbation only rarely extended into the deeper aerobic clay/sand, and usually consisted of in filled burrows. The infilled burrows always had a much lower redox state than the surrounding sediment, a complete reversal of the picture found in sediments outside the OMZ. At one station in the centre of the OMZ the interface between the two layers of sediments contained structures indicating a past high-energy environment.

4.2 We hypothesise that the anoxic sediment is produced by the rapid downwards flux of dead plankton and organic material through the OMZ, particularly during and immediately following the southwesterly monsoon period, and that the nodules represent episodic terrigenous input from flash floods down terrestrial wadis which lead to the shore zone and then into shallow waters.

4.3 Our initial results also suggest that the anoxic bioturbated sediment layer forms a thin skin on the surface of the clay/sand substrate within the OMZ which is likely to be rapidly burnt off following the southwesterly summer monsoon while at the same time slumping down slope into deeper more aerobic water. This will have significant implications for the nature of the bioturbating communities of benthic infauna, which must be able to withstand these very unusual and highly stressed conditions.

4.4 A remarkable death assemblage of vertebrate bones and invertebrate remains was discovered in sediments within the OMZ. The sediment was obtained from an Agassiz trawl station in the OMZ, and contained sharks teeth, squid beaks, teleost bones, and bones from large marine mammals, some of which were in a partly fossilized state. The mud was extremely anoxic, semi fluid and slightly cohesive, and also contained numerous nodules which may have been of terrestrial origin.

The details of the station are as follows. The Agassiz trawl was fished from 19° 10.73' N, 58° 12.61' E, water depth 353 m at 22.58 G.M.T., to 19° 11.10' N, 58° 13.15' E, water depth 367 m at 23.45 G.M.T. on 25.10.94, a distance of about 2 nm, towing at 1.5 knots on a course of c. O45°. When the Agassiz trawl was taken in board it was found to contain a large quantity of mud (c. 1.5 cubic metres). A small sample of the mud was retained unsieved (1.45%), and then the remainder sieved through a 1.5 mm sieve - whereupon the death assemblage, together with a large number of rock balls or nodules representing 3 % of the total volume and ranging in size from O.5 to 1.5 cm, was discovered.

At a scientific meeting the following day it was agreed that the death assemblage material should by in the curatorship of Craig Young, Harbour Branch Laboratory, and the rock balls should be in the curatorship of Peter and Azra Meadows. Craig Young would then coordinate the study of the death assemblage, and Peter and Azra Meadows would coordinate the study of the rock balls, with colleagues in the USA and UK. Our aim is to produce a multi-author paper within as short a period of time as possible, to be coordinated by Craig Young.

Radioactive dating will be required to determine whether the assemblage represents a single or multiple event. It certainly seems likely that the OMZ has extended upwards to the sea surface at least once, thus causing a mass mortality of larger pelagic organisms. The discovery may be very important, and have implications for palaeoclimate indicators, the extent of the oxygen minimum zone and historical changes in the pattern and strength of the monsoons.

5. SUMMARY

5.1 Our results indicate that sedimentary ecosystems within the OMZ have unusual and on occasion unique characteristics. Bioturbation occurred within and outside the OMZ, with some of the highest densities of burrows being recorded at the stations in the 840 to 860 m water depth range, towards the lower diffuse boundary of the OMZ. Lowest redox conditions were recorded within the OMZ, and the surface bioturbated layers were very anaerobic, often semifluid (very low shear strength) and extremely heterogeneous on a micro scale. Subsurface layers were sometimes more aerobic and almost always more cohesive (higher shear strength). A unique death assemblage was recorded within the OMZ.

5.2 In summary, sediment properties are often very different from those in more normal aerobic environments elsewhere in the world's oceans, with a high degree of biological activity in semifluid and very anaerobic mud. Full documentation and analysis will now be conducted and submitted for publication. It is expected that this will take 18 to 24 months to complete and will include collaborative work with scientists in the UK and USA, together with laboratory work to be conducted by two postgraduate students, one of whom, Mr Murray, was on the cruise.

Oliver, G.

MOLLUSCA

The intertidal and near shore molluscan fauna of Oman is very rich with some 1200 species recorded. Of particular interest is the local endemism associated with the south Arabian upwelling which has a striking impact on the Dhofar coast. Endimism is not confined to the immediate vicinity of the lower water temperature areas and is also present at Masirah. The parameters leading to isolation and subsequent speciation beyond the low temperature area are uncertain. The opportunity to examine the offshore and deep water molluscan fauna adjacent to the Bay of Masirah may clarify the inshore regime. Also as the inshore fauna is now becoming increasingly well known there is the opportunity to study the relationships of the deep water fauna and the relative faunistic compositions throughout the oxygen minimum zone.

Zonation of Mollusca through the Oxygen Minimum Zone:

The following data are derived primarily from the series of Agassiz Trawls and Epibenthic Sledge tows. Data from box cores will not be available until the samples are sorted. Trawl samples were taken from 45 - 3400 m. This series encompassed the entire oxygen minimum zone with the exception of the fully oxygenated inshore <30 m region. The bivalve data are represented on the figure 10.

Molluscan species diversity is low at all depths but both the 45 m and 3400 m stations have not been fully assessed as the catches are not sorted in any detail. The composition of the deepest stations is typically bathyal but the species richness is less than similar situations in the N. Atlantic. Above 100 m the stations were relatively rich but peculiar in that a number of genera often associated with the deep sea were present, namely *Solemya*, *Nucinella*, *Bathyarca* and *Parvamussium*.

Species diversity decreases towards the minimum oxygen levels with apparently no molluscs at around 600 - 800 m. To either side of this void, molluscan diversity is very low but those species that do occur may be present in large numbers. This observation applies most to the translucent mussel *Amygdalum* which is concentrated at about 350 m. The large gastropods *Tibia* and *Fiches* were found with the mussel, both genera are typically shallow water tropical forms. Molluscs appear again at around 900 m with the notable occurrence of a large Lucinid bivalve and a large nuculid belonging to the genus *Acila*. Gastropods were dominated by the Turridae and Naticidae which are a regular component of bathyal and abyssal faunas. The lucinids are probably very patchily distributed, one box core taking 17 individuals. At the next station at 1200 m. the dominant mollusc was the large *Propeamussium watsoni*. Large size is a feature of this region and may indicate rapid growth and abundance of food. Sampling between 1200 and 3000 m was not possible due to the precipitous terrain. Samples from beyond 3000 m indicate a typical deep sea assemblage dominated by protobranch bivalves and the filibranch *Limopsis*.

The OMZ clearly reduces the diversity of molluscs and this effect is visible in shallow waters. The combination of the effects of seasonal temperature fluctuations, the OMZ and the narrowness of the shelf along the southern Omani coast probably create an unstable regime unsuitable for many of the truly tropical elements. Availability of niches may arise frequently, allowing speciation or the possibility of chance invasions through time dependent on climatic conditions.

Notes.

Presence of Haemoglobin:- Many of the mollusca from within the OMZ contained blood red pigments assumed to be haemoglobin. This was present in the mussel *Amygdalum*, *Lucina*, *Thyasira*, *Propeamussium*, *Vesicomya* and *Indocrassatella*. Haemoglobin was not apparent in many of the 3300 m species with the exception of *Vesicomya*.

Presence of Symbiotic Bacteria:- The presence of bacteria is most noticeable by the modification of the gills which are swollen and darkly pigmented. This was observed in *Lucina* and *Thyasira* from 850 - 1150 m and *Vesicomya* from 3300 m. The occurrence of symbiotic bacteria does not relate *per se* to the OMZ but may indicate pockets of high sulphide enrichment indicative of seeps.

Vesicomyidae:- At least three species of vesicomyid have been collected from 150 m, 360 m, and 3300 m. The diversity of this family appears to be particularly high in the Indian Ocean.

A good size series of a number of species was obtained and will allow an assessment of growth rates to be made. *Lucina*, *Amygdalum*, Vesicomyidae sp. A and *Limopsis* are available in sufficient numbers.

A rocky substrate faunule was collected at 967 m. This consisted of numerous tubiculous polychaetes along with chitons, 2 species of key-hole limpet, a slit limpet and a white cocculinid limpet. The rock appears to be a consolidated sediment previously bored by piddocks and crustaceans. Its origins are obscure.

In general the molluscan collections are sufficiently rich to allow adequate comparison with the results of the "Investigator", "Valdivia" and "John Murray" expeditions.

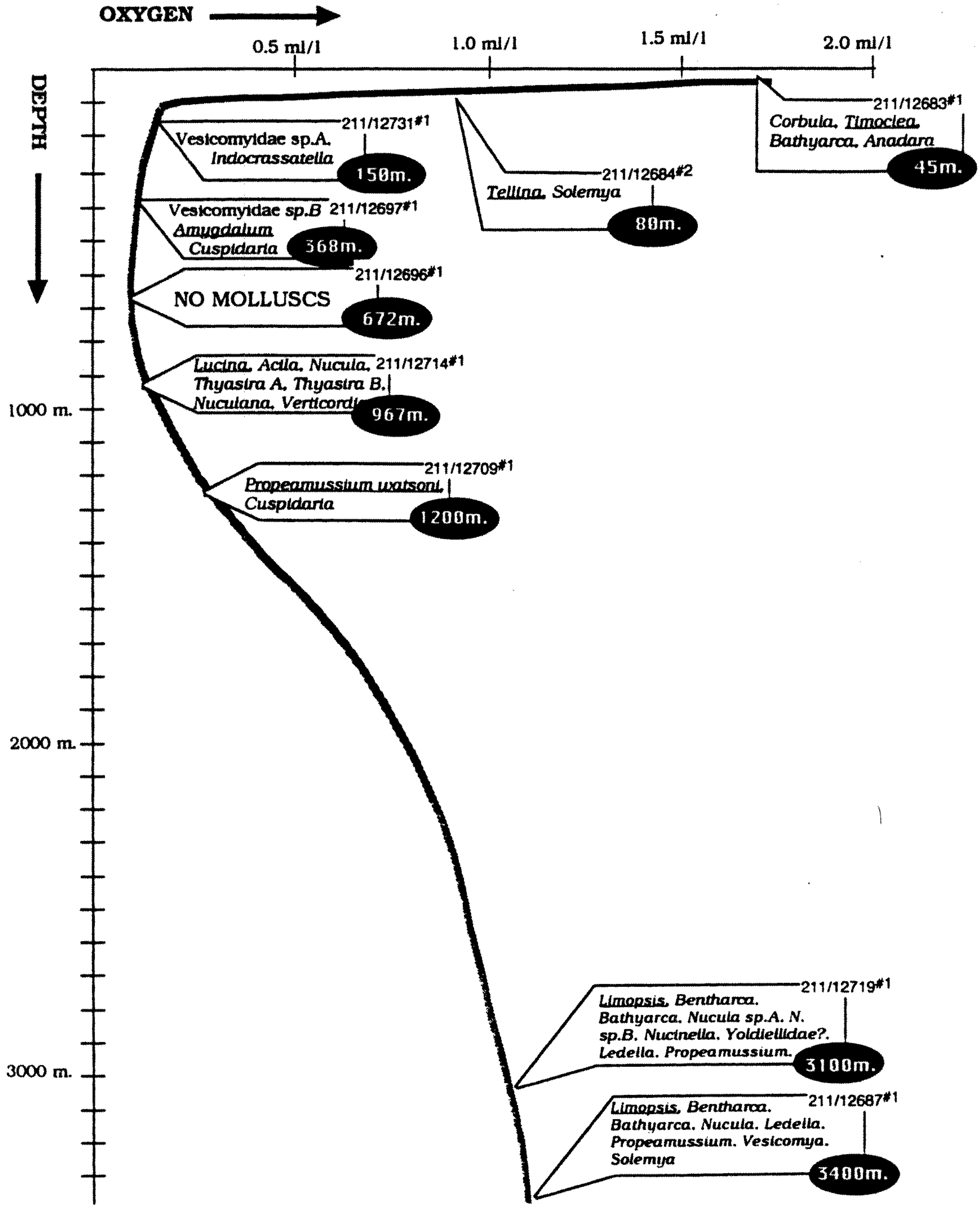


Figure 10: The distribution of bivalves from Agassiz and dredge hauls.

Patience, A. J.

The MEASUREMENT of DISSOLVED OXYGEN in SEA WATER
(with notes on BOXCORE INCUBATIONS, GRANULOMETRY sampling, PORE-WATER EXTRACTION and CHN sampling)

The sampling strategy and analyses completed during the cruise are summarised in table 11. Below are explanatory notes which clarify some of the techniques used.

Introduction

Dissolved oxygen ($D.O_2$) analyses were completed following an adaptation of the classical Winkler method (Winkler, 1888) and essentially as outlined in Strickland and Parsons (1972) with only slight modifications to accommodate the use of a micro-burette (Titi-lab^{TM-1}). The method has changed little since its conception and has been evaluated in some detail by Carpenter (1964) and Carritt and Carpenter (1966).

The method involves the introduction of a divalent manganese solution to the water sample in a BOD bottle, followed by a strong alkali. The precipitated manganous hydroxide is dispersed evenly throughout the sample. Any $D.O_2$ oxidises an equivalent amount of divalent manganese to basic hydroxides of higher valency states whilst iodine, equivalent to the original $D.O_2$ of the sample, is liberated. The iodine is titrated against a standardized thiosulphate solution. The titration volume is thus proportional to the concentration of dissolved oxygen in the original sample. The thiosulphate molarity is calibrated by titration against the KIO_3 whose molarity is known very accurately.

Sampling Strategy

Water samples for $D.O_2$ analyses were taken from:

1. CTD niskin bottles (for $D.O_2$ profiles of the water column and cross calibration with the CTD oxygen concentrations)
2. The bottom water overlying the sediment in multi-core tubes
3. The overlying water of box-core sub-cores used in incubation experiments.
4. The overlying water from a suite of cores used in a biological stagnation experiment undertaken by Dr A. Gooday and Dr B. Bett.

Samples from group 1 and 2 were siphoned, using a rubber tube, into 160 ml BOD bottles. The bottles were rinsed twice with the sample water and a volume of water at least 2/3 that of the bottle is allowed to overflow before the bottles are stoppered carefully ensuring no air bubbles are trapped. The flow of the water through the tube was regulated to minimise any turbulence which may serve to oxygenate the samples. Samples were typically removed less than 5 minutes after the multi-core or CTD reached the sea surface. The rapid removal of the samples into BOD bottles was especially important for the multi-core samples whose water is effectively open to the atmosphere. The CTD water is, however, enclosed and is less susceptible to diffusion problems.

Table 11: Summary of the sampling and analyses completed (by A. Patience and D. Smallman) during Discovery cruise 211.

Station No. #Drop	Position N	Position E	Water Depth (m)	CTD D.O$_2$ Profile	CTD Nuts/ Phyto.	Multi-Core D.O$_2$ BW	MC Sliced sediment cores G'chem	P.W.	C/N	Box Incubation D.O$_2$	Core Cores Nuts.	LANDER Deployments D.O$_2$	Nuts.	Video
12671#1(A1)	19 01.01	59 00.24	3380	S/M/BW	—									
12672#2	19 00.00	58 49.05	3334	SW/BW										
12677#1	19 12.71	58 26.31	1124	BW										
12682#1	19 19.09	58 16.65	600	FP										
12682#3	19 18.70	58 15.74	742				3, 4	—	—					
12682#5	19 18.66	58 15.55	685			—	1, 3	—	—					
12682#7	19 18.77	58 15.55	630							—	—			
12685#2	19 18.91	58 15.44	680			—								
12685#5	19 18.98	58 15.26	672				(?)	—	—					
12685#7	19 18.65	58 15.48	667			—	8							
12686#1	19 14.58	58 23.01	840			—	4							
12687#3	18 59.96	59 00.45	3348			—								
12687#5	18 59.67	59 00.10	3393				5, 10	—	—					
12687#8	18 59.33	58 59.09	3350			—	(?)	—	—					
12687#10	18 59.42	59 00.92	3397					—	—					
12689#2	19 49.37	58 23.71	70											—
12690#1	19 22.00	58 15.43	402			—	3, 12	—	—					
12690#3	19 22.00	58 15.46	418							—	—			
12692#1	19 21.83	58 15.42	384					—	—					
12694#1	19 22.77	58 12.60	121				8							
12695#1	19 21.97	58 95.47	416	FP										
12695#5	19 22.02	58 15.55	402					—	—					
12706#1	19 17.25	58 30.41	1010			—								
12703#1	19 22.34	58 11.42	115									—	—	—
12708#3	19 22.28	58 11.43	106				8		—					
12708#5	19 22.18	58 11.44	119			—			—					
12708#6	19 22.34	58 11.49	122							—	—			
12708#7	19 22.31	58 11.40	106						—					
12711#1	19 14.31	58 22.93	841	FP										
12711#3	19 14.10	58 22.86	833				1, 6	—	—					
12713#2	19 14.29	58 22.87	823						—					
12713#3	19 14.13	58 22.84	827						—					
12713#4	19 14.16	58 23.13	862							—	—			
12717#1	19 21.93	58 15.44	412									LOSS	LOSS	LOSS
12718#1	19 16.59	58 29.85	983				9, 12	—	—					
12718#2	19 16.62	58 29.77	1004							—	—			
12718#3	19 16.77	58 29.91	1002			—			—					
12720#1	19 20.80	58 14.72	427			—								
12722#2	19 16.73	58 29.71	1002			—			—					
12722#5	19 16.69	58 29.65	999	S/M/BW										
12723#1	19 15.39	58 30.01	1292	FP										
12723#3	19 14.33	58 31.56	1268				4, 6	—	—					
12723#5	19 14.38	58 31.46	1252			—			—					
12725#1	19 13.82	58 31.44	1296											
12725#3	19 14.14	58 31.30	1254			—			—					
12725#4	19 13.91	58 31.63	1310							—	—			
12725#7	19 14.02	58 31.32	1277	BW										
12728#1	19 13.38	58 32.90	1617			—	4	—	—					
12732#1	19 13.51	58 14.39	400			—								

Key: D.O$_2$ = dissolved oxygen; S = surface water; M = mid water; BW = bottom water;
FP = full water column profile; Nuts = nutrients; Phyto = phytoplankton;
G'chem = geochemical samples, nos. refer to specific core tube nos. if known;
PW = pore waters. --- = successful recovery of samples

Samples from groups 3 and 4 were recovered using 10 ml glass syringes. Several ml of sample were removed and flushed out of the syringe thus removing any air bubbles or contaminated water lying in the dead space. It was especially difficult to remove all the contaminated (potentially oxygenated) water when sampling the cores involved in the stagnation experiment due to the configuration of the tubes some of which contained some trapped air bubbles. The possible consequences of this are highlighted in the discussion below.

Laboratory Procedure

Reagents were added to both the BOD bottles and the syringes as soon after the sampling as possible.

1.25 ml of $MnSO_4$ was added to the BOD bottles using an automatic pipette followed immediately by 1.25 ml of alkaline iodide solution. During each addition the pipette tips were placed just under the surface of the water. The bottles were stoppered and shaken to disperse the dense reagents and allow full precipitation of the manganous-manganic hydroxide. The precipitate was left to settle half way down the bottle, then the bottles were inverted once more before the white precipitate was again left to settle to approximately three quarters the height of the bottle. At this stage 2 ml of conc. sulphuric acid was added to the solutions again using an automatic pipette. The bottles were again stoppered and shaken thus dissolving the white precipitate. A yellow/stray colouration of the solutions was observed at this stage, the intensity of which was shown to be roughly proportional to the concentration of oxygen present in the samples.

Three 10 ml aliquots were titrated against the thiosulphate (either 0.00125 N or 0.0005 N depending on the $D.O_2$ concentration of the sample). A blank correction for the effects of the reagents on the titration volume was showed to be 0.13 ml 0.0005 N Na thiosulphate.

A similar procedure was performed on the 10 ml sample in the syringes except only 0.1 ml of $MnSO_4$ and alkaline iodide were added followed by 0.2 ml conc. sulphuric acid. None of the samples were allowed to equilibrate to room temperature after the addition of the $MnSO_4$ and Alkaline iodide because the titrations were completed immediately afterwards acidification and therefore any inherent instability in the solutions due to temperature differences were nullified.

Reproducibility

The triplicate analyses completed on all large volume samples (CTD and multi-core water) gave good reproducibility of results. The typical standard deviations for varying concentrations of $D.O_2$ are given below:

$\sigma n\text{-}1 = 0.059$ at the 4,5 ml O_2/l level (n=3)
$\sigma n\text{-}1 = 0.006$ at 1 ml O_2/l level (n=3)
$\sigma n\text{-}1 = 0.003$ at the 0.3 ml O_2/l level (n=3)

Results and Discussion

The D.O_2 results from the CTD and multi-core samples are summarised in Table 12 and Figure 11. Surface water (5 m depth) values ranged between around 3.0-4.5 ml O_2/l which is as expected being close to saturation values at ambient sea surface temperatures (25-30 °C) and salinities (35-36 ‰). The very sharp upper boundary of the oxygen minimum zone (OMZ) is situated at around 50 m depth and D.O_2 concentrations remained low as deep as 1000-1300 m (fig. 11a). The upper boundary roughly coincides with a strong thermocline which was observed in the CTD profiles. The CTD data (averaged every 2 m) of temperature, salinity, transmitometry and D.O_2 from all the casts was copied onto floppy discs for cross calibration with the Winkler method. Initial evaluation of the data indicates that the CTD D.O_2 values are at least two times too low at surface water concentrations and perhaps an order of magnitude too low within the OMZ!

D.O_2 values in the OMZ however, are slightly higher than expected ranging from around 0.15~0.50 ml/l depending on the sediment type and water depth. These slightly elevated results may be due to diffusion of O_2 from the air into the sample during sampling although the seawater is only very briefly exposed to air during this time. All reagents and other possible sources of error were systematically checked and verified. These slightly high results are perhaps especially surprising because, during October in the Arabian sea one would expect the OMZ to be intensified due to the degradation of the strong organic pulse through the water column to the benthic layer during the monsoonal driven upwelling period which reaches an acme in the summer months (Prell and Streeter, 1982). However, this Ekman transport driven upwelling may, conceivably, have served to mix the mid and bottom waters resulting in slightly more oxygenating conditions in the OMZ, although such episodic ventilation of the mid and bottom waters would almost certainly have been observed by the numerous CTD drops and mooring stations completed in the area.

Wyrtki (1971), Slater and Kroopnick (1984) and Hermelin and Shimmield (1990) all show that the OMZ is in fact more intense (<0.2 ml O_2/l at the 600 m level) north of Masirah island (20° 30' N 58° 40' E) than to the south of it where the OMZ is typically <0.5 ml O_2/l. This intensification of the OMZ in the northern Arabian sea reflects the higher euphotic zone productivity of these waters compared to the southern Arabian sea (Ryther et al., 1966). All these findings are consistent with the concentrations of D.O_2 found in this study as all samples were recovered south of Masirah island. Thus, although some of the results within the OMZ appear to be slightly too high, the bulk of the D.O_2 values are indeed consistent with previous work on the area.

It will be interesting to note the results of Mr C.Young who is studying denitrification in the sediments from this area as, according to Sen Gupta et al., (1976), this process can only proceed at oxygen concentrations less than 0.3 ml/l. Denitrification has also been observed close to the outflowing of the Persian gulf at oxygen concentrations less than 0.16 ml/l (Deuser, et al., 1978).

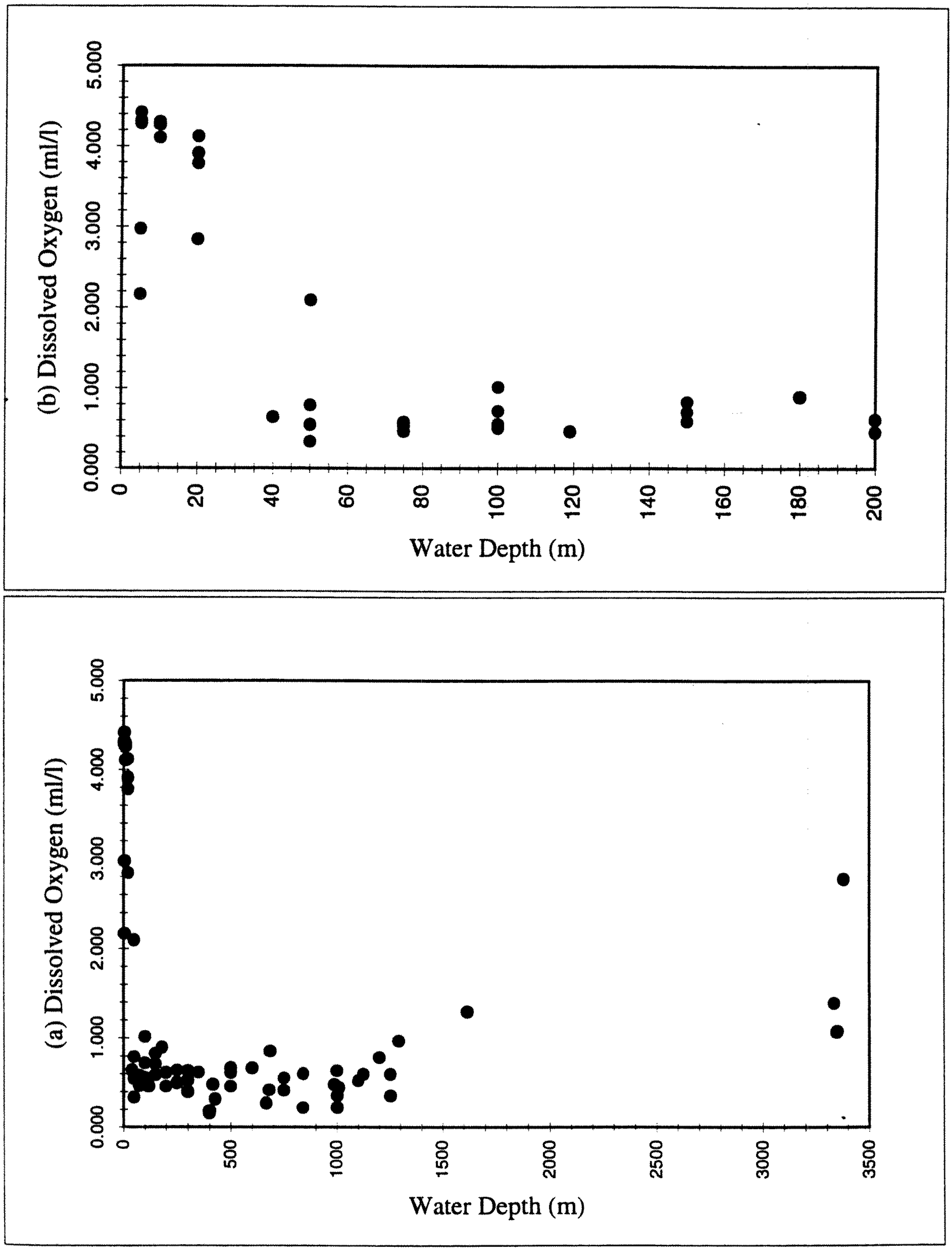


Figure 11: Dissolved oxygen (D.O_2) concentrations (ml/l), using the Winkler technique, from CTD and multicore samples versus water depth(m). (a) D.O_2 results throughout the water column (0-3500 m). (b) D.O_2 variations in the uppermost 200 m.

Table 12: D.O_2 concentrations using Winkler method from CTD and multicore water samples.

Station No. #Drop	Sampling method	Position N	Position E	Water Depth(m)	D.O_2 ml/l
12671#1	CTD	19 01.01	59 00.24	10	4.107
12671#1	CTD	19 01.01	59 00.24	500	0.663
12671#1	CTD	19 01.01	59 00.24	3380	2.776
12672#2	CTD	19 00.00	58 49.05	5	2.164
12672#2	CTD	19 00.00	58 49.05	3334	1.388
12677#1	CTD	19 12.71	58 26.31	1124	0.593
12682#1	CTD	19 19.09	58 16.65	5	4.417
12682#1	CTD	19 19.09	58 16.65	10	4.295
12682#1	CTD	19 19.09	58 16.65	20	4.120
12682#1	CTD	19 19.09	58 16.65	50	2.092
12682#1	CTD	19 19.09	58 16.65	75	0.529
12682#1	CTD	19 19.09	58 16.65	100	0.717
12682#1	CTD	19 19.09	58 16.65	150	0.705
12682#1	CTD	19 19.09	58 16.65	200	0.610
12682#1	CTD	19 19.09	58 16.65	250	0.493
12682#1	CTD	19 19.09	58 16.65	300	0.397
12682#1	CTD	19 19.09	58 16.65	500	0.607
12682#1	CTD	19 19.09	58 16.65	600	0.664
12682#5	MC	19 18.66	58 15.55	685	0.852
12685#2	MC	19 18.91	58 15.44	680	0.418
12685#7	MC	19 18.65	58 15.48	667	0.268
12686#1	MC	19 14.58	58 23.01	840	0.221
12687#3	MC	18 59.96	59 00.45	3348	1.069
12687#8	MC	18 59.33	58 59.09	3350	1.075
12690#1	MC	19 22.00	58 15.43	402	0.185
12695#1	CTD	19 21.97	58 95.47	5	4.319
12695#1	CTD	19 21.97	58 95.47	10	4.290
12695#1	CTD	19 21.97	58 95.47	20	2.841
12695#1	CTD	19 21.97	58 95.47	40	0.640
12695#1	CTD	19 21.97	58 95.47	50	0.544
12695#1	CTD	19 21.97	58 95.47	100	0.556
12695#1	CTD	19 21.97	58 95.47	150	0.586
12695#1	CTD	19 21.97	58 95.47	200	0.608
12695#1	CTD	19 21.97	58 95.47	250	0.637
12695#1	CTD	19 21.97	58 95.47	300	0.523
12695#1	CTD	19 21.97	58 95.47	350	0.614
12695#1	CTD	19 21.97	58 95.47	416	0.478

Station No. #Drop	Sampling method	Position N	Position E	Water Depth(m)	D.O_2 ml/l
12706#1	MC	19 17.25	58 30.41	1010	0.442
12708#5	MC	19 22.18	58 11.44	119	0.461
12711#1	CTD	19 14.31	58 22.93	5	4.281
12711#1	CTD	19 14,31	58 22.93	20	3.783
12711#1	CTD	19 14.31	58 22.93	50	0.788
12711#1	CTD	19 14.31	58 22.93	75	0.466
12711#1	CTD	19 14.31	58 22.93	100	1.012
12711#1	CTD	19 14.31	58 22.93	150	0.826
12711#1	CTD	19 14.31	58 22.93	180	0.894
12711#1	CTD	19 14.31	58 22.93	200	0.456
12711#1	CTD	19 14.31	58 22.93	300	0.630
12711#1	CTD	19 14.31	58 22.93	500	0.458
12711#1	CTD	19 14.31	58 22.93	750	0.414
12711#1	CTD	19 14.31	58 22.93	841	0.599
12718#3	MC	19 16.77	58 29.91	1002	0.224
12720#1	MC	19 20.80	58 14.72	427	0.315
12722#2	MC	19 16.73	58 29.71	1002	0.353
12722#5	CTD	19 16.69	58 29.65	5	2.971
12722#5	CTD	19 16.69	58 29.65	500	0.458
12722#5	CTD	19 16.69	58 29.65	999	0.476
12723#1	CTD	19 15.39	58 30.01	5	4.302
12723#1	CTD	19 15.39	58 30.01	10	4.260
12723#1	CTD	19 15.39	58 30.01	20	3.909
12723#1	CTD	19 15.39	58 30.01	50	0.336
12723#1	CTD	19 15.39	58 30.01	75	0.578
12723#1	CTD	19 15.39	58 30.01	100	0.506
12723#1	CTD	19 15.39	58 30.01	250	0.503
12723#1	CTD	19 15.39	58 30.01	750	0.551
12723#1	CTD	19 15.39	58 30.01	1000	0.632
12723#1	CTD	19 15.39	58 30.01	1100	0.522
12723#1	CTD	19 15.39	58 30.01	1200	0.782
12723#1	CTD	19 15.39	58 30.01	1292	0.966
12723#5	MC	19 14.38	58 31.46	1252	0.592
12725#3	MC	19 14.14	58 31.30	1254	0.354
12728#1	MC	19 13.38	58 32.90	1617	1.292
12732#1	MC	19 13.51	58 14.39	400	0.155

Box-core Incubation Experiments

Two sub-cores from six box-core drops were sampled for oxygen and nutrient uptake. These cores were submerged in bottom water collected using the CTD and allowed to equilibrate, over several hours, to the ambient temperature and $D.O_2$ saturation levels in the constant temperature laboratory (CT lab.). The tops of the cores were then sealed and the overlying water was subsequently homogenised using an electric stirring rod attached to the underside of the seal which also had a passage through which the water may be sampled. 10 ml of water was drawn off three times over the space of 2 to 3 days for both $D.O_2$ and nutrient analyses. The nutrient samples were preserved frozen and the $D.O_2$ samples were analyzed immediately. The water temperature and volume were also noted at each sampling time. The $D.O_2$ raw data (table 13) has not yet been interpreted but there are clear indications of differing O_2 uptake rates from different sediment types and water depths.

Nutrient Analysis of sea water and Pore Waters.

Pore waters were extruded from sectioned multi-core sediments by centrifuging and filtering the resulting supernatant water using 0.45 μm filters in preparation for nutrient (SO_4, PO_4, NO_3, NO_2 and NH_4) analysis using an auto-analyzer. These analyses will also be completed on filtered CTD and box-core incubation experiment water samples. All these samples were successfully transported back to the UK preserved in Dry ice.

Geochemistry/Granulometry

Two cores from fourteen multi-core drops were sectioned at 1 cm intervals between 0-10 cm and at 2 cm intervals below this level. These sediments, which were transported back to the UK in the 10 °C container, may be used for bulk sediment geochemistry and granulometry.

Sediment dry bulk density and C/N samples

Exactly 5 cm^3 of sediment was sampled, using modified syringes, from sectioned multi-core tubes for water contents, dry bulk density and C/N determinations. Both these and the pore water sampling (see below) were completed at each station in either duplicate or triplicate wherever possible. Total carbon and nitrogen contents in the sediments have already been completed whilst work on organic carbon and nitrogen determination is underway.

The downcore variations in sediment water content (% wet weight) from a suite of water depths spanning the OMZ are shown in figure 12. Generally, the water content decreases with depth in the sediment consistent with compaction during sedimentation. The cores from below 1200 m depth display a rapid decrease in the top 2 cm below which the water contents decrease much more gradually. The cores from within the OMZ (shaded) however, decrease in a more linear manner although with some irregularities especially in the upper 4-5 cm. The surface water content increases from around 60 (%Wet Wt.) at 1002 m to 85 (%Wet Wt.) at 3397 m. In the other OMZ cores, the surface values are also high, typically around 75. The water contents throughout the 3397 m core remain relatively high, possibly due in part to an increase in clay minerals which are known to hold considerable quantities of structural moisture. The core recovered from 106 m water depth has very low water contents primarily due to its very sandy texture and the winnowing it has most likely suffered. The dry bulk densities (essentially the inverse of water content) will be used in the calculation of sediment flux variations when a time scale has been produced, probably using a combination of ^{14}C, oxygen isotope ($\delta^{18}O$) stratigraphy and ^{210}Pb dating.

Additional Sampling at Station A1-JGOFS (19 01.01 N 59 00.24 E)

Finally, at station 12571#1 (A1-JGOFS) the water column was sampled using the CTD in preparation for nutrient, phytoplankton and chlorophyll analysis as part of a collaboratory effort with Plymouth Marine Laboratory (PML) to achieve a seasonal sampling. These samples were successfully transported back to the UK in hand luggage preserved in dry ice.

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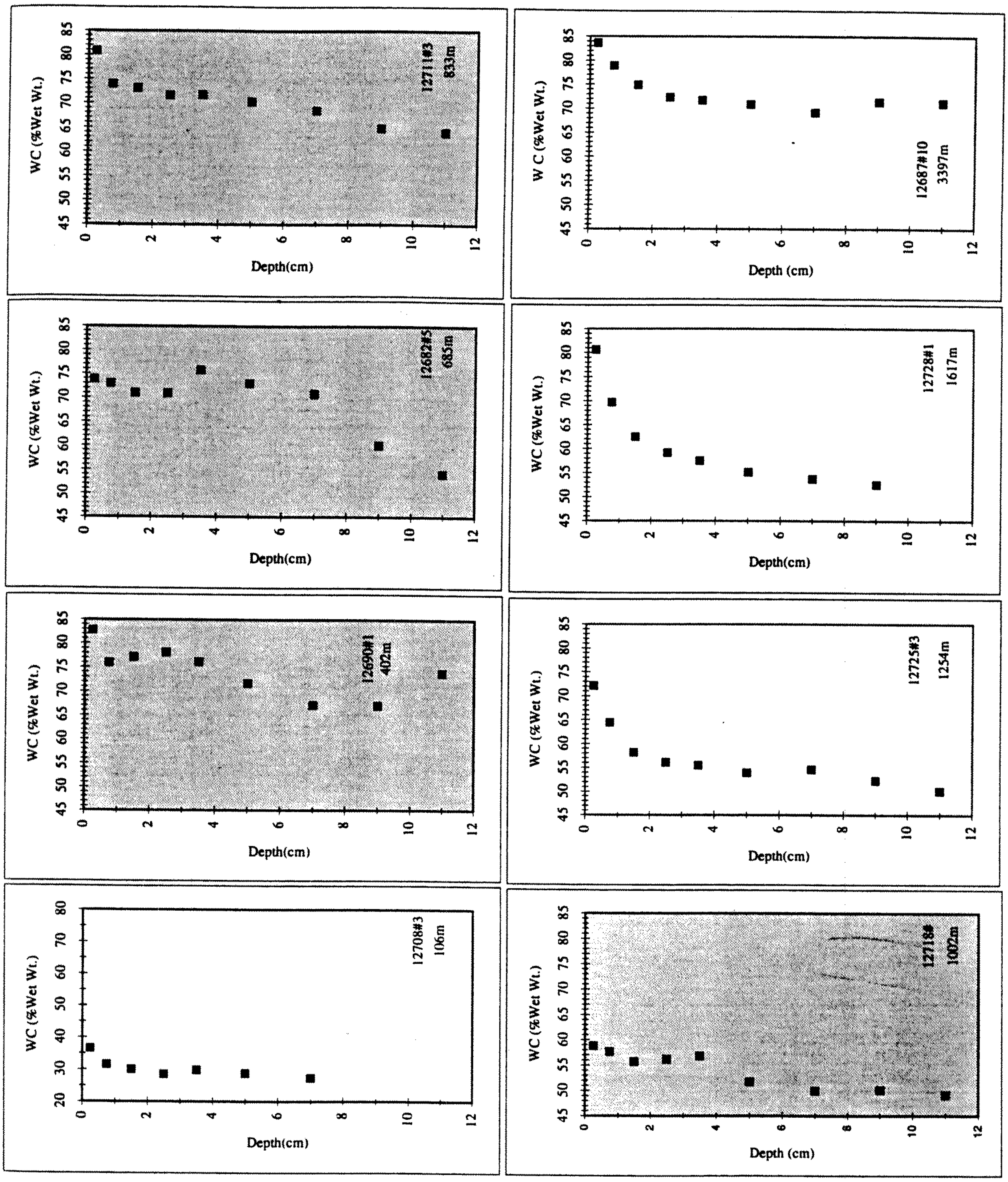

Figure 12: Downcore variations in sediment water content (% wet weight) from a suite of cores whose water depths span the oxygen minimum zone (OMZ). The shaded graphs represent those cores situated within the heart of the OMZ.

Table 13: Raw data from box core incubation experiments.

12690#3			D.O_2	D.O_2			O_2 Utiltn	O_2 Utiltn
	Date	Time (GMT)	ml/l	ml/l	Interval	Interval	ml/l/day	ml/l/day
			Core 1A	Core 1B	hrs-mins	days	Core 1A	Core 1B
T_0	22/10/94	04-15	1.590	1.996				
					8.00	0.333	0.673	-0.931
T_1	22/10/94	14-15	1.366	2.306				
					21-13	0.884	-0.657	0.152
T_2	23/10/94	11-28	1.947	2.172				
12695#7			D.O_2	D.O_2			O_2 Utiltn	O_2 Utiltn
	Date	Time (GMT)	ml/l	ml/l	Interval	Interval	ml/l/day	ml/l/day
			Core 1A	Core 1B	hrs-mins	days	Core 1A	Core 1B
T_0	25/10/94	06-00	4.398	4.468				
					30-45	1.281	2.416	2.180
T_1	26/10/94	12-45	1.303	1.676				
					40-00	1.667	0.779	1.005
T_2	28/10/94	04-45	0.004	0.000				
12708#6			D.O_2	D.O_2			O_2 Utiltn	O_2 Utiltn
	Date	Time (GMT)	ml/l	ml/l	Interval	Interval	ml/l/day	ml/l/day
			Core 1A	Core 1B	hrs-mins	days	Core 1A	Core 1B
T_0	28/10/94	05-05	3.719	3.654				
					25-55	1.080	2.475	2.507
T_1	29/10/94	07-00	1.046	0.946				
					50-15	2.094	0.405	0.349
T_2	31/10/94	09-15	0.198	0.215				
12713#4			D.O_2	D.O_2			O_2 Utiltn	O_2 Utiltn
	Date	Time (GMT)	ml/l	ml/l	Interval	Interval	ml/l/day	ml/l/day
			Core 1A	Core 1B	hrs-mins	days	Core 1A	Core 1B
T_0	31/10/94	09-30	3.911	3.797				
					54-45	2.281	1.399	1.411
T_1	02/11/94	16-15	0.721	0.578				
					14-20	0.597	0.997	0.642
T_2	03/11/94	06-35	0.126	0.195				
12718#2			D.O_2	D.O_2			O_2 Utiltn	O_2 Utiltn
	Date	Time (GMT)	ml/l	ml/l	Interval	Interval	ml/l/day	ml/l/day
			Core 2A	Core 2B	hrs-mins	days	Core 1A	Core 1B
T_0	06/11/94	15-10	4.148	4.568				
					21-25	0.892	1.524	1.247
T_1	07/11/94	12-35	2.789	3.456				
					16-25	0.684	1.558	0.906
T_2	08/11/94	05-00	1.723	2.836				
12725#4			D.O_2	D.O_2			O_2 Utiltn	O_2 Utiltn
	Date	Time (GMT)	ml/l	ml/l	Interval	Interval	ml/l/day	ml/l/day
			Core 1A	Core 1B	hrs-mins	days	Core 1A	Core 1B
T_0	08/11/94	05-00	4.042	3.809				
					26-09	1.090	1.107	0.782
T_1	09/11/94	07-09	2.835	2.957				
					27-56	1.164	0.480	0.676
T_2	10/11/94	11-05	2.276	2.170				

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Rogers, A.

BENTHIC POPULATION DIFFERENTIATION

There has been only a single study to date on genetic differentiation in populations of marine organisms (in this case amphipods) located at different depths on the slope (France, 1994) and this found marked genetic differentiation in these populations. The implications of this in terms of vertical dispersion of larvae on the slope and isolation and eventual speciation of vertically separated populations are considerable. Material collected during cruise 211 will be used to further investigate the genetic differentiation of slope populations.

To this end populations of a number of taxa located at different depths have been collected and frozen at -45°C. These include populations of a spider crab located between 200 and 700 m. Populations of *Munidopsis* spp. located between 900 - 1200 m, red prawn located between 900-1200 m and a bivalve *Limopsis tenella* between 3000 and 3400 m. Allele frequencies will be obtained for these populations using starch gel electrophoresis and genetic differentiation between intra specific populations will be calculated using F-statistics. Sample sizes for most of these populations are extremely large (up to 300) for genetic studies and will allow fairly accurate estimates of fits of genotype frequencies in these populations to those expected under Hardy Weinberg equilibrium. This data will be compared to data obtained on reproduction in these species to give a good overall picture of reproductive strategy and its effects on genetic population structure.

The presence of an OMZ along the slope investigated may influence the genetics of the organisms under investigation. For example vertically separated populations may be more structured than expected due to selection for certain genotypes in different oxygen regimes at different depths in the OMZ.

As well as material collected for studies of differentiation down the slope, material has also been collected for a number of other projects. Single populations of some species were collected for examination of fits of genotype frequencies to HW equilibrium in combination with studies on reproduction by P.A. Tyler and C.M. Young. These include populations of anemones and the mussel *Amygdalum* sp. (?) *politum*. Bivalves of the genera *Ledella* and *Nucula* have been collected for genetic comparison of species located in other oceans. Tissue samples were taken from rat tail fish for comparison with material collected in the Atlantic by N. Merrett.

Three nemerteans were collected and fixed for taxonomic ascription by ADR.

A list of samples collected is shown in Table 14:

Table 14: Sample list

Station	Taxa	Score
12687/2	*Limopsis tenella*	120
	Grenadier	4 (tissue sample)
12689/1	Spionid polychaete A	23
12690/2	Spionid polychaete B	13
12691/1	Nemertean	1
12696/1	Spider crabs	200
12697/1	Spider crabs	46
	Amygdalum (?) *politum*	120
12701/1	Spider crabs	100
12702/1	*Munidopsis* sp.	300
	Grenadiers	6 (tissue sample)
	Red prawns	120
	Anemone sp.1	109 (tissue sample)
	Anemone sp.2	7 (tissue sample)
	Anemone sp.3	9 (tissue sample)
12707/1	Spider crabs	18
12708/6	Nemertean	1
12709/1	*Ypsilothuria* sp.	10
	Synaphobranchus sp.	2
12710/2	Nemertean	1
12714/1	*Munidopsis* sp.	200
	Red prawns	125
	Grenadiers	59
12719/1	*Limopsis tenella*	120
	Brotulid (fish)	1 (tissue sample)
12730/2	*Limopsis tenella*	55
	Ledella sp.	116
	Nucula sp.	100
12731/1	Spider crabs	37
	Pelagic crabs	70
12733/1	Spider crabs	140

Scheltema, A.H.

APLACOPHORA

Aplacophora have not been reported before from the Arabian Sea, and few (both in numbers and numbers of species) from the Indian Ocean far further to the south. Thus, the finding of Aplacophora between 84 and 3400 m off the coast of Oman significantly increases our knowledge of the zoogeography of this molluscan class, which is common and sometimes abundant in other areas of the world ocean.

The R.R.S. *Discovery* 211 collections include 162 specimens and 9-10 species distributed among 6-7 genera and families. They were taken between 84 and 3,400 m depths as follows: 84, 900, 972, 1265-1344, 3150, and 3,382-3,400 m. Although samples are not yet sorted, cursory examination of surface sediments revealed no Aplacophora in box cores from oxygen depleted depths between 400 and 900 m. It is hypothesized that inability to secrete their aragonite spicules may be partly responsible for their seeming absence from the least oxygenated depths. All species examined alive showed a bright pinky red colour denoting the presence of haemoglobin, a situation also noted in many bivalves from this area.

At 3,000 m, the aplacophoran species are more diverse than at equivalent depths in the Atlantic, with 6 species represented. One of these, belonging to the family Prochaetodermatidae, is abundant, not unusual for this family, for of all Aplacophora, it has many attributes of an opportunistic species. Unusual, however, is its abundance at depths greater than 2,500 m. The most numerous aplacophoran from 3400 m is a new species belonging to the genus *Rhabdoderma*. It is closely related to two other southern hemisphere species, one from off southwest Africa, the other from off southeast Australia.

Several specimens of Prochaetodermatidae have been frozen for molecular genetic analysis of the 18s rDNA segment. This analysis will be the first for the subclass Chaetodermomorpha, and should add importantly to our understanding of the phylogenetic position of Aplacophora within the Mollusca. Two species have been fixed in glutaraldehyde for TEM studies, generally lacking for the Aplacophora.

Smallman, D.

BENTHIC LANDER DEPLOYMENTS

(All times GMT. Local time = Z+4 hrs)

After successful wire trials of both transponders (11.5 and 13.5 kHz), and the associated releases, to a depth of 3,300 m, locations for the initial deployments were considered. Of the three deployments undertaken the first two at 70 m and 100 m were made with attached lines such that for safety reasons the lander was buoyed at the surface. The final deployment was to a depth of 400 m without a surface safety/life line.

Lander Deployments

1) Deployment at R.R.S. *Discovery* Station 12689#2 on 19° 49.37'N, 58° 23.71'E
Time of deployment, 0812 hrs 21 Oct. 1994
Bottom depth, 70 m
Sea state, slight; wind about 7 knots
Visibility, 11 miles

The lander was contacted acoustically for recovery at 0905 hrs 22 Oct 1994. Both transponders replied, indicating a distance to the lander of approx 400 m. The command signal was given utilizing the 11.5 kHz system (the back up system was not used). The lander surfaced, being easily observed from the ship by means of its two surface marker buoys, and was grappled and recovered inboard by 0940 hrs.

A number of problems in the functioning of the system emerged from this deployment:
a) Although all of the releases fired, one weight had caught itself in its holding bracket, a square shaped design. To remedy this fault all the brackets were cut into a U-shaped type design. However, the recovery showed that the lander was sufficiently buoyant to rise to the surface even with one of it's three weights still attached.
b) A problem with the benthic chamber lid was evident, whereby the pressure of water through the open chamber forced the lid backwards to such a degree that the power supply to the top of the lid stirring mechanism was interfered with causing additional problems with the electrical systems to the sampling syringes. This problem was alleviated by the incorporation of a 45° angled bracket to the chamber frame to stop movement of the lid beyond this angle.
c) Repositioning and reorientation of the camera system was considered to be necessary to allow a better view of the chamber, although a reasonable video of this deployment was obtained.
d) The burn wire release seemed not to be operating. To replace this, a counter-weight type system was devised with the help of the RVS technicians in order to allow lid closure on lander contact with the sea bed.

After the alterations summarised above were made it was considered that the lander was ready for us to proceed with a further deployment.

2) Deployment at R.R.S. *Discovery* Station 12703#1 on 19° 22.34' N, 58° 11.42' E
Time of deployment, 0450 hrs 25th Oct
Bottom depth, 103 m
Sea state and wind, calm

The lander was contacted acoustically at 0655 hrs 26th Oct. Both transponders replied, indicating a range of 600 m. The lander was given the command signal again utilizing the 11.5 kHz system (the back up system again was not required). The lander surfaced, was easily observed from the ship, and was grappled for at 0719 hrs and was inboard at 0745 hrs. One of the lander weights had not fired. This was later found to be caused by a wire being disconnected from the firing mechanism in the retractor. The wire presumably having become unattached during the closure of the retractor assembly. All but one of the other lander systems worke, the only exception being that only 6 of the ten syringes had taken a sample. This was attributed to constrictions in the tubing owing to air pockets. Assembly of the syringe in future deployments should be completed whilst completely submersed in Milli-Q water. Owing to this success it was felt that a deployment without the lifeline could now be safely achieved.

3) Deployment at R.R.S. *Discovery* Station12717#1 on 19° 21.93' N, 58° 15.44' E
Time of deployment 0502 hrs 31st Oct. 1994. A stray line with two glass spheres in orange "hardhats" was attached to the lander frame
Bottom depth 396 m
Sea state, slight to moderate with a maximum wind strength of Force 4
Visibility, more than 11 miles

The lander was contacted acoustically at 05.50 on 1 Nov., with both transponders responding perfectly and indicating a range of 900 m to the lander. This was in agreement with the distance of approx. 0.5 nm given by the bridge, *Discovery* being NW of the lander position. The ship's position was 19° 22.30' N and 58° 14.94' E at the time the command signal was given, after confirmation at 0630 hrs of the safest distance of approach from the bridge, using the 11.5 kHz transponder. During this time the ship was slowly moving towards the lander position. The lander was successfully interrogated over the next 10 minutes using the 11.5 kHz transponder, but thereafter all contact was lost. No contact was achieved using the 13.5 kHz transponder when this was also attempted. This indicated that the lander was at the surface (owing to the inability of the acoustics to work in air) and a visual search was maintained in order to detect it using a rota of lookouts posted at various positions around the ship. A surface current of 1.0 - 1.5 knots was evident during the whole of the search period. The following positions were recorded during the search of the lander over the first 24 hours. Time, 0800hrs 1st Nov., 19° 22.30' N, 58° 16.00' E; time 1000 hrs , 19° 20.20' N, 58° 16.00' E; time 1100hrs, 19° 19.98' N, 58° 14.14' E; time 1200 hrs , 19° 17.57' N, 58° 15.54' E. This took into account the drift of the lander. The search was finished at 1323 hrs. 31st Oct. This search included a 0 .5 mile grid extension survey as requested by the principal scientist. This search included periods in which the transducer was deployed to interrogate the acoustic deployments, particularly the angle to which was extended to the proposed lander position. During this time several sightings of the lander were reported; however, none proved conclusive when investigated by altering course or heaving to. The search was called off at sunset. The search was resumed on the morning of the

1st Nov. This included a survey SSW of the original lander position, on the basis of estimated downcurrent drift, which extended to a position 19° 04.50' N, 58° 04.50' E. This continued until 1043 hrs on the 1st Nov when a circular interrogation of the lander deployment site was made (19° 21.76' N, 58° 14.99' E) at positions of 0.3 and 0.5 nautical mile radii from the site. This utilised continuous soundings from the PES fish, in the hope that any angular discrepancy might be disregarded. Again no communication between the the acoustic unit and the lander was achieved.

The lander deployment site was finally dragged using an Agassiz trawl frame, from 0235 until 0830 hrs 2 Nov. No contact with the lander was made. However, large amounts of old wire were recovered wrapped around the trawl. It is considered that, under the circumstances, the most likely event was that the lander did surface but was not observed initially, perhaps because incomplete ballast release made it too low in the water, and that it then escaped detection by being carried away to the SW in the strong surface current.

Wolff, G.A.

ORGANIC BIOGEOCHEMISTRY

Aims/Approach:

To determine the influence of benthic fauna on organic matter (OM) remineralisation/burial at various sites within, and below the oxygen minimum zone (OMZ) in the Arabian Sea. In particular, the organic biogeochemical study is concerned with the detailed molecular characterisation of surficial and sedimentary OM. The variability in the concentrations and distributions of biological markers can be useful in determining the extent of sediment reworking (Santos *et al.*, 1994). Hence, characterisation of free and bound lipids amino acids and sugars in surficial and deeper sediments will be undertaken on return to the UK.

Collection of samples:

Thirty two sediment cores were collected using the multicorer. The details of these are summarised in Table 1. Typically, cores taken for organic geochemistry were sliced as follows: surface material (*e.g.*. fluff, mudballs), 0-5, 5-10, 10-20, 20-30, 30-40, 40-50, 50-60, 60-70, 70-90, 90-110, 110-130, 130-150 mm. Samples were immediately frozen (-20°C), then freeze-dried. The dried samples were stored (-20°C) prior to transport. Frozen cores were also collected at all sites; these will be used for determination of water content of the sediments, sedimentology and, where possible, as additional replicates for organic geochemical studies.

At a number of stations, samples were collected for collaborative studies with other cruise participants (see below and Table 15).

Homogenisation experiment:

Recently, a method for collection of material for bacterial counts, nematode identification and quantification and for organic geochemistry from the same sediment samples has been developed by Liverpool University and the Natural History Museum. This has proved to be useful in studies carried out in the North Atlantic, therefore, a similar approach was adopted at two sites on the Oman Margin (Table 1). All samples will be worked up on return to the UK. Briefly, sediment cores were sliced to 50 mm in 10 mm sections. Each section was diluted with artificial sea-water to a known volume (typically 70 ml) and homogenised using a vortex mixer. A measured sample (1 ml) was taken for bacterial counts (DS, DML), whilst the rest of the sample was split equally for nematode extraction (ND, NHM) and organic geochemistry (GW, LU). The bacterial and nematode samples were preserved in formalin, whilst sediment for organic geochemistry was treated as for normal core sections (see above).

Other studies:

Sediment samples collected at the 820 - 860 m station were extremely rich in polychaete mudballs. Samples were collected in order to determine carbon, nitrogen and hydrogen contents, and for more detailed molecular studies which will attempt to determine the function of the structures. (In collaboration with Drs. Levin, Gooday and Hoover).

The abundance of gromids at 1250 m also provided an excellent opportunity to collect specimens for biochemical analyses. A detailed study of these unusual foraminiferans will be undertaken in collaboration with Dr. Gooday.

Reference

SANTOS V., D.S.M. BILLETT, A.L. RICE AND G.A. WOLFF (1994) Organic matter in deep sea sediments from the porcupine abyssal plain in the north-east Atlantic. I. Lipids. *Deep-Sea Res.*, ***41***, 787-819.

Table 15. Details of cores taken for Organic Biogeochemistry

Station No.	Depth (m)	Use/Fate
12708-7	106	Organic geochemistry
12708-3	106.5	Organic geochemistry
12708-5	107	Organic geochemistry
12694-1	120.5	Organic geochemistry
12693-1	196	Frozen
12692-1	384	Organic geochemistry
12690-1	389	Organic geochemistry, Homogenisation
12695-2	394	Organic geochemistry, Homogenisation
12695-2	402	Organic geochemistry, Homogenisation
12695-8	409	Organic geochemistry, Homogenisation
12698-3	422	Frozen
12699-1	552	Frozen
12704-1	673	Organic geochemistry, Frozen
12685-9	705	Organic geochemistry
12713-2	823	Organic geochemistry
12713-3	827	Organic geochemistry, Frozen
12711-3	833	Organic geochemistry
12715-2	857	Mudball study
12705-1	912	Frozen
12718-3	981	Organic geochemistry
12718-1	983	Organic geochemistry
12706-1	1002	Frozen
12723-5	1252	Organic geochemistry
12725-3	1254	Organic geochemistry, Gromid biochemistry
12725-5	1255	Frozen, Gromid biochemistry
12723-3	1268	Organic geochemistry
12725-1	1296	Organic geochemistry, Gromid biochemistry
12728-1	1629	Organic geochemistry
12687-8	3384	Organic geochemistry
12687-3	3392	Organic geochemistry, Homogenisation
12687-5	3393	Organic geochemistry, Homogenisation
12687-10	3397	Organic geochemistry, Homogenisation, Frozen