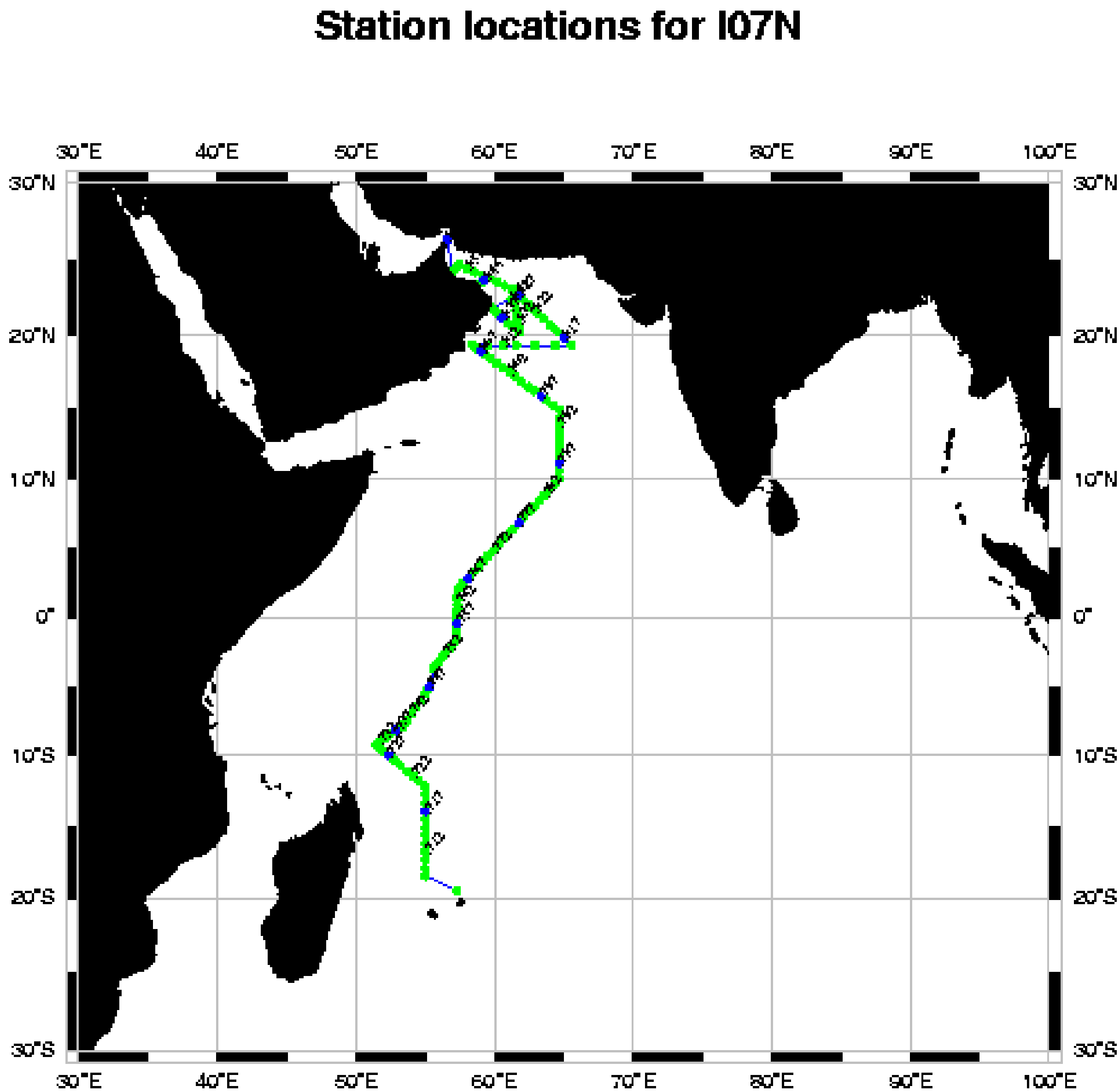
Highlights

WOCE Line:	**I07N,** R/V Knorr Cruise 145/10 in the Indian Ocean
WOCE EXPOCODE:	**316N145_10**
Co-Chief Scientists:	Donald B. Olson RSMAS/MPO University of Miami 4600 Rickenbacker Cswy. Miami, FL 33149 U.S.A. Ph. (305) 361-4074 FAX: (305) 361-4662 TWX/TELEX 810/848-6067 email: dolson@rsmas.miami.edu Scott Doney National Center for Atmospheric Research P.O. Box 3000 Boulder, CO 80307 Ph. (303)497-1639 FAX: (303) 497-1700 email: doney@ncar.ucar.edu David L. Musgrave Institute ofMarine Science University of Alaska Fairbanks, AK 99775 Ph: (907) 474-7837
Ship:	R/V Knorr
Ports of call:	Pt. Louis, Mauritius to Muscat, Oman
Cruise Dates:	15 July to 24 August 1995

C.1.2. Cruise Summary



(created by WOCE staff)

Cruise Track:
The cruise track is shown in Fig. 1 with expanded depictions to show stations in the Amirante Passage and Oman coastal region in more detail in Fig. 2a,b.

Number of Stations:
There were 156 stations with CTD/rosette and lowered ADCP. The rosette was a 36 bottle rig with 10 liter bottles. Details are included below.

Sampling:
Measurements on the bottle samples included salinity, oxygen, nitrate, nitrite, phosphate, silicate, total CO2, alkalinity, C-14, tritium, helium, iodine, barium, CFC's 11

and 12. Bottles were fired to catch extreme in properties and obtain a sampling frequency that included samples at least every 100 m in the upper layers and 300 m in the deep waters. The bottle spacing is shown in Fig. 3. Underway measurements included acoustic Doppler current profiling (ADCP), IMET meteorological sampling and continuous CO2 and NO2 measurements.

Floats, Drifters and Moorings:
Eleven ALACE floats were deployed as discussed below. No drifters or moorings were deployed.

C.1.3. List of Principal Investigators

Table C.1: The principle investigators involved in the cruise effort; cruise personnel and their duties are given in table C2.

Analysis	Institution	Principal Investigator
Basic Hydrography (Salinity, O2, Nutrients, CTD)	SIO	James H. Swift
CFC	RSMAS	Rana Fine
He/Tr	RSMAS	Zafer Top
AMS 14C and Ra-228	Princeton	Robert Key
TCO2 & Alkalinity	U Hawaii	C. Winn
TCO2	SIO	Charles Keeling
Barium	OSU	Kelly Faulkner
Transmisometer	TAMU	Wilf Gardner
ADCP and LADCP	U Hawaii	Erik Firing
ALACE Floats	SIO	Russ Davis
UW PCO2	Princeton	Robert Key
UW Air chemistry	U Hawaii	C. Winn
UW Meteorology (IMET)	WHOI	B. Walden
UW Thermosalinograph	WHOI	

C.1.4. Scientific Program and Methods

The major contributions of I7 to the overall Indian Ocean WHP effort include:

1) Interior water mass properties and transports across the Mascarene Basin. These will complement I3 which provides an east-west section through the basin and is closed to the African continent by I7a (Toole). The section is laid out approximately perpendicular to the topography of the southern Mascarene plateau out to the central Mascarene Plain at 55 E. This portion of the cruise will be modified to connect with Toole's line such that the combination forms a continuous section in mid-basin. The line moves northwards up the central Mascarene Basin to a point northwards of the inflow from the break in the Mascarene plateau at 17 S before cutting westward to close on the deep topography north of the tip of Madagascar.

2) Short section across the deep Amirante Passage to provide another realization of the deep water mass properties and the baroclinic structure in this important passage between the Mascarene and Somali basins. This complements the earlier work of Fieux and Swallow (1988), Barton and Hill (1989), an April 1995 section by NOAA and a planned repeat cross section by I2. The planed cruise track crosses the deep western boundary current upstream of the Western Channel of the Amirante Passage (see Johnson and Damuth, 1979). It then takes the ship northwards to the edge of the Anton Brun bank from where a section across the central portion of the passage will be done. This section repeats one of the Barton and Hill (1989) sections.

3) There are three ways of moving around the Seychelles, 1) moving westward into the Somali Basin and crossing the equator on the deep axis of the basin, 2) completing the section from the shallow topography on the northern edge of the Seychelles, or 3) moving eastward around the Seychelles and crossing the equator at approximately 57 E. In order to save time the proposed course crosses the bank. According to the sailing directions this requires crossing the bank edge south of 5 S. Restrictions require that the ship use the approaches to Mahe as depicted on DMA 61541.

4) A cross equatorial section is to the east of the 1987 occupations of Johnson (1990), Johnson et al. (1991a). This allows an investigation of their suggested eastward deep water flow along the equator.

5) Repeat occupation of the 1986-87 lines across the Carlsberg Ridge at approximately 60 E. On the Somali basin side this will provide a picture of the representative nature of the broad deep flow along the Carlsberg from the equator. On the northern side of the ridge the section provides another realization of the southeastward flow of waters in the southern Arabian basin. The important question is whether the weak transports found on this section in 1987 SW monsoon (Johnson et al., 1991b) are typical of this season. It is hoped that repeat hydrography will allow at some time another look at the stronger NE monsoon flow suggested in the 1986 cruise. The WHP re-occupation of this section is nicely complemented by the I1 section and German WOCE work in the Owens fracture zone. Finally, the properties along the northern flank of the Carlsberg Ridge will be compared to I1 stations along the Chagos-Laccadive ridge at 10N to consider the possible addition of deep waters to the Arabian Sea from the Central Indian basin to the east.

6) Occupation of a line along 65 E in the central Arabian basin will provide a first deep realization of the extent of tilted density surfaces in the S.W. monsoon. The 1987 occupation suggests the monsoon effects are felt at least as deep as 1200 m. The strength of mid-ocean upwelling during a, hopefully, more typical SW monsoon is also important in relationship to the monsoonal response of the upper waters. Finally the line will be closed into the Oman coast in the proximity of Maseria Island. This will provide a closed estimate of the cross basin fluxes which are not available

from earlier station data. This section is offset from the JGOFS line such that it cuts through a gap in the Owens Ridge. In agreement with JGOFS this will allow three synoptic sections to be accomplished along the Oman coast during the SW monsoon.

7) A deep line of stations will be completed up the center of the Gulf of Oman, including the distribution of properties in proximity to the Murray Ridge. The end of this line in the Arabian Basin corresponds to the center of the oxygen minimum zone in the thermocline. The coverage along the Murray ridge allows a check on the suggested anticyclonic flow over this feature (Qurishee, 1984). A line of stations up the center of the Gulf of Oman and then into the coast off Sohar provides a detailed investigation of the inflow of Arabian (Persian) Gulf Water into the basin. The final station in the Straits of Hormuz is meant to further specify the Arabian Sea Water properties. This station is placed in the deep trough between As Salamah wa Banatuh Island and Musandam Peninsula. Again this is in a restricted area for inshore dhow traffic. Therefore special permission must be obtained from Oman or the station will have to be done off Jazirat Musandam.

Table C.2: Parameters, contributing institutions and personnel

University of Alaska	David Musgrave, Co-Chief Scientist (console, data checking)
National Center for Atmospheric Research	Scott Doney, Co-Chief Scientist (console, data checking)
Scripps ODF CTD, Salts, Oxygen and Nutrients	Carl Mattson, Watchleader (Electronics) Bob Williams, O2 (Data processing) John Boaz, Watchleader (Bottle Data Processing/O2) Mary Johnson (CTD Processing) Craig Hallman (Salts/O2) Rhonda Kelly (Nuts) Stacey Morgan (Nuts) Piers Chapman (Salts)
University of Miami	Donald Olson, Chief Scientist Shery Zimmerman, Graduate Student (Salt) John Hargrove, Graduate Student (ADCP) Alexis Zubrow, REU Student, Harvard Kevin Sullivan (CFC) Craig Neill (CFC) Evan Howell (CFC, deck) Srinivasan Ashwanth (Tritium/helium) Donald Cucchiara (salts, sampling)

LODYC (U. of Hawaii)	Elodie Kestenare (ADCP)
University of Hawaii	Rolf Schottle (CO2) Angela Adams (CO2) Jennifer Phillips (CO2) Kelly Angeley (CO2)
Princeton	Tasha Zahn (C-14)
Observers	Sultan bin Rashed bin Ali Al-Rasbi Mohammed bin Khamis bin Saif Al-Muzaini Address for both: Ministry of Regional Municipalities and Environment P.O. Box 323 Muscat Oman PC 113

Preliminary Results:
WOCE WHP line I7N has just completed the portion of the leg south of the equator. All operations are going well. The following are some of the preliminary results for the Mascarene Basin and the region around the Seychelles.The cruise track consisted of a line up the central Mascarene Basin and then a line into the western boundary on the Farquhar Ridge. This segment in the northern Mascarene Basin angled northwest into the Anton Brun Bank cutting the deep western boundary current at a right angle. The track then turned northeast across the Amirante Trench and the Amirante Ridge and then northeast to the Seychelles Bank. An upward-tilting of isotherms below 3800 dbar along the flank of the Farquhar Ridge indicated a northward flowing deep western boundary current that intensified within the 200 km of Anton Brun Bank. Within 500 km of the ridge, the transport below 3800 dbars was 3.0 Sv (northward) relative to 3800 dbars. The transport in the 200 km closest to the ridge was 1.3 Sv (northward). Some reversals in the station-pair transports occurred at distances greater than 200 km from the boundary.

There were four stations with bottom depths greater than 3800 m across the Amirante Trench. The deep western boundary current was indicated by uplifted isotherms on the western side of the trench. The total transport below 3800 dbars was 1.6 Sv with a slight (0.2 Sv) southward flow in the last station pair on the eastern side of the trench. These results are not significantly changed if the transport is taken below the 1.2 degree potential temperature using the pressure at the isotherm for the zero-velocity surface. This result is quite similar to the Fieux and Swallow (1988) estimate of 0.8-2.05 Sv (relative to 3800 dbars) and certainly less than Barton and Hill (1989) estimate of 3-5 Sv. The lowered ADCP gave evidence for the cores of these currents but is contaminated by barotropic tides to the extent that transports from limited current profiles are not feasible.

Northeast of the Amirante Ridge there is a sudden change in deep water properties with the deep high oxygen, low silicate waters being absent. The waters in the cul-de-sac between the ridge and the Seychelles Bank have definite northern properties that apparently arise from a flow through the passage between the two topographic features. Another interesting feature in the deep water masses is the existence of a higher oxygen form of Indian Common Water along the northern blank of the Seychelles platform. Again as in the cul-de-sac the trend to high oxygen, low silicate below the silicate maximum associated with circumpolar deep waters is absent. The waters just above the silicate max, however, trend to higher oxygen on a set of stations between Seychelles and the equatorial wave guide.

Equatorial currents extending from around 2.5 south northwards to 1.5 N. Surface currents were to the east at -.50 m/s and there was evidence of upwelling. This is somewhat surprising given the winds and the season! Perhaps the current pattern is evidence of a wave or meander. There was an undercurrent at approximately 175 m with a secondary current max of -.50 m/s. Deeper the flow was reversed to the east at mid-depth and then reversed back to the west near the bottom. Both of these were a little less than -.10 m/s in the lowered ADCP.

A deep southwestward flow of cold (<1.3 theta), oxygen rich (3.7 ml/l) low silica (140 uM) water is observed just north of the Carlsberg ridge. The transport below the depth of the 1.7 deg potential temperature surface is 2 Sv relative to a zero velocity surface at 1.7 deg theta. A Somali Basin origin via the Owens fracture zone for this deep water is supported by the water mass properties and flow direction, though substantial modification must occur enroute. North of the boundary current, the deep water profiles in the Arabian Basin are characterized by a low oxygen, high silica bottom boundary layer likely due to remineralization at the sediment water interface. The mid-depth inflow or mixing of northern high silica, low oxygen water leads to a residual, local oxygen maximum approximately 350--500 m above the bottom at about 45.86 sigma-4.

Coming into the Omani coast east of Ras al Madraka we encountered three cool strips with shallowing mixed layers. The first was at 14.5 N with a 0.5 C temperature drop and a 35 m shoaling in mixed layer. This is south of the wind jet maximum that occurred at 15.5 north and had winds of only 13.5 m/s. The next cool strip was at 16.5 N an involved a one degree step and a 45 m decrease in mixed layer depth. This was followed by an increase in temperature and mixed layer followed by a 2 C drop at 17.5 N where the mixed layer went to around 25 m depth. This was followed at around 19 N where we entered the coastal upwelling plume off Ras al Madraka. Our lowest temperature there was 22.5 C. This seemed to be the same plume that R/V Thompson (JGOFS) surveyed to the west at the shelf end where it had 20 C water. It seems that these offshore features are tied to open ocean upwelling. They seem to be too far from any cape to be of coastal origin, but analysis of available AVHRR data will be required to verify this. As per plans extensive work was carried out in the Gulf of Oman with three sections one across the mouth of the Gulf at Ras al Hadd and two into the Oman coast off Muscat and Sohar. A final station was occupied just northeast of the Masandam peninsula where there is a deep region (approx. 200 m) between the traffic separation lanes and the inshore dhow lane.

Individual Group Reports:

Acoustic Doppler Current Profiling.
Preliminary Cruise Report (23 August 1995) -

Acoustic Doppler Current Profiler Observations on I7N
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All data are to be considered preliminary at this time. For information on the data contact:

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Ocean velocity observations were taken on the WHP Indian Ocean Expedition line, I7N, using two acoustic Doppler current profiler (ADCP) systems and accurate navigation data. The two systems are the hull-mounted ADCP and a lowered ADCP mounted on the rosette with the CTD. The data were taken aboard the R/V KNORR from July 15, 1995 to August 23, 1995 between Port-Louis, Mauritius and Muscat, Oman. The purpose of the observations was to document the upper ocean horizontal velocity structure along the cruise track, and to measure vertical profiles of the horizontal velocity components at the individual hydrographic stations. The observations provide absolute velocity estimates including the ageostrophic component of the flow. Figure 1 shows the cruise track and the near surface currents measured by the hull-mounted ADCP.

Hull-mounted ADCP:
The hull-mounted ADCP is part of the ship's equipment aboard the KNORR. The ADCP is a 150 kHz unit manufactured by RD Instruments. The instrument pings about once per second, and for most of the cruise the data were stored as 5-minute averages or ensembles. The user-exit program, ue4, receives and stores the ADCP data along with both the P-code navigation data from the ship's Magnavox receiver and the Ashtech gps receiver positions. The P-code data are used as navigation for the ADCP processing. The ship gyro is providing heading information for vector averaging the ADCP data over the 5-minute ensembles. The user-exit program calculates and stores the heading offset based on the difference between the heading determination from the Ashtech receiver and from the ship gyro. The ADCP transducer is mounted at a depth of about 5 meters below the sea surface.

As setup parameters, we used a blanking interval of 4 meters, a vertical pulse length of 16 meters, and a vertical bin size of 8 meters. We used a 5 minute sampling interval for the entire cruise.

Bottom tracking was activated during the shallow water transits near Port-Louis, Seychelles Islands crossing, and along the coasts of Muscat. For the processing of the ADCP data aboard ship, we used a rotation amplitude of 1.007, a rotation angle of -0.5 degrees (added to the gyro minus gps heading), and a time filter width of 0.0208 days (30 minutes). Final editing and calibration of the ADCP data has not yet been done.

A complete set of preliminary plots was generated during the cruise. The plots consist of: vector plots with velocity averaged over several depth intervals, and over a tenth or a twentieth of degrees in spatial grid; and contour plots of u (positive east) and v (positive north) typically averaged over 0.1 degree of longitude or latitude, depending on the track. The velocity was measured from a depth of 21 meters to a depth of about 300 to 400 meters, typically, during the first part of the cruise. During the last twenty days (in Arabian sea), the depth range decreased to about 150 to 250 meters during the nighttime due to a strong diurnal variability in scattering.

Lowered ADCP:

The second ADCP system is the lowered ADCP (LADCP), which was mounted to the rosette system with the CTD. The LADCP yields vertical profiles of horizontal velocity components from near the ocean surface to near the bottom. The unit is a broadband, self-contained 150 kHz system manufactured by RD Instruments, model BBCS 150, serial no. 1246. We used single ping ensembles. Vertical shear of horizontal velocity was obtained from each ping. These shear estimates were vertically binned and averaged for each cast. By combining the measured velocity of the ocean with respect to the instrument, the measured vertical shear, and accurate shipboard navigation at the start and end of the station, absolute velocity profiles are obtained (Fisher and Visbeck, 1993). Depth is obtained by integrating the vertical velocity component; a better estimate of the depth coordinate will be available after final processing of the data together with the CTD profile data. The shipboard processing results in vertical profiles of u and v velocity components, from a depth of 60 meters to near the ocean bottom in 16 meter intervals. These data have been computer contoured to produce preliminary plots for analysis and diagnosis.

CTD casts were made at stations 708-856 on the I7N cruise. LADCP casts were made at all stations except: stations 718 to 719 (a fuse had blown inside the instrument), station 720 (data have not been recovered, a problem linked to the previous one) and stations 855-856 (shallow water). The deep casts often have noise problems below 3000 meters or so due to poor instrument range and interference from the return of the previous ping.

Navigation:
The ship used a Magnavox receiver for navigation, with data coming in at once every two seconds. We have stored this once every two seconds data for the entire cruise. We also decimated this once every two seconds data by a factor of 10 to 20-second intervals and stored these processed files as daily matlab files of latitude, longitude and time.

The Ashtech receiver uses a four antennae array to measure position and attitude. The heading estimate was used with the gyro to provide a heading correction for the ADCP ensembles. The Ashtech data was stored by the ADCP user-exit program along with the ADCP data.

References:

Fisher, J. and M. Visbeck, 1993. Deep velocity profiling with self-contained ADCPs; J. Atmos. Oceanic Technol., 10, 764-773.

ALACE Float Deployments:
Eleven ALACE floats were deployed as part of the program. These are ballasted to a nominal depth between 900 and 1000 m. These units have a planned lifetime of five years. The launch positions for these are:

Number	Deployment Time	Position	Station
509	16-07-95 0842 Z	18 01.17 S	710
		55 00.17 E	
475	17-07-95 1806 Z	15 05.11 S	715
		55 00.48 E	
499	19-07-95 0226 Z	12 14.99 S	720
		52 19.18 E	
510T	20-07-95 2305 Z	10 00.02 S	727
		52 19.18 E	
511T	24-07-95 0705 Z	07 30.93 S	741
		53 37.73 E	
512T	26-07-95 2129 Z	03 14.94 S	750
		56 00.44 E	
513T	28-07-95 0944 Z	00 52.10 S	756
		57 14.65 E	
514T	29-07-95 2139 Z	00 55.99 N	762
		57 17.60 E	
515T	01-08-95 0223 Z	03 35.06 N	769
		58 47.60 E	
520T	03-08-95 0359 Z	06 23.64 N	776
		61 21.33 E	
531T	06-08-95 0500 Z	10 32.42 N	786
		64 39.79 E	

The launches cover the southern end of the I7N track up to a point just north of the Carlsberg Ridge. Deployments were accomplished earlier north of this from JGOFS cruises. The addition of the T on the serial number above indicates a temperature profiling float.

The floats nominal depth range encompasses primarily the upper levels of the Indian Ocean Common Water as depicted by an oxygen minimum and either salinity maximum (floats 475, 499, 510, 512 and 515) or in a region of rising salinity below the Antarctic Intermediate Water layer (floats 509, 511, 513) or the more saline Red Sea water in the north (floats 520 and 531). In particular ALACE 511 is deployed in common waters moving southward along the Armiante Ridge into the northern-most reaches of the Mascarene Basin. All of the floats are one to several hundred meters below the 27.2 potential density surface along which the Red Sea and Antarctic Intermediate Waters mix.

CO2 Group Summary-I7N:

	Alkalinity	**Total CO2**
Total Samples Ran From Rosette (Including Replicates)	2805	2805
Replicates	216	216
CRMs	74	150
Surface Sea Water	74	----

Comments: Overall the data set appears very good from looking at the data quality indicators. As a general guideline for practical data quality objectives we are looking for approximately +/- 1.0 uM/Kg for DIC and +/-3.0 uM/Kg. The entire data set falls within or near to those objectives. We encountered very few instrument difficulties during the cruise. Most every instrument problem encountered was fixed prior to analysis of any project samples. I expect to have very little data flagged as uncertain for the final WOCE deliverable. In general, the instrumentation is in decent working order and there are adequate consumables for the next group's leg. In addition, I will forward you the Replicate/CRM statistics I have already sent back to our laboratory.

Statistics for the DIC:
(All values are in uM/Kg. n= number of samples, x=mean, SD=std dev.)

CRM's:

SOMMA1	Batch 27 n = 10 x = 1985.27 SD = 1.06
	Batch 26 n = 53 x = 1976.89 SD = 1.34
	Batch 23 n = 8 x = 1991.43 SD = 1.11

SOMMA2 Batch 27 n = 10 x = 1985.08 SD = 0.77
Batch 26 n = 56 x = 1976.04 SD = 0.87
Batch 23 n = 8 x = 1990.24 SD = 1.11

Duplicates:

SOMMA1 n= 104 mean of diff.= .866 SD of diff.= .728
SOMMA2 n= 97 mean of diff.= 1.03 SD of diff.= .833

Alkalinity statistics. All values in uM/Kg:

CRMS:

Cell 2 CRM Batch#26 n=29 mean=2185.21 S.D.=3.838
minus outliers n=27 mean=2184.493 S.D.=2.862

CRM Batch#27 n=4 mean=2221.35 S.D.=2.110
No outliers

CRM Batch #23 n=3 mean=2223.133 S.D.=0.946
No outliers

Cell 13 CRM Batch #26 n=27 mean=2181.948 S.D.=3.192
minus outliers n=25 mean=2181.34 S.D.=2.448

CRM Batch #27 n=3 mean=2219.733 S.D.=2.040
No outliers

CRM Batch #23 n=2 mean=2219.9 S.D.=0.4
No outliers

ALL CRM Batch #26 n=56 mean=2183.638 S.D.=3.899
minus outliers n=52 mean=2183.051 S.D.=3.076

CRM Batch #27 n=7 mean=2220.657 S.D.=2.229
No outliers

CRM Batch #23 n=5 mean=2221.84 S.D.=1.764

Surface Water Samples:

Cell 2 First Carboy n=19 mean=2334.197 S.D.=5.412
No outliers

Second Carboy n=15 mean=2354.82 S.D.=7.588
minus outliers n=14 mean=2353.0 .D.=3.465

Cell13		First Carboy n=21 mean=2326.189 S.D.=4.553 minus outliers n=18 mean=2326.815 S.D.=2.640
		Second Carboy n=12 mean=2350.342 S.D.=5.721 No outliers greater than 2 sigma
ALL		First Carboy n=40 mean=2329.993 S.D.=6.386 minus outliers n=37 mean=2339.403 S.D.=5.334
		Second Carboy n=27 mean=2352.83 S.D.=7.175 minus outliers n=26 mean=2349.944 S.D.=4.83

Replicates:

Cell 2		n=63 mean of difference=2.270 S.D. of diff=2.566 minus outliers n=55 mean of difference=1.430 S.D. of diff=1.213
Cell 13	n=57	mean of difference=2.184 S.D. of diff=3.289 minus outliers n=53 mean of difference=1.430 S.D. of diff=1.581

Inter-Cell Comparison:

n=77 mean of difference=3.166 S.D. of diff=4.130
minus outliers n=69 mean of difference=1.93
S.D. of diff=1.704

CFC Sampling:

Chloroflurocarbon Sampling on I7N

As part of the suite of transient tracers sampled on WOCE I7N chloroflourocarbons eleven and twelve (CFC-11 and CFC-12) were analyzed from rosette casts. These anthropogenic gases have atmospheric histories dating from the middle of this century. The concentrations of these trace gases provide a clue to the time scales involved with atmospherically derived gases introduced into the ocean. This process, typically referred to as ventilation, is of interest in relation to the uptake of carbon dioxide by the ocean and the balance between the introduction of oxygen in the surface layers to its consumption by respiration of organic matter in the ocean interior. The latter is of particular interest because of the pronounced oxygen minimum zones found in the Arabian Sea.

Water samples were drawn with glass syringes and analyzed for CFC-11 and CFC-12 by two technicians standing complementary 12-hour watches. A total of 2,834 water samples were drawn at 146 of 149 stations. The ability to sample so many stations, especially across the equator, was greatly due to the decision to steam at a speed less than maximum between those stations. The extra time allowed the samples drawn on one station to be processed before the next cast arrived on deck. Enough samples were drawn on a cast to cover the CFC signal plus several bottles in deeper CFC-free water.

Three stations were utilized to obtain additional bottle blank information. On these stations, the closing of the bottles was started at bottle 15, 19, or 28 and continued around the rest of the rosette. This alternate firing procedure closed the bottles that normally sampled upper waters (118-136) in deep, CFC-free waters. These casts plus the deeper routine sampling will provide the final bottle blank values that will be applied.

The CFC analyses were done via a custom-built extraction system from Dr. Rana Fine's group at the University of Miami. The extraction system employs a purge-and-trap process to remove the dissolved gases from the water collected in glass syringes. These gases are then separated and measured with an electron-capture gas chromatograph. The analytical system operated almost constantly with little loss of time or samples. Throughout the cruise, the analytical blanks were zero or near zero (averaging <0.003 pM CFC-11/kg and <0.001 pM CFC-12/kg water). The precision of the duplicate water analyses was generally 1% or better. The changes in sensitivity of the electron-capture detector were compensated for with regular standard analyses. The peaks in the chromatograms were integrated automatically with a PC-based data acquisition package. Due to the very busy sampling and analyses schedule the smallest peaks were not reintegrated under manual software control. This part of the post-acquisition processing will be done after the cruise. Preliminary results were compiled on disk and transferred to the archiving computer onboard. Vertical profiles were printed and examined as a check on data integrity.

Air analyses were also done as time permitted throughout the cruise. 53 samples were taken via a diaphragm pump with a inlet at the bow. The atmospheric concentrations were close to 513 part per trillion for CFC-12 and 268 parts per trillion CFC-11. The atmospheric values were slightly different on either side of the equator. These are preliminary values, as are the water concentrations. Extensive post-cruise processing of the data will change the values slightly.

Contact:
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IMET DATA STATUS REPORT

Cruise:	I7 (Knorr 145-10)
Dates:	15 July - 23 August, 1995
Location:	Port Louis, Mauritius to Muscat, Oman
Chief Scientist:	Donald Olson

Equipment in Use:
The following IMET sensors were installed and in use during I7.

Type	Serial Number	Label
Air Temperature	119	TMP
Barometric Pressure	118	BPR
Precipitation	113	PRC
Relative Humidity	115	HRH
Sea Surface Temperature	108	SST
Short Wave Radiation	003	SWR
Wind Speed and Direction	004	WND

Data:
The data was logged to ASCII text files, one per day. With this document you have received complete copies of the data on exabyte tape. The tape contains a single tar archive which contains one file per day. The files are named YYMMDD.dat, where YYMMDD is the year, month, and day which is covered in the file. Logging began on July 15th at 04:06UTC, and ended on August 23rd at 10:55UTC.

On August 16th at 00:00UTC, GPS course and speed over ground information was added to the items recorded in these files. Course and speed over ground information is not included for times prior to 08/16-00:00. The following data items were recorded once per minute during this cruise:

Item Name	Description
CTIME	Computer time
GP20P_TP	Port GPS 200 time & position
GP20S_GC	Stbd GPS 200 course over ground
GP20S_GS	Stbd GPS 200 speed over ground
GP20S_TP	Stbd GPS 200 time & position
GYRO	Ship's heading (Gyro syncro)
IMET_AIR	Air temperature (degrees C)
IMET_BPR	Barometric pressure (millibars)
IMET_HUM	Relative humidity (percent)
IMET_PRC	Precipitation (millimeters)
IMET_SEA	Sea surface temp (degrees C)
IMET_SWR	Short wave radiation (watts/sq m)
IMET_WNC	Compass reading (degrees) [NOT CALIBRATED]

IMET_WND	Wind direction (ship relative)
IMET_WNS	Wind speed (m/s, ship relative)
SPDLOG	Ship's speed (EDO Speedlog)
SSCND	Sea surface conductivity (mmho/cm)
SSTMP	Sea surface temperature (C)

There were a few large gaps in the data during the cruise. Any gap longer than 15 minutes while under way, and any gap longer than one hour while on station are listed below, with a short explanation of each. If only a subset of the data items are missing for the period indicated, the missing items will be listed along with the notes. In the table below OS stands for on station, and UW stands for under way.

Date	**Start**	**Stop**	**Length**	**W/OS**	**Notes (Including data affected)**
07/22	11:22	12:00	38 min.	UW	Data Logging Computer Failure [all data]
07/23	02:07	02:23	15 min.	UW	Data Logging Computer Failure [all data]
08/05-06	22:54	04:04	5.2 hr.	Both	Data Logging Computer Failure [all data]
08/19	05:56	06:13	17 min.	UW	Interface Device Failure [GYRO] *
08/16-19	03:19	07:30	3.2 day	Both	Interface Device Failure [SPDLOG] *
08/21	02:27	03:02	35 min.	UW	Device Configuration Change [GP20P_TP]

* The interface device which provides both gyro and speedlog data was inoperable for 3.2 days. Gyro information every five minutes was recovered from ADCP data files and merged into this data set.

World Ocean Circulation Experiment
Indian Ocean I7N
R/V Knorr Voyage 145/10

ODF Operations Preliminary Cruise Report
August 23, 1995

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Oceanographic Data Facility
Scripps Institution of Oceanography
La Jolla, Ca. 92093-0214

Summary:

A hydrographic survey consisting of 149 CTD/Rosette stations were performed on a South to North cruise track along 54-65 E from 20 S to 26 N in the Southwestern Indian Ocean through the Arabian Sea to the last station in the Strait of Hormuz. The R/V Knorr departed Port Louis, Mauritius on 15 July 1995. The first station started at number 708. The last station was number 856. During most stations all 36 rosette bottles were tripped for a total of 5117 water sampler bottles for the cruise. Salinity, dissolved oxygen and nutrient measurements were taken at all stations from every bottle that was tripped. The cruise ended in Matrah, Oman on 23 August 1995. Eleven ALACE floats were deployed during the first half of the cruise.

Scientific Personnel

Name	**Title**	**Affiliation**	**Duties**
Donald B.Olson	Professor	RSMAS	Chief Scientist
David L. Musgrave	Assoc Professor	U. Alaska-FB	Co-PI/Btl Data/Rosette
Scott Doney	Scientist I	NCAR	Co-PI/Btl Data/Rosette
Carl W. Mattson	Pr Electronic Tech	STS/ODF	TIC/Watch Leader/ET/Rosette
John Boaz	Marine Tech	STS/ODF	Watch Leader/O2/Rosette/Btl data
Stacey R. Morgan	SRA	STS/ODF	Nutrients
Rhonda M. Kelly	SRA	STS/ODF	Nutrients
Craig M. Hallman	SRA	STS/ODF	Oxygen/Salt/Rosette
Robert T. Williams	Programmer Analyst	STS/ODF	Oxygen/Rosette/Btl data
Mary C. Johnson	SRA	STS/ODF	CTD data Processing
Evan A. Howell	Grad Student	RSMAS	Ctd Console/Rosette/CFC
Alexis A.S. Zubrow	UnderGrad Student	RSMAS	Ctd Console/Rosette
Shery Zimmerman	Grad Student	RSMAS	Ctd Console/Rosette
Donald D. Cucchiara	Marine Tech	RSMAS	Salt/Rosette
Piers Chapman	Director US WOCE	TAMU	Salt/Rosette
Elodie Kestenare		JIMAR	LADCP/ADCP
John T. Hargrove	Grad Student	RSMAS	LADCP/ADCP
Rolf G. Schottle	Research Assoc III	U. Hawaii	TCO2/Alkalinity

Name	Title	Affiliation	Duties
Kelly J. Angeley	Analytic Chemist	U. Hawaii	TCO2/Alkalinity
Angela K. Adams	Grad Student	U. Hawaii	TCO2/Alkalinity
Jennifer A. Phillips	UnderGrad Student	U. Hawaii	TCO2/Alkalinity
Tasha A. Zahn	Lab Assistant	PU/OTL	C14/Ra-228/PCO
Kevin F. Sullivan	Marine Tech Spec	RSMAS	CFC
Craig Neill	Consultant	RSMAS	CFC
Ashwanth Srinivasan	Grad Student	RSMAS	He/Tr
Ken Feldman	SSG Tech	WHOI	Res Tech
Mohammed Al-Muzaini		MRME	OMAN Observer
Sultan Al-Rashi	Chemist	MRME	OMAN Observer/TCo2

Scientific Personnel WOCE I07N

1. Programs

Table 1.0 Principal Programs of WOCE I7N

Analysis	Institution	Principal Investigator
Basic Hydrophogy (Salinity, O2, Nutrients, CTD)	SIO	James H. Swift
CFC	RSMAS	Rana Fine
He/Tr	RSMAS	Zafer Top
AMS 14C and Ra-228	Princeton	Robert Key
TCO2 & Alkalinity	U. Hawaii	C. Winn
TCO2	SIO	Charles Keeling
Barium	OSU	Kelly Faulkner
Transmisometer	TAMU	Wilf Gardner
ADCP and LADCP	U. Hawaii	Erik Firing
ALACE Floats	SIO	Russ Davis
UW PCO2	Princeton	Robert Key
UW Air Chemistry	U. Hawaii	C. Winn
UW Meteorology (IMET)	WHOI	B. Walden
UW Thermosalinograph	WHOI	

The principal programs of I7N are shown in Table 1.0. The basic hydrography program is described in detail in this report.

1.1. Basic Hydrography Program

The basic hydrography program consisted of salinity, dissolved oxygen and nutrient (nitrite, nitrate, phosphate and silicate) measurements made from bottles taken on CTD/rosette casts plus pressure temperature, salinity and dissolved oxygen from CTD profiles. Rosette casts at 149 stations were made to within 10 meters of the bottom. No major problems were encountered during any phase of the operation. The resulting data set met and in many cases exceeded WHP specifications. The distribution of samples is illustrated in figures 1.1.0 and 1.1.1.

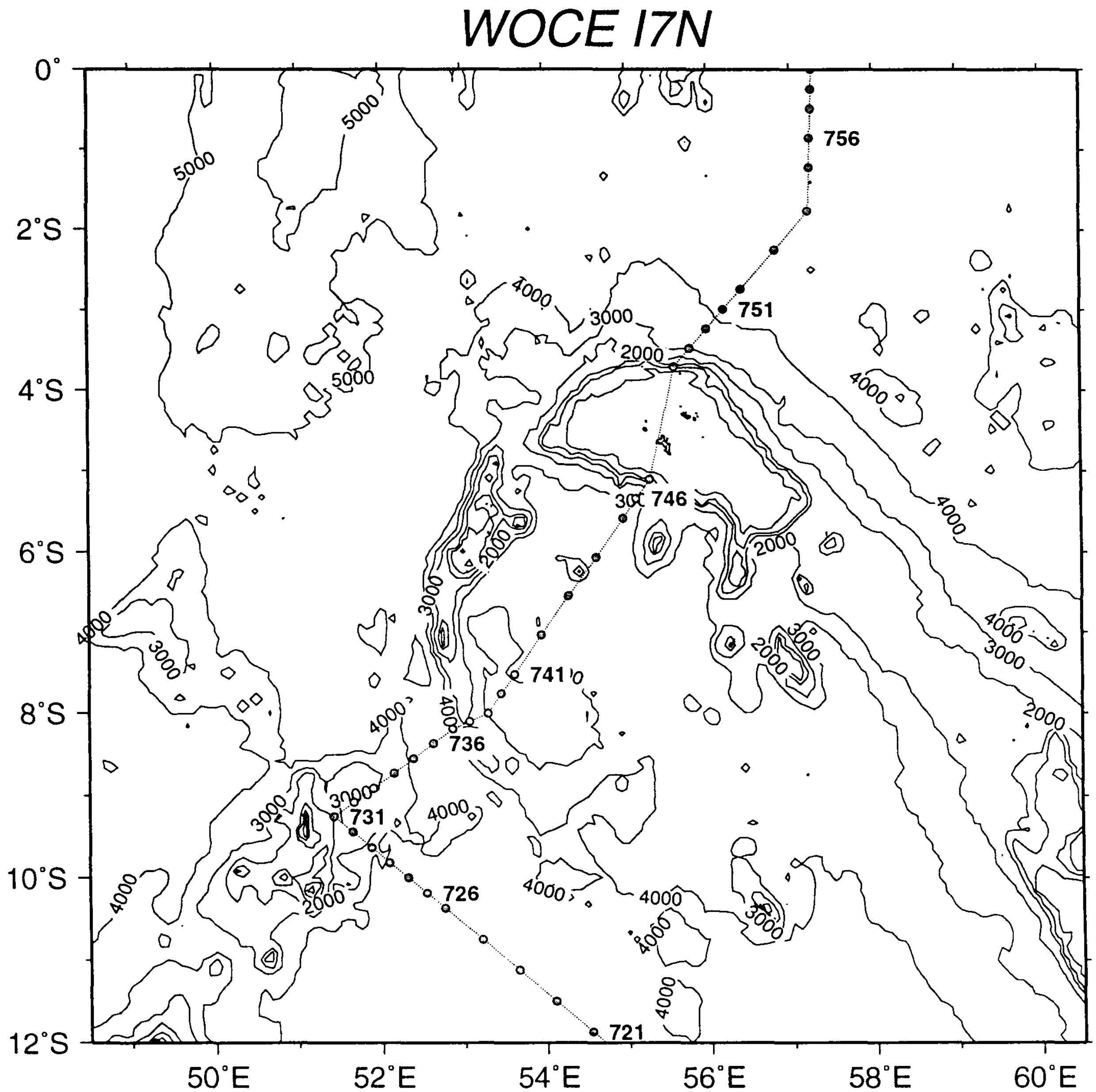

Figure 1.1.0 Sample distribution, stations 709-786 (WOCE I7N)

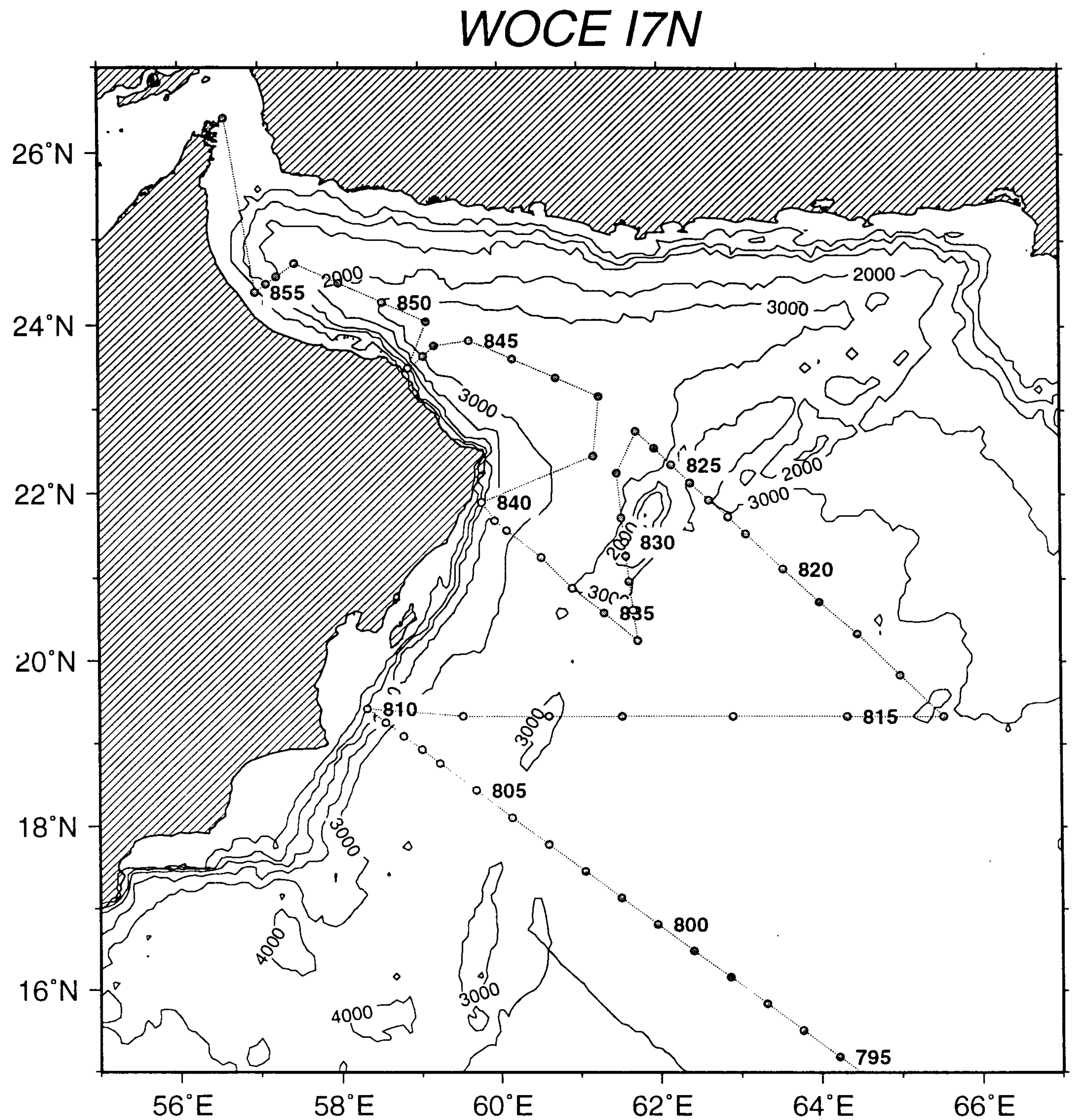

Figure 1.1.1 Sample distribution stations 787-856.

2. Description of Measurement Techniques

2.1. Water Sampling Package

Hydrographic (rosette) casts were performed with a 36-place 10-liter rosette system consisting of a 36-bottle rosette frame (ODF), a 36-place pylon (General Oceanics 1016) and 36 10-liter PVC bottles (ODF). Underwater electronic components consisted of an ODF-modified NBIS Mark III CTD and associated sensors, SeaTech Transmisometer, RDI LADCP, Benthos altimeter and Benthos pinger. The CTD was mounted horizontally along the bottom of the rosette frame, with the transmissometer, a dissolved oxygen and a secondary PRT sensor deployed alongside. The LADCP was vertically-mounted to the frame inside the bottle rings. The Benthos altimeter provided distance-above-bottom in the CTD data stream. The Benthos pinger was monitored during a cast with a precision depth recorder (PDR) in the ship's laboratory. The rosette system was suspended from a three-conductor electromechanical (EM) cable. Power to the CTD and pylon was provided through the cable from the ship. Separate conductors were used for the CTD and pylon signals.

Each rosette cast was performed to within 10 meters of the bottom, unless the bottom returns from both the pinger and altimeter were extremely poor. Bottles on the rosette, each identified with a unique serial number. Usually these numbers corresponded to the pylon tripping sequence 1-36 with the first bottle tripped being bottle serial #1. Bottles serial numbered 1-36 were used on all casts except during stations 719-721 when bottle 37 was used in place of bottle 29. Bottle 29 was reinstalled prior to sta 722. Averages of CTD data corresponding to the time of bottle closure were associated with the bottle data during a cast. Pressure, depth, temperature, salinity and density were immediately available to facilitate examination and quality control of the bottle data as the sampling and laboratory analyses progressed.

The deck watch prepared the rosette approximately 45 minutes prior to a cast. All valves, vents and lanyards were checked for proper orientation. The bottles were cocked and all hardware and connections rechecked. Upon arrival on station, time, position and bottom depth were logged and the deployment begun. The rosette was moved from the starboard hangar into position under a projecting boom using an air-powered cart on tracks. Two stabilizing tag lines were threaded through rings on the frame. CTD sensor covers were removed and the pinger turned-on. Once the CTD acquisition and control system in the ship's laboratory had been initiated by the console operator and the CTD and pylon had passed their diagnostics, the winch operator would raise the package and extend the boom over the side of the ship. The package was then lowered into the water, the tag lines removed and the console operator notified by radio that the rosette was at the surface.

At the end of the cast while the rosette was at the surface two air tuggers spun with tag lines terminating in large snap hooks were manipulated on long poles by the deck watch to snag recovery rods on the rosette frame. The package was then lifted out of the water under tension from the tag lines, the boom retracted, and the rosette lowered onto the cart. Sensor covers were replaced, the pinger turned-off and the cart with the rosette moved into the hangar for sampling. A detailed examination of the bottles and rosette would occur before samples were taken, and any extraordinary situations or circumstances noted on the sample log for the cast.

Rosette maintenance was performed on a regular basis. O-rings were changed as necessary and bottle maintenance performed each day to insure proper closure and sealing. Valves were inspected for leaks and repaired or replaced.

The R/V Knorr portside CTD Markey winch was used on stations 708-856. A new ctd wire was installed on this winch during a port stop in Durban during the previous leg (I5W/I4). New ctd wire was installed on stbd winch at the start of the leg in Port Louis. This wire checked out ok and was available as a backup. The stbd winch was never used on I7N.

2.2. Underwater Electronics Packages

CTD data were collected with a modified NBIS Mark III CTD (ODF CTD #1). This instrument provided pressure, temperature, conductivity and dissolved O2 channels, and additionally measured a second temperature (FSI temperature module) as a calibration check. The pressure sensor is a Paine model 211-35-440-05 strain gage 0-8850 PSI transducer. The primary temperature sensor is a Rosemount model 171BJ. Other data channels included elapsed-time, an altimeter, several power supply voltages and a Transmisometer. The instrument supplied a standard 15-byte NBIS-format data stream at a data rate of 25 fps. Modifications to the instrument included revised pressure and dissolved O2 sensor mountings; ODF-designed sensor interfaces for O2, FSI PRT and the SeaTech Transmisometer; implementation of 8-bit and 16-bit multiplexer channels; an elapsed-time channel; instrument id in the polarity byte and power supply voltages channels.

The CTD pressure sensor mounting had been modified to reduce the dynamic thermal effects on pressure. The sensor was attached to a section of coiled stainless-steel tubing threaded into the end-cap pressure port. The transducer was also insulated. The NBIS temperature compensation circuit on the pressure interface was disabled; all thermal response characteristics were modeled and corrected in software.

The O2 sensor was deployed in a pressure-compensated holder assembly mounted separately on the rosette frame and connected to the CTD by an underwater cable. The O2 sensor interface was designed and built by ODF using an off-the-shelf 12-bit A/D converter. The Transmisometer interface was a similar design.

Although the secondary temperature sensor was located within 1 meter of the CTD conductivity sensor, it was not sufficiently close to calculate coherent salinities. It was used as a secondary temperature calibration reference rather than as a redundant sensor, with the intent of eliminating the use of DSRTs as calibration checks. Due to a previously detected calibration drift in this sensor during the I9 leg, one rack of electronic DSRTs was employed anyway as an additional check.

Standard CTD maintenance procedures included soaking the conductivity and O2 sensors in distilled water between casts to maintain sensor stability, and protecting the CTD from exposure to direct sunlight or wind to maintain an equilibrated internal temperature.

ODF CTD #1 was used throughout the leg with the exception of two casts. The first such cast, was during a test cast designated station 888 cast 88. CTD#1 was replaced with an FSI ICTD for testing purposes only. This happened after station 747 at the same position as station 746. This data was not used or reported for WOCE purposes. The second occasion was on station 841 cast 2, when the MKIII CTD was again replaced with the FSI ICTD. This occurred during the simultaneous casts conducted with the JGOFS rosette on the R/V Thompson. This cast was done to test and check the FSI ICTD and compare the data set with the MKIII. On August 19 the R/V Knorr rendezvoused with the R/V Thompson at WOCE station 841 (JGOFS station 2). The JGOFS and WOCE rosettes were simultaneously deployed for two casts each. CTD#1 was used on cast 1.

The General Oceanics 1016 36-place pylon provided generally reliable operation and positive confirmation of all except 7 bottle trip attempts. The General Oceanics pylon deck unit was not used. Instead, an ODF-built deck unit and external power supply were employed. The pylon emits a confirmation message containing its current notion of bottle trip position, an invaluable aid in sorting out mis-trips.

2.3. Navigation and Bathymetry Data Acquisition

Navigation data was acquired from the ship's Trimbal GPS receiver via RS-232. It was logged automatically at one-minute intervals by one of the Sun Sparcstations. Underway bathymetry was logged manually from the ship's 12 khz Raytheon PDR at five-minute intervals, then merged with the navigation data to provide a time-series of underway position, course, speed and bathymetry data. These data were used for all station positions, PDR depths, and for bathymetry on vertical sections [Cart80].

2.4. CTD Laboratory Calibration Procedures

Pre-cruise pressure and temperature calibrations were performed on CTD #1 at the SIO/ODF Calibration Facility (La Jolla) in December, 1994, immediately prior to WOCE I9N. This was the fifth consecutive Indian Ocean leg for this CTD (ODF CTD #1). CTD#1 is being shipped back to the ODF calibration laboratory for the post-cruise pressure and temperature calibration. These calibration data will be compared with the pre-cruise calibration to determine if any changes occurred. These data will aid in the cruise data post processing stage.

2.5. CTD Shipboard Calibration Procedures

CTD Pressure and Temperature:
ODF used three independent methods to check for temperature or pressure instability during the course of the cruise. First, Primary temperature as checked by comparing it to the secondary PRT sensor. Two different temperature probes were used for the

secondary PRT sensor. The first such sensor (FSI OTM #1322) experienced a drift of -0.008C during I9N, but had stabilized to a constant offset during I8N and I3. This offset was noted to be 0.010C at the beginning of this leg and remained so throughout the leg. The spare sensor (FSI OTM #1321) was installed in place of #1322 at the start of sta 722. This OTM indicated 0.000C offset while it was used and working p_operly, however, this OTM would intermittently cut in and out. OTM #1322 was reinstalled at the start of sta 788. FSI OTM #1322 was used on stations 708-721, 788-856. FSI OTM #1321 was used on stations 722-787. The data from both secondary probes indicated that no temperature shift occurred in the primary temperature channel. Pressure was checked during a port stop at the beginning of the previous I4/I5W leg. A Paroscientific Digi-Quartz secondary pressure reference was used as a pressure calibration transfer standard. No shifts in the CTD pressure calibration were indicated.

Second, an additional check on temperature and pressure was made by using DSRT's. One rack of digital SIS DSRT's was used on selected stations. Each rack contained two thermometers and one pressure meter. These measurements indicated no shifts in CTD temperature or pressure calibrations.

Third, pressure and temperature shifts during a cruise can be detected based on the conductivity calibration. These conductivity checks indicated there were no significant shifts in the CTD pressure or temperature during this leg.

While in the Gulf of Oman, sea surface temperatures sometimes exceeded 30 Deg C. On several stations the sea surface temperature exceeded the upper limit of the primary temperature on CTD #1. This limit was 31.255 Deg C. The secondary sensor remained in range. The temperature from the secondary sensor was used for bottle data calculations. The station numbers that were affected by high sea surface temperatures were 845 and 852-856.

Conductivity:
The CTD rosette trip pressure and temperature were used with the bottle salinity to calculate a bottle conductivity. Differences between the bottle and CTD conductivities were then used to derive a conductivity correction as a linear function of conductivity. Bottle salinity analysis is discussed in section 2.10.

CTD Dissolved Oxygen:
A new CTD O2 sensor (#5-01-10) was installed before the leg began and was used throughout the leg. There are a number of problems with the response characteristics of the Sensormedics O2 sensor used in the NBIS Mark III CTD, the major ones being a secondary thermal response and a sensitivity to profiling velocity. Because of these problems, CTD rosette trip data are indirectly calibrated to O2 check samples. Down-cast CTD O2 data are derived by matching the up-cast rosette trips along isopycnal surfaces. The differences between CTD O2 modeled from these derived values and check samples are then minimized using a non-linear least-squares fitting procedure. The general form of the ODF O2 conversion equation follows Brown and Morrison [Brow 78] and Millard [Mill 82], [Owen 85]. Oxygen sample analysis is discussed in section 2.11.

2.6. CTD Data Acquisition, Processing and Control System

The CTD data acquisition, processing and control system consisted of Sun SPARCstation LX computer workstation, ODF-built CTD and pylon deck units, CTD and pylon power supplies and a VCR recorder for real-time analog backup recording of the sea cable signal. The Sun system consisted of a color display with track-ball and keyboard (the CTD console), 18 RS-232 ports, 2.5 GB disk and 8-mm cartridge tape. Two other Sun LX systems were networked to the data acquisition system, as well as to the rest of the networked computers aboard the Knorr. These systems were available for real-time CTD data display as well as providing hydrographic data management and backup. Two HP 1200C color ink jet printers provided hardcopy from any of the workstations.

The CTD FSK signal was demodulated and converted to a 9600 baud RS-232C binary data stream by the CTD deck unit. This data stream was fed to the Sun SPARCstation. The pylon deck unit was also connected to the Sun through a bi-directional 300 baud serial line, allowing rosette trips to be initiated and confirmed through the data acquisition software. A bitmapped color display provided interactive graphical display and control of the CTD rosette sampling system, including real-time raw and processed data displays, navigation, winch and rosette trip displays.

The CTD data acquisition, processing and control system was prepared by the console watch a few minutes before a deployment. A console operations log was maintained for each deployment, containing a record of every attempt to trip a bottle as well as any pertinent comments. Most CTD console control functions, including starting the data acquisition, were performed by pointing and clicking a trackball cursor on the display at pictures representing functions to perform. The system would then present the operator with a short dialog prompting with automatically-generated choices that could either be accepted as default or overridden. The operator was instructed to turn on the CTD and pylon power supplies, then to examine a real-time CTD data display on the screen for stable voltages from the underwater unit. Once this was accomplished, the data acquisition and processing was begun and a time and position automatically associated with the beginning of the cast. A backup analog recording of the CTD signal was made on a VCR tape, which was started at the same time as the acquisition. A rosette trip display and pylon control window then popped up, giving visual confirmation that the pylon was initializing properly. Various plots and displays were initiated. When all was ready, the console operator informed the deck watch by radio.

Once the deck watch had deployed the rosette, the deck watch leader provided the winch operator with a target depth (wire-out) and lowering rate (normally 60 meters/minute for this package). The package would then begin its descent.

The console operator would examine the processed CTD data during descent via interactive plot windows on the display, which could also be initiated from other workstations on the network. Additionally, the operator would decide where to trip bottles on the up-cast, noting this on the console log.

The rosette distance above bottom (DAB) was monitored on the PDR by the deck watch leader. The rosette mounted pinger would transmit a ping that would be displayed on the ship's PDR system that indicated the rosette DAB. At approximately 100 meters above the bottom the altimeter would normally begin signaling a bottom return on the console. The winch displays and altimeter readout allowed the deck watch leader to refine the target depth relayed to the winch operator and safely approach to within 10 meters of the bottom.

Bottles would be tripped by pointing the console trackball cursor at a graphic firing control and clicking a button. The data acquisition system would respond with the CTD rosette trip data and a pylon confirmation message in a window. All tripping attempts were noted on the console log. The console operator would then direct the winch operator to the next bottle stop. The console operator was also responsible for generating the sample log for the cast.

After the last bottle was tripped, the console operator would inform the deck watch that it was ok to bring the rosette on deck. Once on deck, the console operator would terminate the data acquisition and turn off the CTD, pylon and VCR recording. The VCR tape was filed. Frequently the console operator would also bring the sample log to the rosette room and serve as the sample cop.

2.7. CTD Data Processing

ODF CTD processing software consists of some 35-odd programs running under the Unix operating system. The initial CTD processing program (ctdba) is used either in real-time or with existing raw data sets to:

- Convert raw CTD scans into scaled engineering units, and assign the data to logical channels.
- Filter specific channels according to specified filtering criteria.
- Apply sensor or instrument-specific response-correction models.
- Provide periodic averages of the channels corresponding to the output time-series interval.
- Store the output time-series in a CTD-independent format.

Once the CTD data are reduced to a standard-format time-series, they can be manipulated in a number of various ways. Channels can be additionally filtered. A time-series can be transformed into a pressure-series, or a longer interval time-series. Calibration corrections to the series are maintained in separate files and are applied whenever the data are accessed.

ODF data acquisition software acquired and processed the CTD data in real-time, providing calibrated, processed data for interactive plotting and reporting during a cast. The 25 hz data from the CTD were filtered, response-corrected and averaged to a 2 hz time-series. Sensor correction and calibration models were applied to pressure, temperature, conductivity and O2. Rosette trip data were extracted from this time-series in response to trip initiation and confirmation signals. The calibrated 2 hz time-series data were stored on disk (as was the 25 hz raw data) and were available in real-time for reporting and graphical display. At the end of the cast, various consistency and calibration checks were performed, and a 2.0 db pressure-series of the down-cast was generated and subsequently used for reports and plots.

CTD plots generated automatically at the completion of deployment were checked daily for potential problems. The two PRT temperature sensors were inter-calibrated and checked for sensor drift. The CTD conductivity sensor was monitored by comparing CTD values to check-sample conductivities and by deep TS comparisons with adjacent stations. The CTD dissolved O2 sensor was calibrated to check-sample data.

As noted earlier in this report, the seawater temperatures in the Gulf of Oman exceeded the capacity of the primary CTD temperature sensor on stations 845 and 852-856. Only the up-cast data were affected on station 845, so the down-cast data are complete. The other 5 casts were affected on both down- and up-casts. The off-scale data on these casts were eliminated by starting the CTD pressure-series from the pressure of the first on-scale temperature.

An attempt was made to re-average the off-scale casts using the secondary temperature sensor (PRT2 - an FSI sensor with a greater range), which was located about 3-4 inches away from the primary sensor. The data were noisy because PRT2 and the conductivity sensor were not measuring the same water at the same time, so they did not correlate well enough to generate acceptable salinity data. The PRT1 temperature data were reported with the final data. The PRT2-averaged data were used for generating temperatures to report with bottle data; the average PRT1-PRT2 difference at surface trips was .005 degrees C for the on-scale casts from stations 846 through 851. Except for station 845, differences between CTD and bottle salinities using the PRT2 temperatures were similar to the differences using on-scale PRT1 on nearby casts.

A few casts exhibited conductivity offsets due to biological or particulate artifacts. The conductivity sensor was soaked in RBS solution prior to station 801 to eliminate suspected organic growth on the sensor, evidenced by a continuing small drift in the data. The slope and offset corrections to conductivity shifted at this cast because of the cleaning. The deep drift was no more than .005 psu in salinity within each group, before and after the cleaning, and were more stable after cleaning the sensor. Two upcasts (stas 839 and 843) were used for pressure-series data instead of down-casts because of extended sections of biological contamination in the middle of the down-casts that washed off before the up-casts.

2.8. Bottle Sampling

At the end of each rosette deployment water samples were drawn from the bottles in the following order:

- CFCs
- Helium-3
- Oxygen
- Total CO2
- Alkalinity
- AMS 14C
- Tritium
- Nutrients
- Salinity
- Barium

Note that some properties were subsampled by cast or by station, so the actual sequence of samples drawn was modified accordingly.

The correspondence between individual sample containers and the rosette bottle from which the sample was drawn was recorded on the sample log for the cast. This log also included any comments or anomalous conditions noted about the rosette and bottles. One member of the sampling team was designated the sample cop, whose sole responsibility was to maintain this log and insure that sampling progressed in proper drawing order.Normal sampling practice included opening the drain valve before opening the air vent on the bottle, indicating an air leak if water escaped. This observation together with other diagnostic comments (e.g., "lanyard caught in lid", "valve left open") that might later prove useful in determining sample integrity were routinely noted on the sample log.

Drawing oxygen samples also involved taking the sample draw temperature from the bottle. The temperature was noted on the sample log and was sometimes useful in determining leaking or mis-tripped bottles.

Once individual samples had been drawn and properly prepared, they were distributed to their laboratory for analysis. Oxygen, nutrients and salinity analyses were performed on computer-assisted (PC) analytical equipment networked to Sun SPARCStations for centralized data analysis. The analyst for a specific property was responsible for insuring that their results updated the cruise database.

2.9. Bottle Data Processing

The first stage of bottle data processing consisted of validating individual samples, and checking the sample log (the sample inventory) for consistency. At this stage, bottle tripping problems were usually resolved, sometimes resulting in changes to the pressure, temperature and other CTD properties associated with the bottle. Note that the rosette bottle number was the primary identification for all samples taken from the bottle, as well as for the CTD data associated with the bottle. All CTD trips were retained whether confirmed or not so that they can be available to assist in resolving bottle tripping problems.

Diagnostic comments from the sample log were then translated into preliminary WOCE quality codes, together with appropriate comments. Each code indicating a potential problem would be investigated.

The second stage of processing would begin once all the samples for a cast had been accounted for. All samples for bottles suspected of leaking were checked to see if the property was consistent with the profile for the cast, with adjacent stations and where applicable, with the CTD data. All comments from the analysts were examined and turned into appropriate water sample codes. Oxygen flask numbers were verified, as each flask is individually calibrated and significantly affects the calculated O2 concentration.

The third stage of processing would continue until the data set is considered "final". Various property-property plots and vertical sections were examined for both consistency within a cast and consistency with adjacent stations. In conjunction with this process the analysts would review (and sometimes revise) their data as additional calibration or diagnostic results became available. Assignment of a WHP water sample code to an anomalous sample value was typically achieved through consultation with one of the chief scientists.

WHP water bottle quality flags were assigned with the following additional interpretations:

3 An air leak large enough to produce an observable effect on a sample is identified by a code of 3 on the bottle and a code of 4 on the oxygen. (Small air leaks may have no observable effect, or may only affect gas samples.)

4 Bottles tripped at other than the intended depth were assigned a code of 4. There may be no problems with the associated water sample data.

WHP water sample quality flags were assigned using the following criteria:

1 The sample for this measurement was drawn from a bottle, but the results of the analysis were not (yet) received.

2 Acceptable measurement.

3 Questionable measurement. The data did not fit the station profile or adjacent station comparisons (or possibly CTD data comparisons). No notes from the analyst indicated a problem. The data could be correct, but are open to interpretation.

4 Bad measurement. Does not fit the station profile, adjacent stations or CTD data. There were analytical notes indicating a problem, but data values were reported. Sampling and analytical errors were also coded as 4.

5 Not reported. There should always be a reason associated with a code of 5, usually that the sample was lost, contaminated or rendered unusable.

9 The sample for this measurement was not drawn.

WHP water sample quality flags were assigned to the CTDSAL (CTD salinity) parameter as follows:

2 Acceptable measurement.

3 Questionable measurement. The data did not fit the bottle data, or there was a CTD conductivity calibration shift during the cast.

4 Bad measurement. The CTD data were determined to be unusable for calculating a salinity.

8 The CTD salinity was derived from the CTD down cast, matched on an isopycnal surface.

WHP water sample quality flags were assigned to the CTDOXY (CTD oxygen) parameter as follows:

2 Acceptable measurement.

4 Bad measurement. The CTD data were determined to be unusable for calculating a dissolve oxygen concentration.

5 Not reported. The CTD data could not be reported.

9 Not sampled. No operational dissolved oxygen sensor was present on this cast.

Note that all CTDOXY values were derived from the down cast data, matched to the upcast along isopycnal surfaces.

Table 2.9.0: Shows the number of samples drawn and the number of times each WHP sample quality flag was assigned for each basic hydrographic property:

Table 2.9.0 Frequency of WHP quality flag assignments.

Stations 708-856

	Reported Levels	Bottle Codes 2	3	4	9	Water Sample Codes 1	2	3	4	5	9
	5117	5099	8	6	4						2
Salinity	5107					05041		52	13	1	10
Oxygen	5107					05092		6	8	1	10
Silicate	5108					05102		2	4	0	9
Nitrate	5108					05101		1	6	0	9
Nitrite	5108					05101		1	6	0	9
Phosphate	5108					05097		5	6	0	9

2.10. Salinity Analysis

Salinity samples were drawn into 200 ml Kimax high alumina borosilicate bottles after 3 rinses, and were sealed with custom-made plastic insert thimbles and Nalgene screw caps. This assembly provides very low container dissolution and sample evaporation. As loose inserts were found, they were replaced to ensure a continued airtight seal. Salinity was determined after a box of samples had equilibrated to laboratory temperature, usually within 8-12 hours of collection. The draw time and equilibration time, as well as per-sample analysis time and temperature were logged.

Two Guildline Autosal Model 8400A salinometers (55-654 and 57-396) located in a temperature-controlled laboratory were used to measure salinities. The salinometers were modified by ODF and contained interfaces for computer-aided measurement. A computer (PC) prompted the analyst for control functions (changing sample, flushing) while it made continuous measurements and logged results. The salinometer cell was flushed until successive readings met software criteria for consistency, then two successive measurements were made and averaged for a final result.

The salinometer was standardized for each cast with IAPSO Standard Seawater (SSW) Batch P-126, using at least one fresh vial per cast. The estimated accuracy of bottle salinities run at sea is usually better than 0.002 PSU relative to the particular Standard Seawater batch used. PSS-78 salinity [UNES81] was then calculated for each sample from the measured conductivity ratios, and the results merged with the cruise database.

Lab temperature in lower lab (Autosal location) was very stable and consistent. It rarely varied from 19-21 degrees C. As a result both autosals were setup on 21 deg bath temp. #57-396 had a slightly higher noise level than #55-654 so it was only used when #55-654 required maintenance. #55-654 required a cell cleaning after station 760. It was reinstated at sta 775. Triplicate samples were drawn on sta 775, one box each was ran on each machine, one box was ran two weeks later on #57-396 as a test. Autosal #55-654 was used on stations 708-760, 775-856. Autosal #57-396 was used on stations 761-7752.11. Oxygen Analysis

Samples were collected for dissolved oxygen analyses soon after the rosette sampler was brought on board and after CFC and helium were drawn. Nominal 125 ml volume-calibrated iodine flasks were rinsed twice with minimal agitation, then filled via a drawing tube, and allowed to overflow for at least 3 flask volumes. The sample temperature was measured with a small platinum resistance thermometer embedded in the drawing tube. Draw temperatures were very useful in detecting possible bad trips even as samples were being drawn. Reagents were added to fix the oxygen before stoppering. The flasks were shaken twice; immediately after drawing, and then again after 20 minutes, to assure thorough dispersion of the MnO(OH)2 precipitate. The samples were analyzed within 30 minutes to 5 hours of collection.

Dissolved oxygen analyses were performed with an SIO-designed automated oxygen titrator using photometric end-point detection based on the absorption of 365 nm wavelength ultra-violet light. Thiosulfate was dispensed by a Dosimat 665 buret driver fitted with a 1.0 ml buret. ODF uses a whole-bottle modified-Winkler titration following the technique of Carpenter [Carp 65] with modifications by Culberson et. al [Culb 91], but with higher concentrations of potassium iodate standard (approximately 0.012N) and thiosulfate solution (50 gm/l). Standard solutions prepared from preweighed potassium iodate crystals were run at the beginning of each 12 hour watch, which typically included from 1 to 3 stations. Standards were made up every 4-5 days and compared to assure that the results were reproducible, and to preclude the possibility of a weighing error. Reagent/distilled water blanks were determined to account for oxidizing or reducing materials in the reagents. Carbon Disulfide was added to the thiosulfate as a preservative. The auto-titrator generally performed very well.

The samples were titrated and the data logged by the PC control software. The data were then used to update the cruise database on the Sun SPARCstations.

Blanks, and thiosulfate normalities corrected to 20C, calculated from each standardization, were plotted versus time, and were reviewed for possible problems. New thiosulfate normalities were recalculated after the blanks had been smoothed. These normalities were then smoothed, and the oxygen data was recalculated.

Oxygens were converted from milliliters per liter to micro-moles per kilogram using the in-situ temperature. Ideally, for whole-bottle titrations, the conversion temperature should be the temperature of the water issuing from the bottle spigot. The sample temperatures were measured at the time the samples were drawn from the bottle, but were not used in the conversion from milliliters per liter to micro-moles per kilogram because the software was not available.

Aberrant drawing temperatures provided an additional flag indicating that a bottle may not have tripped properly. Measured sample temperatures from mid-deep water samples were about 4-7C warmer than in-situ temperature. Had the conversion with the measured sample temperature been made, converted oxygen values, would be about 0.08% higher for a 6C warming (or about 0.2M/Kg for a 250M/Kg sample).
Oxygen flasks were calibrated gravimetrically with degassed deionized water (DIW) to

determine flask volumes at ODF's chemistry laboratory. This is done once before using flasks for the first time and periodically thereafter when a suspect bottle volume is detected. All volumetric glassware used in preparing standards is calibrated as well as the 10 ml Dosimat buret used to dispense standard Iodate solution.Iodate standards are pre-weighed in ODF's chemistry laboratory to a nominal weight of 0.44xx grams and exact normality calculated at sea. An experimental comparison with 0.0100N CSK Standard Solution Potassium Iodate (Sagami Chemical Research Center) showed good agreement (a difference of <0.1%). Potassium Iodate (KIO3) is obtained from Johnson Matthey Chemical Co. and is reported by the suppliers to be 99.4% pure. All other reagents are "reagent grade" and are tested for levels of oxidizing and reducing impurities prior to use.

No major problems were encountered with the analyses. The temperature stability of the laboratory used for the analyses was poor, varying from 22 to 28C over short time scales. Portable fans were used to assist in maintaining some temperature stability. The oxygen data were used to calibrate the CTD dissolved O2 sensor.

2.12. Nutrient Analysis

Nutrient samples were drawn into 45 ml high density polypropylene, narrow mouth, screw-capped centrifuge tubes which were rinsed three times before filling. Standardizations were performed at the beginning and end of each group of analyses (one cast, usually 36 samples) with a set of an intermediate concentration standard prepared for each run from secondary standards. These secondary standards were in turn prepared aboard ship by dilution from dry, pre-weighed primary standards. Sets of 6-7 different concentrations of shipboard standards were analyzed periodically to determine the deviation from linearity as a function of concentration for each nutrient.

Nutrient analyses (phosphate, silicate, nitrate and nitrite) were performed on an ODF-modified 4 channel Technicon Auto-Analyzer II, generally within one hour of the cast. Occasionally some samples were refrigerated at 2 to 6C for a maximum of 4 hours. The methods used are described by Gordon et al. [Atla71], [Hage72], [Gord92]. The colorimeter output from each of the four channels were digitized and logged automatically by computer (PC), then split into absorbence peaks. All the runs were manually verified.

Silicate is analyzed using the technique of Armstrong et al. [Arms67]. Ammonium molybdate is added to a seawater sample to produce silicomolybdic acid which is then reduced to silicomolybdous acid (a blue compound) following the addition of stannous chloride. Tartaric acid is also added to impede PO4 contamination. The sample is passed through a 15 mm flowcell and the absorbence measured at 820nm. ODF's methodology is known to be non-linear at high silicate concentrations (120 M); a correction for this non-linearity is applied in ODF's software.

Modifications of the Armstrong et al. [Arms67] techniques for nitrate and nitrite analysis are also used. The seawater sample for nitrate analysis is passed through a cadmium column where the nitrate is reduced to nitrite. Sulfanilamide is introduced, reacting with the nitrite, then N-(1-naphthyl)ethylenediamine dihydrochloride which couples to form a red azo dye. The reaction product is then passed through a 15 mm flowcell and the absorbence measured at 540 nm. The same technique is employed for nitrite analysis, except the cadmium column is not present, and a 50 mm flow-cell is used.

Phosphate is analyzed using a modification of the Bernhardt and Wilhelms [Bern67] technique. Ammonium molybdate is added to the sample to produce phosphomolybdic acid, then reduced to phosphomolybdous acid (a blue compound) following the addition of dihydrazine sulfate. The reaction product is heated to 55C to enhance color development, then passed through a 50 mm flowcell and the absorbence measured at 820 nm.

Nutrients, reported in micromoles per kilogram, were converted from micromoles per liter by dividing by sample density calculated at zero pressure, in-situ salinity, and an assumed laboratory temperature of 25C.

Na2SiF6, the silicate primary standard, is obtained from Fluka Chemical Company and Fischer Scientific and is reported by the suppliers to be 98% pure. Primary standards for nitrate (KNO3), nitrite (NaNO2), and phosphate (KH2PO4) are obtained from Johnson Matthey Chemical Co. and the supplier reports purities of 99.999%, 97%, and 99.999%, respectively.

No major problems were encountered with the measurements. The pump tubing was changed three times, and deep seawater was run as a substandard. The temperature stability of the laboratory used for the analyses was poor, varying from 22 to 28C over short time scales. Portable fans were used to assist in maintaining some temperature stability.

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