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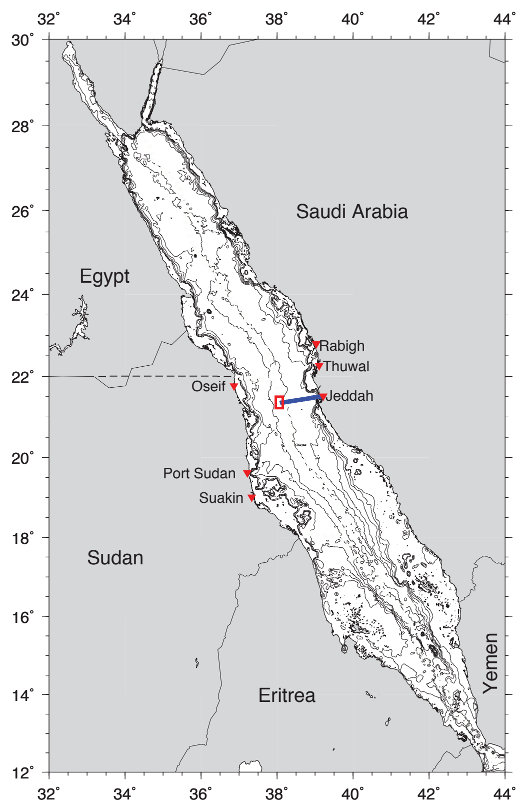
Woods Hole Oceanographic Institution
King Abdullah University of Science and Technology

R/V *Oceanus* Voyage 449-6 Red Sea Atlantis II Deep Complex Area
19 October–1 November 2008

by

Dr. Amy S. Bower (WHOI), Chief Scientist



Collaborative Technical Report

Funding for this report was provided by the King Abdullah University of Science and Technology (KAUST) under a cooperative research agreement with Woods Hole Oceanographic Institution.

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Approved for Distribution:

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1. Introduction

The purpose of this report is to summarize the research activities conducted during *R/V Oceanus* Voyage 449-6 (also referred to as KAUST Leg 2) in the Red Sea. The cruise began on 19 October 2008 at 1700 Local Time (LT), when the *R/V Oceanus* departed Jeddah Commercial Port. On the cruise were 15 scientists from five countries, including Saudi Arabia, United States, Egypt, Hong Kong and Sudan. The cruise ended on 1 November 2008 when the Oceanus returned to the Jeddah Commercial Port.

a. Cruise Objectives

The original objectives of this cruise were to (1) conduct a large-scale survey of the hydrography and currents of the entire Red Sea, (2) collect water samples for metagenomics and bacterial diversity studies from throughout the Red Sea, (3) investigate microbial phosphorous cycling in the Red Sea and (4) explore the geophysical and biological environment of the famous Red Sea deep brine pools. Only Sudan granted clearance for work throughout the Red Sea. Without clearance from other neighboring countries, the objectives of the cruise were revised to reflect a focus entirely on the Atlantis II Deep Complex Area, defined for the purposes of this cruise as between latitudes 21˚ 13'N and 21˚ 30'N and longitudes 37˚ 58'E and 38˚ 9'E. The scientists involved in this cruise, both on board and ashore, worked quickly to modify the cruise objectives in light of the last-minute restriction in the allowed operating area. The new goals of the cruise were to (1) investigate the physical characteristics of the brine pools to observe possible changes in hydrothermal activity; (2) investigate water properties and currents above the brine pools to detect possible influence of the brine pools on the local ocean circulation; (3) collect water and sediment samples for metagenomics and bacterial diversity studies from brine and non-brine areas, (4) investigate microbial phosphorous cycling in the area of the Atlantis II Deep; and (5) explore the geophysical and biological environment of the Atlantis II brine pools.

b. Preliminary Findings

(1) Temperature measurements in the southwest basin of the Atlantis II Deep suggest a decrease in the temperature by 1-2˚C of the Lower Convective Layer (LCL) compared to measurements made in the 1990s. Temperature was measured in two ways, first with the Onset "Hobo" temperature loggers and then with the high-range CTD. This suggests that the hydrothermal activity may have slowed down or stopped sometime during the past decade.

(2) Temperature measurements in the A-II Deep also revealed at least two well-mixed upper convective layers above the LCL, which had been observed previously. The horizontal scale of these layers was however not known. By "tow-yoing" the Hobo up and down through the brine pool, we found that these layers were continuous throughout the SW Basin and into the Western Basin.

(3) A small brine pool was found along the western wall of the central rift valley, with maximum measured temperatures of about 33˚C. This pool, which we named the

Oceanus Seep, may be connected to the Valdivia Deep to the west. This could not be confirmed due to the restriction on the allowed operating area.

(4) Water properties at intermediate depths varied from east to west across the rift valley, with slightly warmer, saltier more oxygen-rich water on the western wall. This suggests the presence of a weak Deep Western Boundary Current along the western wall, which may carry recently convected water southward through the Red Sea.

(5) At several positions around the operating area that were not over the brine pools, a thick layer of slightly warm, saline water was observed at the bottom. Current measurements indicated that these thin dense layers were flowing downslope. This suggests that dense briny water is seeping out of the walls of the rift valley and flowing down the walls.

(6) Sediment samples were in general not sulfidic, but characterized by significant amounts of iron. If the brine water turns out to be alkaline (to be tested back at WHOI), the lack of hydrogen sulfide would be consistent with thermodynamic models of the relationship between pH and the reduction potential.

(7) We found the surface phosphate concentrations were nearly an order of magnitude lower than was reported in the 1970's and 1980's. This implies a very intense competition for phosphorus between groups of microbes. Indeed, we found a statistically significant daily cycle in phosphate concentrations, which implies an interplay between light-utilizing microbes (i.e. picophytoplankton) and heterotrophic microbes that operate independent of light.

2. Cruise Participants

1. Amy Bower, Chief Scientist (WHOI)
2. Frank Bahr (WHOI)
3. Erich Horgan (WHOI)
4. Ellen Roosen (WHOI)
5. Marshall Swartz (WHOI)
6. Stephen Swift (WHOI)
7. George Tupper (WHOI)
8. Benjamin Van Mooy (WHOI)
9. Rania Siam (American University of Cairo)
10. Ahmed Shebl (American University of Cairo)
11. Chun Kwan Stanley Lau (Hong Kong University of Science and Technology)
12. Yue Him (Tim) Wong (Hong Kong University of Science and Technology)
13. El Sheikh Bashir Ali (Institute for Marine Research, Red Sea University, Sudan)
14. Haitham Al-Jahdali (KAUST)
15. Alaa Al-Barakati (King Abdullaziz University Department of Marine Physics)
16. Capt. Waleed Al-Muhana (Saudi Arabian Naval observer)

3. Cruise Narrative

19 October
The *R/V Oceanus* was underway from Jeddah Commercial Port at 1700 on 19 October 2008 for Leg 2 of the inaugural KAUST-WHOI Red Sea oceanographic expedition. Weather conditions at departure were excellent. On board were 15 scientists from five countries, including Saudi Arabia, the United States, Egypt, China and Sudan. KAUST and WHOI together worked extraordinarily long and hard on the preparations for this cruise, and the scientists on board were thrilled to be underway!

The vessel transited to the Atlantis II Deep Complex Area in about six hours, and conducted a test Conductivity-Temperature-Depth (CTD) cast beginning at 2330 near 21˚ 30'N, 38˚ 9'E (CTD 1). The purpose was to test all the components of the new KAUST sampling package. Everything was found to be in excellent working order. A digital camera mounted on the CTD rosette took photographs at 10 sec intervals and caught images of one fish and one jellyfish during the cast. At the completion of the cast, a bathymetric survey of the Atlantis II Deep Complex Area began. Everyone was feeling well and was in good spirits.

20 October
The bathymetric survey continued until 0800 on 20 October, when we stopped temporarily to conduct water sampling for the AUC and HKUST groups for marine genomics and bacterial diversity studies. Five casts were made to collect large volumes of seawater at various depths between 20 m and 1500 m (CTDs 2-6). The sampling went very well. Sampling was completed around 1700, at which point we resumed the bathymetric survey.

21 October
All of the east-west lines from the bathymetric survey were completed at about 0800. A shallow cast was conducted at the end point for phosphorous, nutrient and carbonate chemistry (CTD 7). The ship then proceeded to the Discovery Deep to make the first hydrocast into the brine water (Hydrocast 1). On this first cast, only a pinger and the "Hobo" temperature data logger were lowered on the wire. The logger returned an impressive temperature profile, with maximum temperatures in the brine layer of about 45˚C.

The ship then proceeded to the Southwest Basin of the Atlantis II Deep and conducted another hydrocast with the Hobo temperature logger (Hydrocast 2). This time, two Niskin bottles were also attached to the wire to attempt to capture some brine water samples for salinity measurements and genomics studies (Figure 1). A completely successful cast indicated brine water temperatures of about 68˚C (Figure 2). Both Niskin bottles closed properly and were not damaged by the immersion in the hot brine water. HKUST scientists collected small samples for genomics. Additionally, black mud was found on the bottom of the wire, a sample of the mineral deposits at the bottom of the brine pool.

Figure 1. Scientists work with Niskin bottles on the hydrowire. From left to right is Frank Bahr (WHOI), Elsheikh Bashir Ali (IMR/Sudan), and Haitham Jahdali (KAUST).

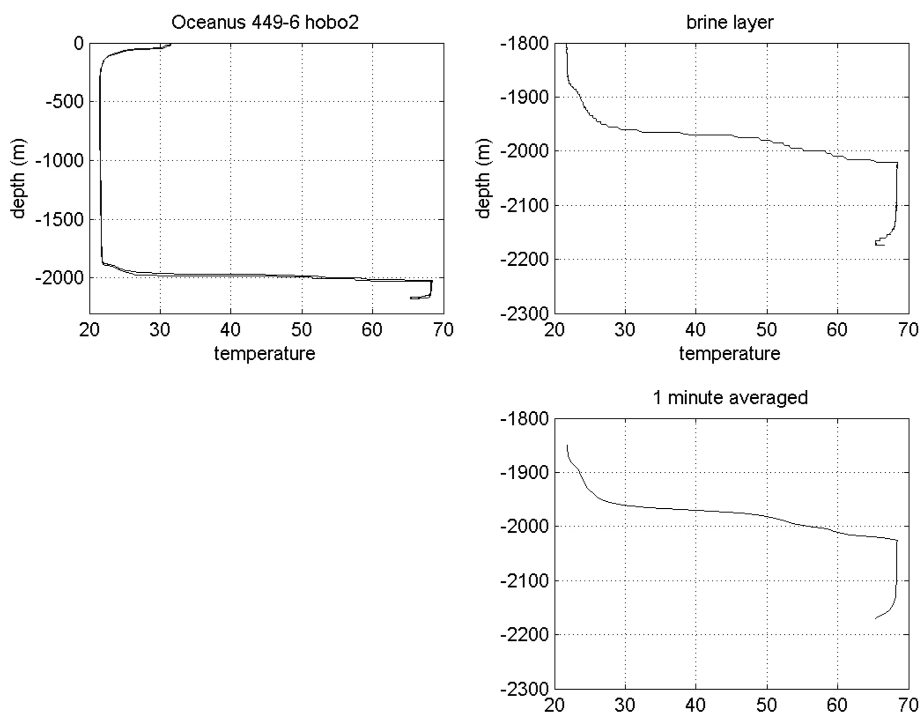


Figure 2. Temperature profile from the SW Basin of the Atlantis II Deep collected with an Onset "Hobo" temperature logger attached to the hydrowire. The depth is determined from the wire out.

Around 1900, the bathymetric survey was resumed, with work on the north-south transects of the box. There was some (albeit faint) evidence of the interface in the acoustic returns from the echosounders.

22 October
Weather today was perfect for shipboard work, with a light breeze and lower temperature and humidity. Around 0800, the bathymetric survey was halted temporarily and the ship returned to the center of the SW Basin of the Atlantis II Deep. Beginning around 0900, three hydrocasts were conducted, each with 10 Niskin bottles and one Hobo temperature logger (Hydrocasts 3-5). On the first cast, the three bottom bottles did not close because of a stiff plunger on bottle 7 (from the top). The bottle was repaired and the cast was repeated. All 10 bottles closed on this cast and the next, providing large-volume brine water samples for the AUC, HKUST and WHOI biology and chemistry groups. The water collected in the bottles was clearly from the hot brines; it was warm and water from some of the bottles was tinged yellow/orange due to its mineral content. The Hobo logger, attached to the top bottle, indicated temperatures consistent with the lower convective layer on all casts. Samples from near the top of the brine layer were yellow/orange, whereas those from near the bottom were clear, possible evidence of precipitation of iron particles at the brine interface due to the presence of dissolved oxygen in the overlying ocean water. The top bottle was cooler than the rest on the third of these casts, suggesting that perhaps it had not been closed in the brine layer. However, the Hobo temperature logger, attached to this bottle, indicated brine layer temperatures.

The Hobo temperature logger showed maximum brine water temperatures around 68.3˚C in the SW Basin of the A-II Deep. This is about 1-2˚C cooler than in the 1990s, and may be due either to horizontal variations in the temperature of the brine pool's lower convective layer, or a slowing or cessation of hydrothermal activity. We planned to conduct a transect across the basin in an attempt to resolve these two possibilities.

Later in the day we rigged the A-frame in preparation for the first gravity core in the Atlantis II brine pool. This operation was postponed, however, because it was found that the pulley holding the wire needed lubrication.

23 October
Winds increased today to more than 20 knots, the highest we have experienced so far. During the night, bathymetry measurements were made along a northwest-southeast line in preparation for the first TowCam today. After that, the ship continued the large-scale bathymetric survey until morning. A CTD cast (CTD 8) was made at the beginning of the first TowCam line, and water samples were collected for chemistry (WHOI) and calibration (salts and oxygen).

Following the CTD cast, a test run was made along the first TowCam line using the hydroweight as a substitute for the TowCam. This was done to gain some experience in the careful ship handling that is required for TowCam operations under the current weather conditions. The TowCam is towed about 5 meters above the sea floor. Bathymetric maps and a forward-looking altimeter are used to avoid obstacles. In light of the very rugged rift bathymetry that we have observed so far on this cruise, TowCam operation will prove to be quite challenging.

TowCam was eventually postponed for today and a CTD transect over the SW Basin of the Atlantis II Deep was conducted to get some information on the impact of the brine layer on the deep ocean above it (CTDs 9-17). In the process of this transect, we located thin brine layers at several locations away from the main brine pool (CTD 9), evidence of small pools or seeps. The digital camera on the CTD captured an image of the interface between the thin bottom layer of brine and the ocean water.

24 October
In the morning we finished the CTD transect across the SW Basin of the Atlantis II brine pool, stopping at the station over the pool to collect some large-volume samples for genomics analysis (CTDs 13-14). We then proceeded to a position near the deepest part of the pool and extracted a core of sediment using the gravity corer (Gravity Core 1). The core tube was about 2.8 meters, and a core of length 2.6 meters was collected. Small samples were taken by AUC, and the bulk of the core was claimed by HKUST. A second core will be made in the Discovery Deep for the AUC group in the following days. During the evening, we completed the large volume profile at the A-II deep brine pool with casts to 200 and 700 m and to collect brine water (CTDs 18 and 19).

After completion of the large volume profile at the Atlantis II Deep, the ship moved into position to conduct a “tow-yo” with a Hobo on the hydrowire across the SW Basin of the A-II Deep. The ship steamed slowly in a NNW direction while the Hobo was winched slowly up and down through the brine layer. While not as precise in its depth measurement as a CTD, the Hobo revealed two characteristics of the brine pool: (1) the temperature of the LCL was constant throughout the basin, and (2) the upper convective layers were consistently present in every profile.

Several days ago it was discovered that the gravimeter on board was not working properly. After intense e-mail traffic to diagnose the problem, the SSSG technician on board (Alex Dorsk) swapped out the gyro. All indications thereafter were that the unit was functioning normally. However, this meant that the parts of the gravimeter/bathymetry survey that we had already completed would have to be re-done.

During the night, more of the bathymetric survey was completed, this time with the gravimeter working. Bathymetric surveys were also conducted along two possible lines along which the TowCam would collect magnetometer data at ~ 200 m above the seafloor. Although the TowCam will be used to carry the magnetometer, the emphasis on these lines will be on obtaining magnetometer measurements and not digital photographs. This allows us to tow the vehicle higher above the bottom.

25 October
Most of the day was spent preparing for the first magnetometer tow on TowCam (CT 1), which commenced in the late evening.

26 October
Following the nighttime TowCam/Magnetometer tow (CT 1), the bathymetry/gravity survey was continued. Around 0830, the survey was interrupted to conduct three

hydrocasts for brine water sampling, one at the SW Basin of Atlantis II Deep (Hydrocast 6; AUC) and two in Discovery Deep (Hydrocasts 7 and 8; one for AUC and one for HKUST). This was followed by a gravity core (Gravity Core 2) in Discovery Deep. The second long TowCam/Magnetometer tow (CT 2) was carried out overnight.

27 October
The second long TowCam/Magnetometer tow finished in the morning. We then steamed down to Discovery Deep, where activities included four CTD casts for large-volume samples at 20, 50, 200, 700 and 1500 m by AUC and HKUST (CTDs 20-23). We then surveyed TowCam line A6, and the near-bottom TowCam tow (CT 3) started around 2200 LT. It continued until about 0400 LT on 28 October.

28 October
After the TowCam tow, two hours more of bathymetry/gravity survey were completed. Then a short (about two miles) bathymetric line was run across a valley between CTD stations 9 and 10, looking for a possible connection between Oceanus Seep (CTD 9) and the downslope flow seen at CTD 10. The depth of this valley appeared to be only about 1430 m, not deep enough to connect the two locations. A CTD cast (CTD 24) was inadvertently made at the next valley to the north, where there was no evidence of warm bottom water on the cast profile. We then proceeded to the location of the valley seep for another CTD (CTD 25).

The valley station was not deep enough to connect the Oceanus Seep with the (weak) downslope flow seen at CTD 10. We decided then to investigate further the Oceanus Seep, where a large temperature anomaly had been found at the bottom of CTD 9. We first ran two north-south bathymetry lines over the deep. The western line showed what appeared to be two channels separated by a high mound. The eastern run (just 0.25˚ to the east of the western line) showed a wide, flat-bottomed deep about 1 nm wide with maximum bottom depths of about 1550 m. We did a CTD tow-yo (CTD 26) along this line in the afternoon of 28 October, starting at the north side of the valley and proceeding southward at about 1 knot. The CTD was continuously winched up and down between about 1450 dbar and 5 meters above the bottom.

High temperatures, similar to what was observed on CTD 9, were observed at the northern end of the deep. Bottom depth varied by 10’s of meters along the ship’s track. Toward the southern end of the deep, temperatures higher than 30˚C were observed. In two of the upcasts, large variability was observed in the temperature record, with temperature varying between 20˚ to >30˚C between scans. After some analysis, we interpreted this variability to be caused by the rosette being dragged through the water at the sharp brine interface. Twelve downcasts were made across the deep, and they defined the north-south extent of the deep and its temperature structure.

After the CTD Tow-Yo, a TowCam tow (CT 4) was made along A7 during the night. The magnetometer did not work properly, but a good photo sequence was obtained.

29 October
In the morning, a full-depth CTD cast (CTD 27) was conducted along the western edge of the box, south of CTD 9, to look for evidence of the warm, salty, high oxygen water that was observed at CTD 9 and surrounding stations at intermediate depths. Similar anomalies were observed at this station as were observed at CTD 9 and 10.

Following the CTD cast, the ship returned to Oceanus Seep for another CTD TowYo across the potential vent, this time along an east-west section. The first tow (CTD 28) did not go over the vent site because we did not set up far enough to the east for the ship to get on course. The second try went well (CTD 29), except that the ship passed to the south of a small depression where we believe the pool is located. After this second tow, the CTD returned to the surface with some damage, including a bent bail, scraped up LADCP and some other scrapes and bends of the frame. After a thorough inspection, it was decided that the CTD could go back in the water after some minor repairs, although a spare LADCP would have to be installed. While the CTD frame was being repaired, a short gravity core was conducted in the Oceanus Seep area (Gravity Core 3). This short core looked very similar to the core from Discovery Deep. Some of the scientists observed shells of foraminifera (a protozoan) in the core mud. The purpose of the core was to collect some of the whitish sediment that appears to coat much of the bottom in the camera images. None was detected in the core top material. The core will go back to WHOI for further analysis.

After the core, the Eh sensor from TowCam was attached to the CTD before the lowering into the new brine. The Hobo was also suspended under the CTD by 5 meters. The cast (CTD 30) showed moderately warm water at the bottom, around 33˚C. The Eh sensor showed strong evidence of a reducing environment, consistent with vent water. Some drift occurred during the station such that we were not in the bottom of the depression when the CTD reached the sea floor.

When the CTD cast was completed, we picked up a couple of hours of survey runs, then set up for the Line A7 TowCam repeat (CT 5). Some small glitches occurred on the first deployment, so the TowCam was recovered and the tow restarted along Line A7.

30 October
Because of the delay in the start of TowCam along Line A7, it was clear that we would not have time to do Line A8 later in the cruise. So it was decided to leave the TowCam down and just continue the tow from Line A7 into A8. This decision was made based on information from Dan Fornari that the magnetometer was the most important aspect of these tows. The camera would stop sometime during A8, but this was deemed an acceptable penalty for the time saved in recovering, recharging and redeploying the TowCam.

The TowCam run went very well. The magnetometer functioned properly throughout the tow. The camera stopped sometime along Line A8, as expected but captured some dramatic images beforehand. The tow made several dips down into the upper layer of the A-II brine pool.

31 October
After the TowCam run along Lines A7 and A8, four CTD stations were occupied around the perimeter of the Red Box to look at "far field" water properties and currents, especially at intermediate depth (CTD 31-34). While these casts were going on, the high-range NCTD, which had flooded on the first cast, was repaired. We returned to the A-II SW Basin and first hung the NCTD 50 m below the rosette (CTD 35). This allowed the NCTD to just enter the Lower Convective Layer of the brine pool. The unit appeared to work well, reading temperatures similar to the Hobo. We then conducted one cast (NCTD 1) with the NCTD and a Hobo strapped to a strongback on the hydrowire and lowered to the bottom of the Atlantis II brine pool. The data has been e-mailed back to WHOI for analysis, but preliminary analysis looks good.

1 November
The final cast ended around 0000 on 1 November. The bathymetry/gravity survey was continued for another two hours until it was time to head for Jeddah. The ship tied up in the Jeddah Commercial Port around 1000 on 1 November 2008, bringing to a close Voyage 449-6.

4. Data Collected

a. Underway Data

Many types of oceanographic and meteorological observations were collected continuously along the ship track as follows:

i. IMET Meteorological Observations

A full suite of meteorological measurements was collected continuously along the ship's track, including air temperature, barometric pressure, humidity, short-wave radiation, wind speed and direction. The sensors (IMET) were mounted on a bow mast and are similar in quality to sensors being used on the KAUST meteorological buoy and tower. A plot of true wind speed and direction is shown in Figure 3. Wind direction was consistently from the north or northwest. Wind speed was low during the first several days, but then increased significantly for the remainder of the cruise. Maximum sustained winds were about 14 m/s (27.2 knots).

ii. Thermosalinigraph

Sensors mounted in the ship's clean seawater intake system continuously measured sea surface temperature, sea surface salinity and fluorescence.

iii. Hull-mounted ADCP

R/V Oceanus was outfitted with two shipboard ADCP's: a 75 KHz Ocean Surveyor instrument and an older 150KHz NB instrument, both made by Teledyne RD Instruments. Single ping measurements over a vertical range of 700 m (350 m) at a rate of about 2.5 seconds (1 second) per ping were averaged over five minutes to provide vertical profiles of horizontal velocity estimates (NB150 values in parentheses). Both instruments used 8 m vertical bins. The older NB150 filled the role of a backup to the

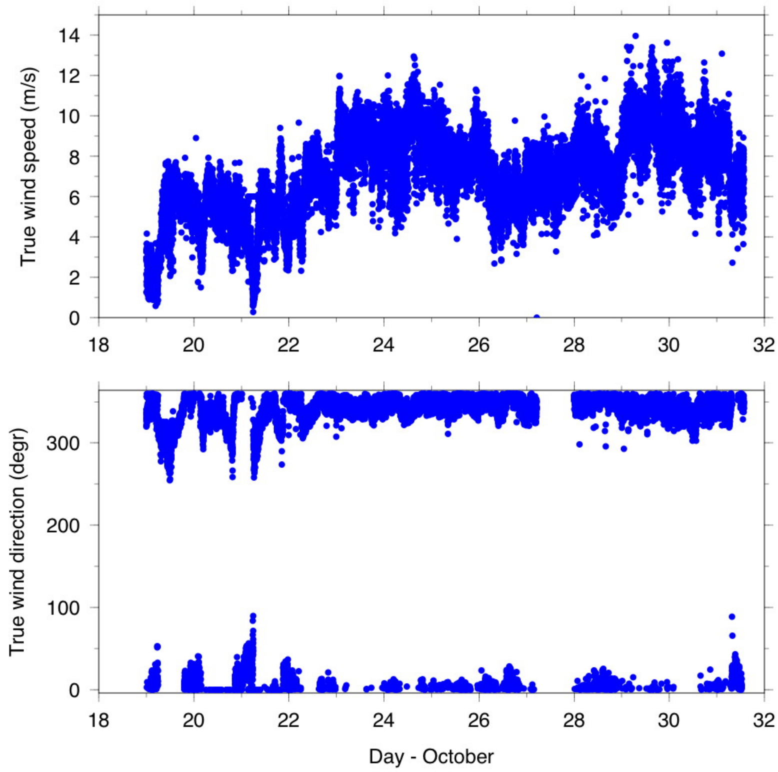


Figure 3. Wind speed and direction along the track of the *R/V Oceanus* in the Red Sea.

OS75. Fortunately data from the NB150 was redundant since the OS75 performed without problems.

A shipboard ADCP by design measures velocity relative to the ship. Velocity profiles were rotated from ship's reference frame into earth coordinates using the ship's heading provided by the ship's gyro compass. The accuracy of the gyro heading was further improved by the differential GPS heading device, typically called "Ashtech" after the company that manufactures it. The ship's velocity, calculated from GPS positions, was subtracted from the ADCP profiles to provide estimates of absolute, or earth referenced, velocity.

iv. Bathymetry

During all underway transits and most stations, water depths were measured using the Knudsen hull-mounted echosounding system. Based on the first CTD station to about 1500 meters, an average sound speed was computed to be 1541 m/s. This was used throughout the cruise to estimate bottom depth from acoustic travel time. Depths over the brine pools have not been corrected for the much larger sound speeds in the brine layers.

Both high-frequency (12 kHz) and low-frequency (3.5 kHz) chirp data were recorded. For most of the cruise, the high frequency settings were: 6 ms chirp signal, auto gain control, power = 3, processing gain = 3, Tx blank = 7, and sensitivity off. Low frequency settings were: 1.5 msec chirp signal, auto gain control, power = 1, processing gain = 0, Tx blank = 7, and sensitivity off. Screen displays generally used contrast = -1. For underway monitoring both channels were displayed in a split screen with a 500 m window and the autoscaling function turned on. In addition to ascii (*.kea) files, we recorded both the binary screen dumps in Knudsen's proprietary *.keb files and industry standard segy formatted seismic data files. Water depths in the ascii files were monitored for quality by inspection. After exclusion of zeros and values less than 1000 m, water depths were combined and gridded using the GMT 'blockmean' function with a cell size of 5sec in latitude and longitude. These data were interpolated using the GMT 'surface' function with tension factor set to 0.95. Plots were made using GMT. We gridded depths from the high frequency system. The echo character of the seafloor was generally prolonged and subbottom reflectors were identified only along the northern edge of the study area. Hyperbolae were common over 90% of the terrain. In general, there was good agreement between maps generated with the Knudsen single-channel system and maps generated from multibeam data collected in the same area by R/V Sonne and R/V Meteor in the 1980s and 1990s. The shape of the seafloor was similar and features were identified in the same locations. Reflections from the brine interface could be identified along the edges of the Southwest and East basins of the Atlantis II Deep. Figure 4 shows bathymetry of the area and the cruise tracks from which bathymetry was compiled.

b. Station Data

A total of 43 vertical profile stations were occupied during *Oceanus* 449-6, as listed in Table 1 in the Appendix and plotted in Figure 5. Stations included multiple CTD casts, hydrocasts and gravity cores, and one high-range CTD cast.

i. Hydrographic Rosette/CTD System and Ancillary Systems

A modified SeaBird 9/11+ rosette/CTD system was purchased and prepared at WHOI for the KAUST Hydrographic program. Onboard Oceanus for the OC449-6 cruise, this system was used for all rosette/CTD stations and was deployed on the Oceanus' 0.322 inch 3-conductor UNOLS CTD wire on the DESH-5 winch, overboarding with the Oceanus' hydro-boom.

Included on this rosette were a complete horizontally-mounted SBE9+ CTD with dual temperature and conductivity sensors, a SeaBird oxygen sensor, Biospherical underwater PAR (Photosynthetically Available Radiation) light sensor, WETLabs integrated chlorophyll-a/turbidity sensor, WETLabs 25-cm pathlength, 660 nm wavelength transmissometer, and a bottom-finding 200 kHz altimeter. At the center of the rosette frame, a SBE32C carousel holds twelve 10-liter sampling bottles.

Inside the rosette on selected stations we mounted a deep-sea electronic camera and strobe with external battery pack. The camera lens was oriented to take pictures out to the side of the rosette. These images were taken at 10 second intervals, stored internally and recovered from the camera after the rosette was secured on deck. The purpose of this imaging was to photograph the water column and, hopefully, any organisms that passed by. The camera provided images on nine rosette deployments, the results of which are discussed elsewhere in the report.

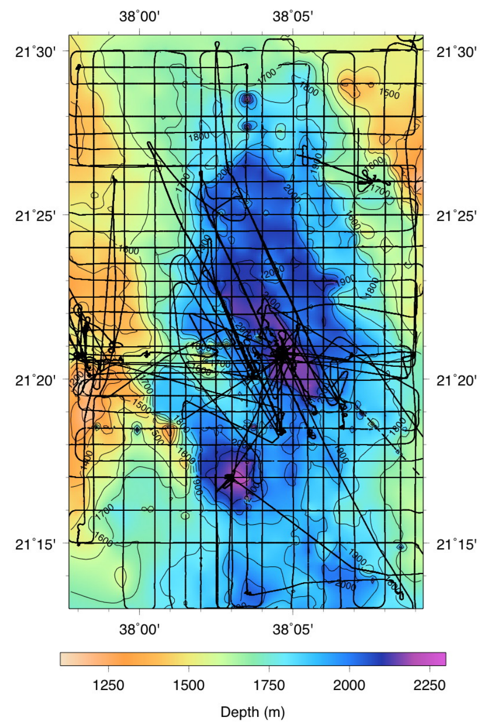


Figure 4. Bathymetry of the Atlantis II Deep Complex Area as measured during *R/V Oceanus* 449-6 in the Red Sea.

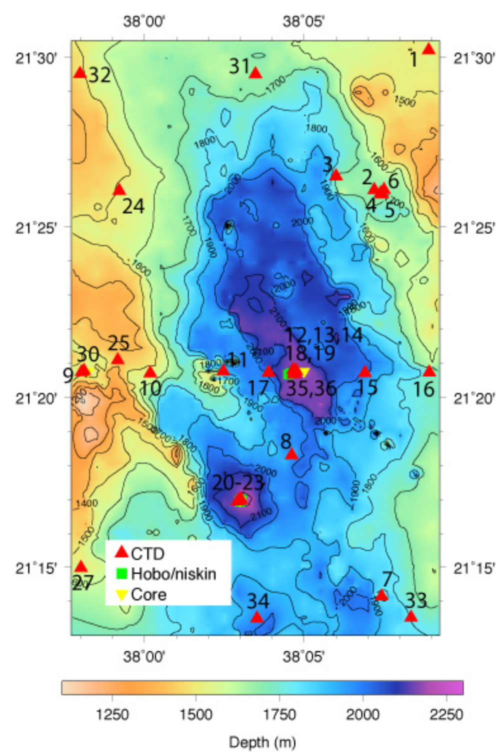


Figure 5. Station positions during *Oceanus* 449-6 to the Red Sea overlain on bathymetry collected during the cruise. "Hobo/Niskin" is the same as "Hydrocast."

Signals from the SBE9+ CTD were delivered into the Oceanus Main Lab to the SBE11+ deck unit, and acquired using SeaSave version 7.14D software resident on the Oceanus onboard computer system. The normally-installed surface PAR sensor onboard *Oceanus* was used for the SBE11+ surface PAR sensor. It was discovered early in the cruise that the location of the surface PAR caused it to be shaded by the satellite antenna and crane, and so this sensor was relocated to a less obstructed location.

On Station CTD 29, while working close to the seafloor, the rosette hit what is believed to be a rock outcropping. This was not observed in the winch tension record, and so during the deployment no action was taken. On recovery, the rosette frame was found to have been hit from above, damaging the protective upper frame ring and one sidebar, bending the stainless steel support bale, damaging a 10-liter sampling bottle, and damaging the upward LADCP and the PAR sensor, both of which extend above the protective ring.

Based on the damage, it was obvious that the frame protected the core sensors as it should. After changing the LADCP, straightening the bale and removing the broken bottle and PAR sensor, we continued on to the next station with only about a 1 hour delay for evaluation and maintenance.

The entire Rosette/CTD system will be returned to WHOI, where the damaged sensors and bottle will be repaired, the bent frame and bale parts will be replaced, and the system prepared for storage until it will be used again.

ii. LADCP

The CTD rosette package was outfitted with two Teledyne RD Instrument 300 KHz WorkHorse Lowered ADCP's along with a 48-volt rechargeable battery pack for power. They were mounted in upward and downward looking positions and collected velocity profiles over 20 vertical bins of 8 m length. Since the motion of the CTD package is unknown, the velocity profiles were converted into vertical shear, which was then averaged into 20 m depth bins and vertically integrated to estimate a velocity profile over the full water column. The horizontal translation given by the CTD station start- and end position provided the required integration constant.

iii. Hydrocasts and Hobo

Since it was well-known before the cruise that the CTD could not be lowered into the hottest brine water, 10 PVC Niskin bottles were brought on the cruise for attachment to the hydrowire. The wire was then lowered to the bottom (as indicated by an acoustic pinger also attached to the hydrowire) and a messenger sent to begin the sequence of closing the bottles. This method worked extremely well for retrieving brine water samples. On only one cast did some of the bottles not trip due to a stiff plunger. On all hydrocasts, the Hobo temperature logger (see next section) was attached in order to measure the temperature at the top bottle. This was done to confirm that the bottles were indeed in the Lower Convective Layer of the brine pool.

If there is a “hero” amongst the various instruments used during this cruise, it is the “Hobo” temperature logger, manufactured by Onset Computer Corporation of Pocasset, Massachusetts. This logger has a very high maximum temperature threshold (125˚C), making it ideal for measuring brine pool temperature (the CTD can only measure up to 35˚C, and immersion in the hot brine water would likely have damaged the CTD electronics). Two Hobo Model U-12 Stainless Temperature Data Loggers with 5-inch probes, Model U12-015-02, set to sample once per second, were used to measure ocean temperatures in two deep brine areas in the Red Sea, Atlantis-II Deep and Discovery Deep. They appeared to work properly and returned good data on each of the deployments. Prior to the cruise, both instruments were calibrated and pressure tested to 2500 meters using facilities at the Woods Hole Oceanographic Institution. PVC housings were manufactured at Woods Hole to provide some protection for the external 5-inch probes. On two CTD full-depth ocean profiles (CTDs 5 and 8), the instruments were attached to the CTD rosette package and agreed well with the Seabird temperature sensor on the CTD.

The Hobos were used in several different configurations: (a) attached to the CTD rosette for cross-check against CTD temperature, (b) attached to the hydrowire with hydroweight and pinger for vertical profiles and tow-yo, (c) attached to the top bottle on Niskin hydrocasts to confirm that bottles were in the brine layer, (d) hung 5 meters below the CTD rosette and (e) attached to the high-range NCTD for simultaneous measurements of brine water temperature. The photo below shows the hobo in its housing attached to winch wire. Table 2 in the Appendix lists how the Hobo was used for each deployment.

Specifications of the instrument appear to be conservative – that is – the instrument performs as well or better than specified (see Table 2 in Appendix). Since the instrument is designed for a maximum depth of 1500 meters, we elected to fill it completely with silicone oil to prevent the instrument from crushing.

iv. Gravity Cores

Three giant gravity cores (GGC) were taken with the help of many aboard the ship. The first GGC was taken in the southwest basin of the AII Deep for HKUST scientists Stanley Lau and Tim Wong. A 2.8 meter barrel was attached to the core head and 2.67 m of sediment was recovered. The sediment was black and odorless. It was cut into 45 cm sections and then frozen. Stanley and Tim will take it back to Hong Kong where they will do bacterial studies on it. The second GGC was taken in the Discovery Deep for AUC scientists Rania Siam and Ahmed Shibl. A 2.8 m barrel was attached to the core head and, unfortunately, it over penetrated by about 50 cm. The seafloor sediment ended up in the core head stem. The sediment in the stem was collected as best as possible and the remaining sediment in the barrel was also cut into 45 cm pieces and frozen. It will go back with Rania and Ahmed. The sediment at this site was drastically different from the sediment from the AII Deep site. It was more reddish brown and had obvious layers of foraminifera and pteropods. The third GGC was taken at the Oceanus Seep (coined by Amy Bower, the chief scientist). Since we had a difficult time locating the bottom with the bottom profiler, we could not get a good idea what thickness of sediment was there. The echosounder returns led us to believe that the bottom was possibly rocky with only a thin layer of sediment. Therefore, a short barrel of 1.22 m was attached to the core head. Upon recovery, it was discovered that this core over penetrated as well. There was about 80 cm of sediment up in the core head stem. The sediment from the core head stem was collected and placed in plastic bags. The rest of the sediment will go back to WHOI where it will be split in half. This sediment was similar to the Discovery Deep with obvious foraminifera and pteropods near the top 50 cm of the sediment and was also reddish brown in color. Since this area has not been cored before, it was a pleasant surprise to everyone that there was sediment and that it was so thick. All coring operations were very successful during the cruise.

Core #	Lat.	Lon.	Water depth (m)	Recovery (m)
GGC-1	21 20.769 N	38 04.992 E	2170	2.67
GGC-2	21 16.976 N	38 02.985 E	2180	2.80
GGC-3	21 20.765 N	37 58.222 E	1554	2.01

v. High-Range CTD (NCTD)

A WHOI-designed experimental high-range CTD, known as the "NCTD" was deployed on several stations. This sensor was brought to enable sensing the high temperatures and conductivities in the brines. The instrument is an internally-recording CTD built into a titanium housing with special sensors which are expected to give results up to 6500 m depth, 80˚C and 500 ppt salinity, and the ability to provide its temperature signal to the SBE9 CTD for real-time reading. It was intended to be hung below the rosette by a 50 m long conducting wire tether and to be dipped into brines where the temperature would exceed the limits for the SBE9 equipment (greater than 35˚C).

The first NCTD deployment on station CTD 1 provided inconsistent data, and the sensor was found to have a seawater leak which rendered the data questionable. After being reconstructed during the cruise, the NCTD was sufficiently repaired to use again, and it yielded useful data on station CTD 34 and CTD 35. On its final deployment, it was strapped to a strongback along with a Hobo and lowered on the hydrowire to the bottom of the SW Basin of the A-II brine pool. The plots below show a portion of the preliminary data record, which indicates temperatures in the LCL of nearly 68˚C and salinities over 250 ppt (Figure 6).

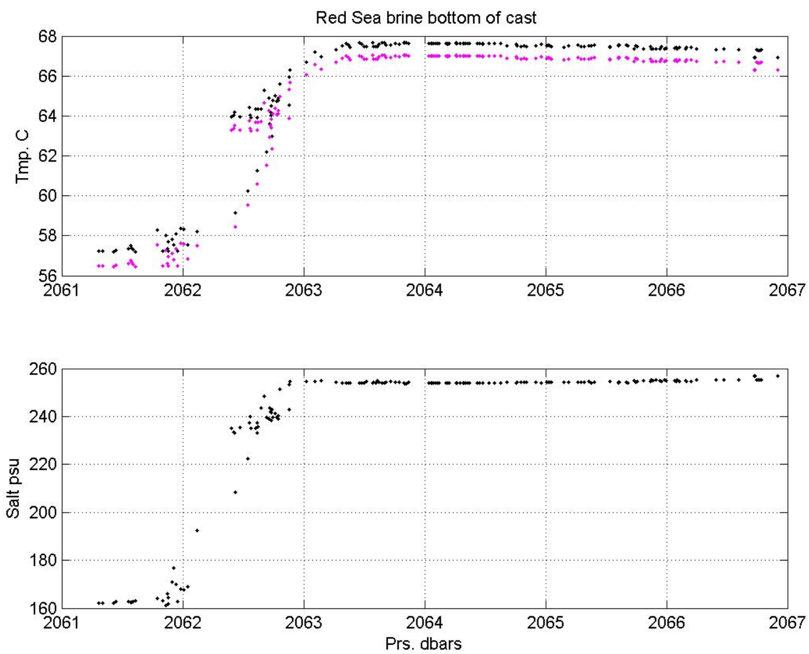


Figure 6. Preliminary temperature and salinity profiles from the LCL in the SW Basin of the Atlantis II Deep from the high-range CTD (NCTD 1).

d. Tows

In addition to the 43 vertical profile stations, 9 "tows" were completed using various instruments to provide ultra-high spatial resolution measurements. These included the WHOI TowCam/Magnetometer, the Hobo temperature logger and the CTD (see Table 1). Positions of the individual tows are shown in Figure 7, and details are given in the following subsections.

i. TowCam and Magnetometer

Operational Summary

The WHOI – MISO (Multidisciplinary Instrumentation in Support of Oceanography) Facility mini-TowCam was used for five tows during the *R/V Oceanus* cruise OC449-6, known as the KAUST Leg II hydrography cruise. The system was configured to collect

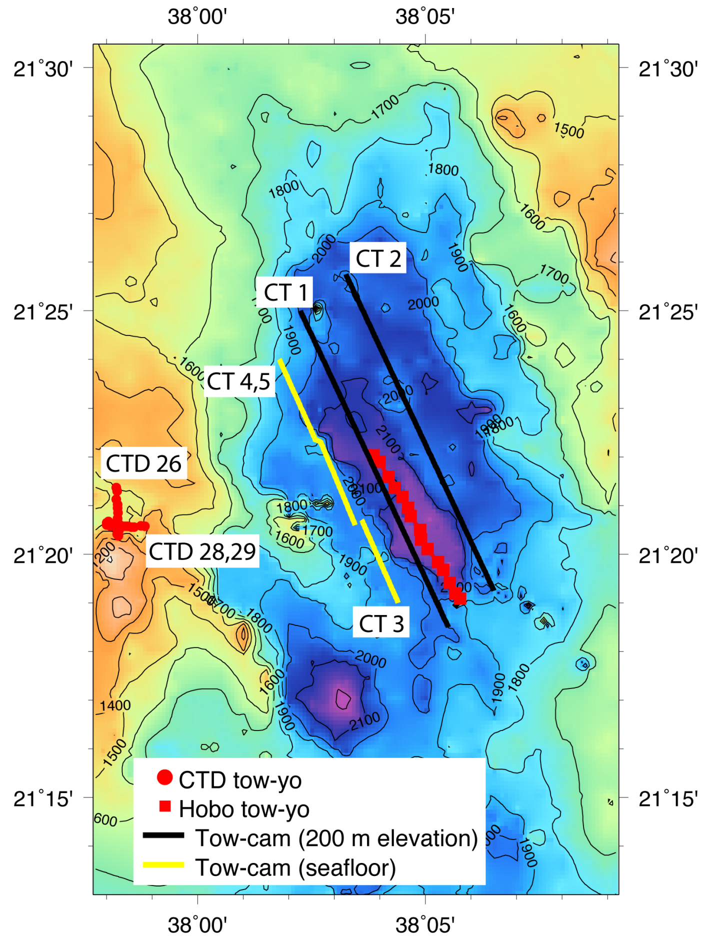


Figure 7. Chart showing the locations of the 9 tows carried out during *Oceanus* 449-6 to the Atlantis II Deep Complex Area.

digital photographic, CTD, eH, turbidity, and magnetometer data and six (6) 5-liter Niskin samples. Camera s/n6005 and s/n6006 were used for various lowerings with a delay time of 0-60 minutes and photo interval of 10 sec. Towing speed was between 0.5 to 1 kts for most lowerings. Three green laser dots, which are visible in each photograph in the bottom third of each frame, are spaced 20 cm and 10 cm apart, for a total of 30 cm.

The TowCam system was primarily used to conduct water column and bottom surveys with all sensors running independent of the type of tow. Tows CT1 and CT2 (M1 and M2) were transects approximately 200 meters over the bottom for magnetometer data. Tows CT3, 4 and 5 were conducted to collect bottom images of areas adjacent to the western Atlantis II Deep. Approximately 5,200 3.3 megapixel digital color photographs of the seafloor were collected. In addition to the processed, date/time stamped images, files were made of CTD data as well as layback information calculated using the camera depth and wire out. HTML web galleries and QT movies were also produced from the imagery and made available via the shipboard network within a few hours of the end of each lowering for use by the science party for operations planning.

OC449-6-Camera Tow Synopses

TowCam #1 26 October, 2008 (11:40:10Z –21:50Z) 10 sec rep rate, delay-time 60 minutes Camera s/n 6006 f-4.7

The first camera lowering was designed to test the system at depth and to fly about 200 m above the A II Deep Brine on the first of two magnetometer lines. The waypoints for this tow are 21° 18.5’ N, 38° 05.5’ E start, and 21° 25.02’ N, 38° 02.24’ E end. We lowered the TowCam to 500 m, did a full 360 turn, then lowered to 1000 m, and did another 360 turn before we began along the line at the first waypoint. Six Niskin water bottles were triggered for testing purposes. The lasers on the TowCam worked well. The distance between the port and starboard laser is 30 cm, with one laser in between which is 10 cm starboard of the port laser. The green laser dots appear roughly in line in the bottom third of each image. Images were made in the water column only.

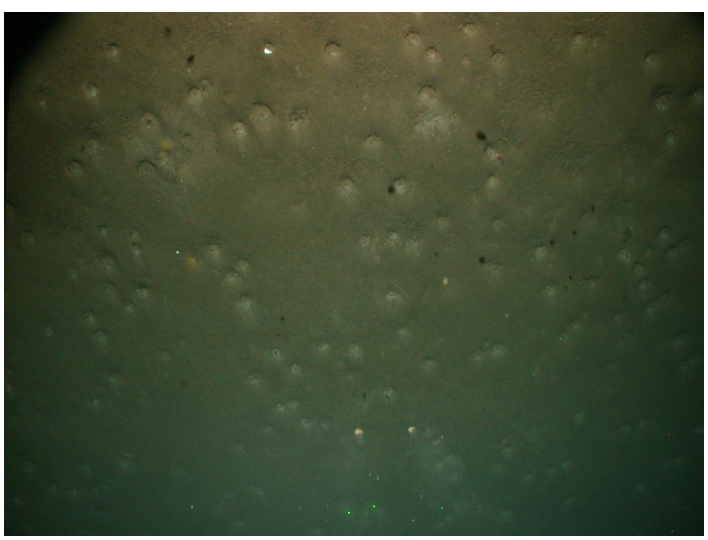
TowCam #2 27-28 October, 2008 (19:55:50Z –06:42Z) 10 sec rep rate, delay-time 60 minutes Camera s/n 6006 f-4.7

This camera lowering was to run a magnetometer line parallel to the previous magnetometer line. The waypoints for this tow are 21° 19.157’ N, 38° 06.554’ E start, and 21° 25.750’ N, 38° 03’248’ E end. One 360 degree turn was executed at 1000 m depth prior to starting the tow at the first waypoint. The magnetometer recorded data. Images were made in the water column only.

TowCam #3 27-28 October, 2008 (17:42Z –00:38Z) 10 sec rep rate, delay-time 60 minutes Camera s/n 6006 f-2.6

Line A6. The waypoints for this tow are 21° 19.0’ N, 38° 4.4’ E start, and 21° 20.7’ N, 38° 3.6’ E.

The image below (2008_10_27_20_06_37.jpg) is of a very soft sediment area with small mounds, most likely constructed by invertebrates (polychaete worms, bivalves, etc.) living in the surface sediments. These organisms rely on access to the surface for feeding and respiration.



A difficult image (2008_10_27_19_53_36.jpg) to interpret, and the only one of its kind. Ship's position when image was taken was 21° 19.331 N X 38° 4.257 E.

Image (2008_10_27_21_49_17.jpg) of sediment ridges with evidence of invertebrates movements over, or just underneath, the bottom surface.

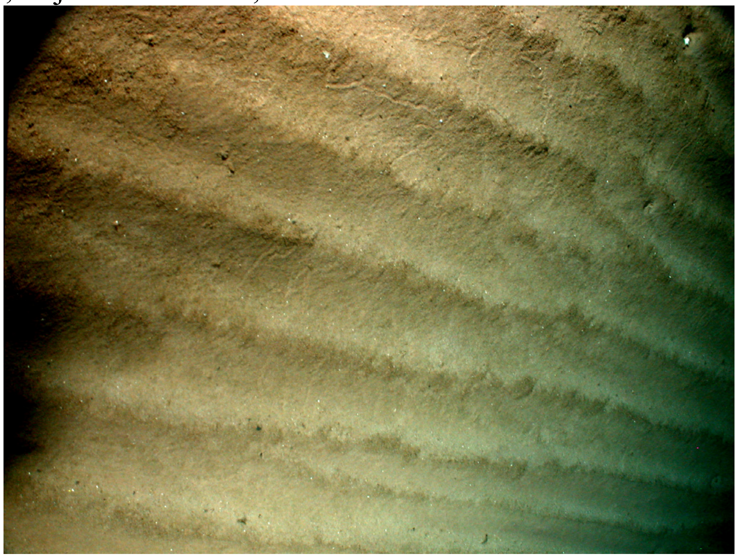
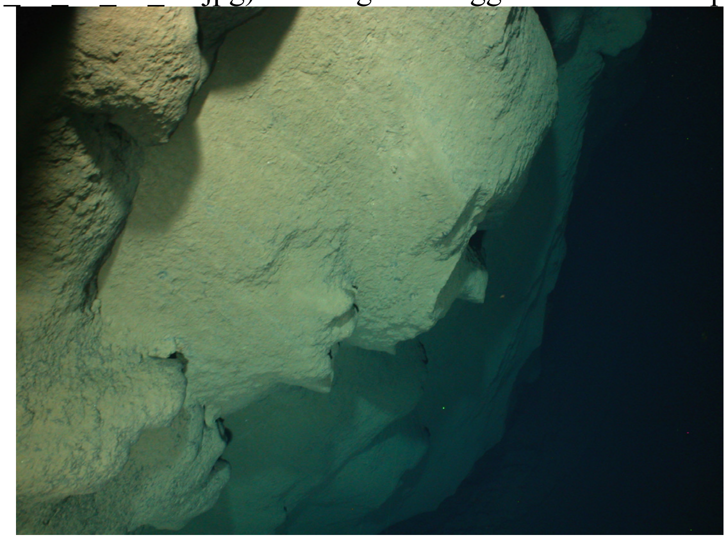


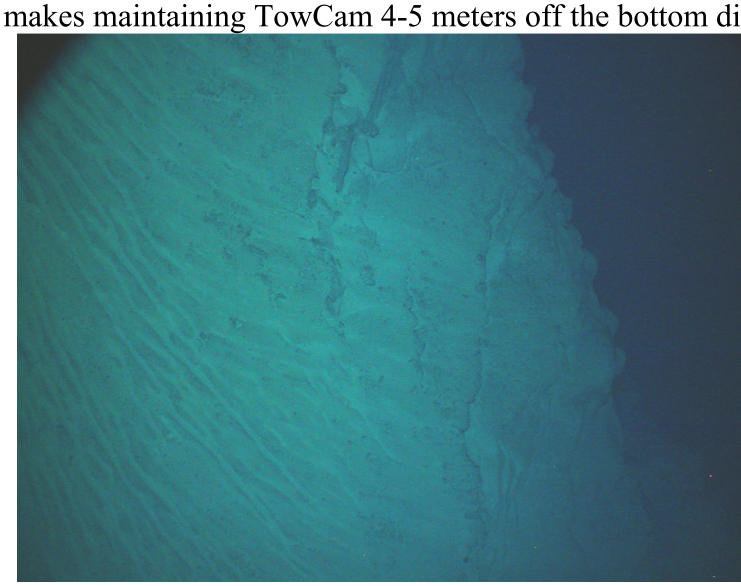
Image (2008_10_27_19_17_36.jpg) showing how rugged the bottom topography can be.



TowCam #4 28 October, 2008 (17:26Z –23:28Z) 10 sec rep rate, delay-time 60 minutes Camera s/n 6006 f-2.6

Line A7. Magnetometer did not log data. Images seemed very dark in general.

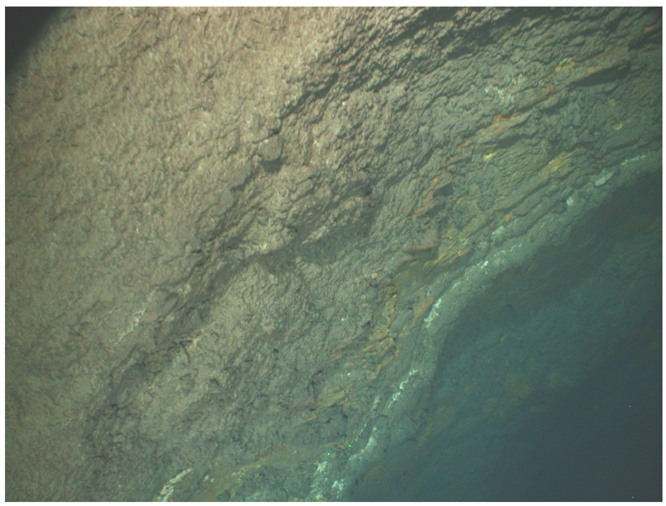
Image "2008_10_28_22_16_25.jpg" showing the sharp small-scale topographical changes which makes maintaining TowCam 4-5 meters off the bottom difficult at times.



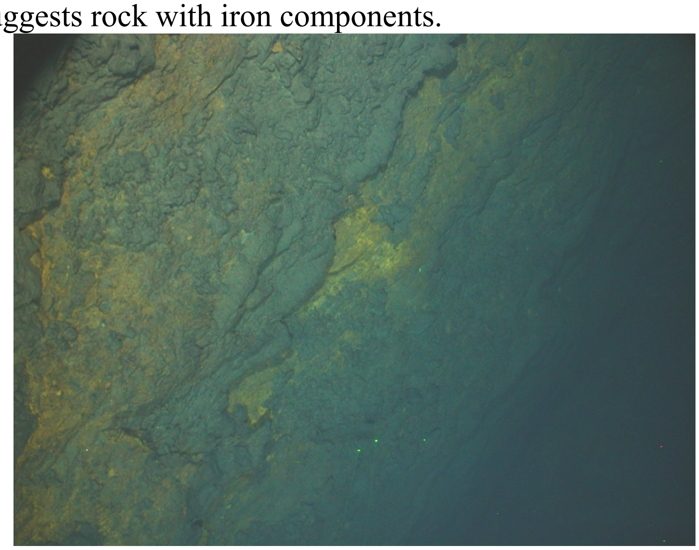
TowCam #5 29 October, 2008 (01:00Z –09:20Z) 10 sec rep rate, delay-time 60 minutes Camera s/n 6006 f-2.6

Line A7 was re-done because the magnetometer did not record data; it was renamed Line A7a and the end sand start points were shifted 150 m to the east, while remaining parallel to the original Line A7. The decision was made during the tow to continue to Line A8 and complete that proposed tow as well. The start and ending coordinates for this line are 21° 20.39 N X 38° 03.68 E X start 21° 24.613 N X 38°01.401 E end.

The next two images suggest a bottom with little to no sediment relative to much of the other bottom images with Towcam. This image (2008_10_30_06_00_58.jpg) shows rock with localized color differences.



This image (2008_10_30_06_00_48.jpg) is taken ten seconds after the previous image. The coloration suggests rock with iron components.



OC449-6-CTD-Cam
A TowCam DSPL camera ("CTD CAM"), a battery, a Benthos 381 strobe unit and a junction box were mounted onto the KAUST CTD rosette in order to image and identify zooplankton in the water column. While very few images of zooplankton were taken, this camera set up provided important images to help in describing and identifying boundaries, both of the brine pools during CTD 8, and of the bottom itself.

The CTD Cam was used on almost all the deep CTD casts including CTD #'s 1, 8, 9, 12, 15, 16, 17, 21 and 26. The camera was set to begin taking pictures immediately upon deployment (no delay) and with a repetition rate of 10 sec.

CTD Cam OC449-6 CTD1
Camera SN 6005 F 4.7

CTD Cam OC449-6 CTD8
Camera SN 6005 F 4.7

This image (2008_10_23_11_07_41.jpg) of bottom boundary layer at 11:08 Z, 10-23-2008

CTD Cam OC449-6 CTD9
Camera SN 6005 F 4.7

CTD Cam OC449-6 CTD12
Camera SN 6005 F 4.7

CTD Cam OC449-6 CTD15
Camera SN 6005 F 4.7

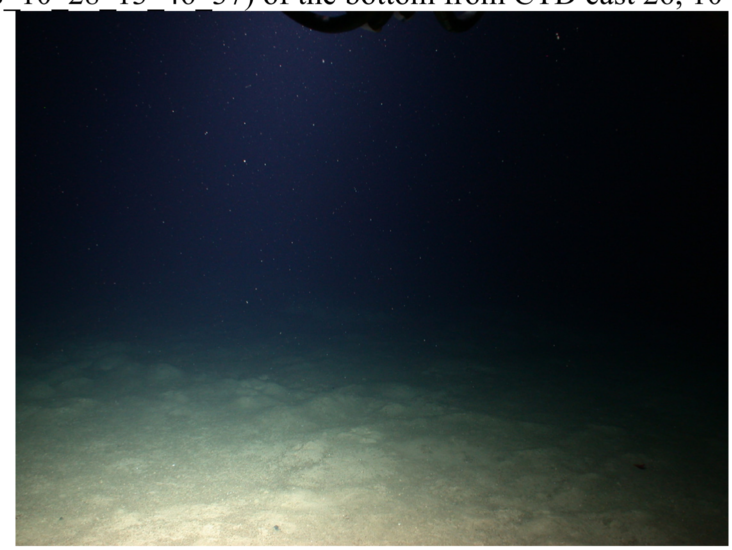
CTD Cam OC449-6 CTD16
Camera SN 6005 F 4.7

CTD Cam OC449-6 CTD17
Camera SN 6005 F 4.7

CTD Cam OC449-6 CTD21
Camera SN 6005 F 3.7

CTD Cam OC449-6 CTD26
Camera SN 6005 F 3.7

An image (2008_10_28_13_46_37) of the bottom from CTD cast 26, 10-28-2008.



ii. CTD

The CTD was used to make three high-resolution sections across the Oceanus Seep (see Table 1) by "tow-yoing" it across the area where moderately warm water had been observed in CTD 9. On the first of these (a north-south transect), water warmer than 30˚C was observed in a thin bottom layer. The movement of the CTD through the interface apparently caused a significant amount of turbulence that showed up in the CTD record. The downcasts for this tow show a much more quiescent brine pool in a depression of about 1550 meters depth. The second CTD tow-yo across this pool was called off when the ship drifted off-course in moderate winds. The third tow-yo (an east-west transect) did not observe the same warm water as the first, and it was later determined that the line was too far south. But this tow better defined the limits of the brine pool, and measurements of the pool characteristics ended with a full-water depth cast at the center of the pool, with the Hobo hanging 5 meters below the rosette and an Eh sensor attached to the CTD. The Hobo measured temperatures of about 33˚C at the sea floor, and the Eh sensor measured values of -250, strong evidence of vent waters.

iii. Hobo

One of the most surprisingly successful operations during this cruise was the tow-yo of a Hobo through the entire width of the SW Basin of the Atlantis II Deep and into the Western Basin. A pinger attached to the hydrowire was used to repeatedly lower the Hobo to the bottom of the brine pool as the ship steamed slowly forward. After reaching the bottom, the wire was raised at a slow rate (20 m/min) from the bottom to 1900 meters, then 40 m/min up to 1700 meters. The cycle was then repeated for the next lowering. The result was 13 closely spaced profiles through the brine pool (Figure 8). Two remarkable features emerged: (1) the consistency of the maximum temperature (around 68˚C) and the continuity of the upper convective layers through the basin.

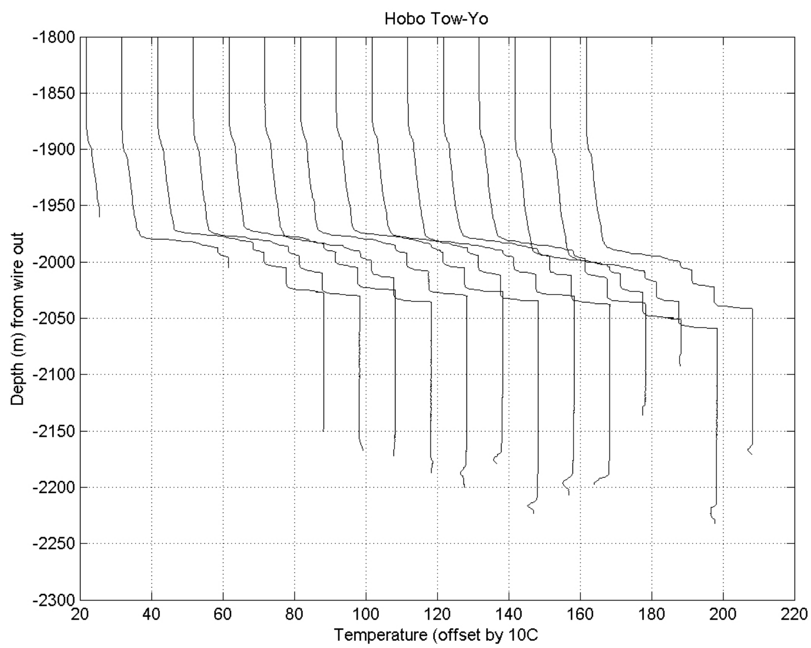


Figure 8. Temperature profiles across the SW Basin of the Atlantis II Deep collected by tow-yoing a Hobo temperature logger.

f. Water Samples

i. AUC

The goal for the AUC scientists was to filter water from non-brine and brine areas. This included filtering large volumes of brine pools, deep, mid-layer and surface water through different sized filters for DNA isolation, processing and sequencing in our laboratories. Sediments from brine pools were also collected for similar metagenomic analysis.

On October 27th we completed the large-volume water filtration from the following sites and completed the following tasks:
*None brine site: 4 different depths (50-200-700 and 1500 meters).
*Atlantis II brine: brine pool and the 4 different depths (50-200-700 and 1500meters). In addition a smaller anoxic sample in the brine interface (20 liters) was filtered.

*Discovery Deep brine: brine pool and the 4 different depths (50-200-700 and 1500meters).
*Gravity core: we collected 6 sections from the Discovery Deep brine (an entire core).

Table 3 in the Appendix references each of these tasks to a CTD, hydrocast or gravity core number. See Table 1 for positions.

ii. HKUST

During Leg II of the Red Sea expedition on R/V Oceanus, the HKUST team collected ocean water, brine water and sediment samples from three locations for metagenomics and bacterial diversity studies. Two of the sampling locations were the Atlantis II Deep and the Discovery Deep, from which brine samples were collected from the basin and ocean water samples were collected from the depth of 20, 50, 200, 700 and 1500 m. A sediment core of 2.6 m long was also obtained from the Atlantis II Deep. The other sampling location (21°26.07' N, 38°07.35' E) was outside the basins. At this location, ocean water samples were collected also from 20, 50, 200, 700 and 1500 m.

All ocean water and brine samples collected were immediately filtered sequentially through 1.6 um and 0.22 um membranes to capture bacterial cells. After that, the membranes were frozen in DNA extraction buffer for transportation to our lab in HK. The sediment core was divided into 6 sections and kept frozen for further processing in HK A summary of sampling is given in Table 4 in the Appendix.

iii. Phosphorous (WHOI and Institute for Marine Research, Red Sea University, Sudan)

The overarching goal of our studies in the Red Sea was to gain a better understanding of how microbes interact with the nutrient phosphorus in the upper water column. As the emphasis of the KAUST Leg 2 cruise shifted from a broad spatial survey to a more geographically focused effort, we, in turn, shifted our emphasis toward understanding variability of phosphorus cycling through time during the cruise. However, our most immediate contribution involves a change in phosphorus cycling not over the course of days, but over the course of decades: we found the surface phosphate concentrations were nearly an order of magnitude lower than was reported in the 1970's and 1980's. This implies a very intense competition for phosphorus between groups of microbes. Indeed, we found a statistically significant daily cycle in phosphate concentrations, which implies and interplay between light-utilizing microbes (i.e. picophytoplankton) and heterotrophic microbes that operate independent of light. We took samples for the analysis of number of molecular indicators of phosphorus utilization, and when we analyze these samples in our labs at WHOI, we are certain to gain important new insights on microbial phosphorus competition. We also incubated microbes in surface sweater under conditions of enhanced nitrogen and phosphorus availability. Not surprisingly, given the historical low concentrations of phosphorus, we found that nitrogen did not stimulate enhance phosphorus utilization. This result leaves open the possibility that phosphorus may act as the "master nutrient", whose availability effectively regulates the levels of primary production and, thus, the size and character of the entire food web in the Red Sea. A summary of sampling for phosphorous studies is in Table 5 in the Appendix.

iv. Chemistry (WHOI)

Dan McCorkle (WHOI) was interested in obtaining water from two shallow sites, some water in the brine and two deep water profiles from surface to bottom. Water was collected from five different sites for him. The following samples were collected from all five sites: alkalinity/DIC, C 13, nutrients, cations and O 18. For the last deep cast water was also collected for C 14 dating. All of the analysis will be done once the samples reach Woods Hole. None were done aboard the *Oceanus*.

Water sites for shallow depths:

1) Lat.: 21 14.172 N
   Long.: 38 07.322 E
   Water depth: 1729 m
   Depth water collected: surface, 10, 20, 30, 50, 75 (chlorophyll max.)

2) Lat.: 21 20.726 N
   Long.: 38 03.878 E
   Water depth: 1995 m
   Depth water collected: surface, 10, 20, 40, 50, 75, bottom

Brine site:

Lat.: 21 20.761 N
Long.: 38 04.507 E
Water depth: 1729 m
Depth water collected: 2090, 2095, 2100, 2105, 2110, 2115, 2120

Deep sites:

1) Lat.: 21 18.302 N
   Long.: 38 04.602 E
   Water depth: 1959 m
   Depth water collected: 25, 75, 100, 200, 300, 400, 600, 800, 1000, 1200, 1600, bottom

2) Lat.: 21 26.075 N
   Long.: 37 59.206 E
   Water depth: 1520 m
   Depth water collected: 25, 75, 100, 200, 300, 400, 600, 800, 1000, 1200, 1350, bottom

5. Acknowledgements

The scientific participants of KAUST Leg 2 on the *R/V Oceanus* gratefully acknowledge the financial and logistical support provided by King Abdullah University of Science and

Technology (KAUST). Logistical support was kindly provided by Yasser Kattan, Abdulaziz Al-Suwailem, Haitham Al-Jahdali and James Luyten. Without their considerable effort, Leg 2 would not have happened. We are also grateful to the administrative staff at WHOI who also worked very hard to make Leg 2 a reality. Special thanks go to Larry Madin, Bob Detrick, Al Suchy, Liz Capporelli, Kerry Heywood and Barbara Costello. Finally, none of our research would be possible without the dedicated officers and crew of the *R/V Oceanus,* who worked hard to bring *Oceanus* to the Red Sea and who patiently and skillfully guided our at-sea operations.

6. Contact Information

For more information about the cruise and the data described in this report, please contact:

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7. Appendix (Tables)

Table 1. Event log for Oceanus 449-6

Event	Date (UTC)	Time (UTC)	Latitude (N)	Longitude (E)	Cast Depth (db)	CTD Camera	LADCP	P (Ben/Ali)	HKUST Samples	AUC Samples	HOBO	Nutr (Ellen)	Carb (Ellen
CTD 1	19 Oct	2056	21° 30.106’	38° 8.990’	1561	ON	ON	Y	N	N	N	N	N
CTD 2	20 Oct	0517	21° 26.081’	38° 7.326’	50	OFF	OFF	N	Y	Y	N	N	N
CTD 3	20 Oct	0609	21° 26.424’	38° 6.434’	1501	OFF	OFF	N	Y	Y	N	N	N
CTD 4	20 Oct	1031	21° 25.973’	38° 7.868’	205	OFF	OFF	N	Y	Y	N	N	N
CTD 5	20 Oct	1222	21° 26.024’	38° 7.620’	704	OFF	OFF	Y	Y	Y	N	N	N
CTD 6	20 Oct	1428	21° 26.083’	38° 7.535’	52	OFF	OFF	Y	N	Y	N	N	N
CTD 7	21 Oct	0516	21° 14.125’	38° 7.604’	199	OFF	OFF	Y	N	N	N	Y	Y
Hydrocast 1	21 Oct	0656	21° 17.013’	38° 3.003’	2214 m wire	OFF	OFF	N	N	N	1	N	N
Hydrocast 2	21 Oct	1310	21° 20.612’	38° 4.713’	2173 m wire	OFF	OFF	N	N	N	2	N	N
Hydrocast 3	22 Oct	0613	21° 20.761’	38° 4.507’	2135 m wire	OFF	OFF	Y	N	Y	3	Y	Y
Hydrocast 4	22 Oct	0925	21° 20.733’	38° 4.711’	2139 m wire	OFF	OFF	Y	Y	N	4	N	N
Hydrocast 5	22 Oct	1336	21° 20.720’	38° 4.590’	2134 m wire	OFF	OFF	N	Y	Y	5	N	N
CTD 8	23 Oct	0326	21° 18.364’	38° 4.674’	1967	ON	ON	Y	N	N	N	Y	Y
CTD 9	23 Oct	1025	21° 20.717’	37°57.988’	1547	ON	ON	N	N	N	N	N	N
CTD 10	23 Oct	1251	21° 20.755’	38° 0.282’	1550	OFF	ON	N	N	N	N	N	N
CTD 11	23 Oct	1511	21° 20.742’	38° 2.484’	1892	OFF	ON	Y	N	N	N	N	N
CTD 12	23 Oct	1841	21° 20.940’	38° 4.691’	2002	ON	ON	N	N	Y	N	N	N
CTD 13	23 Oct	2220	21° 20.653’	38° 4.648’	50	OFF	OFF	N	Y	Y	N	N	N
CTD 14	23 Oct	2332	21° 20.690’	38° 4.637’	1500	OFF	ON	N	Y	Y	N	N	N
CTD 15	24 Oct	0154	21° 20.699’	38° 6.936’	2010	ON	ON	Y	N	N	N	N	N
CTD 16	24 Oct	0512	21° 20.737’	38° 8.923’	1754	ON	ON	N	N	N	N	N	N
CTD 17	24Oct	0859	21° 20.807’	38° 3.834’	2019	ON	ON	N	N	N	N	Y	Y
Gravity Core 1	24 Oct	1300	21° 20.365’	38° 5.055’	2170 m	OFF	OFF	N	Y	N	N	N	N
CTD 18	24 Oct	1535	21° 20.747’	38° 4.724’	201	OFF	OFF	N	Y	Y	N	N	N
CTD 19	24 Oct	1709	21° 20.714’	38° 4.702’	700	OFF	OFF	N	Y	Y	N	N	N
HOBO Tow-Yo	24-25 Oct	1926-0618	21° 18.997’-21° 22.113’	38° 5.736’-38° 3.891’	2223 m wire	OFF	OFF	N	N	N	Y	N	N
Tow Cam CT1 Magnetics line 1	25 Oct	1332-2153	21° 18.50’-21° 25.02’	38° 05.50’-38° 02.24’									
Hydrocast 6	26 Oct	0530	21° 20.676’	38° 4.500’	2130 m wire	OFF	OFF	N	N	Y	6	N	N
Hydrocast 7	26 Oct	0835	21° 16.930’	38° 2.993’	2147 m wire	OFF	OFF	N	N	Y	7	N	N
Hydrocast 8	26 Oct	1207	21° 16.991’	38° 3.046’	2145 m wire	OFF	OFF	N	Y	N	8	N	N
Gravity Core 2	26 Oct	1524	21° 16.646’	38° 3.153’	2180 m	OFF	OFF	N	N	Y	N	N	N

Table 1 continued.

Event	Date (UTC)	Time (UTC)	Latitude (N)	Longitude (E)	Cast Depth (db)	CTD Camera	LADCP	P (Ben/Ali)	HKUST Samples	AUC Samples	HOBO	Nutr (Ellen)	Carb (Ellen
Tow Cam CT2 Magnetics line 2	26-27 Oct	2159-0543	21° 19.157'-21° 25.750'	38° 6.554'-38° 3.248'									
CTD 20	27 Oct	0937	21° 16.978'	38° 2.963'	51	OFF	OFF	N	Y	Y	N	N	N
CTD 21	27 Oct	1057	21° 16.944'	38° 2.987'	1499	ON	ON	N	Y	Y	N	N	N
CTD 22	27 Oct	1344	21° 17.012'	38° 3.012'	700	OFF	OFF	N	Y	Y	N	N	N
CTD 23	27 Oct	1515	21° 16.984'	38° 2.981'	200	OFF	OFF	N	Y	Y	N	N	N
Tow Cam CT3 Line A6	27 Oct-28 Oct	1742-0142	21° 18.41'-21° 21.07'	38° 4.69'-38° 3.09'		-	-	N	N	N	N	N	N
CTD 24	28 Oct	0427	21° 26.039'	37° 59.192'	1532	OFF	ON	Y	N	N	N	Y	Y
CTD 25	28 Oct	0744	21° 21.005'	37° 59.154'	1460	OFF	ON	N	N	N	N	N	N
CTD 26 Tow-Yo	28 Oct	1127-1438	21° 21.596'-21° 20.062'	37° 58.279'-37° 58.368'	1597	ON	ON	Y	N	N	N	N	N
Tow Cam CT4 Line A7	28 Oct	1848-2320	21° 20.69'-21° 23.28'	38° 3.47'-38° 2.39'		-	-	N	N	N	N	N	N
CTD 27	29 Oct	0403	21° 14.994'	37° 57.994'	1544	OFF	ON	Y	N	N	N	N	N
CTD 28 Tow-Yo	29 Oct	0712-0845	21° 20.310'-21° 20.634'	37° 58.704'-37° 57.697'	1750 m wire	OFF	ON	Y	N	N	09	N	N
CTD 29 Tow-Yo	29 Oct	0940-1209	21° 20.668'-21° 20.846'	37° 59.390'-37° 57.930'	1652 m wire	OFF	ON	N	N	N	10	N	N
Gravity Core 3	29 Oct	1413	21° 20.765'	37° 58.222'	1554 m	OFF	OFF	N	N	N	N	N	N
CTD 30+EH	29 Oct	1805	21° 20.782'	37° 58.097'	1540 m wire	OFF	ON	N	N	N	11	N	N
Tow Cam CT5 Lines A7-A8	29 Oct	0100-0933	21° 20.39'-21° 25.86'	38° 3.64'-38° 0.08'		-	-	N	N	N	N	N	N
CTD 31	30 Oct	1157	21° 29.490'	38° 3.468'	1702	OFF	ON	Y	N	N	12	N	N
CTD 32	30 Oct	1426	21° 29.518'	37° 58.003'	1491	OFF	ON	N	N	N	13	N	N
CTD 33	30 Oct	1835	21° 13.422'	38° 8.582'	1923	OFF	ON	N	N	N	14	N	N
CTD 34	30 Oct	2106	21° 13.424'	38° 3.612'	2067	OFF	ON	N	N	N	15	N	N
CTD 35 NCTD	31 Oct		21° 20.812'	38° 4.604'	2021	OFF	ON	N	N	N	16	N	N
NCTD 1	31 Oct	1753	21° 20.527'	38° 4.602'	bottom	N	N	N	N	N	17	N	N

Table 2. Hobo deployment configurations during Oceanus 449-6

	Event	Serial Number	Second Serial Number	How Attached
1	CTD 5	2005458	2005482	On CTD frame near sensors
2	Hydrocast-Hobo 1	2005458	N/A	1.4m above hydroweight
3	Hydrocast-Hobo 2	2005482	N/A	1.4m above hydroweight
4	Hydrocast-Hobo 3	2005482	N/A	On top bottle of 10-bottle hydrocast
5	Hydrocast-Hobo 4	2005458	N/A	On top bottle of 10-bottle hydrocast
6	Hydrocast-Hobo 5	2005458	N/A	On top bottle of 10-bottle hydrocast
7	CTD 8	2005458	2005482	On CTD frame near sensor
8	Hobo To-Yo-24 Oct	2005482	N/A	1.4m above hydroweight
9	Hydrocast-Hobo 6	2005482	N/A	On top bottle of 10-bottle hydrocast
10	Hydrocast-Hobo 7	2005482	N/A	On top bottle of 10-bottle hydrocast
11	Hydrocast-Hobo 8	2005482	N/A	On top bottle of 10-bottle hydrocast
12	CTD 28-To-yo	2005458	N/A	Hanging 5m Below CTD
13	CTD 29-To-yo	2005458	N/A	Hanging 5m Below CTD
14	CTD 30	2005458	N/A	Hanging 5m Below CTD
15	CTD 31	2005458	N/A	Hanging 5m Below CTD
16	CTD 32	2005458	N/A	Hanging 5m Below CTD
17	CTD 33	2005458	N/A	Hanging 5m Below CTD
18	CTD 34	2005458	N/A	Hanging 5m Below CTD
19	CTD 35	2005482	N/A	Hanging 50 m below CTD with Hi-Range CTD
20	NCTD Cast 1	2005482	N/A	2m above hydroweight with NCTD

Table 2 continued.

Specifications from the manufacturer, Onset Computer Corporation, appear below:

Measurement Range	-40 to +125˚C
Accuracy	± 0.22 C. at +25 C
Drift	0.05 deg. C./year +0.1 deg C./1000hrs above +100 deg. C.
Response time in 1 m/s (2.2 mph) airflow	2.25 minutes, typical to 90%
Response time in water	20 seconds typical to 90% (this corresponds to an e-folding time scale of about 8.2 seconds)
Time accuracy	± 2 minutes per month at 25 C
Operating environment	Air, water, steam, 0 to 100% RH
Operating temperature	Logging: -40 to +125 C., launch/readout: 0 to 50 C., per USB specification
Battery life	3 year typical use, factory replaceable
Memory	64K bytes (43,000 12-bit measurements)
Construction	316L stainless steel with O-ring seal (food grade)
Weight	82 g (2.9 Oz)
Logger dimensions	17.5 x 101.6 mm, (0.69 x 4.00 inches)
Probe dimensions	4 x 124 mm (.016 x 4.90 inches)
Pressure/depth rating	2200 psi (1500m/4900 ft maximum)
Vibration rating	Navy spec: NAVMAT P-9492 (non-probe model only)
NIST certificate	Available for additional charge: temperature range -30 to +120 C.
CE	The CE marking identifies this product as complying with all relevant directives in the European Union (EU).

Table 3. AUC Water and Sediment Samples

Summary of work on Oceanus Leg II

Event type	Number	Volume of water filtered	Sediments collected	General location	Depth	Comments
CTD	2	110 liters	N/A	None-brine	50 m	1.
CTD	3	110 liters	N/A	None-brine	1500 m	2.
CTD	4	110 liters	N/A	None-brine	200 m	
CTD	5	110 liters	N/A	None-brine	700 m	
CTD	6	100 liters	N/A	None-brine	50 m	3.
Hobocast	3	50 liters	N/A	Atlantis II brine pool	2090-2135 m	4.
Hobocast	5	80 liters	N/A	Atlantis II brine pool	2089-2155 m	5.
CTD	12	20 liters	N/A	Atlantis II	2000 m	6.
CTD	13	110 liters	N/A	Atlantis II	50 m	
CTD	14	110 liters	N/A	Atlantis II	1500 m	
CTD	18	110 liters	N/A	Atlantis II	700 m	
CTD	19	110 liters	N/A	Atlantis II	200 m	
Hobocast	6	100 liters	N/A	Atlantis II brine pool	2084-2150 m	
Hobocast	7	100 liters	N/A	Discovery brine pool	2102-2168 m	
CTD	20	110 liters	N/A	Discovery Deep	50 m	
CTD	21	110 liters	N/A	Discovery Deep	1500 m	
CTD	22	110 liters	N/A	Discovery Deep	700 m	
CTD	23	110 liters	N/A	Discovery Deep	200 m	
Gravity Core	2	N/A	6 sections of entire core	Discovery Deep	280 cm into sea bed	

1. 3um and 8um filters broke
2. Filtered through 2 different membrane sets
3. Repetition of CTD 2
4. Last 3 bottles were not fired and the water was yellowish (may be interface)
5. First bottle was colder than expected. The first 4 bottles were yellow and the remaining ones were clear. Filtered separately (clear and yellow)
6. Anoxic samples

Table 4. HKUST Water and Sediment Samples

Location	Event	Depth (m)	Amount of samples collected
21°26.07' N, 38°07.35' E	CTD 2	50	4 L
	CTD 3	1500	4 L
	CTD 4	200	4 L
	CTD 5	700	4 L
	CTD 5	20	4 L
Atlantis II	CTD 13	20 & 50	4 L each depth
	CTD 14	1500	4 L
	CTD 18	200	4 L
	CTD 19	700	4 L
	Hobocast 4	>2100 (brine pool)	100 L
	Hobocast 5	>2100 (brine pool)	20 L
	Gravity core 1		2.6 m core
Discovery	CTD 20	20 & 50	4 L each depth
	CTD 21	1500	4 L
	CTD 22	200	4 L
	CTD 23	700	4 L
	Hobocast 8	>2100 (brine pool)	100 L

Table 5. WHOI/IMR Water Samples for Phosphorous Analysis

10/20/2008	PO4	TDP	APA	Lipids	RNA	FC	Nuts	Notes
OC449-6-1	12							full water column
OC449-6-5	3	3	3	3	2			all from ship's uncontaminated seawater
OC449-6-6	3	3	3	3				all from 20m
10/21/2008								
OC449-6-7	6	6	6	6	2			8:00 a.m. profile of upper 200m
experiment 1								set up with ship's uncontaminated seawater
t=0	3	3	6	3	2			all from ship's uncontaminated seawater
t=0+	3							all from immed after exp 1 initiated
t = 12	3	3	3					set up with ship's uncontaminated seawater
10/22/2008								
OC449-6-HOBO-3-hydrocast	4							10:00 a.m. from intake, w/ & w/o As reduction
OC449-6-HOBO-3-hydrocast				3				noon, brine waters
OC449-6-HOBO-4-hydrocast	4							2:00 p.m. from intake, w/ & w/o As reduction
OC449-6-HOBO-4-hydrocast				3				4:00 p.m. brine waters
exp 1								
t = 24	3	3	3					set up with ship's uncontaminated seawater
10/23/2008								
OC449-6-8	12	12		12		12		full water column profile
OC449-6-11	3							

10/24/2008	PO4	TDP	APA	Lipids	RNA	FC	Nuts	Notes
OC449-6-15	6	6	6	6		6	6	upper 125m
10/25/2008								
exp2-surface t = 0	3	3	3	3	2	3		all from ship's uncontaminated seawater
exp2-surface t = 6	3	3	3	3	2	3		all from ship's uncontaminated seawater
10/26/2008								
exp2-surface t=12	3	3	3	3	2	3		all from ship's uncontaminated seawater
exp2-amend t=12	9	3				3		set up with ship's uncontaminated seawater
exp2-surface t=18	3	3	3	3	2	3		all from ship's uncontaminated seawater
exp2-surface t=24	3	3	3	3	2	3		all from ship's uncontaminated seawater
exp2-amend t=24	9	3	3	3		3		set up with ship's uncontaminated seawater
exp2 - surface t=30	3	3	3	3	2	3		all from ship's uncontaminated seawater
10/27/2008								
exp2-surface t = 36	3	3	3	3	2	3		all from ship's uncontaminated seawater
exp2-amend t = 36	3	3				3		set up with ship's uncontaminated seawater
exp2 -surface t = 42	3	3	3	3	2	3		all from ship's uncontaminated seawater
exp2 - surface t=48	3	3	3	3	2	3		all from ship's uncontaminated seawater
exp2 - amend t=48	3	3	3	3		3		set up with ship's uncontaminated seawater
10/28/2008								
OC449-6-24	9							9 depths
OC449-6-26	9							9 depths
OC449-6-27	10							10 depths
10/29/2008								
OC449-6-28	6	6	6	6	4	6		full water column
OC449-6-31	3							1 depth

PO4 - Phosphate analyses conducted on board
TDP - total dissolved phosphorus, to be analyzed at WHOI
APA - Alkaline phosphatase activity, to be assayed at WHOI
Lipids - Intact polar lipids, to be analyzed at WHOI
RNA - Pho gene expression, to be analyzed at WHOI
FC - plankton counts by flow cytometry, to be analyzed at WHOI
Nuts - Nutrients, to be analyzed at WHOI.