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CRUISE REPORT No. 42

RRS *CHARLES DARWIN* CRUISE 143
22 NOV - 20 DEC 2002

SCHEHEREZADE II:
Geological and biological surveys of the Arabian Sea
and the continental slope of Oman

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2003

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ABSTRACT

This 28 day cruise was planned to investigate the geophysical and biological interactions in benthic environments in the Gulf of Oman and north-western Arabian Sea. The main objectives of the cruise were to produce a map of the bathymetry of the area and to investigate the geological processes that are, and have in the recent past been, active and look at the influence of the benthic community and activity on sediment acoustic properties.

In fact the topography of the study area was vastly different to that indicated on the GEBCO or gravity-derived bathymetry maps, which had indicated a generally smooth continental slope running parallel to the coast. The reality was that this part of the Oman margin is highly incised by numerous submarine canyon systems, some of which are 4km in width in mid-slope and hundreds of metres deep. Thus the cruise objectives were modified slightly to incorporate an investigation of the influence of the canyons on the fauna and the Oxygen Minimum Zone (OMZ).

Following successful EM12 multibeam mapping and the production of both contours and acoustic backscatter maps, over 120 stations were occupied to help us characterise the interactions between the biota and sediments, station work included intensive sampling of one transect in the north of the area and a comprehensive southern sampling transect for comparative studies. High resolution geophysics and photographic stations were also undertaken. Virtually all of the interpretive work will be carried out post-cruise.

ACKNOWLEDGEMENTS

We gratefully thank the Government of the Sultanate of Oman for permission to work in their territorial waters.

KEYWORDS

AGASSIZ TRAWL, ARABIAN SEA, BATHYMETRY, BENTHIC COMMUNITIES, BIOLOGICAL SURVEYS, *CHARLES DARWIN*, CRUISE 143 2002, CTD OBSERVATIONS, EM12, GEOLOGICAL SURVEYS, KASTEN CORER, MEGACORE, MINI PROFILER VEHICLE, MPV, MULTIBEAM SURVEYS, OMAN GULF, OXYGEN MINIMUM ZONE, PISTON CORING, SCHEHEREZADE II, SHRIMP, SOUND VELOCITY PROBE, SVP

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ABSTRACT

This 28 day cruise was planned to investigate the geophysical and biological interactions in benthic environments in the Gulf of Oman and north-western Arabian Sea. The main objectives of the cruise were to produce a map of the bathymetry of the area and investigate the geological processes that are, and have in the recent past been, active and look at the influence of the benthic community and activity on sediment acoustic properties.

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	Leg 1	Leg 2	Affiliation
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CDSP = Challenger Division for Seafloor Processes

GDD = George Deacon division for Ocean Processes

UKORS = United Kingdom Ocean Research Services

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P Gauld	Chief Officer
P Oldfield	2nd Officer
T Owoso	3rd Officer
K Jethwa	Chief Engineer
A Greenhorn	2nd Engineer
A Healy	3rd Engineer
J Harnett	3rd Engineer
S Corbett	ET Officer
D Hewison	Engineer Cadet
G Pook	CPO (D)
K Luckhurst	PO (D)
P Allison	Seaman
J Dale	Seaman
T Edwards	Seaman
I Thompson	Seaman
P Searle	PO (MM)
C Perry	SCM
P Lynch	Chef
A Duncan	A/Chef
P Robinson	Steward

ITINERARY

RRS Charles Darwin Cruise 143

Leg 1

Sailed Port Sultan Qaboos	22nd November, 2002
Arrived Port Sultan Qaboos	1st December, 2002

Leg 2

Sailed Port Sultan Qaboos	1st December, 2002
Arrived Port Sultan Qaboos	20th December, 2002

CRUISE OBJECTIVES

This cruise was planned to investigate the geophysical and biological interactions in benthic environments in the Gulf of Oman and north-western Arabian Sea. The Gulf of Oman and Straits of Hormuz contain a diversity of environments and are therefore ideal locations for the simultaneous study of a variety of physical and biogeochemical processes. The Gulf of Oman experiences a pronounced monsoon regime, with the NE monsoon season occurring between December and March, and a reversed SW monsoon from June to September. Strong winds, particularly associated with the SW monsoon, induce upwelling of nutrient rich water that sustains high primary and heterotrophic production. The substantial heterotrophic biomass and the associated high biological oxygen demand are responsible for the formation of an oxygen minimum zone (OMZ) which is believed to extend from approximately 100 m to 1,000 m water depth and which has a profound effect on biological and geochemical processes occurring in both the water column and sediments.

The main objectives of the cruise are to:

- Produce a map of the bathymetry of the area and understanding of the geological processes that are, and have in the recent past been, active.
- Determine the influence of benthic community structure and activity on sediment acoustic properties.
- Investigate the interrelationships between seafloor sedimentary, geochemical and biological processes in the Gulf of Oman and northern Arabian Sea, and their influence on sediment acoustics.
- Characterise down-slope mixing and dispersal of the outflow from the Arabian Gulf into the Gulf of Oman and its influence on the OMZ and biogeochemical processes in the water column.
- Investigate the influence of hydrography and bottom-water stagnation on the distribution, genetic diversity and trophic biology of the benthic biota.

In fact the topography of the study area was vastly different to that indicated on the GEBCO world bathymetry maps, which had indicated a generally smooth continental slope running parallel to the coast. The reality was that this part of the Oman margin is highly incised by numerous submarine canyon systems, some of which are 4 km in width in mid-slope and hundreds of metres deep. Thus the cruise objectives were modified slightly to incorporate an investigation of the influence of the canyons on the fauna and the OMZ.

EM12 Survey Plan

The objective of the.EM12 survey was to try and produce highly detailed bathymetry and acoustic reflectivity maps, with, if practicable, 100% coverage of this rather poorly known area. It was planned that a preliminary interpretation of the data would be undertaken during the cruise, so that results could be used to guide and direct the video, sampling and high resolution sidescan sonar surveys that will be carried out during Leg 2. To this end, preliminary image processing was carried out on board, producing bathymetric contour and acoustic reflectivity maps at an appropriate scale.

Data annotation

All data was recorded with reference to GMT and Julian day numbers.

CRUISE NARRATIVE

All times are GMT (local time = GMT +4). The technical details of the various gear used during the station work will be developed in more detail in the appropriate technical report section, this narrative will deal simply with the timing of events and where appropriate the scientific rationale behind decisions.

Thursday 21st November (Day 325)

After waiting on the quayside for an hour or so at Port Sultan Qaboos for the vessel to dock at the end of the passage from Cape Town, the science party joined the vessel at 0800 and began to mobilise and install the laboratory equipment.

Friday 22nd November (Day 326)

The opportunity to sit the piston core bomb in its bucket was taken whilst the vessel moved off the quayside to the bunkering station. However, a hydraulic hose on the core stand failed and this had to be replaced before the bucket could be correctly stowed. Prior to sailing the Master and First Officer gave the scientific party a safety briefing. The vessel sailed form Port Sultan Qaboos clearing the breakwater at 0933, and then making best possible speed to a deep water (ca. 3,000 m) site for a Sound Velocity Probe (SVP) dip prior to running the calibration lines for the EM12 multibeam system. Both a fire and a boat drill were held at 1215 during passage. At 1225 the vessel hove to for deployment of the SVP, however a brake on the hydro winch was stuck on, and had to be stripped and repaired before the station could begin. Station 55701#1 was started at 1429 and completed at 1716 in ca.3,150 m of water. By 1823 the 3.5 kHz fish was deployed and the system was logging[1]. However, the only software that worked for the 3.5kHz system seemed to be an old version that logged the data to ZIP disks (instead of the profiler data being logged directly to the workstation hard drive in the computer room as had been the case on previous cruises such as CD126). After deployment of the 3.5 kHz fish the vessel was manoeuvred and the first EM12 calibration line begun at 1940.

Saturday 23rd November (Day 327)

The last EM12 calibration line was completed and the vessel steamed to the start of Line 1A, which was begun at 0508, at a speed of 8.0 knots. (NB. the derived calibration values for the EM12 were Roll = +0.8°, Pitch = 0°). At 0737 the 3.5 kHz system was stopped as there was no time stamp being written to the data. After 2 minutes this fault was rectified and the system re-started. Survey line 2 was terminated 1 nautical mile early due to local fishing

[1] Upon arrival in Port Sultan Qaboos it was noted that the 3.5 kHz system was not actually wired up on deck and this had to be undertaken during the remainder of the port-call and transit to the work area.

activity and at 2112 the 3.5 kHz had to be re-started due to problems with the disk drive accepting a new ZIP (something that was to happen at irregular intervals throughout the cruise).

Sunday 24th November (Day 328)

Surveying continued without incident until 0154 when the vessel had to deviate from the planned track line for 30 minutes to avoid a local fishing vessel. At 1927 it was noticed that the 3.5 kHz logging clock (DOS clock) was out of synchronisation. It had started to advance at approximately 3+ times normal speed. Despite re-setting the DOS clock, the problem persisted. Puzzlingly the clock was apparently stable and OK until the Start of Line 5. Therefore the problem began between 1935 and 2327. After two more re-sets, the DOS clock seemed to be behaving itself again and logging was re-started (again the loss of time synchronisation was a problem that occurred at infrequent intervals throughout the cruise). Also the 3.5 kHz data were at times extremely noisy, although once the vessel altered course much of the noise disappeared suggesting that this may be due to a "speed through the water" problem.

Monday 25th November (Day 329)

At 0600 it was noted that there appeared to be a systematic 40° offset in the gyro reading, such that instead of the ship's head being 180°, the EM12 was logging and displaying the bathymetry as though the ship was heading 140° but with a 180° course over the ground, which was most definitely not the case. It should be possible, using the PRISM software, to replace the logged heading value with that of the ships course made good, but it is not yet known if this can be done using the Neptune processing system. As the data that we were collecting could still be used, it was decided to carry on with the survey plan. The EM12 was powered down and re-started at 0624, but the offset was still present. A hardware fault is suspected and investigations were ongoing. At the start of Line 8, the new line heading of 000° was being logged by the EM12 as 320°. By 1200, following some investigation of various parts of the hardware, the EM12 system was once again using the correct heading data, although the technicians did not actually find any faults that they could repair and identify as the cause of the problem. By 1900, it was noted that the EM12 had once again lost the ships heading. Looking back at the previous data it has been noticed that this may actually have happened 3-4- times previously, but as it occurred only on very short transit legs between survey lines the error wasn't picked up. The technicians now seem to think that the NMEA coding output from the gyro may be the problem, possibly due to a fault somewhere in the "Level A" system, and this is being looked at.

Tuesday 26th November (Day 330)

Due to the continuing problems with the EM12 gyro readings (the gyro was out again at 0345 after the turn to start Line 13) all the gyro repeaters around the vessel were disconnected to see if it was a “loading” problem (i.e. too many repeaters being driven by a single source), but this did not have the desired effect. At 0732, the start of Line 15, EM12 was reading ca.180° instead of approximately 000°, which means that it may now prove very difficult to determine exactly when the system is running correctly. This was the time to examine whether or not to carry on using the swath or switching to sampling whilst a solution to the swath gyro problem is found. Meanwhile the technicians began to dismantle various components along the route of the gyro feed circuit to yet again see if they can rectify the problem. By 1145 the gyro hardware had been dismantled and re-assembled and the EM12 gyro logging seemed to be following quite closely the indicated vessel course. At the end of Line 16B there was a loop turn rather than a simple turn to port to see how the gyro follows the course of the vessel. By 1241 the loop turn was completed and the test of the gyro seems to have been a success. It would seem that the dismantling and re-assembling of the gyro circuit had done the trick, as there were no components or software items that could be identified as “either being faulty or the culprit”. A close watch will have to be kept on the system and the problem must be fully investigated hopefully for this cruise but also for the benefit of the next cruise. The EM12 survey continued without incident.

Wednesday 27th November (Day 331)

At 0110 the EM12 survey was suspended to begin the first of the piston cores stations. This station (55702#1) was located on a well sedimented spur mid-way up the continental slope to obtain a good pelagic section away from the direct influence of any northward-flowing (Antarctic) bottom water. The corer was launched at 0330 and safely recovered at 0443, after which the vessel resumed the EM12 survey at 0534. At 0950 the Master required that the survey speed slow to 5 knots as the vessel was operating in what he considered poorly charted shallow waters (< 100 m). By 1014 after altering course to move the vessel slightly offshore the water depth had increased to >100 m and the survey speed was once again increased to 8 knots. After completing the EM12 survey along Line 30, the vessel moved to the second of the piston coring sites, 55073#1, located on the upper slope with the hope of obtaining a long pelagic section that may contain influences from the Arabian Gulf outflow. In such shallow water the corer was recovered by 1844 when the EM12 was re-started and the vessel moved off to begin Line 31.

Thursday 28th November (Day 332)

The EM12 survey progressed without major incident, the 3.5 kHz logger requiring a re-start at 1000. By 1136 however the 3.5 kHz profiler records had become so noisy as to be unreadable, and the vessel speed was slowed to 7 knots over the ground (8.2 knots through the water). The record cleared significantly and so speed was gradually increased to 7.5 knots at 1217, and then back to 8 knots at 1455 just after starting Line 35.

Friday 29th November (Day 333)

After completing Line 38 at 0900, the vessel moved to site 55074#1. Here the piston corer was deployed to obtain a deep water (>3,100 m) section that may contain overbank deposits from the adjacent channel mouth. This channel mouth is formed at base of a very distinct canyon, which, at the foot of the continental slope has changed from a broad (2-3 nautical miles), deep (>500 m) slope orthogonal canyon, to a channel that would probably discharge any load in a northerly direction (on the slope the canyon had a very distinct north-easterly orientation). During the coring operation the 3.5 kHz fish was recovered to try and identify any mechanical or electrical sources of the very noisy records that we were getting. Upon recovery of the fish, it was found that most of the fairing had torn itself to pieces. The rubber of the fairing being very weak, speculation was that it seemed as though the rubber had perished, possibly due to it being sat in the sun on deck for extended periods. Once the piston corer was recovered and the samples stowed, station 55074#2 was occupied. This was a CTD station so that we would have an accurate oxygen profile upon which to base initial planning of the biological sampling sites. On recovery, water bottles were fired at 3140, 3028, 2524, 2021, 1520, 771, 522, 272, 125, 75 and 2 metres. The day finished as it had begun with a resumption of the EM12 survey.

Saturday 30th November (Day 334)

The day began with the completion of the deepest EM12 lines that would be run during the first leg of the cruise. The rest of the day was taken up by three piston core stations and the steaming between them en-route into Muscat for the end of the first leg. At 0520 after the completion of Line 41, the vessel moved onto Station 55705#1 for a piston core site south of the headland of Ra’s al Hadd which will hopefully give a good pelagic section showing what, if any, influence northward flowing bottom waters have had on the sediment deposition. Station 55706#1 was taken on the mid-slope area to the northeast of Ra’s al Hadd and will hopefully show the effects of both northward flowing bottom water and southerly flowing Arabian Gulf outflow. The final piston core station 55707#1 was taken on the upper slope to investigate what sediments (if any) were being transported across the narrow continental shelf as opposed to being funnelled straight down one of the many canyons that dissect the shelf. However, this final station was not quite as successful as al the others in that the bottom barrel was bent and less than 0.4 m of a partly washed out section was recovered (along with a catch sample). Following the coring stations the EM12 was re-started and “fill-in” lines were occupied en-route to a planned CTD station located approximately 9 nautical miles offshore Muscat.

Sunday 1st December (Day 335)

At station 55708#1 the CTD was launched at 0241 and water samples collected at depths of 400, 211 and 20 metres to investigate the influence of Arabian Gulf outflow at the northernmost extremity of our survey area. The CTD was recovered at 0255 and course made for Port Sultan Qaboos. The Pilot was aboard by 0356 and the vessel secured alongside by 0430. This was the End of Leg 1.

During the port call the piston coring gear was discharged ashore to make space for the launch and recovery of equipment during Leg 2, scientific personnel were exchanged, and fresh water supplies and air freight taken.

The vessel sailed on Leg 2 at 1200 and was clear of the harbour by 1220 when preparations began to launch the Widescan fish (for continuity with SOC Biological Protocols these, and subsequent, deployments were each given a station number, 55709#1 etc.). The Widescan was launched at 1235 at 1 knot, which was increased to 3 knots. However the fish was crashed into the seafloor with far too much cable out (depth = ca. 65m, cable = ca, 225m). The fish was recovered, repaired, and re-launched, however the wire-out meter started to read backwards. Thus upon trying to haul, due in part to inaccurate wire out readings and a partially obstructed view, the fish was hauled out of the sea and up into the towing block, causing significant damage to the towfish. It was later inferred that the problem with the cable meter reading backwards was probably due to the proximity of the signal cable being adjacent to the electrical power cable that powered the Widescan winch. With this setback plans were modified to continue surveying a large canyon off Muscat with the EM12, and the 3.5 kHz fish was redeployed at 1508. In order to fulfil one of the main aims of the project (looking at how biology affects geoacoustics), it decided that where required we would attempt to always take either Kasten or Plastic barrelled gravity cores at the same sites as megacores were obtained. Where this was not the case, the one of the meagacore sample tubes would be held or sub-sampled for geological work.

Monday 2nd December (Day 336)

The EM12 survey of the large canyon systems offshore Muscat were completed by 0600, and the vessel headed for the first station on the northern biological transect (Fig X). The USBL probe was lowered at 0825, but despite repeated attempts, the USBL could not be successfully used. Efforts to try and rectify this were ongoing. One megacore was taken at location ‘S3’, 4 attempts were required in the very soft sediments at location‘S2’, and two attempts in the sandy sediments at 'S1'. At 1800 the vessel moved to approximately 1 nautical mile northwest of 'S3' for the first SHRIMP run of he cruise, however the brake on the conducting winch failed. By 2100 the problem had been diagnosed as a faulty solenoid control valve and this was remedied by using a similar valve from the 6 mm hydro winch. Following this repair the fibre-optic termination was load tested as the vessel moved back to 'S3' where a Kasten Core was taken at 2308.

Tuesday 3rd December (Day 337)

The vessel then transited to 'S2' where another Kasten core was obtained, after which Site 'S1' was occupied and 4 attempts made to recover a good sand sample using just a 1 m barrel on the Kasten core. The longest sample recovered was just 15 cm plus the cutter sample. Following the corer operations the vessel moved back to the SHRIMP launch site to the northwest of 'S3' and the system deployed at 0608. After 2 hours and 15 minutes on the seafloor the vehicle was recovered. During this run the floodlights had failed repeatedly, and this was investigated once the system was recovered. After SHRIMP was recovered, he vessel offset to the south into the adjacent canyon. Here one megacore was taken at site 'C3'. three (all overfilled) megacores taken at site 'C2', whilst at 'C1' no samples were recovered, the core tubes being either broken off or badly damaged. Following the megacoring, the new Plastic barrelled gravity corer was used for the first time. Unfortunately the first sample recovered was lost on deck, and of the four other deployments on this evening, three recovered sediment.

Wednesday 4th December (Day 338)

The day began with one Plastic gravity core followed by a Kasten core and two megacores. At 0700 after almost 24 hours of intermittent though futile testing and trials, it was decided to raise the USBL probe so that transit times between stations could be increased. After the probe was recovered a further Kasten core was taken and then the CTD was deployed. Between 1215 and 1255 an emergency drill and muster station was held. Following recovery of the CTD, SHRIMP was again deployed for a traverse across the canyon floor, followed by a further Kasten core deployment, however, on this occasion there was no recovery.

Thursday 5th December (Day 339)

The Master had insisted that all Widescan work be conducted during the hours of daylight as he was given anecdotal evidence that there are many unmarked and unlit fishing nets deployed at night, especially inshore which is just where the Widescan targets were. Therefore following recovery of the empty Kasten corer, the vessel transited to the start of the planned Widescan survey area – the target of the Widescan was to try and see if we could map the heads of the submarine canyons, or whether they were all directly connected with the onshore wadis. By 0209 the fish was deployed and surveying begun. However, due to the very steep topography it was proving extremely difficult to follow the seafloor at the optimum altitude and at 0440 the fish crashed into the seabed. At 0450 the fish was recovered and the spare fish deployed at 0524. However it was proving very hard to keep the fish within 20 m of the seabed and so the decision was taken to fly higher than optimum for safety's sake. The Widescan survey re-started in earnest at 0606 and proceeded without further incident until darkness began to fall and the fish was recovered at 1348. After recovery the vessel steamed toward the southern transect off Ra's al Hadd, arriving at the 2,000 m isobath and beginning the CTD deployment at about 1810. Following the CTD station a megacore was taken at the same site.

Friday 6th December (Day 340)
Two megacores were taken at the start of the day, the second unsuccessful returning to the deck with 2 broken and 2 cracked core tubes. After this the EM12 was re-started and a shelf-edge survey begun at 0533. The Widescan was launched at 1137 though no seabed could be detected until 1207. Surveying continued until the system required a PC re-set at 1354, but within a minute there was a total loss of sonar data with what may have been seawater ingress into the cable or connectors. Therefore the survey line was terminated 1.5 nautical miles early, the fish recovered and the vessel moved to the 900 m contour for the start of the next SHRIMP site. At 1447 the EM12 logging was stopped and the SHRIMP deployment begun. At this station it was planned to tow SHRIMP from the 900 m isobath, upslope to 500 m, but at 2010 there was a power loss to the vehicle. After 11 minutes power was restored and the SHRIMP survey continued until 2244 when hauling began. After recovery of SHRIMP and a change of cable through the starboard gantry and Plastic Barrelled gravity core was deployed.

Saturday 7th December (Day 341)
After recovery of the gravity core that was deployed the previous night, a further gravity core and 3 Kasten cores were taken before the vessel moved onto station for the first of a planned 4 x 1/2 hour (on the seafloor) SHRIMP deployments. The first deployment of SHRIMP began at 0832 and the four deployments occurred with the only incident of note being a power loss problem between 1146-1230, SHRIMP finally being recovered at 1908. At 2030 the first Agassiz trawl of the leg was shot.

Sunday 8th December (Day 342)
After recovery of this first trawl at 0049 a second Agassiz trawl was shot at 0235 and recovered at 0645. Also during this time the 3.5 kHz PC "lost" its drive mapping and BIOS. This was fixed by 0610. The rest of the day was taken up with three further SHRIMP deployments, the system being recovered at 2208 and a Kasten core being deployed at 2325.

Monday 9th December (Day 343)

The first 2 Kasten stations of the day had excellent recovery of sediments, but at the third site, despite having 3 attempts, less then 1 m of sediment was recovered. The vessel then steamed back to the northern transect area and 7 megacore stations were occupied. Once the Megacorer was recovered from the last site the 3.5 kHz and 10 kHz fish were also recovered and at 2221 EM12 logging re-started to fill-in a data gap on passage toward Muscat for fresh water replenishment.

Tuesday 10th December (Day 344)

The EM12 fill in line was completed at 0143 and the vessel headed for the pilot station off Port Sultan Qaboos. The vessel was alongside and taking freshwater by 0436. By 0735 the vessel was away and had cleared the breakwater by 0747. The EM12 was re-started at 0822 and the 10 kHz and 3.5 kHz fish deployed by 0848. The Widescan was again deployed for a shelf-edge survey and the system was logging data by 1032. At 1207 Widescan logging ceased, the fish was recovered, the vessel increased speed to 8 knots and finished the EM12 survey at 1319. By 1357 the vessel was hove to for drift tests on the SHRIMP site, once the drift test was completed the instrument was deployed at 1458 in just 299 m of water. There were two further SHRIMP sites completed during the rest of the day.

Wednesday 11th December (Day 345)

The SHRIMP was recovered from the final site of yesterday by 0040 and the Agassiz trawl deployed at 0126. However, the trawl was recovered to change the wire run and re-deployed (same station number) by 0242. After a successful catch the trawl was streamed twice more but became fouled on the seafloor at 0758 with approximately 400 m of wire out. The vessel was slowly dropped astern and after some excellent manoeuvring by the Second Officer, the trawl was freed from the seabed and recovered at 0912. Following the trawl recovery the vessel was repositioned to continue the EM12 and Widescan survey of the shelf edge along this important part of the northern biological transect, with the fish deployed at 1018. However, despite numerous system re-sets and checking of the towfish, we could not get any sonar signals recorded and so the Widescan was recovered at 1055 and the survey continued using just the EM12 until 1431. The rest of the day was used to occupy a downslope transect of seven consecutive megacore stations.

Thursday 12th December (Day 346)

The morning was taken up by a series of Kasten and Plastic Barrel gravity cores. The first three stations were successful, but upon recovery of the second Plastic Barrel gravity core of the day, the barrel was missing! The final two Kasten cores of the morning were also failures, both being recovered empty. The dynamometer record suggested that the corers probably fell over and didn't penetrate the seafloor, this lack of penetration may have been due in large part to the fact that we were attempting to core inside broad flat-floored canyon and may have hit cobbles or pebbles. During the afternoon two SHRIMP runs were undertaken. During the first run there were indications that the 35 mm still camera was not operating correctly, so upon recovery this was investigated. Whilst this camera "surgery" was undertaken, the conducting cable and MPV were successfully tested (the MPV has been upgraded since last used at sea). After the successful MPV test and the clearing of the 35 mm still camera, SHRIMP was launched for its second deployment of the day, however this was terminated earlier than planned as indications were that the 35 mm still camera was still not operating correctly. Two excellent megacores were recovered during the evening.

Friday 13th December (Day 347)

The first two stations of the day were both Agassiz trawls, which were followed by two further SHRIMP runs. Following recovery of SHRIMP after completion of the second run at 1526, the conducting cable had to be re-routed from the starboard gantry through to the aft A-frame for towing the MPV. This procedure in fact required the whole termination module to be stripped as the actual stainless steel pressure vessel housing for the fibre-optic termination was too large to pass through the cable sheaves. Whilst I am sure there will be a number of engineering reasons put forward for this, as a user it was very frustrating as it meant the loss of several hours of ship-time whenever instruments requiring different towing or deployment points are to be used with the fibre optic cable. I feel that with some advance planning in regard of the size and diameters of the shipboard cable sheaves this downtime could have been mitigated with a modified design for the termination pressure housing. Deployment of the MPV was begun at 1831 and the depressor weight went into the water at 1904. The system was deployed (at 0.5 – 1.0 knot) and the vessel increased to the survey speed of 2.5 knots as the cable was veered. The plan for the MPV was to survey down the northern biological sampling transect, into the northern canyon and then out into the probable fan-channel area to see if we could identify areas of active erosion or deposition.

Saturday 14th December (Day 348)

The vessel crossed the 'end of line' point at 0947 but surveying continued until the deep towed vehicle had also crossed the line (when the vessel was at the end of line point there was 5,422 m of cable out). By 1046 the vehicle had crossed the end of line point and hauling was begun, with the system being recovered by 1330. Upon recovery the vessel made for a deep water survey area, approximately 30 nautical miles northeast of Ra's al Hadd, that had been identified on Leg 1 as a possible area of deep fluid escape structures (based on 3.5 kHz profiles). The vessel arrived on station and deployment of the MPV was begun by 1840 and surveying begun by 2123. During this second deployment it was noted that the time stamp was out from the standard used on the ship. The difference was that the MPV logger clock was running FAST by 9minutes and 22 seconds. This will be important when using the data from run#1. The clock was re-set to the correct time at 19:11:15 GMT and the survey continued.

Sunday 15th December (Day 349)

The survey of the “fluid escape” area was completed and the vessel manoeuvred to complete a transect upslope crossing the southern biological transect sampling sites. The deep tow survey was completed by 1739 and the system was recovered and stowed by 1832 when the vessel steamed to the next (SHRIMP) station site which was over the “fluid escape” area. During the transit the fibre-optic termination was once again dismantled as the cable was re-routed through the starboard gantry. SHRIMP was deployed at 2238 after a drift test.

Monday 16th December (Day 350)

The SHRIMP station was completed at 0310 and the gear hauled, coming onboard at 0439. An Agassiz trawl was deployed at 0536 and reached the seafloor at 0741. The trawl was continued for just over an hour before hauling began and the net was recovered on deck at 1152. SHRIMP was deployed again at 1304 but signal problems forced a recovery of the system at 1322. Fault diagnosis suggested that a mis-feed on the winch wreathing gear was compressing at least two layers of cable leading to very high attenuation in the fibres. The solution advised and undertaken was to stream the cable at 6 knots to a length of ca. 6 km (which is where the attenuation problems appeared to be) to relive the stress on the pinch point and then carefully re-wind the cable ensuring that the layers were spooled correctly. At 1732 the cable streaming was underway and the operation was completed by 2225 with the “fault” cured. The cable was yet again transferred from the aft A-frame through to the starboard gantry, re-connected to SHRIMP and deployment completed at 2354.

Tuesday 17th December (Day 351)

This day was spent working entirely in deep water (> 3 km), which, due to the wire-time, severely cut the number of stations that could be occupied. The first SHRIMP site was located over a second part of the “fluid escape” area, and was completed by 0503. The vessel was then repositioned to the east in an area of similar water depth to see if seafloor conditions were the same as at the “fluid escape’ area, running the EM12 along the transit route. This second SHRIMP station began at 0820 and the gear was recovered and stowed by 1319. At 1720 the CTD was deployed in 3145 m of water and 12 bottles were fired as the system was recovered. An acoustic release was also attached to the CTD frame during this deployment for communications testing prior to deployment of the Roughsnap. The CTD was secured on deck by 2038. Another Agassiz trawl was taken in the “fluid escape” area

Wednesday 18th December (Day 352)

The first station of the day was a megacore where it was hoped to obtain a sample of what appeared from the SHRIMP video to be jelly lakes (decaying jellyfish) and bacterial mats. A Kasten core was also taken at this same site. Following the Kasten site the vessel transited to the south of Ra's al Hadd at a speed of 9 knots allowing collection of EM12 data along the transit route. The vessel hove to at the next station, and the Kasten corer was deployed at 1144, however upon recovery there was no sample recovered as the catcher doors didn't close. The catcher was cleaner and the corer re-deployed. After a successful sample the Megacorer was deployed at the same site. Upon recovery of the Megacorer the vessel moved upslope by approximately 7 nautical miles, which translated to a decrease in depth from 2,000 m to 1400 m. At the shallower site the sampling was reversed with the already rigged megacore being deployed followed by a Kasten core. The Kasten corer was recovered by 2006 and the vessel moved northwest to the final SHRIMP site, which was to act as a reconnaissance for deployment of the Roughsnap time-lapse camera system.

Thursday 19th December (Day 353)

The vessel arrived on station at 0500 and by 0510 the SHRIMP had been deployed in ca. 3,300 m of water. The system reached the seafloor at 0645 and undertook a near 3-hour survey, the vehicle being recovered aboard at 1108. The vessel then re-positioned itself and the Roughsnap was deployed at 1132 (this system is due to be left in situ until September 2003). Once the Roughsnap was safely on the seabed at 1240, the vessel was repositioned to try and get a core through any overbank deposits at the distal end of the northern study area canyon. The corer was recovered at 1520, by when there was only enough time left to undertake the final EM12 fill-in line on the transit back into Port Sultan Qaboos. Therefore the 3.5 kHz and 10 kHz fish were recovered and the vessel steamed to the start of the final EM12 which was begun at 1756 and completed at 2202.

Friday 20th December (Day 354)

The vessel passed the Port Sultan Qaboos breakwater at 0319, and was fast at the quayside by 0348. The samples and most of the Challenger Division equipment was loaded into a chilled container, along with a significant amount of the CTD gear for shipment back to SOC. Personnel departed the vessel at various times during the afternoon and evening, End of Cruise.

VESSEL NAVIGATION AND EM12 DATA PROCESSING

A track chart of the entire cruise can be found in Figure 1, which is superimposed upon the shipboard-produced bathymetry contours.

Navigation

There were several DGPS systems onboard. The data was transferred to the PRISM and ERDAS systems, and was unedited raw data. It was transferred in ASCII on a daily basis, in a format that was understandable. The data was then graphed by speed. It has been found that for high frequency data (such as one second sampling) the instantaneous speed is a very sensitive indicator of positional error. If the instantaneous speed is then compared with a smoothed speed value, this can be used to edit the dataset and remove spurious points. A second quality control was introduced when the positional change from 1 position to the next was less than 1 m. The 1 m value was chosen to be within the nominal accuracy of the system. Once both these checks were passed a graph of speed and heading (against time) was created to verify the authenticity of speed (e.g. 8 knots) and heading values. Finally the data was reduced to one minute positional values using a 61 second low pass filter. All data gaps were linearly interpolated. The largest gap in navigational data loss was about 10 minutes, but fortunately this was relatively unusual. As the ship was generally travelling in a straight line and at a constant speed, this interpolation was considered insignificant.

EM12 Backscatter Data

The EM12 acquisition system archives its data in a single file (usually one per hour). This “raw.all” file holds bathymetric, sound velocity, positional, and backscatter data. An extraction program (available solely on a Sun workstation) can read this format and create NetCDF files for processing with the PRISM software. The NetCDF files can either hold backscatter or bathymetry data. The files also contain position and time information. The resulting data is then checked. The main test is the contiguous nature of the time code. If timing errors were found the data was either corrected (preferably) or erased. The NetCDF files were then transferred to a LINUX system (Red Hat LINUX 7.3 on a 1.3 GHz PC) as this system was considerably faster than the SUN workstation available onboard.

The next step in PRISM data processing is the configuration. This defines the processing steps required for a particular data type. Data characteristics vary from one acquisition system to the next and so often have to be specifically defined. The set up for *RRS Charles Darwin* EM12 backscatter data was defined as:

```
mrgnav -i %1 -o %0 -n navfile.nav -l 0,0
filter -i %1 -o %0 -b 1,21 -z -v 130,255
```

```
filter -i %1 -o %0 -b 1,301 -h -v 130,255
filter -i %2 -o %0 -b 31,301 -L -v 130,255
wtcombo -i %2 , %1 -o %0 -c 1,1 -a -128
restorehdr -i %1 -h %5
resol -i %2 -o %0 -r res
sshead –i %1 –o %0 –a 5.0
shade -i %1 -o %0 -n 128 -t 1,254
```

To explain this in sonar terms (in order):
Merging of ship navigation with the imagery, assuming difference between the ship position and transducer array is zero. The 'navfile.nav' file contains ship position. This supersedes the positional data already recorded in the NetCDF files as the new data has been corrected.

Low pass filter of the imagery, taking a kernel of 1 line (ping) by 21 pixels and filling any zero pixels (i.e. those with no data) with a value from the surrounding pixels. Only valid pixel values are used in the calculations. Valid pixels have values between 130 and 255.

High pass filter of the imagery, taking a kernel of 1 line by 301 pixels. The average of the kernel is subtracted from the central pixel value and resulting value stored. This measures the pixel variation along the line and removes any DC shift. Only valid pixel values are used in the calculations. Valid pixels have values between 130 and 255. The results are biased by adding 128 (to keep the range of values between 0 and 255).

Low pass filter of the imagery taking a kernel of 13 lines by 301 pixels and filling all pixels with an average value. This measures a regional backscatter variation. Only valid pixel values are used in the calculations. Valid pixels have values between 130 and 255.

Weighted combination of the high and low pass filters by addition of pixels and subtraction of 128.
i.e. $X_{new} = 1 * (Average_{large\ area}) + 1 * (X_{old} - Average_{line} + 128) - 128$
This reunites the high and low frequency filtered data, having removed line dropouts and filled any holes in the imagery.

Restore the header sidescan information to the weighted combination file, as the filter process removes the sidescan information embedded in the NetCDF file.

Reduce the resolution of the imagery to the required value. If fewer pixels are required in the output resolution than is available in the input resolution, the data is averaged. This increases signal-to-noise ratio.

Check the vehicle heading in comparison with the track heading. If the difference is more than 5.0° use track heading. This was useful when the ship gyro data was 'stuck'.

Across-track equalisation of illumination on an equal range basis. This assumes that the backscatter from a particular range should normalise about a given amount (in this case 128) for each piece of data. The near-range pixels and far-range pixels are generally darker than mid-range pixels. This is due to the transducer's beam pattern and differences in seafloor backscatter response in terms of angle of incidence. The result of this is to amplify the near and far-range pixels by about 1.2 and reduce the mid-range pixels by 0.9. These values are calculated from each individual data segment being processed. Only valid pixel values are used in the calculations. Valid data have values between 1 and 254.

The processing command PRISM was applied with a resolution of 20 m and a maximum course deviation of 45°. Processing usually took about 3 minutes, but was dependant on the amount of data present in and near the box. The imagery results were stored in an intermediate format (LAN) file, which was then transferred to the PC Windows disk partition (rather than the LINUX disk partition – both being on the same PC). This was because ERDAS Imagine™ is not available under the LINUX operating system. The ERDAS Imagine™ software is a powerful image processing package. Within the ERDAS environment, many techniques and processes have been created by SOC to handle sidescan sonar imagery, backscatter imagery, and bathymetric grids. A key reason for utilising ERDAS Imagine is its viewing capabilities and map composition functions, in addition to many standard image processing techniques.

The processed imagery (LAN) was imported into ERDAS Imagine's format and viewed. As much of the far range imagery overlaps the imagery of the next parallel track, the data is displayed in several layers thus retaining all the data. Switching between the different layers allows the interpreter to see and decide which data to retain and which to delete. Generally the user chooses a median line between the far range pixels by digitising a line on-screen. These cut lines were then used to cut and paste the data into a single layer (a grey scale image). On viewing it was noticed that some pixels were anonymously bright. These were generally either on the nadir or at far range and were considerably more than 3 standard deviations above the imagery pixel mean. These pixels were therefore removed. Small gaps in data were also evident and these were filled by interpolation, but, as this can give a false 'smooth' appearance, the interpolated pixels were given a 'noise level' to mimic the surrounding variance.

Four map areas were processed separately and then mosaiced together into a final large image. As an aid to the processing of such a large image, the backscatter resolution was reduced to 50 m (from 20 m). This was found to have a very positive effect on the imagery. It had been established earlier that the quality of backscatter imagery was limited in its resolution. The raw backscatter signal was seen to be very sinuous, possibly over sampled, or a result of an over-zealous automatic gain control. Another possibility is that the return signal is a function of the sonar pulse (lack of deconvolution). The backscatter data seem to be a by-product of the main bathymetry system and thus the internal processing is not fully documented. The main advantages of the PRISM system were the removal of some of the weather dependency, the equalisation of illumination across track ('shading') and the contrast enhancement on the production of final maps

EM12 Bathymetry data

Once transferred to the SUN workstation the data were re-gridded (using the 'xyz2grd' program in GMT) and imported into ERDAS Imagine format (using the PRISM utility 'grd2img'). The bathymetric data was also processed by PRISM in a procedure similar that used for backscatter data. A slightly different set of commands are used compared to that used with backscatter data. This is because the bathymetric values are 16 bit (rather than 8 bit) and have different characteristics. As yet there are no specific filters in PRISM, such as a variable filter size increasing with range, which could be applied to bathymetry data. The program development is on-going. Thus the processing configuration for the EM12 bathymetry was:

```
resol -i %1 -o %0 -r res
sshead –i %1 –o %0 –a 5.0
```

To explain this in sonar terms:

Reduce the resolution of the imagery to the required value. If fewer pixels are required in the output resolution than is available in the input resolution, the data is averaged. This increases signal-to-noise ratio.

Check the vehicle heading in comparison with the track heading. If the difference is more than 5.0° use track heading. This was useful when the ship gyro data was 'stuck'.

The bathymetry data was then transferred to ERDAS, filtered and then displayed. Manipulation of bathymetric data sets within ERDAS Imagine is handled in the same way as topographic digital elevation models (DEMs). The only change is that the bathymetric values have to be negative which a simple –1.0 multiplication, achieves. Contour lines were being produced using the Surfer software. A grid was exported to Surfer and then contour lines were created at the required interval. The result was then imported back into ERDAS as a shape file (vector layer). Other viewing methods were also explored. Shaded relief is very effective in showing small bathymetric variation. The angle of sun illumination is crucial for finding systematic errors such as track lines or far range instabilities. Adding colour then accentuates the actual depth differences in separate features. Modelling the data in three dimensions can give extra insight and understanding. A full reprocessing of all the EM12 data collected will be done post-cruise at SOC to include data collected right at the end of the cruise and to allow time for systematic data cleaning.

The overlay of the backscatter on the bathymetry in three dimensions is a final aid to interpretation. The backscatter data is relatively non-directional (unlike sidescan sonar imagery), as the angle of incidence is relatively high, and thus the results should better represent lithological variation (rather than topography). However, the poor quality of the backscatter imagery did not allow the creation of 3D backscatter on bathymetry with as high resolution as was desired.

EM12 OPERATIONS

At the start of CD143 a calibration of the EM12 system was carried out. No adjustment of pitch calibration was required and a 0.8 degree positive roll calibration adjustment was made. All EM12 Data collected during CD143 was processed and edited using the Simrad Neptune software.

Data from the first leg of the cruise was processed into a series of data files archived as “first look data set”. Following Neptune processing the resulting xyz data files were gridded into 50 m and 100 m grids.

This processing was repeated twice more during the second leg of CD143 as more data was collected. This resulted in the whole area being reprocessed on each occasion and final data grids being produced as sets “Clean2 and Clean3”. Data collected during the final stages of the cruise was archived for future use as it was not possible to repeat the processing cycle in the last few days of the cruise.

Data from “clean 2 and 3” was gridded to a 25 m grid as well as the 50 m and 100 m used for “first look data”. Due to processing constraints the work area could only be gridded as one area at 100 m grid size. At 50 m the work area was divided into three grids and at 25 m into seven grids.

During a two and a half day period near the start of the cruise an intermittent problem with the gyro wiring feed to the scientific logging systems developed. This problem was initially for brief periods only and as a result was first identified a day into the fault. The fault proved elusive particularly as having attempted to trace it logging would appear to be normal for some time only for trouble to reoccur latter.

These periods of gyro error were examined in the Neptune software. Where the error resulted in an offset from the correct heading data could be recovered. Where the error occurred on course changes or varied the swath data for these periods is not included in the processed data set. All data has been included in archive backups of the Mermaid data logger files.

The gyro data periods where unusable data problems occurred were as follows

1.) 327 15:08 to 327 15:30 lag on turn
2.) 327 20:29 to 327 20:44 lag on turn
3.) 328 01:54 to 328 02:26 did not follow course change
4.) 328 03:21 to 328 03:54 did not follow course change

Watch keepers realized we had a problem from this point onwards.

5.) 328 15:15 to 328 15:34 lag on turn
6.) 329 03:18 to 329 08:25 did not follow course, large error
7.) 329 18:35 to 329 19:41 lag on turn
8.) 330 03:40 to 330 09:18 large errors, eventually problem solved at this point.

Due to overlapping coverage the final data set shows only limited degradation from the gyro errors itemized.

All vessel navigation is from differential GPS supplied by the Fugro SeaStar service and as such is accurate to 3 m. This navigation data has been passed through the Neptune data processing software purely to eliminate any navigation spikes and not to process or smooth the navigation source in any way.

SOUND VELOCITY PROBE OPERATIONS

A total of 5 SVP casts were undertaken on the cruise, using the 12-way stainless steel CTD frame or by hanging the probe on the CTD EM wire. The configuration set-up logged in one or five metre increments, outputting real data to an ASCII file. Profiles were utilised to update the EM12 system after each drop.

3.5 kHz OPERATIONS

The 3k5 chirp profiler system comprises of a combined transceiver and correlator unit, a logging and display computer, a 'Chivers' winch and deployment davit mounted on the starboard quarter and the 3k5 transducer fish itself.

The profiler had last been used some time ago and although the major components were set up in position in the laboratory and on the deck, nothing had been connected up. The deck unit and logging computer were relatively easy to set up but a new deck lead had to be made to connect the slip rings in the winch to the deck junction box.

After completing the installation and testing the system it became apparent that the latest version of the logging software only worked with a network connection to a ship's computer system disk drive. The network used was an old PC-NFS connection and could not be made to recognise the ship's network. Clearly something had changed since the last use of this system. In order to get around this an early version of the software was used to record to Zip disks that were subsequently copied on to CD-ROM. This early version of the logging and display software had its own quirks such as printing the incorrect date on the paper output. A more up to date version of the software was eventually tracked down that worked well enough with the Zip drives.

In operation the system is easy to use. A level of 2 on the attenuator and 4 on the detector gave good results. The output power was varied to suit the depth. A minor problem was that to increase power the control had to be turned anti-clockwise. This confused most of the scientific party until clear labels were stuck on the front panel. The deck unit and transceiver operated without problem for the whole cruise. The logging computer suffered from a number of crashes and glitches. As the software used was not the latest it is likely that some, if not all of these would be cured in the newer software. Generally a reboot of the computer cured any problems. It was found on at least two occasions that the computer's clock was advancing itself. This could be a symptom of an old computer.

The transducer fish gave excellent results at ship speeds below 8 knots. Above this, noise dominated. This came from a combination of the fish's location – at higher speeds the fish is closer to the ship's wake and propeller and flow noise. During the first leg an increase of noise was observed at lower speeds. When the fish was recovered four sections of fairing were found to be missing or severely damaged. These were replaced with a combination of new fairing from the spares and fairing from a old cable. This was deployed and an improvement noticed but soon the extra noise reoccurred. On recovery two sections of fairing were found to be missing. Two sections taken from the spare 3k5 fish replaced these. Prior to arriving in Muscat to take on water the fish was recovered and one section of fairing had been ripped off. With no good fairing left to replace this the existing fairing was shuffled down to make a continuous section. The poor state of the fairing could well be down to its continual exposure to sunlight perishing the rubber. It is clear that the fairing stored in the spares box was fine but that salvaged from the cables and the spare fish was poor. A cover for the fish when not in use would be an excellent investment. Also contributing to the noise was the wear on the shims on the fish towing bridle. These need to be replaced as soon as possible to reduce the slop and hence rattle of this item.

In summary, at speeds below 8 knots and with a decent fairing the system gave excellent results. A new computer and/or software that can log to the ship's computer would be a definite improvement as would a cover for the fish and fairing when not in use.

PISTON CORING OPERATIONS

The sites for the piston cores were chosen by looking at areas of suitable sediment thickness on the 3.5 kHz profiles, and comparing these with the reflectivity maps produced from the EM12 data. Sites were chosen to try and get sequences that would be as complete as possible for high resolution climate change studies, and can be seen in Figure 3.

A total of six piston cores were taken, resulting in 48.48 m of core being recovered. Other than bending the final core in very hard sandy sediment, no major problems were encountered. However, a few technical and operational problems should be highlighted for future cruises.

Firstly, the bulwark-mounted adjustable core-barrel stands did not allow the core barrel height to be aligned for easy build of the corer. These stands were previously used aboard *RRS Discovery* and have been modified to fit the bulwark height on that ship. Consequently no adjustment was available on the turn-screws to alter the barrel height without re-welding the base plate further up the turn-screw post. We suggest that for the future OED obtain a second set of stands so each set can be 'ship specific'.

Secondly, it was noted that some of the stainless steel barrels supplied are no longer round – making it impossible to insert the core liner inside them. All of the barrels should be examined and those out of shape should either be re-shaped or scrapped and replaced.

The trigger mechanism had to be completely dismantled and rebuilt at the beginning of the cruise so that the trigger-arm pointed aft whilst attaching it to the wire. This was due to the fact that the forward Rexroth auxiliary winch on the starboard gantry had been removed, yet the necessary modifications to the coring equipment had not been made. Furthermore, using the aft auxiliary winch to deploy the trigger core was far from ideal because of the limited space available between the corer bucket and the bulwark. The chance of injury to the operators is much higher using this configuration.

Table 1. The Piston Corer setup for each of the stations.

Station No.	Barrel length (m)	Pennant length (m)	Freefall (m)	Warp Rebound (m)	Total Pullout (T)	Core Length (m)	Number Sections	Comments
55702	12	19.5	2	4	5.2	7.68	6+TC	
55703	12	16.5	2	1	4.02	10.20	8+TC	Bomb buried
55704	12	17.5	2	2	5.4	11.35	8+TC	
55705	12	17.5	2	2	5.2	10.63	8+TC	
55706	12	17.5	2	2	4.3	8.62	7+TC	
55707	9	12.5	2	0	3.27	0.39	0	Corer bent, part core

CTD OPERATIONS

A total of 5 CTD casts were undertaken on the cruise, Figure 3 (plus the single SVP dip at the start of the cruise), using the cast configuration as follows for the 12-way stainless steel CTD frame:

Sea-Bird 9/11 *plus* CTD system
12 by 10L X-type Niskin bottles
Sea-Bird 13B Oxygen sensor
Benthos PSA-916T Altimeter
10 kHz beacon s/n B1
AML Sound Velocity Probe s/n 3126
Pascal Micro Oxygen sensor & battery pressure case

The Sea-Bird CTD configuration was as follows:

SBE 9 *plus* Underwater unit s/n 09P-23241-0598

Frequency 0—SBE 3P Temperature sensor s/n 03P-4105 (primary)
Frequency 1—SBE 4C Conductivity sensor s/n 04C-2571 (primary)
Frequency 2—Digiquartz temperature compensated pressure sensor s/n 78958
Frequency 3—SBE 3P Temperature sensor s/n 03P-4116 (secondary)
Frequency 4—SBE 4C Conductivity sensor s/n 04C-2580 (secondary)
SBE 5T submersible pump s/n 05T-3002 (primary)
SBE 5T submersible pump s/n 05T-3195 (secondary)
SBE 32 Carousel 24 position pylon s/n 32-24680-0344
SBE 11 *plus* deck unit s/n 11P-24680-0587

The auxiliary A/D output channels were configured as below:

V0---SBE 43B Oxygen s/n 43B-0076
V2---Benthos PSA-916T Altimeter s/n 874
V3---Chelsea MKIII Aquatracka Nephelometer s/n 088245
V4---Pascal Micro Oxygen sensor
V6---SeaTech Light Scattering sensor s/n 338 (low gain, 33 mg l^{-1} full scale range)
V7---Chelsea MKII Alphatracka Transmissometer s/n 161047 (25 cm path)

(NB---An Oceano acoustic release was attached to the frame for cast 005 only, to perform a full-ocean depth communication/release test prior to deployment of Roughsnap.)

SHRIMP OPERATIONS

System Description

SHRIMP – Seafloor High Resolution Imaging Platform – is SOC's deep-towed video and camera imaging system. The system comprises of the vehicle attached to the main tow cable via an electro-optic swivel. At the ship is the vehicle's power supply, fibre-optic multiplexer, vehicle control computer, instrument data logger, video recorders and display monitors.

All signals and data to and from the vehicle are sent via a fibre-optic link. This consists of the main 10 km combined conducting and fibre-optic tow cable, a Focal electro-optical swivel to decouple the vehicle from cable twist, an electro-optical slip ring on the ship's winch and two Focal 903 multiplexer units – one in the vehicle and one on the ship to send and receive the video and data signals.

The vehicle's main imaging instruments are a Simrad charged coupled device (CCD) underwater colour video camera, a Simrad silicon intensified target (SIT) underwater B&W video camera and an Ocean Instrumentation Ltd (OIL) M7 35 mm still camera with F1200 flash unit. The SIT camera was not used during this cruise. Lighting for the CCD camera is provided by a DeepSea Power & Light SeaArc 400 W high intensity discharge (HID) light with a daylight lamp and flood reflector for even illumination. Two 10 mW lasers are mounted 450 mm apart, both pointing vertically down to give a scale for the cameras.

As well as the cameras, the SHRIMP vehicle has a range of attitude sensors: an Advances Orientation Systems Inc. (AOSI) EZ-Compass 3 provides pitch, roll, heading and case temperature data, a Simrad Mesotech 808-A altimeter with a 100 m range for vehicle altitude measurement and a Bell & Howell 500 Bar serial output pressure gauge for vehicle depth measurement. All these instruments have serial outputs that are fed to the vehicle's control computer.

The SHRIMP vehicle's computer combines the serial data streams with vehicle status information and sends it to the ship via an optical RS-232 link – part of the Focal 903 multiplexer. Control commands from the ship to turn on/off lights and cameras are sent via the RS-232 link and operated upon by the vehicle computer. Video signals from the CCD and SIT cameras are fed directly to the ship via the optical link. The high voltage DC supply from the ship is converted to 25 V in the vehicle to power the electronic systems. A 24 VDC to 240 VAC inverter is used to generate the AC voltage required for the HID light.

At the ship a Sorensen 0-600 V, 4.5 A power supply is used to power the vehicle down the cable. The top end Focal 903 multiplexer provides the RS-232 data link and the CCD video feed signal. The video signal is buffered and is fed to the video monitor, the two Hi-8 video recorders, a winch driver's monitor plus and a scientific video recording/monitoring system. The SHRIMP deck unit computer displays and logs the RS-232 data from the vehicle as well as sending the commands to control the vehicle functions.

Laboratory Setup

The SHRIMP deck units are mounted inside transit cases. It is an easy task to strap these down to a suitable bench. The deck unit computer used a PC monitor in one of the cases for display. The video multiplexer was mounted under the fibre-optic cable junction box, aft of the echo sounder racking on the port side of the main laboratory.

The video signal is sent to a video monitor and two Hi-8 video recorders in the main deck unit cases, a video monitor just above the laboratory winch driving position. A feed is also sent to a VHS video recorder and video monitor mounted forward of the echo sounder racking for scientific use.

A very useful add-on used on the cruise both for MPV and SHRIMP was a CORIOScan PC to video converter. This box converts a PC monitor signal to a composite video signal. It can also zoom in and pan to an area of the PC screen for video display. During SHRIMP deployments the CORIOScan was used to display the vehicle altitude data onto a video screen just above the winch driving position. This was mainly used to give the winch operator an indication of the approaching seafloor during deployment prior to getting a visual indication.

Deployment, Survey and Recovery

The SHRIMP vehicle weighs approximately 1000 kg in air. It is an easy task to deploy it from the amidships 'A' frame using just two stay lines. Deploying amidships reduces any pitch motion induced by the ship. It does still suffer somewhat from roll motion. Once deployed the vehicle is switched on and checked for correct operation. If all is in order then it is paid away at 40 m s^{-1}. Progress is initially monitored on the pressure gauge display progressing to the altitude monitor when within 100 m of the seafloor. Visual contact is made when within 10 m of the seafloor. A visual altimeter is formed by a 6 kg lead weight on a 2.5 m tether. This can be viewed on the video monitor and is used as a guide by the winch driver to keep the vehicle at the optimum height off the seafloor.

Once visual contact is made with the seafloor the winch driver keeps the vehicle at the optimum flying height by monitoring the visual altimeter – too low and the weight hits the seafloor, separation of the weight and its shadow indicate that the vehicle is too high. After a brief learning period all the winch drivers became highly adept at flying the vehicle. All commented that a detented centre "off" position for the winch control knob as on the Discovery winch system would be an extremely useful asset.

At the end of the bottom run the stills camera and video recorders are turned off and the vehicle recovered at 40 m s^{-1}. Recovery is accomplished by bringing the vehicle to deck height and attaching two stay lines before bringing the vehicle aboard.

System Performance

For this cruise the SHRIMP system was configured to work using the fibre-optic link. This was the first successful use of SHRIMP in this configuration and showed the enormous potential in this mode of operation over the coax and acoustic links previously employed.

The video-imaging device used during this cruise was the colour CCD camera. The camera performed well although a blue tinge observed in the video images may in part be attributable to this device. Also some low-level interference noise was noticed on the camera output. No obvious cause was found during the cruise although a more thorough investigation will take place once the equipment returns to the UK. The lighting for this camera came from the

400 W HID light. This has a warm-up time of around 6 minutes plus a strike delay that varied from almost instant to over one minute depending on temperature. During the cruise it was found by experiment that the power must be disconnected for approximately 10 minutes before attempting to re-strike the light. In order to eliminate any doubt over operation of the light it was turned on just after the vehicle was deployed and turned off just before recovery. Almost all of the light problems encountered during the cruise could be put down to the operator learning the working subtleties of this kind of lamp.

The 35 mm still camera and flash unit operated reliably throughout the cruise. The only problem was a severe corrosion problem on the camera's connector end cap. This may have been triggered by one of the laser sighting devices flooding early in the cruise and generating a current flow via the end cap. An anode was attached to reduce the rate of corrosion but the end cap will have to be replaced before its next use. The flash mounting frame requires a bracket to fix its position. It was lashed in position for this cruise and whilst adequate is not a preferred solution.

The altimeter, AOSI attitude and heading sensor and the Bell & Howell pressure gauge all performed reliably. From launch 14 onwards it was noticed that the serial data would freeze at a depth of a couple of hundred metres necessitating a reboot of the whole vehicle to cure. This could well be a problem with the 19-way Impulse connectors in the vehicle as this problem has been encountered on both the TOBI and AUTOSUB vehicles that use this type of connector. To improve reliability these connectors must be eliminated from the system.

Powering the vehicle initially were three DeepSea Power and Light 24 V underwater batteries trickle charged by DC-DC converters feeding off the vehicle main power supply. During the first deployment the underwater video light suddenly went out. As the other vehicle functions were unaffected the deployment continued with the stills camera. After a period of 10 minutes the light was relit. The light remained in operation for a few minutes before going out again. This was repeated a number of times before the end of the still camera film finished the deployment. Once back on board the power electronics chassis was removed from the vehicle and investigation revealed that the current limit on the DC-DC converters was only set to 1.75 A. Also only four out of the five converters were operational. This would be insufficient to charge the batteries and power the light accounting for the symptoms encountered. It was evident that doubling this the 3.5 A, whilst well within the limits of the converters, would easily power the whole vehicle including the video illumination thereby eliminating the need for the batteries. The battery free configuration was successfully tested on deck prior to the next launch of the vehicle. One battery was included in the system for launch 2 but this was taken out of circuit for subsequent launches. The batteries remained physically installed on the vehicle although they were not connected.

No problems were encountered with the deck electronics. The laboratory layout worked well – especially with the introduction of the GDD projector to give a large-scale image on a paper screen hung from the laboratory ceiling.

SHRIMP was deployed 21 times during the cruise providing some 45 hours of sea floor imagery data. The greatest depth of a deployment was 3300 m on run 21 and the shallowest was 290 m on run 11.

Summary

During the cruise SHRIMP proved that its use on a fibre-optic link gave a new dimension to underwater imagery. It is now possible to see the sea floor in real time giving scientists the opportunity to view targets and potential work areas without having to wait for the end of a deployment. The real time video also means that the vehicle is easy to keep at its optimum flying height improving the quality of the imagery produced. A whole raft of improvements and modifications was suggested for the system during the cruise to considerably improve its future performance. These will be taken into account for future funding opportunities. The location of the SHRIMP stations are shown in Figure 5.

MEGACORER OPERATIONS

The GDD Bowers & Connelly “Megacorer” was used extensively during the cruise. This is an hydraulically damped multiple corer, capable of taking up to 12 cores of 10 cm internal diameter. The highly variable nature of sediment types encountered required a number of variants to the “rigging” of the corer. On expectation of encountering soft sediments, the base frame of the corer was fitted with outrigger (2 m long pole) bars. The number of coring units deployed and the ballast load of the coring head were altered according to the sediment type encountered – more ballast and fewer tubes for hard ground; more tubes and less ballast for soft ground. The station locations are sown on Figure 6, with Figure 7 providing a “zoom” into the area of the northern transect and Figure 8 a “zoom” into the southern transect.

Extremely soft sediments (e.g. site S2) proved to be somewhat problematic, providing barely enough resistance to the penetration of the core tubes to trigger the coring action. Modification to increase the “sensitively” of triggering in such sediments should be considered for the future. At the opposite end of the sediment spectrum, a number of core tubes were smashed or cracked on very hard ground, ? rock, (e.g. site C1).

Despite these difficulties, high quality cores, with intact sediment-water interfaces, were obtained at all “core-able” sites.

<u>Oxygen analysis – the Winkler titration method.</u>

The Winkler Titration is designed to measure the amount of dissolved oxygen in seawater by binding it with magnesium hydroxide ($Mn(OH)_2$) within a strongly alkaline medium. This is achieved by the chemical conversion of manganese II to manganese III. By acidifying the solution iodide is oxidised to iodine. Iodine is then titrated with thiosulphate resulting in the reduction of iodine back to iodide. The amount of thiosulphate required to reduce all the oxidised iodine is directly related to the original concentration of oxygen in the seawater sample.

Procedure

Oxygen samples were taken from the rosette of water bottles as soon as possible after each CTD cast. The deepest sample was collected first as it is generally the water furthest from equilibrium with the surface temperature and pressure and may become supersaturated and out-gas as the sample warms up. During this cruise oxygen samples were also taken from the core-top water following recovery of the megacorer. These samples provided a measure of near-bottom oxygen concentrations.

Glass sample bottles, each with their own pre-determined volume, are filled to overflowing from the rosette bottles to remove any air bubbles. The filling tube is removed and 1 ml of manganous chloride solution is injected into the sample bottle, immediately followed by 1 ml of alkaline iodide solution. The dense reagents sink to the bottom of the bottle so each sample should be vigorously shaken after addition of the reagents to disperse the manganous precipitate that scavenges the oxygen from the sample. By shaking the bottles you reduce the flocculent size and increase the surface area, thereby increasing the efficiency of the oxidation of $Mn(OH)_2$.

When all of the samples have been collected they are stored in subdued light in a temperature controlled laboratory to thermally equilibrate prior to titration.

Prior to analysing the samples reagent blanks must be determined at the start of each run. Blank measurements are made in a spare sample bottle that must be thoroughly washed before being filled with approximately 100 ml of distilled water. A magnetic stir bar is placed in the bottle before adding 1 ml of sulphuric acid. 1 ml each of sodium hydroxide solution and manganous chloride are the added in sequence. When the solution is clear 1 ml of iodate standard is added and the solution changes from clear to deep orange in colour.

The solution is then titrated with thiosulphate to a dead stop, recorded electrochemically, and the volume used recorded. A second and third 1 ml aliquot of iodate standard are then added and the process repeated until the titrated volumes are consistent to within 0.002 ml.

Seawater samples are prepared for titration by adding the magnetic stirring bar and 1 ml of sulphuric acid. The solution changes to colour from clear to orange (intensity of colour is dependant on the amount of oxygen present in the sample). The samples are then titrated with thiosulphate in the same manner as that used for the blanks. Oxygen values in ml L^{-1} are then calculated from the titrant volumes.

Table 2. Oxygen determinations made from3 separate CTD casts and from the core-top water of 9 megacorer deployments.

Station #	Gear	Depth (metres)	O_2 concentration ml L^{-1}
55710#1	Megacore		0.83±0.19
55712#2	Megacore		0.33
55717#1	Megacore		0.59±0.04
55718#3	Megacore		0.30±0.07
55726#3	CTD	1701	1.34
		1600	1.05
		1500	0.86
		1350	0.49
		1200	0.41
		1050	0.26
		449	0.08
		230	0.52
		100	0.32
		25	4.57
55730#1	CTD	2037	1.88
		1499	0.92
		1099	0.22
		900	0.10
		700	0.07
		600	0.05
		240	0.21
		60	0.75
		50	1.22
		40	4.15
		20	4.30
55752#1	Megacore		1.48±0.03
55753#1	Megacore		0.37±0.02
55754#1	Megacore		0.16±0.03
55765#1	Megacore		0.14±0.02
55775#1	Megacore		2.03±0.05
55786#1	CTD	2900	3.72
		2700	3.67
		2500	3.53
		2299	3.19

Station #	Gear	Depth (metres)	O_2 concentration ml L^{-1}
		2200	3.11
		2100	2.94
		2000	2.69
		500	0.08
		401	0.10
		301	0.18

Measurements taken from both the Winkler titrations and the CTD mounted oxygen sensor were remarkably consistent (Figure X1 <wink2.pdf>). Both methods showed the presence of an oxygen minimum zone (<0.5 ml/L) between 80 and 1300 m depth and the water column was highly depleted of oxygen (<0.2 ml/L) between 400 and 800 m depth (Figure X2<wink1.pdf>).

Figure X3 <ctd1.pdf> shows the presence of the warm, highly saline Gulf outflow water from the north (Straits of Hormuz) at approximately 300-330 m. This water body is also slightly more oxygenated than the surrounding water masses as can be seen by the small increase in oxygen concentration at this depth.

Table 3. Summary of Megacorer operations and samples obtained

Stn 557xx	Units	Ballast	Mac	Meiob	Foram	Chem	Geol	O_2	Misc.	Comment
10#1	8	Full	5	(Y)	Y	Y	Y	3	Gromiids	8/8 good cores
11#1	8	Full	All discarded							2/8 cores over penetrated
11#2	8	Reduced	All discarded (bar *Pelosina* pick)							2/8 cores over penetrated
11#3	10	Nil	-	(Y)	Y	Y	-	-	***Pelosina***	2/10 cores over penetrated
11#4	10	Nil	4	-	-	-	-	-	-	4/10 good cores
12#1	10	Nil	All discarded							Short disturbed cores only
12#2	8	Full	5	-	-	-	-	1	-	6/8 good short sandy cores
17#1	8	Full	4	(Y)	Y	Y	Y	3	Gromiids photo	7/8 good cores
18#1	8	Full	All discarded							6/8 cores over penetrated
18#2	10	Nil	All discarded							
18#3	10	Nil	4	-	-	Y	Y	3	***Pelosina***	6/8 good cores
19#1	8	+40kg	No samples							Tubes smashed
25#2	10	Full	6	(Y)	Y	Y	Y	-	Picks	9/10 good cores
26#1	10	Full	7	(Y)	Y	Y	Y	-	Picks	10/10 good cores
30#2	10	Full	7	Y	-	Y	Y	-	<? Picks>	10/10 good cores
31#1	10	Full	6	Y	-	Y	-	-	<? Picks>	9/10 good cores
32#1	10	Full	No samples							Tubes smashed
52#1	11	Full	8	Y	-	Y	Yss	3	Gromiids	11/11 good cores
53#1	11	Full	8	Y	-	Y	Yss	3	Picks	11/11 good cores
54#1	11	Full	6	2xY	-	Y	Yss	3	PSA Picks	11/11 good cores
54#2	12	Full	8-500 4-250	Y	-	-	-	-	Mesob	12/12 good cores
54#3	12	Full	8-500 4-250	Y	-	-	-	-	Mesob	12/12 good cores
54#4	12	Full	8-500 4-250	Y	-	-	-	-	Mesob, HC, HM	12/12 good cores
54#5	12	Full	8-500 4-250	Y	-	-	-	-	Mesob	12/12 good cores

Stn 557xx	Units	Ballast	Mac	Meiob	Foram	Chem	Geol	O_2	Misc.	Comment
63#1	6	+40kg	-	-	-	-	-	-	PSA	2/6 good cores
63#2	4	+40kg	No samples							1/4 good cores
64#1	12	Full	8-500 4-250	-	-	-	-	-	Mesob, PSA, Micro, Oto	12/12 good cores
65#1	12	Nil	-	Y	-	-	-	2	Micro, Oto, PSA	7/12 good cores
65#2	12	Nil	No samples							2/12 good cores
66#1	12	Full	-	-	Y	-	-	-	Micro, Oto, PSA,	12/12 good cores
67#1	12	Full	-	Y	Y	-	Yss	-	Micro, PSA,	12/12 good cores
74#2	12	Full	-	-	Y	-	-	-	Micro, Oto, PSA,	11/12 good cores
75#1	12	Full	-	Y	Y	-	Yss	3	PSA, Micro,	12/12 good cores
88#1	12	Full	Y	Y	Y	-	Yss	-	Jelly detritus frozen	11/12 good cores
89#3	12	Full	-	-	Y	-	-	-	All cores for forams	12/12 good cores
90#1	12	Full	-	-	Y	-	-	-	All cores for forams	12/12 good cores

Sampling methodology

Mac — Macrobenthos: 0-10 cm section of core cut by extruding from below into measured collar; sediment section placed in chilled seawater with some 4% formalin added; sections from a number of cores combined; material sieved on 250 µm and the resultant residue retained in 4%, borax buffered, formalin.

Mac-500 — Macrobenthos: 0-10 cm section of core cut by extruding from below into measured collar; sediment section placed in chilled seawater with some 4% formalin added; sections from a number of cores combined; material sieved on 500 µm and the resultant residue retained in 4%, borax buffered, formalin.

Mac-250 — Macrobenthos: 0-10 cm section of core cut by extruding from below into measured collar; sediment section placed in chilled seawater with some 4% formalin added; sections from a number of cores combined; material passed through a 500 µm sieve and the residue retained on a 250 µm sieve retained in 4%, borax buffered, formalin.

Meiob — Meiobenthos: three 20 ml syringes used to sub-sample a single Megacore sample, 0-5 cm section retained from each to produce a pooled sample of 10 cm^2, material retained in 4%, borax buffered, formalin.

Foram — Foraminifera: 0-2 cm section of each core cut by extruding from below into measured collar; sediment section placed in chilled seawater with some 4% formalin added

Chem — Organic chemistry: Each core was sectioned at four intervals down to a depth of 5 cm (0-0.5 cm, 0.5-2 cm, 2-3.5 cm, and 3.5-5 cm). Each slice was then homogenised before being split. Half the sample was preserved for pigment analysis and the other half was preserved for additional biochemical analyses, to include %TOM and CHN analysis. On those cores where a significant phytodetrital ‘fluff’ was present on the core surface it was removed with a pipette and preserved separately. All 8 (or 9) samples from each core were frozen at –70°C.

Geol Geology: A single geological sub-core was retrieved from a Megacorer tube whenever spare material was collected; a 65 cm length of 7 cm diameter polycarbonate piston core liner was pushed into the tube, then sealed at both ends using plastic end caps and tape. A total of 5 steel tube samples, 5 plastic sub-cores, and one top 10 cm sample (polythene bag) were collected.

O_2 Oxygen: top water siphoned from cores for oxygen determination by Winkler titration (see separate section above).

Misc. Picks, Gromiids, *Pelosina*: large forams removed from core tops and preserved separately.

PSA: 0-5 cm layer from single core retained frozen (-20°C) in plastic bag for particle size analysis.

HC: 0-2 cm layer from single core retained frozen (-20°C) in aluminium foil lined petri dishes for hydrocarbon analysis.

HM: 0-2 cm layer from single core retained frozen (-20°C) in plastic bag for heavy metal analysis.

Mesob: Mesobenthos sample, the 0-10 cm layer of a single core retain un-sieved in 4%, borax buffered, formalin.

AGASSIZ TRAWL OPERATIONS

The Agassiz trawl was used in a number of locations (Figure 12) to collect megafaunal specimens, primarily for aiding the identification of animals observed on the video during SHRIMP runs. Additional material was also preserved for current and future projects involving molecular phylogenetics, fatty acid analyses and selectivity of deposit feeders.

55744#1 A one-hour tow at c.1,000 m on the Ra’s al Hadd ridge. On recovery the cod-end was partially opened by the knot slipping – possibly as the result of a large plank of wood in the catch. This was a relatively small and clean catch containing numerous actiniarians (*Actinoscypha* sp.) and many natant decapods. Small ophiuroids, of at least three separate species, were also abundant. Other invertebrates included small brachyuran crabs, holothurians (*Ypsilothuria* sp) and two small cephalopods. Several fish were also caught, including Synaphobranchids, a notocanth and a number of “deep-sea soles”.

A representative catch was retained and preserved in formalin in addition to a photographic record. Selected specimens of *Actinoscypha* sp. and *Ypsilothuria* were preserved in 100% ethanol for molecular analysis.

Several specimens of the surface water jellyfish, seen in swarms around the ship, were also caught and were frozen at –70°C for biochemical analysis of fatty acids and pigments.

The wooden plank (mahogany) was heavily bored and covered with chitons and limpets. A small section was removed and preserved separately in formalin.

55745#1 A one-hour tow at c.2,000 m on the Ra's al Hadd ridge. A fair, clean catch containing some large solitary corals and numerous small ones. Large Sea Whips, quill worms, natant decapods and asteroids (*Zoroaster* sp. and ?*Radiaster* sp.) were among the more obvious fauna. Several specimens of the galatheid crab *Munidopsis* sp. were collected along with worm tubes and "mud balls". Two species of holothurian were also collected, *Molpadia* sp. and *Mesothuria* sp.

A representative catch was retained and preserved in formalin in addition to a photographic record. 10 individuals of *Zoroaster* sp. were dissected and tissue was preserved in 100% ethanol and frozen at –70^{o}C for molecular and fatty acid analysis. Both species of holothurian had muscle tissue removed and preserved in 100% ethanol as did 10 specimens of *Munidopsis* sp. and 4 specimens of the decapod *Polycheles* sp.

55759#1 A 'short-hop' trawl at c.1,100 m (wire scope of ~1.2) looking for specimen material identified from previous SHRIMP runs. A small catch including quill worms, natant decapods, *Glyphocrangon* sp., worm tubes, *Actinoscypha* and other actiniarians, 3 species of ophiuroids and the holothurian *Molpadia* sp. A single cephalopod and 5 species of fish, including a Synaphobranchid and a small shark, were also collected.

A representative catch was retained and preserved in formalin in addition to a photographic record. Several specimens of protozoan 'jellyball' gromiids were also obtained and were preserved separately in formalin, 3% gluteraldehyde and frozen at –70°C.

55760#1 Another 'short-hop' trawl (wire scope ~1.2), this time at c.500 m, targeting the abundant gastropods that had been observed on previous SHRIMP footage. Subsequently a large catch of gastropods was recovered, of which the majority of large individuals were empty shells and the living specimens were of a smaller size. Additional material included small (<5mm) translucent bivalves, the spider crab *Encephaloides armstrongi*, several species of small polychaete and numerous specimens of one fish species, which had distinctive bright-red gills.

The sample of live gastropods was preserved in formalin with additional specimens being preserved separately in 100% ethanol and 3% gluteraldehyde and frozen at –70°C. Several specimens of the translucent bivalves were also preserved separately in ethanol. A representative catch was retained and preserved in formalin in addition to a photographic record. An additional 5 individuals of the red-gilled fish were frozen for Dr. Jon Copley (SOES).

55761#1 The third 'short-hop' trawl (wire scope ~1.4) for target specimen material, this time at c.350 m. The net became fast in shallowing depths towards the end of the tow. The ship was reversed on the net with it coming free when ± overhead. The weak-link (2 tonnes) had parted and the frame was bent and distorted. Both the outer-mesh and liner of the net had been badly torn end-to-end.

However, a catch was recovered containing numerous specimens of the small spider crab *E. armstrongi*. Additional material included a brachyuran crab, natant decapods, small gorgonians, ophiuroids and a sponge. A grenadier-type fish was also collected.

A representative catch was retained and preserved in formalin in addition to a photographic record. An additional 40 individuals of *E. armstrongi* were preserved in 100% ethanol and a further 10 individuals were frozen.

55776#1 The 'short-hop' trawl technique was proving successful so was employed again for a c.1,700-1,800 m sample (wire scope ~1.2, 1 knot tow), targeting Thalassinid (burrowing) shrimps observed from SHRIMP. A fair catch was recovered but only contained a single specimen of the target material. Additional invertebrates included numerous decapods (*Glyphocrangon* sp., *Polycheles* sp., *Munidopsis* sp. and natants), two species of ophiuroids, polychaetes, quill worms and solitary corals. Two species of infaunal holothurian (*Ypsilothuria* sp. and *Echinocucumis* sp.) were also collected and preserved separately in 100% ethanol. Several specimens of protozoan Astorhizids were also found in the residue and preserved separately in formalin. A distinctive 'blue-nosed' notocanth fish was also recovered.

A representative catch was retained and preserved in formalin in addition to a photographic record.

55777#1 'Short-hop' (wire scope ~1.2, 1 knot tow) specimen trawl at c.1,100 m in a second attempt to collect the abundant ophiuroids targeted at station 55759#1.

A large catch of ophiuroids was recovered with several different species and sizes in evidence. The catch required extensive washing and sieving in order to extricate additional invertebrate specimens from the mass of ophiuroids. Material collected included many specimens of the galatheid crab *Munida* sp, large Aplacophoran molluscs, several actiniarians (including *Actinoscypha* sp.), annelids, natant decapods, cephalopods, ascidians and various pennatulids (including *Umbellula* sp.). In addition to the ophiuroids, other echinoderms collected included the asteroid *Pythonaster* sp, dendrochirotid and dactylochirotid (Psolidae) holothurians and several small crinoids. Several fish were also collected.

A large sample of, mainly, ophiuroids was preserved separately in formalin in addition to a representative sample of the general catch. Numerous specimens of both the ophiuroids and the small Psolid holothurians were preserved in 100% ethanol and frozen at –70°C. The sample of cephalopods and fish was also preserved in formalin separately from the general catch.

55783#1 A return to a more ‘traditional’ method of fishing for a long trawl at c.3,200 m off Ra’s al Hadd in the area of ‘fluid escape’ features identified from the 3.5 kHz profiler. Some large ‘bites’ were observed during the run and the net took a long time to come off the bottom. Some 60 L of mud was recovered requiring the cod-end to be washed with the fire hose on deck. A very modest catch was eventually returned with the only specimen of note being a very large holothurian (*Pelopatides* ?*mammilata*). Additional material included natant decapods, *Umbellula* sp. and small ophiuroids. Little else was recovered bar rotting jellyfish slime (as observed from SHRIMP) and the net was very smelly (H_2S?).

The single specimen of *Pelopatides* was measured, photographed and described before dissection. Gonad tissue and gut contents were removed and frozen for pigment analysis. Several samples of muscle tissue were also removed and preserved in 100% ethanol for molecular analysis. The remainder of the invertebrate catch was preserved in formalin.

55787#1 A second trawl at the 3,200 m locality off Ra’s al Hadd. Less wire paid out than for 55783#1 and the trawl finished on a very short wire (wire scope ~1.05). Unlike previous trawls there was a good pinger trace throughout the run. Again only a modest but muddy catch was recovered, the highlight being a large specimen of the holothurian *Psychropotes mirabilis*.

The single specimen of *P. mirabilis* was measured, photographed and described before dissection. Gonad tissue and gut contents were removed and frozen for pigment analysis.

Several samples of muscle tissue were also removed and preserved in 100% ethanol for molecular analysis. The remainder of the invertebrate catch was preserved in formalin.

MPV OPERATIONS

The Mini Profiler Vehicle – MPV – is SOC's deep-towed chirp sub-bottom profiler system. The system comprises a neutrally buoyant towed vehicle attached to a 200 m umbilical that is coupled to the main tow cable via a 600 kg depressor weight and electro-mechanical swivel. Aboard the ship are the power supply, vehicle telemetry, sonar filter and correlator electronics and the PC based logging and display system.

The vehicle is towed between 250 and 350 m off the sea floor to give good seafloor coverage and allow relatively easy 'flying' over bumpy terrain. The profiler array and electronic systems are similar to those used in the TOBI chirp profiler. A major difference is that instead of correlating the signal in the vehicle as in TOBI, the raw sonar signal is transmitted back to the ship and correlated in the deck unit. Both raw and correlated signals are logged, with the correlated signal also being displayed. As well as the sonar the vehicle is equipped with a Falmouth Scientific Instruments micro CTD and an Advanced Orientation Systems Inc. EZ-Compass 3 giving pitch, roll, heading and magnetic field data. The CTD gives conductivity, temperature, pressure, time/date, salinity and sound velocity data. These data are transmitted to the ship via a modem link, displayed on the deck unit and passed to the logging and display system.

The logging system is Windows based and run on a Pentium PC with an ADLINK NuDAQ PCI9118 A/D converter card. The A/D card samples both the raw and correlated analogue signals at 45 kHz with 12-bit resolution. It uses the trigger signal as an interrupt to initialise sampling each transmit/receive cycle. The computer's serial port is used to input digital instrument data. The correlated signal is displayed in a scrolling window on the screen, digital instrument data as well as time/date and logging disk status are displayed in on-screen boxes. Both sonar signals as well as the digital instrument data and time/date are recorded onto 1.2 Gbyte magneto-optical disks using an external SCSI dual M-O drive. This gives approximately 6.5 hours of recording time for each side of a disk at a 4 second transmit/receive cycle rate.

The MPV is currently undergoing a series of developments to improve its performance and become more user friendly. Used for the first time on this cruise were a new Windows based logging and display system and a revised cable telemetry method to reduce crosstalk between the instrument data modem and the analogue sonar signal.

Launch & Recovery

The vehicle is launched and recovered in a similar manner to TOBI although with the MPV being much smaller this makes the operation somewhat easier. Unlike TOBI the MPV doesn't have an emergency abort system. Consequently the recovery and stay lines can be taped to the umbilical for easy access during the recovery. The vehicle, attached to the umbilical is deployed over the stern using a suitable launch winch (>0.5 tonne lift) via the main block on the ship's 'A' frame. The umbilical is paid off its winch until the making off eye is reached. This is tied to a deck eye and the free end of the umbilical mechanically connected to the depressor weight and electrically connected to the swivel. Once correct vehicle operation has been confirmed the umbilical is freed from the deck eye and the depressor deployed on the main tow cable over the main block. Recovery is the reverse of this operation. After turning off the vehicle power the depressor is brought on board and the umbilical tied to the deck eye. It is then disconnected from the swivel and depressor and the free end then passed to its winch. The umbilical is then winched in until the recovery and stay lines come aboard. The winch is then stopped and the lines freed from the umbilical. The stay lines are passed through fairleads to their respective capstans. The recovery line is fed over the main block and linked to the recovery/launch winch. The vehicle is brought aboard on the recovery/launch winch using the stay lines for control.

Laboratory set up

The deck electronic packages were set up in the main laboratory. The inboard end of the conducting tow cable was accessed through a BNC socket in the junction box to the rear of the laboratory. Power and all signals to and from the vehicle are fed through this cable. The main deck unit contains the modem, vehicle PSU, sonar filters, correlator, trigger synchronisation electronics and single board computer system. As well as providing the vehicle interface and digital data display, this unit also gives the logging and display system all necessary inputs – sonar, trigger and digital instrument data.

A very useful add-on used on the cruise both for MPV and SHRIMP was a CORIOScan PC to video converter. This box converts a PC monitor signal to a composite video signal. It can also zoom in and pan to an area of the PC screen for video display. During MPV deployments the CORIOScan was used to display the correlated sonar signal from the profiler onto a video screen just above the winch driving position. This gave the winch driver an immediate indication of the result of winch operations on the 'flight' of the MPV vehicle enabling constant altitude to be more easily maintained.

Deployments

During the cruise the MPV was deployed twice for two runs along the sampling transects, Figure 13. Run 1 started at 19.00/347 GMT and lasted approximately 18 hours. The results were not particularly impressive the terrain having a hard seafloor with little sediment. Run 2 started at 19.06/348 GMT and lasted 24 hours. This run showed a lot more structure with penetration up to 40 ms on unprocessed, correlated data. A tow speed of between 2.0 and 2.5 knots was maintained during the two deployments with a flying height of between 250 and 350 m depending on terrain.

System performance

The sub-bottom profiler sonar performed reliably throughout the cruise, as did the CTD. The EZ-Compass 3 had a bad problem with its pitch sensor giving values much too high. This will be investigated when the equipment returns to SOC.

The modem worked well with just three dropouts during the two runs requiring a reboot of the link. The software needs to be made more error tolerant to take account of the occasional data dropout. This also applies to the serial data output to the logging system. A slightly more robust piece of software is required to ensure error free data strings are passed.

The raw analogue profiler signal was kept to within a +/- 5 V range by adjusting the top end gain and monitoring for signal overload. A gain setting of 2.0 on the deck unit profiler receiver module was found to be optimal. In order to equalise raw and correlated signal levels an additional non-inverting amplifier stage was made for the correlator output. The amplifier’s gain was made adjustable in steps of approximately 6 dB. A gain of 20 dB was required to equalise the signals.

The logging and display system worked reliably throughout each deployment. It was found to be necessary to have the whole of the scrolling window within the computer screen otherwise the programme would not update the data in the display when the edge of the window was reached. This was easily overcome by slightly adjusting the position of the window once the programme was started. A black on white image was found to be best for displaying the profiler data. The serial data stream was not so successful. Although when the programme was first started the serial stream updated fairly regularly this rapidly this quickly reduced to updating once every couple of minutes or so. Clearly there is a problem with this interface that requires attention. However as the data was displayed on the deck unit this did not impair the operation of the system although interpolation of the recorded data will be needed for subsequent processing and replay. The logging of the data onto M-O disks was carried out without fuss, the disks automatically changing over at the end of a side. The software used on this cruise was a very early version of that being currently developed. The experience gained on this cruise will be used to develop subsequent versions.

Recommendations from this cruise to be addressed when the equipment returns to SOC include:

Improve the error tolerance of the serial data/modem link software.
Increase the transmit/receive cycle repetition rate of the profiler to 2 per second.
Improve the serial data input into the logging computer.
Add a hard copy output to the logging/display system.
Add an expanded scrolling screen to show sub-bottom detail in real time.
Show scale lines on the scrolling screen.
Add a vertical rate display to the system.
Record the data in SEGY format.

Overall the MPV performed exceptionally reliably and confirmed that the effort put into developing it has been well used.

WIDESCAN OPERATIONS

The Widescan was taken on the cruise to try to map, in high resolution, the shelf edge, looking specifically for the shelf break and also to image the heads of the submarine canyons, and variations in acoustic backscatter on the shelf. The successful Widescan tracks are shown in Figure 14.

Run#1 (55709#1) Widescan was launched just outside Muscat harbour at 1 knot speed, with an increase in towing speed to 3 knots once the fish was submerged. Far too much cable was paid out on this first deployment with the result that the fish was crashed into the seafloor (depth = ca. 65 m, cable out = ca. 225 m). The fish was hauled and the broken tail fins replaced. The fish was then re-launched, but the wire-out meter was reading backwards. There were no altimeter readings from the fish and upon trying to haul, the fish was lifted clear of the sea and up into the towing block shearing several pins off the underwater signal cable and breaking core in the main tow cable. Needless to say this determined that the Widescan station was abandoned. It was later inferred that the problem with the cable meter reading backwards was probably due to the proximity of the signal cable being adjacent to the electrical power cable that powered the Widescan winch.

Run#2 (55729#1) Due to the very steep topography it proved extremely difficult to follow the seafloor at the optimum altitude and, after a couple of hours surveying, the fish crashed into the seabed. The fish was recovered and the spare deployed. However it was proving very hard to keep the fish within 20 m of the seabed and so the decision was taken to fly higher than optimum for safety's sake. The re-started Widescan survey proceeded without further incident until darkness began to fall and the fish was recovered after collecting over 7 hours of good quality data.

Run #3 (55733#1) At first it was difficult to get an altitude reading, although in retrospect it may simply have been because we were too timid, after previous events, to go too close to the seabed. Also the topography at the start of the survey was very rough and it was decided to not even attempt to follow it, but simply let the canyon floors shoot away. Another puzzle was that we were getting very poor range in relation to the previous deployment, and used the 200 m setting for a lot of this deployment. The sidescan recorded almost 2 hours of good data before first the PC unit appeared to hang up and then the signal was lost, possibly due to water ingress into the electrical connections at the fish.

Run#4 (55755#1) The Widescan was again deployed for a shelf-edge survey just offshore Muscat. The system performed well, and almost 1.5 hours of good data were logged before the fish was recovered.

Run#5 (55762#1) This deployment was a total failure. Despite a good deck test, and numerous system re-sets and checking of the towfish, connectors, PC controller we could not get any sonar signals recorded. After 45 minutes of perseverance, it was decided to call it a day and the deployment was abandoned. The system will be examined back at SOC to try and establish the cause of the failure.

KASTEN CORE OPERATIONS

The CHD Hydrowerkstatten Kastenlot corer was used to take 25 cores in locations shown in Figure 15. The corer has a 1, 2 or 3 m square-section barrel which has a section area of 150 x 150 mm. Head weights can be added or removed depending on the barrel length and stiffness of the sediment anticipated. Due to the variable nature of the sediments in the area, the speed at which the corer was lowered into the seabed was altered regularly with varying results (between 10 and 145 m min^{-1}). Judging the correct weight was a problem in soft sediments where the bomb was sometimes buried by a few 10s of centimetres, losing the sediment-water interface. However, Megacorer samples were collected at most of these sites, and so it should be possible to reconstruct the correct depth below seafloor.

The corer was lifted from its horizontal position on the deck using the main coring wire and the Rexroth auxiliary winch. With the corer outboard the Rexroth wire was slackened and removed when the corer was vertical. The recovery procedure was the reverse of deployment.

During one deployment a door on one of the catchers was damaged and was repaired on board. Later in the cruise, a catcher was damaged irreparably whilst coring sand when the one of the door trigger arms was broken off due to failure of a hinge pin.

Table 4. Summary of the relevant Kasten corer setup information.

Station Number	Barrel length (m)	Bomb weight (kg)	Total pullout (T)	Core length (m)	Winch speed (m min^{-1})	Comments
55713#1	2	1000	3.07	1.9	21	Bomb buried
55714#1	3	1000	2.77	3.0	9	Bomb buried
55715#1	1	1000	1.49	0	15	Corer fell over – sandy
55715#2	1	1000	1.47	0	30	
55715#3	1	1000	1.72	0.15	60	Sandy – washed out sample in catcher
55715#4	1	1000	1.46	0	120	
55725#1	2	750	3.22	2.0	14	
55726#2	2	750	2.70	0.1	19	Stony mud – catcher sample only
55728#1	2	750	2.97	0	12	Fell over
55737#1	3	650	2.42	1.23	20	
55738#1	2	800	3.11	2.02	20	
55739#1	2	800	3.28	1.65	26	
55749#1	3	600	3.29	2.75	20	
55750#1	3	600	3.14	2.66	26	
55751#1	1	600	0.97	0	125	
55751#2	1	1000	1.48	0	60	Empty – doors not released
55751#3	1	1000	2.13	0.86	102	
55768#1			3.79	1.2	100	
55770#1	2		3.42	?	100	
55772#1	3		3.64	0	20	Fell over
55772#2	2		3.67	0	95	
55788#2	3	1000	4.66		26	
55789#1			2.95	0	15	Fell over
55789#2	3		4.10		30	

The following analysis procedures were carried out (in chronological order for each core); the remaining material was discarded.

Catcher Sample

A sample was removed from the core catcher by hand and placed in a polythene bag as a record of the deepest material recovered.

S-waves

Two bender transducers were inserted into the exposed sediment at 10 cm depth intervals. Full waveforms were recorded using a digital storage oscilloscope at 10 cm and 20 cm transducer separations for each depth. Despite earthing of the sediment, the received signals were corrupted with 50 Hz electrical pickup which made it impossible to identify shear wave arrivals. The noisy signals were recorded at each depth in core 55713#1 although no shear wave data were recorded on core 55714#1. It may be possible to recover useful signals for 55713#1 post-cruise after digital filtering. On core 55725#1, the signal was stacked 100 times and the resulting output recorded; this technique proved successful as shear waves were clearly identified, especially on the 10 cm transducer separations. First break arrival times were noted, and shear wave velocity was calculated for each 10 cm depth interval. The data recorded at 10 and 20 cm intervals should allow estimates of shear wave attenuation, but will require post-cruise processing.

Undrained Shear Strength

A Pilcon hand held tor vane was used to measure undrained shear strength at 10 cm depth intervals. The values were read directly from the calibrated scale in kPa.

Plastic conduit sub-cores

The full length of the core was sub-sampled for archive purposes using plastic, U-section, (electrical) conduit with one removable/snap-on face. The U-section tube was inserted, excess material was removed, then the surface was cheese-wired flush with the U-section tube edges before the snap-on face was replaced. The ends of the plastic conduit were sealed with tape. Sections were labelled in numerical order from the top of the core towards the base. Depths were recorded relative to the top of the recovered sediment in the barrel (assumed to be the sediment-water interface, but see above); the core catcher was 26 cm long. Conduit of cross-section 7.62 x 5.08 cm was used until this material ran out, after which 5.08 x 5.08 cm conduit, and then 2.54 x 3.81 cm conduit were used (both archive and working sub-cores were taken with the last item).

P-wave sub-samples

Small (6 x 6 cm) box section plastic tubes, cut to 10 cm lengths, were inserted at regular depth intervals (e.g. 10 cm, 20 cm, etc. depending on lithological variability down the core) with their long sides perpendicular to the core axis. Excess material was removed and the ends cut flush with a palette knife. The samples were then sealed with plastic end caps and taped. The orientation relative to the core was marked on each sub-sample. The aim is to measure post-cruise P-wave velocity and attenuation (and their anisotropy) on these sub-samples using a 500 kHz pulse transmission system in a water tank (to give repeatable coupling).

Physical Properties & Grain Size sub-samples

Syringes were used to extract 10 ml core plugs at 10 cm depth intervals which were immediately transferred to 20 ml plastic pots with air-tight lids. These sub-samples will be subjected to post-cruise volumetric (bulk density, grain density, porosity) and grain size analyses.

PLASTIC GRAVITY CORE OPERATIONS

This was an experimental piece of equipment, which worked very well in the mostly soft sediments encountered in this area. The corer utilizes the Hydrowerkstatten Kastenlot corer head weight, and, via an adapter, uses a 2-metre length of Giant Piston Corer PVC liner as a barrel. The plastic barrel is attached to the adapter with two 12mm stainless steel pins. A cutter and 'finger type' catcher was attached to the other end of the barrel in a similar way to the piston corer arrangement. The corer was launched in the same was as the Kastenlot corer. Because of the fragile nature of the plastic barrel great care was taken to use it only where the seabed was thought to be soft sediment, and the corer was lowered into the bottom very slowly (10-15 m min^{-1}). Head weights were removed as detailed in the table below. On recovery the corer is bought on board in the vertical position and held just off the deck. The stainless steel pins in the top of the barrel were withdrawn and the barrel removed to be capped. The bomb weight was then lowered and rotated to the horizontal using the main wire and the Rexroth winch.

One core was lost whilst attempting to pull it from the seabed when the plastic liner broke at the bomb end, during a pull out registering around 4 tonnes. The 10 cm diameter black plastic barrels were ideal for retrieving the continuous samples needed for post-cruise sub-sampling and measurement that will utilise both the multi-sensor core logger and the resonant column (that needs 7 cm diameter, 14 cm long cylindrical samples).

Table 5. Summary of the relevant Plastic corer setup information.

Station Number	Bomb weight (kg)	Total pullout (T)	Core length (m)	Winch speed (m min^{-1})	Comments
55720#1	500	1.57		12	Sample lost on deck
55720#2	500	1.63	1.93	12	
55721#1	500	1.36	1.66	12	
55722#1	500	1.11	0	10	Empty – sand?
55723#1	500	1.21	0.34	12	
55724#1	500	2.20	0.73	11	
55735#1	1000?	2.28	2.0	11	Bomb buried to 0.4m
55736#1	500	2.01	2.0	11	Bomb buried
55769#1		3.18	2.0	19	
55771#1		3.85	0	22	Barrel lost
55793#1		3.87	?	20	

The locations of these stations are shown in Figure 16.

ULTRA SHORT BASELINE NAVIGATION

The Sonardyne USBL underwater navigation system comprises of a transducer head mounted on a pole through the ship's gate valve, a two-box deck unit and two transponder units for attachment to underwater vehicles and equipment.

The transducer head had been re-installed into the gate valve prior to the cruise. The deck units were brought up from the hold and installed into the laboratory during leg 1. The deck units require inputs from the transducer head, the ship's gyro, the vertical reference unit (VRU) – shared by the EM-12 bathymetry system - NMEA DGPS position, and outputs to the level 'A' logging system. Through a combination of reading the manuals, cable tracking and sheer dogged persistence these connections were eventually all located. The ship's gyro synchro input was found to be giving inaccurate readings. This was being reflected in the EM-12 input. The cause of this was traced to there being buffered outputs that were not in fact buffered. Once this had been rectified all inputs were in order.

The two transponder units operate with rechargeable batteries, these being fully charged prior to use. At the beginning of leg 2 a transponder was attached to the megacorer. The transponder details were entered into the deck unit but no replies or positions were displayed. On the second deployment the channel settings of the transponder were altered to those that were found to be the best during trials in May 2000. These were entered into the deck unit but again no positions were displayed. Consulting the manuals the diagnostic display was entered. This seemed to indicate that while replies were being received on the correct frequencies they were not of sufficient strength or number for the unit to recognise them and produce a position fix.

No further attempts were made to use the system, as the top speed of the ship was limited whilst the transponder pole was deployed. This was retracted so that full speed could be used for the remainder of the cruise.

SHIPBOARD WINCH SYSTEM

The ships winch system was used throughout the cruise for Piston, Kasten, Gravity and Mega coring, Agassiz trawling and CTD's.

The winch operated well for the duration of the cruise with exception to the following faults.

At the start of the cruise the CTD brake ram had seized and the first station was completed with the brake being manually forced off. The ram was later repaired and has worked fine ever since.

The brake solenoid failed on the Deep tow winch. It was temporarily swapped with one from the Hydro system to save on down time. The suspect valve was stripped and repaired during the next convenient period when the winch could be shut down. The repaired solenoid operated reliably for the remainder of the cruise.

The Deep tow electro – optical cable developed two optical faults, one about 3 km and the other just under 7 km along its length. This type of attenuation fault is well known and was resolved by streaming the cable. The cable restored its self at about 5.5 km and was streamed to 7 km to ensure that the "injured" section was wound off. After this exercise the cable showed no signs of the fault returning. The most likely cause for the temporary failure was that during MPV operations the scrolling of the cable did not follow correctly for one small period and could not be rectified due to operational conditions.

MISCELLANEOUS

1) Chernikeeff EM Log---The same coefficients were used as during CD141.
2) EA500 Echo Sounder---The hull mounted transducer and PES "fish" were utilised throughout the cruise, with no reported problems. Winch vibration and noise contributes to difficulty in detecting Bottom Tracking in rapidly changing bottom conditions whilst operating in the hull mounted mode, as the power packs for the winch system are located near to the transducer
3) The SurfMet system performed well for the duration of the cruise; periodic flushing with Triton-X solution was required to clean the fluorometer and transmissometer of algae build-up. This was undertaken approximately every 5 days, or whenever the data graph indicated unexpected drift in the measurable signal. The installed orientation of the wind direction continued to be problematic, as onboard the Discovery. (A thirty second average of the wind direction is taken by the SurfMet software, and then sent to the ship's logging system. When on station, the wind is typically shifting from either side of relative north by +/- 20 degrees; the indicator is oriented as north=bow, thus averaged data will reflect values of approximately one-half of the relative wind direction.) The problem cannot be rectified via the software, therefore the wind sensor will need to be physically repositioned to north=stern, as wind direction is not typically positioned from aft whilst on station.

SurfMet configuration was as follows:
Surface instrumentation:
Falmouth Scientific International Ocean Temperature Module (remote location), s/n 1379

Falmouth Scientific International Ocean Temperature Module (housing location), s/n 1361
Falmouth Scientific International Ocean Conductivity Module (housing location), s/n 1353
WetLABS fluorometer, s/n WS3S-246
SeaTech 20cm path transmissometer, s/n T-1019D
(NB---Salinity calculations were made using the housing located sensors.)

Meteorological instrumentation:
Vaisala PTB100A Barometric Pressure sensor, s/n S3440012
Vaisala HMP44L Temperature/Humidity sensor, s/n U1850013
Vaisala WAA Anemometer, s/n S45517
Vaisala WAV Wind Vane, s/n R05426
Didcot/ELE DRP-5 PAR sensor, port, s/n 5144
Didcot/ELE DRP-5 PAR sensor, starboard, s/n 5143
Kipp & Zonen TIR (Pyranometer), port, s/n 962276
Kipp & Zonen TIR (Pyranometer), starboard, s/n 962301

4) Portasal salinometer---A total of 24 CTD and 33 SurfMet salinity samples were taken and analysed throughout the cruise, in order to calibrate and verify the performance of the respective conductivity sensors.

Table 6. Summary of EM12 Survey Lines

Line No.	Start Time	Start Latitude (N)	Start Longitude (E)	End Time	End Latitude (N)	End Longitude (E)
Calib1	1921/326	23° 35.90’	59° 08.97’	2042/326	23° 29.23’	59° 14.77’
Calib2	2049/326	23° 29.73’	59° 14.53’	2148/326	23° 35.70’	59° 09.06’
Calib3	2151/326	23° 35.07’	59° 07.70’	2350/236	23° 27.47’	58° 53.94’
Calib4	2350/236	23° 27.30’	58° 53.80’	0200/327	23° 35.80’	59° 09.00’
1A	0508/327	23° 44.46’	58° 40.47’	0928/327	23° 17.30’	59° 04.00’
2	1005/327	23° 13.64’	59° 01.18’	1509/327	22° 41.78’	59° 28.81’
3	1541/327	22° 44.79’	59° 28.56’	2028/327	23° 14.64’	59° 02.62’
1B	2043/327	23° 15.98’	59° 03.43’	0318/328	22° 35.10’	59° 40.00’
4	0355/328	22° 39.50’	59° 38.90’	1516/328	23° 50.80’	58° 37.40’
5	1535/328	22° 52.82’	58° 38.63’	0320/329	22° 39.87’	59° 42.20’
6	0320/329	22° 39.87’	59° 42.20’	0457/329	22° 32.17’	59° 53.73’
7	0457/329	22° 32.17’	59° 53.73’	0630/329	22° 20.32’	59° 53.98’
8	0643/329	22° 20.00’	59° 55.45’	0823/329	22° 32.83’	59° 55.47’
9	0823/329	22° 32.83’	59° 55.47’	0947/329	22° 40.10’	59° 45.90’
10	0947/329	22° 40.10’	59° 45.90’	1838/329	23° 34.83’	58° 58.23’
11	1912/329	23° 35.97’	59° 03.10’	0134/330	22° 55.00’	59° 38.25’
12	0134/330	22° 55.00’	59° 38.25’	0345/330	22° 40.77’	59° 48.81’
13	0345/330	22° 40.77’	59° 48.81’	0506/330	22° 33.88’	59° 57.75’
14	0506/330	22° 33.88’	59° 57.75’	0651/330	22° 20.25’	59° 58.00’
15	0732/330	22° 20.06’	60° 03.93’	0916/330	22° 33.90’	60° 04.01’
16A	0916/330	22° 33.90’	60° 04.01’	1121/330	22° 45.75’	59° 51.57’
16B	1121/330	22° 45.75’	59° 51.57’	1241/330	22° 53.10’	59° 43.00’
17A	1324/330	22° 51.90’	59° 42.50’	1443/330	22° 43.80’	59° 49.70’
17B	1443/330	22° 43.80’	59° 49.70’	1633/330	22° 33.36’	60° 00.63’
18	1633/330	22° 33.36’	60° 00.63’	1816/330	22° 20.00’	60° 03.25’
19	1900/330	22° 27.84’	60° 07.75’	2049/330	22° 34.28’	60° 07.82’
20	2049/330	22° 34.28’	60° 07.82’	2311/330	22° 48.01’	59° 53.99’
21	2311/330	22° 48.01’	59° 53.99’	0110/331	22° 57.51’	59° 41.40’
22	0534/331	22° 40.36’	59° 36.68’	0618/331	22° 44.77’	59° 33.17’
23	0618/331	22° 44.77’	59° 33.17’	0639/331	22° 43.62’	59° 30.37’
24	0639/331	22° 43.62’	59° 30.37’	0701/331	22° 40.96’	59° 29.38’
25	0701/331	22° 40.96’	59° 29.38’	0709/331	22° 41.11’	59° 28.20’
26	0709/331	22° 41.11’	59° 28.20’	1240/331	23° 13.43’	59° 00.51’

Line No.	Start Time	Start Latitude (N)	Start Longitude (E)	End Time	End Latitude (N)	End Longitude (E)
27	1240/331	23° 13.43’	59° 00.51’	1248/331	23° 14.46’	59° 00.49’
28	1248/331	23° 14.46’	59° 00.49’	1315/331	23° 17.68’	59° 02.20’
29	1315/331	23° 17.68’	59° 02.20’	1448/331	23° 27.08’	58° 54.40’
30	1509/331	23° 26.54’	58° 56.90’	1604/331	23° 21.00’	59° 01.90’
31	2017/331	23° 29.50’	59° 14.40’	0130/332	22° 57.39’	59° 41.91’
32	0200/332	22° 00.49’	59° 44.33’	0416/332	22° 48.66’	59° 59.82’
33	0450/332	22° 51.82’	60° 03.05’	0716/332	23° 04.39’	59° 47.62’
34	0752/332	23° 00.75’	59° 44.75’	1401/332	23° 37.96’	59° 14.05’
35	1442/332	23° 40.50’	59° 18.60’	2028/332	23° 04.42’	59° 48.61’
36	2106/332	23° 07.96’	59° 50.94’	2324/332	22° 55.94’	60° 06.08’
37	0025/333	23° 00.10’	60° 09.46’	0246/333	23° 12.00’	59° 54.40’
38	0330/333	23° 09.20’	59° 51.40’	0900/333	23° 43.99’	59° 22.48’
39	2223/333	23° 15.51’	59° 57.42’	0036/334	23° 00.27’	60° 14.90’
40	0036/334	23° 00.27’	60° 14.90’	0300/334	22° 36.90’	60° 11.80’
41	0300/334	22° 36.90’	60° 11.80’	0426/334	22° 23.00’	60° 11.50’
42	1526/335	23° 34.90’	58° 57.30’	1848/335	23° 55.45’	58° 39.55’
43	1915/335	23° 57.27’	58° 42.86’	2127/335	23° 57.27’	58° 42.86’
44	2222/335	23° 41.68’	59° 01.54’	0128/336	24° 00.12’	58° 48.10’
45	0200/336	24° 02.47’	58° 48.10’	0600/336	23° 37.49’	59° 10.04’
46	0533/340	22° 18.83’	59° 52.50’	0706/340	22° 18.83’	59° 52.50’
47A	0706/340	22° 18.83’	59° 52.50’	0847/340	22° 38.69’	59° 38.81’
47B	0847/340	22° 38.69’	59° 38.81’	1007/340	22° 47.12’	59° 29.70’
48A	1015/340	22° 41.26’	59° 29.07’	1150/340	22° 36.69’	59° 40.28’
48B	1150/340	22° 36.69’	59° 40.28’	1356/340	22° 31.40’	59° 51.12’

Table 7. Summary of Stations

Station No.	Type	Day/Time Start	Start Lat	Start Long	Day/Time End	End Lat	End Long	Depth	Comments
55701#1	SVP	326/1429	23° 35.85	59° 08.90	326/1716	23° 36.19	59° 08.94	ca. 3100	
55702#1	Piston	331/0406	22° 44.15	59° 35.31				968	7.68 m
55703#1	Piston	331/1754	23° 25.71	58° 59.18				647	10.2 m
55704#1	Piston	333/1245	23° 29.64	59° 13.99				3106	11.35 m
55704#2	CTD + SVP	333/1511	23° 29.57	59° 14.06	333/1800	23° 29.81	59° 13.49	3101	bottles fired @ 3140, 3028, 2524, 2021, 1520, 771, 522, 272, 125, 75 & 2
55705#1	Piston	334/0622	22° 22.40	60° 08.00				2193	10.63 m
55706#1	Piston	334/1121	22° 41.96	59° 55.50				1425	8.62 m
55707#1	Piston	334/1847	23° 08.53	59° 04.64				425	0.39 m
55708#1	CTD	335/0222	23° 41.47	58° 42.32	333/0255	23° 41.84	58° 42.34	1435	bottles fired @ 400, 211, 20
55709#1	Widescan	335/1235			335/1306				crashed, connectors damaged
55710#1	Mega	336/0912	23° 21.83	59° 06.03				1422	8/8 cores
55711#1	Mega	336/1111	23° 22.76	59° 02.09				793	2/8 overfull, very soft sediment, discarded
55711#2	Mega	336/1231	23° 22.77	59° 02.16				802	2/8 cores
55711#3	Mega	336/1330	23° 22.81	59° 02.12				792	2/10 cores
55711#4	Mega	336/1451	23° 22.79	59° 02.14				1451	4/10 cores
55712#1	Mega	336/1616	23° 23.07	58° 59.10				352	sandy, discarded
55712#2	Mega	336/1704	23° 23.07	58° 59.03				334	small samples, sandy
55713#1	Kasten	336/2308	23° 22.14	59° 05.64				1309	1.9 m
55714#1	Kasten	337/0109	23° 22.77	59° 02.13				800	2.7 m
55715#1	Kasten	337/0237	23° 23.07	58° 59.10				353	no recovery
55715#2	Kasten	337/0257	23° 23.11	58° 59.13				361	no recovery
55715#3	Kasten	337/0316	23° 23.07	58° 59.12				358	0.15 m
55715#4	Kasten	337/0400	23° 23.07	58° 59.10				353	no recovery
55716#1	SHRIMP	337/0608	23° 21.54	59° 02.51	337/0905	23° 20.41	59° 03.65	ca. 1400	765 frames + 180 min video (lighting irregular)
55717#1	Mega	337/1143	23° 21.18	59° 03.19				1341	7/8 cores (1 geol)

Station No.	Type	Day/Time Start	Start Lat	Start Long	Day/Time End	End Lat	End Long	Depth	Comments
55718#1	Mega	337/1345	23° 21.67	58° 59.29				ca. 800	6/8 cores, overfilled, very soft sed. - discarded
55718#2	Mega	337/1453	23° 21.69	58° 59.30				ca. 800	6/8 cores, overfilled, very soft sed. – discarded
55718#3	Mega	337/1600	23° 21.67	58° 59.30				ca. 800	6/8 cores, very soft sed. (1 geol)
55719#1	Mega	337/1739	23° 22.30	58° 58.48				ca. 325	not bottoming, 4 broken + 3 damaged tubes
55720#1	Plastic	337/1928	23° 22.88	59° 00.62				580	2 m recovered, lost on deck
55720#2	Plastic	337/2010	23° 22.89	59° 00.59				582	1.93 m
55721#1	Plastic	337/2110	23° 22.97	59° 00.00				508	1.66 m
55722#1	Plastic	337/2201	23° 23.01	58° 59.62				444	no recovery
55723#1	Plastic	337/2241	23° 23.00	58° 59.80				473	0.34 m
55724#1	Plastic	338/0052	23° 20.57	59° 04.34				1656	0.73 m
55725#1	Kasten	338/0314	23° 20.28	59° 09.88				1995	2 m
55725#2	Mega	338/0515	23° 20.31	59° 09.85				2010	9/10 cores (1 geol)
55726#1	Mega	338/0759	23° 19.87	59° 07.34				2075	10/10 (1 geol)
55726#2	Kasten	338/1011	23° 19.89	59° 06.95				1968	small sample beyond catcher
55726#3	CTD + SVP	338/1207	23° 19.99	59° 06.81	338/1410	23° 20.01	59° 07.38	1935	bottles @ 2036, 1701, 1600, 1500, 1350, 1200, 1050, 750, 450, 230, 101 & 21
55727#1	SHRIMP	338/1800	23° 19.27	59° 10.34	338/2030	23° 18.23	59° 10.31	2300-2400	180 min video
55728#1	Kasten	338/2324	23° 18.28	59° 10.31				2425	no recovery
55729#1	Widescan	339/0207			339/1344				
55730#1	CTD + SVP	339/1810	22° 46.40	59° 57.30	339/2019	22° 47.32	59° 50.01	2000	12 bottles fired @ 2037, 1500, 1100, 900, 700, 600, 500, 240, 60, 50, 40 & 20
55730#2	Mega	339/2243	22° 46.24	59° 57.52				1980	10/10 cores (1 geol)
55731#1	Mega	340/0107	22° 41.51	59° 56.01				1414	9/10 cores
55732#1	Mega	340/0311	22° 34.30	59° 53.32				695	2 tubes cracked
55733#1	Widescan	340/1139			340/1402				
55734#1	SHRIMP	340/1643	22° 35.19	59° 53.30	340/2244	22° 32.31	59° 52.16	900-330	2 x 180 VHS
55735#1	Plastic	341/0022	22° 37.99	59° 54.24				1017	2 m recovered, head buried

Station No.	Type	Day/Time Start	Start Lat	Start Long	Day/Time End	End Lat	End Long	Depth	Comments
55736#1	Plastic	341/0157	22° 40.11	59° 55.63				1246	2 m recovered, head buried
55737#1	Kasten	341/0315	22° 41.52	59° 56.17				1423	1.23 m recovered
55738#1	Kasten	341/0431	22° 41.55	59° 57.75				1563	2.02 m recovered
55739#1	Kasten	341/0635	22° 46.34	59° 57.60				1994	1.65 m recovered
55740#1	SHRIMP	341/0929	22° 46.54	59° 57.70	341/1000	22° 46.41	59° 57.60	ca. 2000	
55741#1	SHRIMP	341/1313	22° 42.21	59° 56.46	341/1345	22° 42.04	59° 56.36	ca. 1500	
55742#1	SHRIMP	341/1521	22° 40.27	59° 55.65	341/1601	22° 40.10	59° 55.53	ca. 1200	
55743#1	SHRIMP	341/1738	22° 38.10	59° 54.20	341/1840	22° 37.68	59° 53.86	ca. 1000	
55744#1	Agassiz	341/2225	22° 39.66	59° 51.29	341/2345	22° 41.49	59° 50.59	ca. 1200	
55745#1	Agassiz	342/0416	22° 45.80	59° 59.55	342/0515	22° 47.51	59° 58.88	ca. 2100	
55746#1	SHRIMP	342/0942	22° 49.08	59° 45.88	342/1025	22° 49.06	59° 46.22	ca. 2450	
55747#1	SHRIMP	342/1326	22° 44.62	59° 45.52	342/1615	22° 43.34	59° 45.50	ca. 2450	
55748#1	SHRIMP	342/1952	22° 39.17	59° 49.11	342/2120	22° 39.60	59° 48.59	ca. 1650	
55749#1	Kasten	343/0006	22° 44.46	59° 45.56				1964	2.75 m recovered
55750#1	Kasten	343/0145	22° 43.67	59° 45.52				1895	2.66 m recovered
55751#1	Kasten	343/0336	22° 33.97	59° 45.58				236	no recovery
55751#2	Kasten	343/0359	22° 33.97	59° 45.48				211	no recovery
55751#3	Kasten	343/0410	22° 34.04	59° 45.49				210	0.86 m recovered
55752#1	Mega	343/1115	23° 20.72	59° 08.05				1692	11/11(1 stainless for geol)
55753#1	Mega	343/1325	23° 23.47	59° 03.51				1093	11/111(1 stainless for geol)
55754#1	Mega	343/1447	23° 22.98	59° 00.00				504	11/111(1 stainless for geol)
55754#2	Mega	343/1611	23° 23.02	58° 59.99				505	11/11
55754#3	Mega	343/1851	23° 23.01	58° 59.93				511	12/12
55754#4	Mega	343/2004	23° 23.08	58° 59.91				492	12/12
55754#5	Mega	343/2126	23° 23.09	59° 00.06				528	12/12
55755#1	Widescan	344/1018			344/1207				
55756#1	SHRIMP	344/1515	23° 22.96	58° 58.91	344/1814	23° 23.00	59° 00.07	300–500	
55757#1	SHRIMP	344/1948	23° 22.65	59° 02.49	344/2100	23° 22.81	59° 02.06	800-900	

Station No.	Type	Day/Time Start	Start Lat	Start Long	Day/Time End	End Lat	End Long	Depth	Comments
55758#1	SHRIMP	344/2238	23° 23.43	59° 03.74	345/0007	23° 23.62	59° 03.09	1000-1200	
55759#1	Agassiz	345/0317	23° 23.37	59° 03.67	345/0358	23° 23.70	59° 03.52	ca. 1100	
55760#1	Agassiz	345/0526	23° 23.47	58° 59.40	345/0551	23° 23.86	58° 59.27	400-500	
55761#1	Agassiz	345/0720	23° 22.98	58° 59.10	345/0845	23° 23.23	58° 58.87	ca. 350	anchored!
55762#1	Widescan	345/1018			345/1055				System failure
55763#1	Mega	345/1503	23° 23.02	58° 59.15				363	2/6 cores
55763#2	Mega	345/1548	23° 23.00	58° 59.10				357	1/6 cores
55764#1	Mega	345/1641	23° 22.94	58° 59.98				502	12/12 cores
55765#1	Mega	345/1817	23° 22.76	59° 02.05				789	
55765#2	Mega	345/1929	23° 22.79	59° 02.00				776	
55766#1	Mega	345/2101	23° 23.52	59° 03.55				1103	
55767#1	Mega	345/2246	23° 22.10	59° 05.60				1390	
55768#1	Kasten	346/0129	23° 17.33	59° 11.21				2399	1.2 m recovered
55769#1	Plastic	346/0306	23° 17.96	59° 10.78				2411	48 cm recovered
55770#1	Kasten	346/0448	23° 17.17	59° 11.31				2367	1.2 m recovered
55771#1	Plastic	346/0715	23° 19.21	59° 15.50				2855	barrel missing!
55772#1	Kasten	346/0921	23° 20.20	59° 14.80				2801	no recovery
55772#2	Kasten	346/1114	23° 20.24	59° 14.79				2800	no recovery
55773#1	SHRIMP	346/1350	23° 20.47	59° 09.65	346/1450	23° 20.12	59° 09.74	1976-1991	
55774#1	SHRIMP	346/1722	23° 20.53	59° 07.96	346/1810	23° 20.92	59° 08.00	1694-1740	
55774#2	Mega	346/2028	23° 20.68	59° 07.96				1684	12/12
55775#1	Mega	346/2300	23° 20.39	59° 09.89				1990	12/12
55776#1	Agassiz	347/0213	23° 20.58	59° 08.19	347/0245	23° 20.98	59° 07.81	ca. 1650	
55777#1	Agassiz	347/0430	23° 22.57	59° 03.59	347/0532	23° 23.45	59° 03.32	1050-1100	
55778#1	SHRIMP	347/0948	23° 20.95	59° 08.01	347/1102	23° 20.57	59° 08.04	1670-1700	
55779#1	SHRIMP	347/1317	23° 22.26	59° 05.65	347/1447	23° 21.55	59° 05.53	1380-1400	
55780#1	MPV	347/1904			348/1046				
55781#1	MPV	348/2123			349/1740				

Station No.	Type	Day/Time Start	Start Lat	Start Long	Day/Time End	End Lat	End Long	Depth	Comments
55782#1	SHRIMP	350/0017	23° 00.94	60° 03.13	350/0310	23° 00.00	60° 04.18	3175-3200	
55783#1	Agassiz	350/0755	23° 00.49	60° 03.77	350/0954	23° 00.56	60° 04.01	ca. 3200	
55784#1	SHRIMP	351/0122	22° 58.59	60° 08.73	350/0345	22° 57.85	60° 08.20	ca. 3150	
55785#1	SHRIMP	351/1025	22° 42.20	60° 39.05	351/1153	22° 42.34	60° 39.66	ca. 3185	
55786#1	CTD + SVP	351/1718	22° 58.01	60° 08.21	351/2038	22° 58.16	60° 08.39	ca. 3145	bottles fired @ 3182, 2900, 2700, 2500, 2400, 2299, 2200, 2100, 2000, 500, 401, 301
55787#1	Agassiz	351/2221	22° 58.41	60° 07.99	351/2337	22° 58.76	60° 04.24	ca. 3150	
55788#1	Mega	352/0313	23° 01.00	60° 02.98				3185	11/12
55788#2	Kasten	352/0551	23° 01.03	60° 03.00				3185	
55789#1	Kasten	352/1230	22° 22.51	60° 06.30				2023	no sample, catcher doors did not close
55789#2	Kasten	352/1346	22° 22.48	60° 06.36				2020	
55789#3	Mega	352/1529	22° 22.49	60° 06.35				2030	
55790#1	Mega	352/1814	22° 22.38	59° 58.58				1420	
55790#2	Kasten	352/1934	22° 22.34	59° 58.67				1406	
55791#1	SHRIMP	353/0638	23° 30.27	59° 29.91	353/0938	23° 29.33	59° 30.17	ca. 3300	
55792#1	Roughsnap	337/0608	23° 29.98	59° 30.00				3300	
55793#1	Plastic	353/1430	23° 33.97	59° 22.72				3303	

Station type	Total Number of Stations	Successful	Failure
SVP	1	1	-
Piston Core	6	6	-
CTD (+SVP)	5	5	-
Widescan	5	3	2
Megacore	36	28	8
Kasten Core	25	17	8
SHRIMP	21	21	-
Plastic Core	11	8	3
Agassiz Trawl	9	9	-
MPV	2	2	-
Roughsnap	1	1	-
	122	101	21
		82.8%	17.2%

TABLE 8. 3.5 kHz ROLL ARCHIVE

Roll No.	Start Time	End Time	Survey Lines
1	1823/326	0420/327	Calib 1 – Calib 4
2	0420/327	2028/327	1A – 3
3	2028/327	1926/328	1B – 4
4	1933/328	2306/328	4
5	2307/328	1839/329	4 – 10
6	1840/329	0651/330	11 – 14
7	0651/330	1324/330	15 – 16B
8	1324/330	0107/331	17A – 21
9	0108/331	1604/331	22 – 30
10	1605/331	1430/332	31 – 34
11	1430/332	1125/333	35 - 38
12	1757/333	0230/335	39 – 41
13	1508/335	0740/336	42 – 45
14	1000/336	1430/337	n/a
15	1642/337	0535/340	n/a
16	0536/340	0536/340	46 - 48
17	0609/342	1610/343	
18	0901/344	0630/346	
19	0640/346	1350/349	
20	1350/349	2255/353	
21	2300/351	1520/353	

TABLE 9. 3.5 kHz CD ARCHIVE

CD No.	First File	Last File
1	P3261828	P3280800
2	P3280900	P3300000
3	P3300100	P3311700
4	P3311800	P3330900
5	P3331000	P3351600
6	P3351700	P3371500
7	P3371600	P3390900
8	P3390928	P3402300
9	P3410000	P3422000
10	P3422100	P3450400
11	P3450500	P3470700
12	P3470800	P3481400
13	P3480900 P3481500	P3491200
14	P3490000 P3490600 P3491300	 P3490700 P3510200
15	P3510300	P3522300
16	3530000	P3531500

TABLE 10. WIDESCAN DATA ROLL ARCHIVE

Roll No.	Start Time	End Time	Deployment No.
1	1713/335	1344/339	1 & 2
2	1138/340	1400/340	3
3	1027/344	0647/347	4 & 5

Figure. 1. Cruise Track lines.

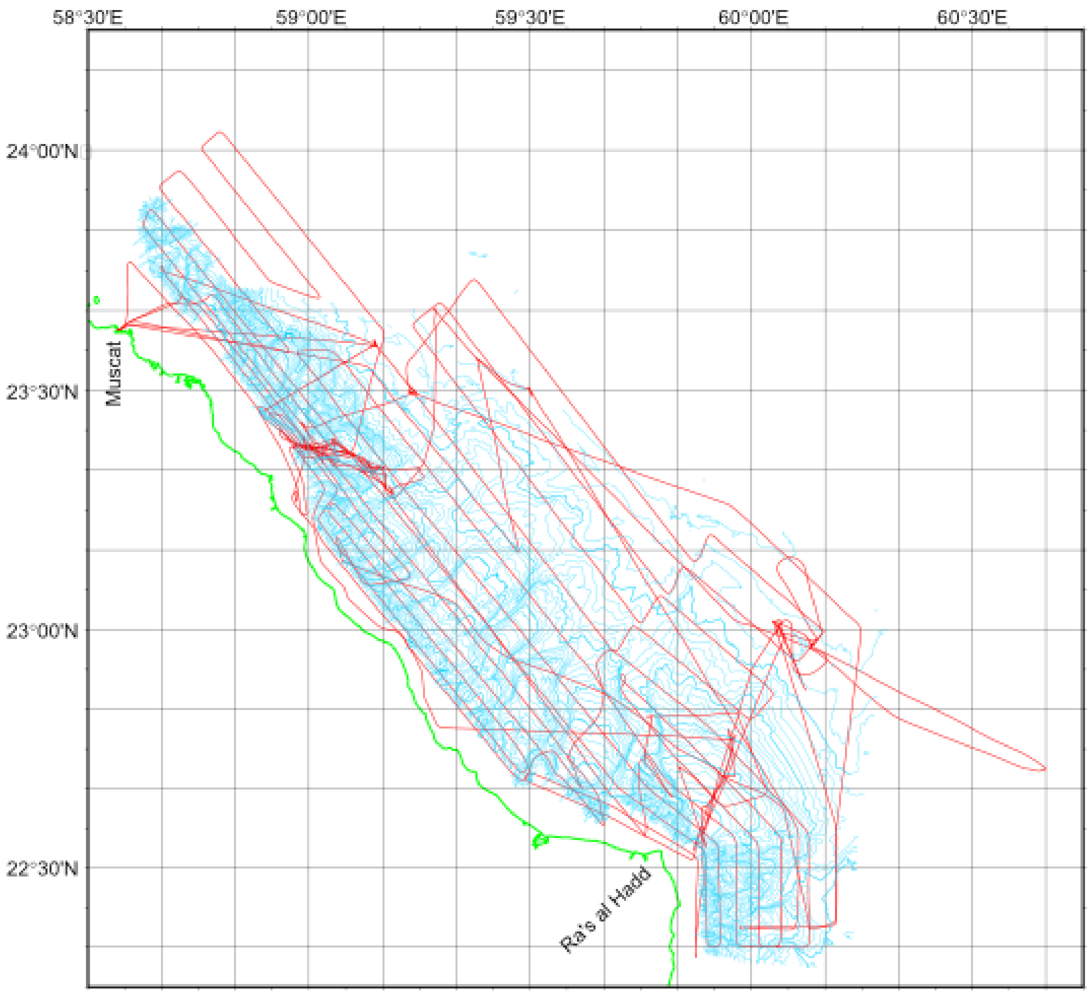

Figure. 2 Location of Piston Core Stations, superimposed upon draft bathymetry

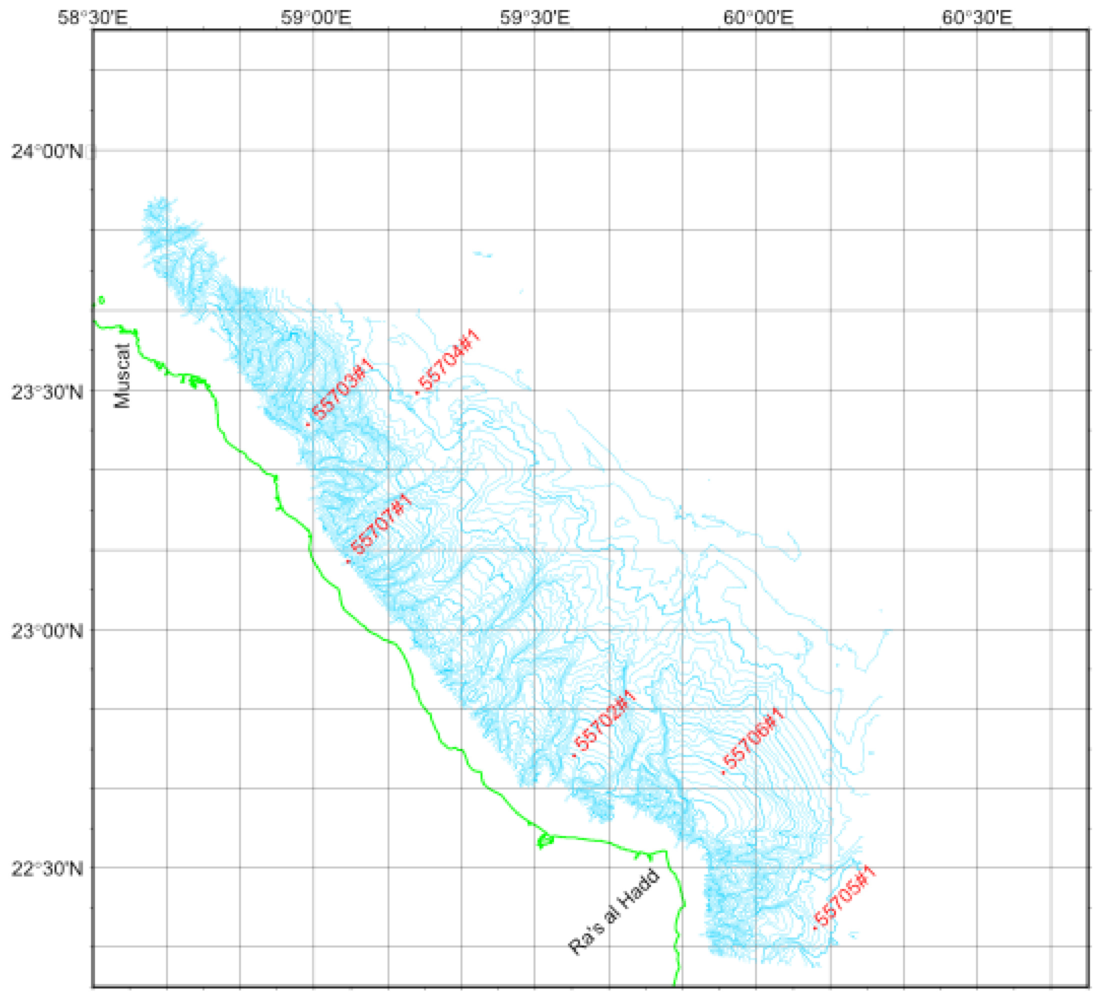

Figure 3. CTD & SVP Stations superimposed upon draft bathymetry

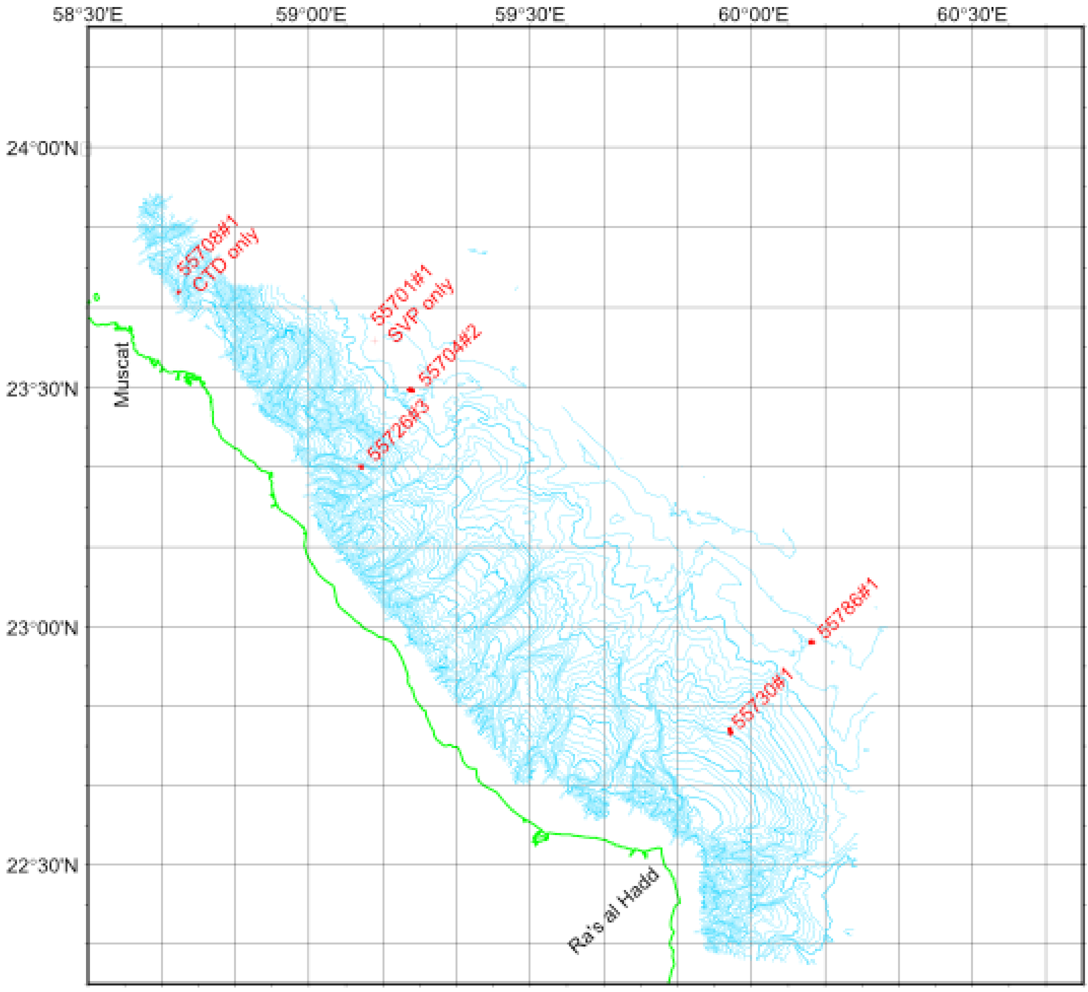

Figure 4. SHRIMP station locations superimposed upon draft bathymetry

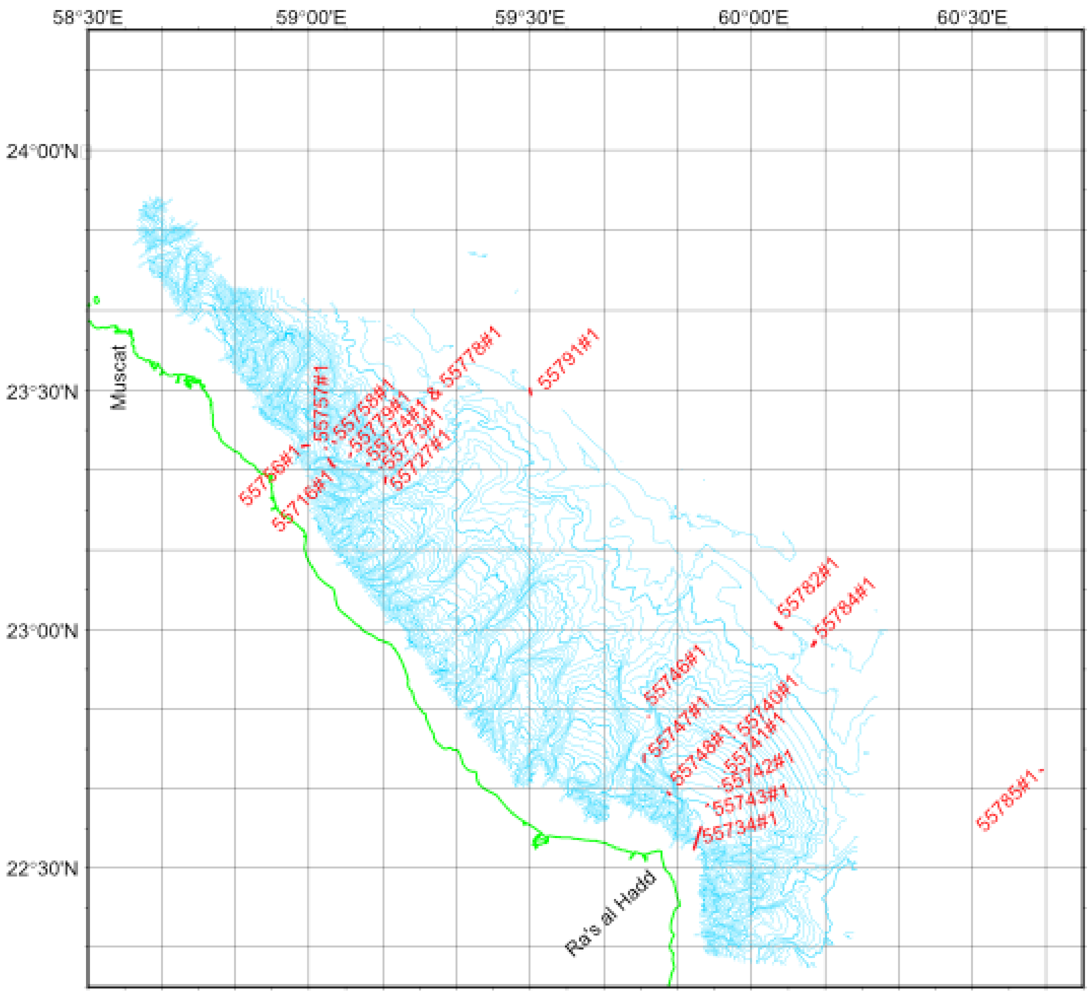

Figure 5. Megacore stations superimposed upon draft bathymetry

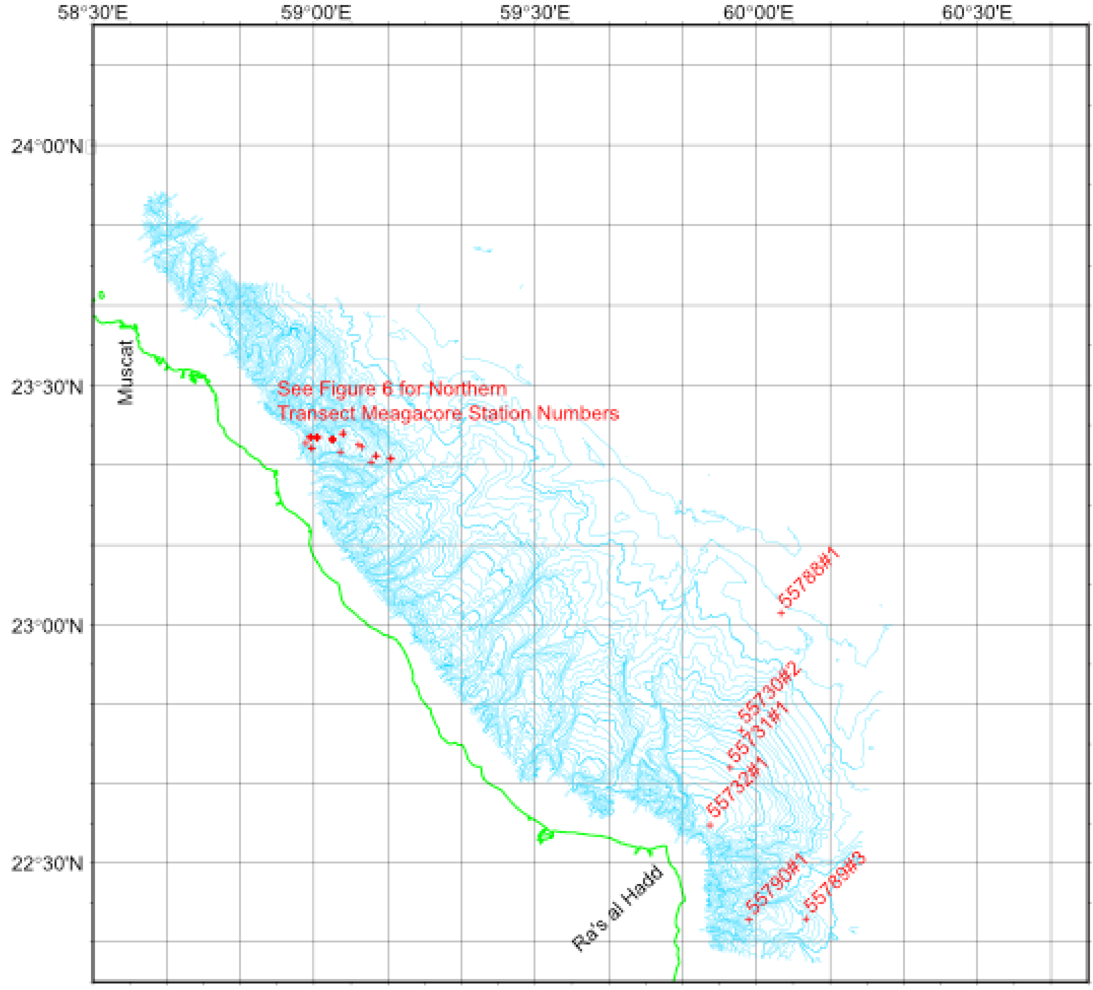

Figure 6. Megacore Stations along the "Northern transect" superimposed upon draft bathymetry

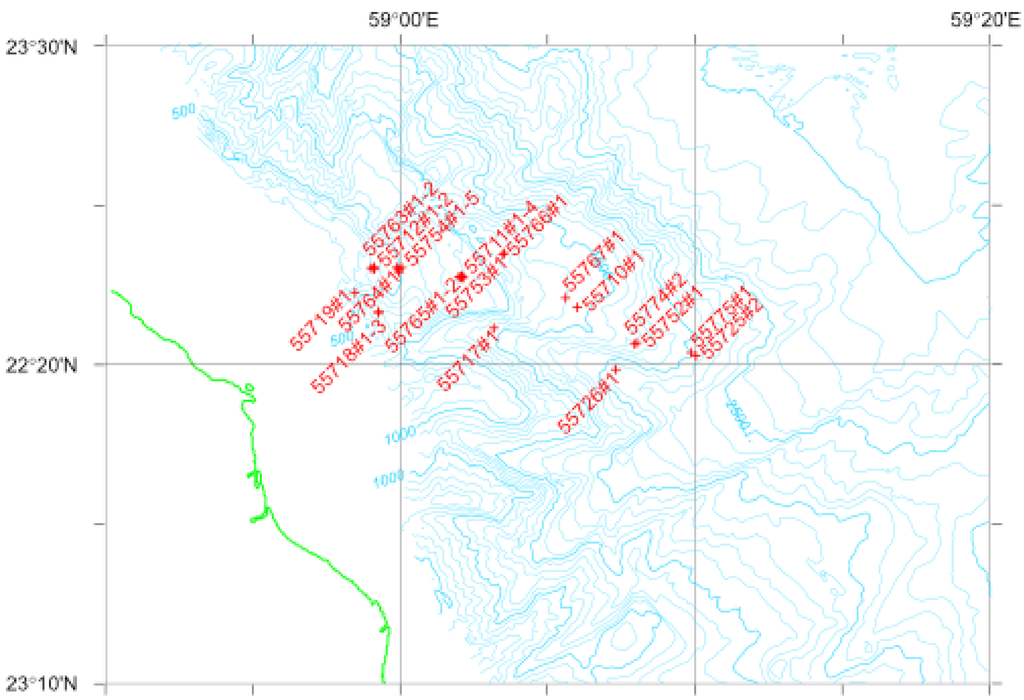

Figure 7. Winkler O_2 titrations vs. CTD sensors

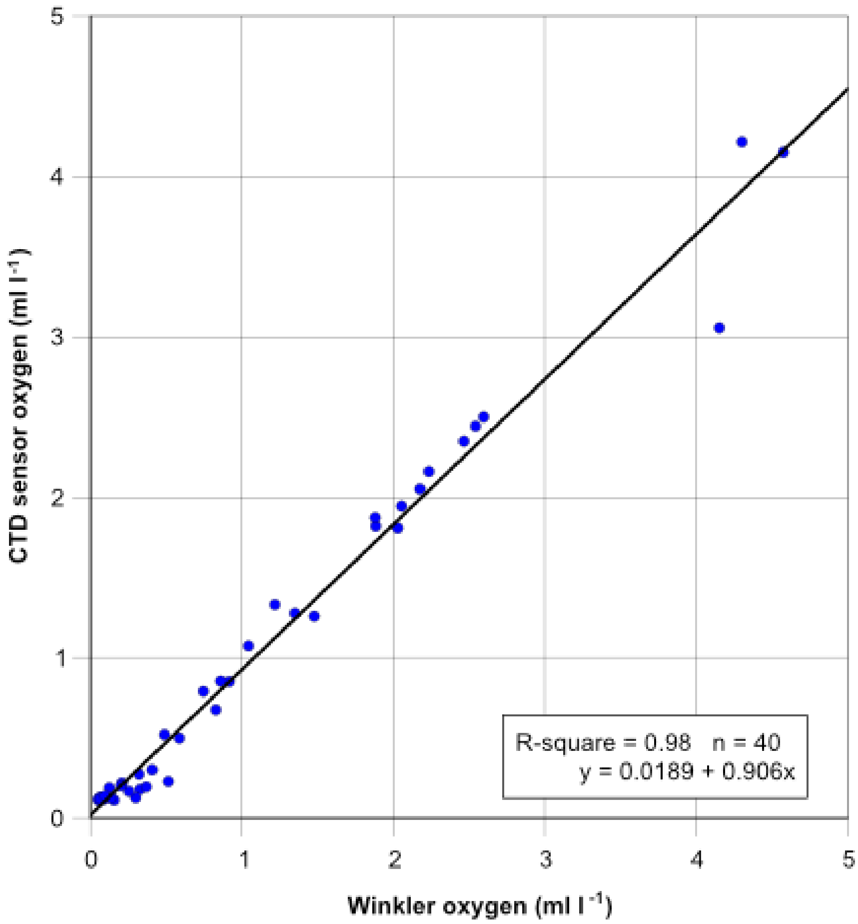

Figure 8. Winkler O_2 and CTD Sensor O_2 comparison by depth

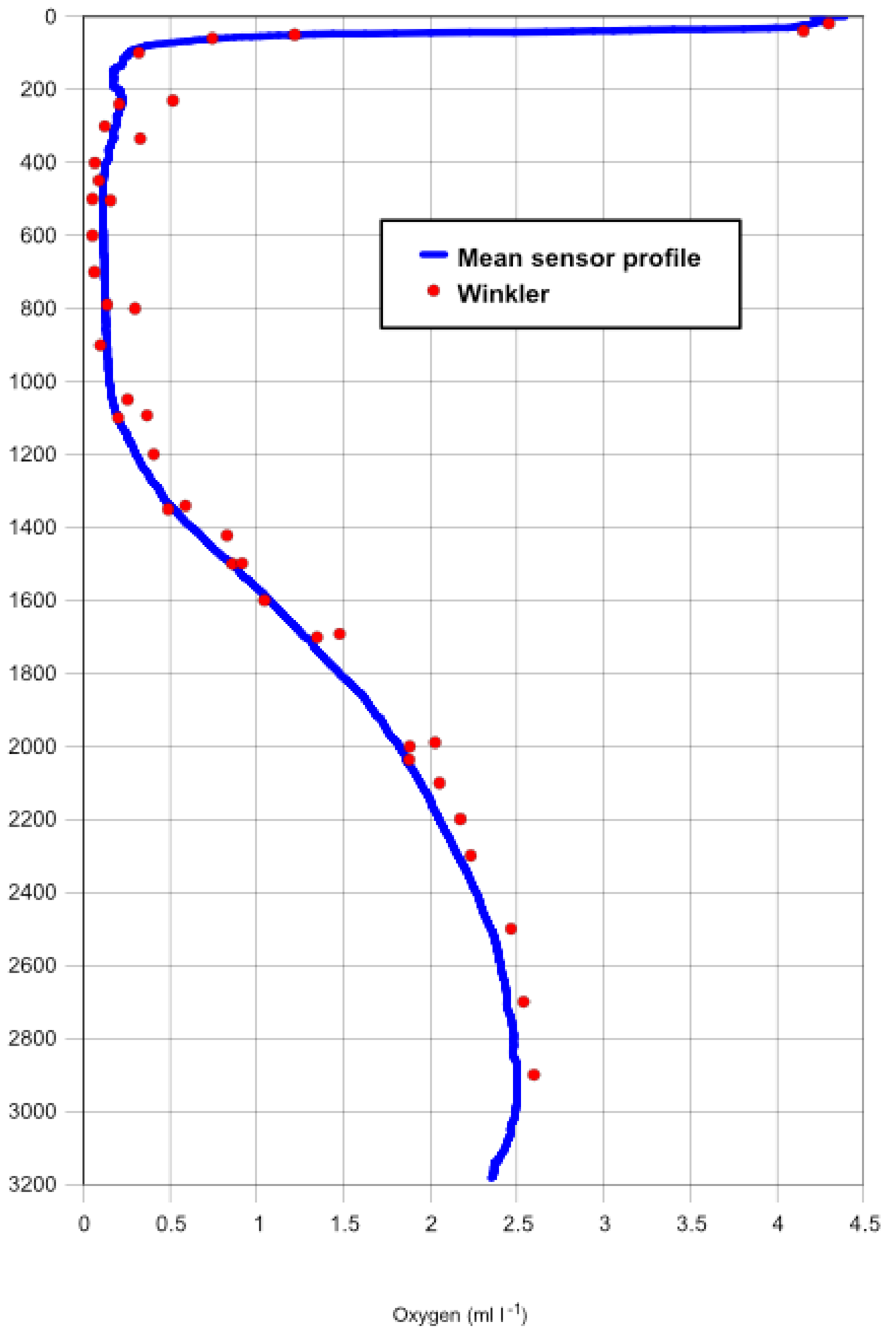

Figure 9. Station 55704 CTD profiles and "zoom" of the upper 600 m showing influence of Arabian Gulf outflow.

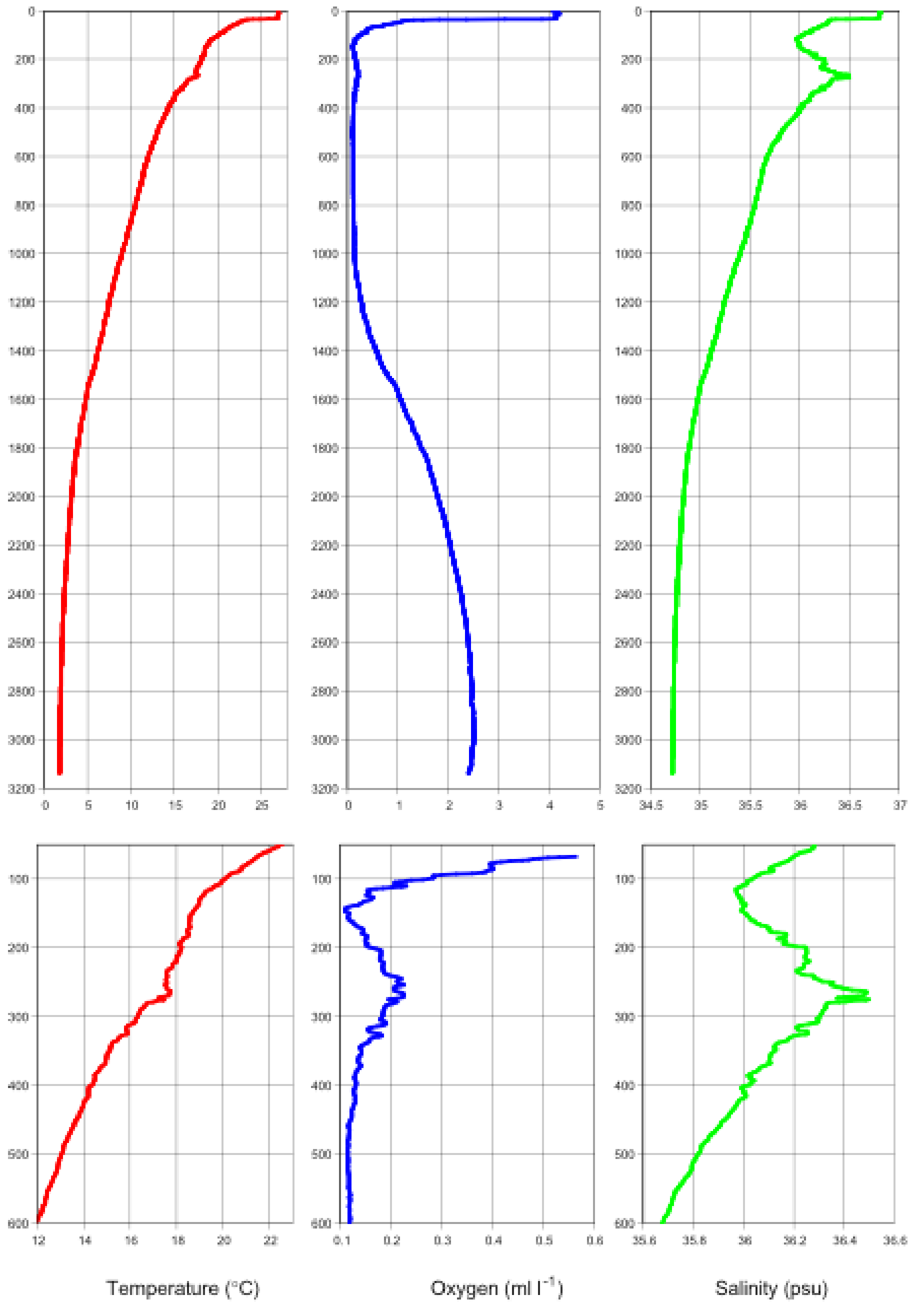

Figure 10. Agassiz Trawl Station locations superimposed upon draft bathymetry

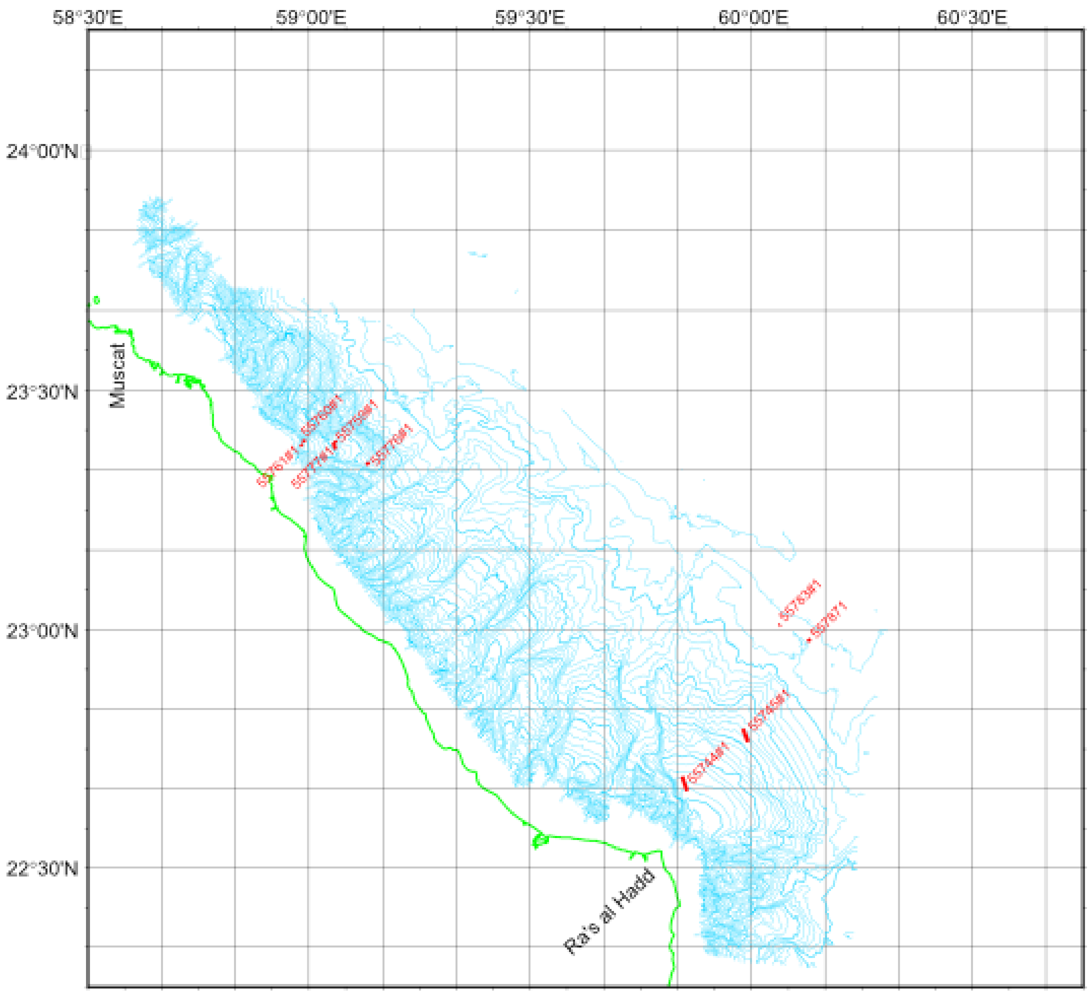

Figure 11. MPV transect locations superimposed upon draft bathymetry

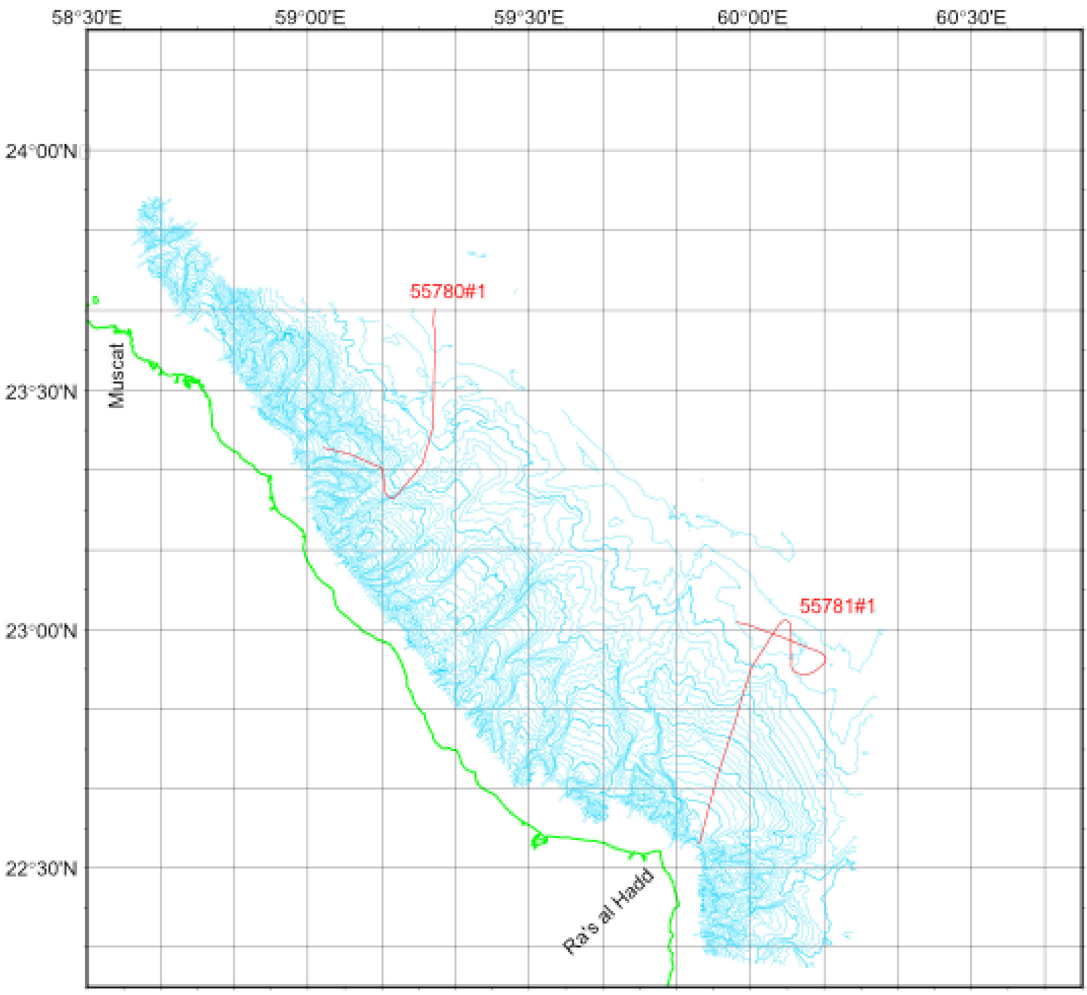

Figure 12. WIDESCAN track lines superimposed upon draft bathymetry

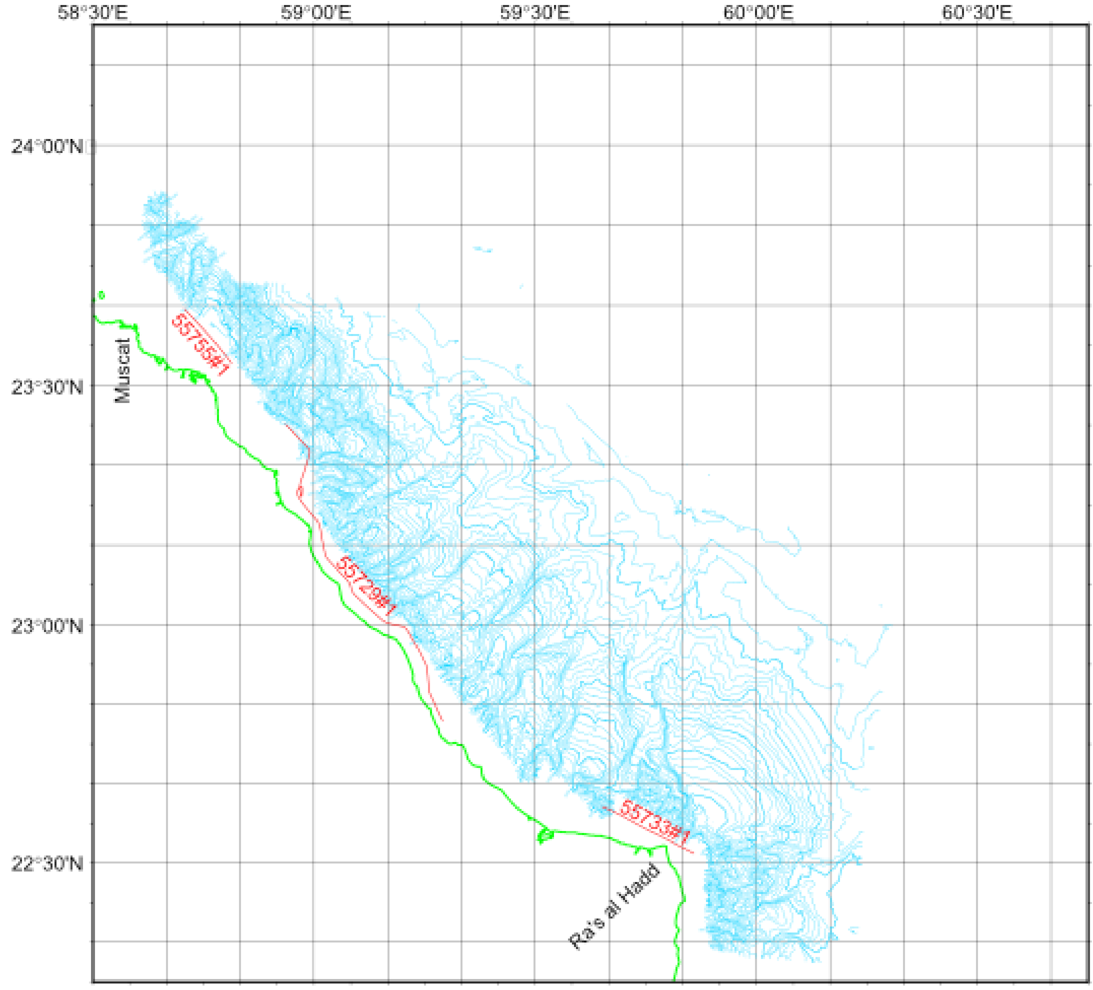

Figure 13. Kasten Core Stations superimposed upon draft bathymetry

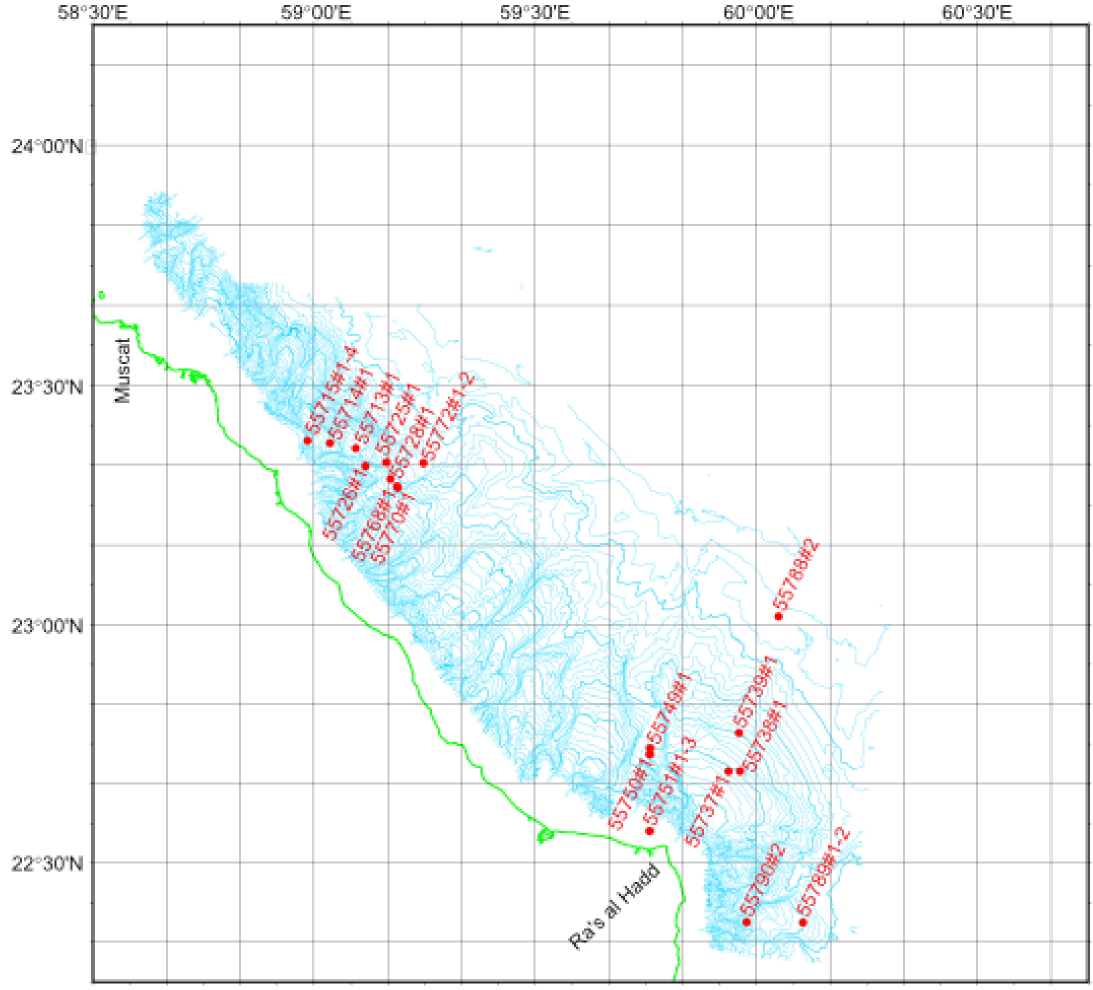

Figure 14. Plastic Gravity Core Stations superimposed upon draft bathymetry