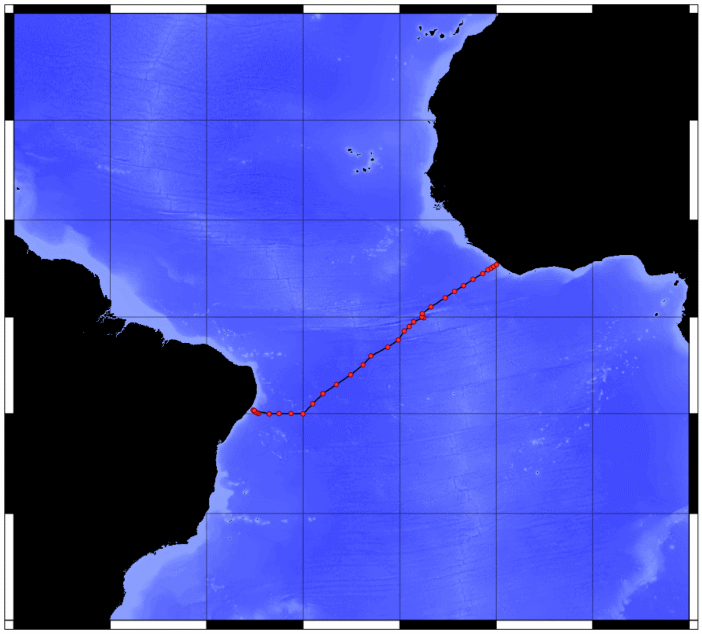
CRUISE REPORT: SAVE1

(Updated APR 2011)



HIGHLIGHTS

Cruise Summary Information

WOCE Section Designation	**SAVE1**
Expedition designation (ExpoCodes)	**316N19871123**
Chief Scientists	**Taro Takahashi/LDEO** **Peter B. Rhines/UW**
Dates	1987 NOV 23 - 1987 DEC 13
Ship	*R/V Knorr*
Ports of call	Recife, Brazil to Abidjan, Ivory Coast
Geographic Boundaries	5° 28.5' N 35° 11' W 9° 58' W 10° 0.3' S
Stations	34
Floats and drifters deployed	0
Moorings deployed or recovered	0

Chief Scientist's Contact Information

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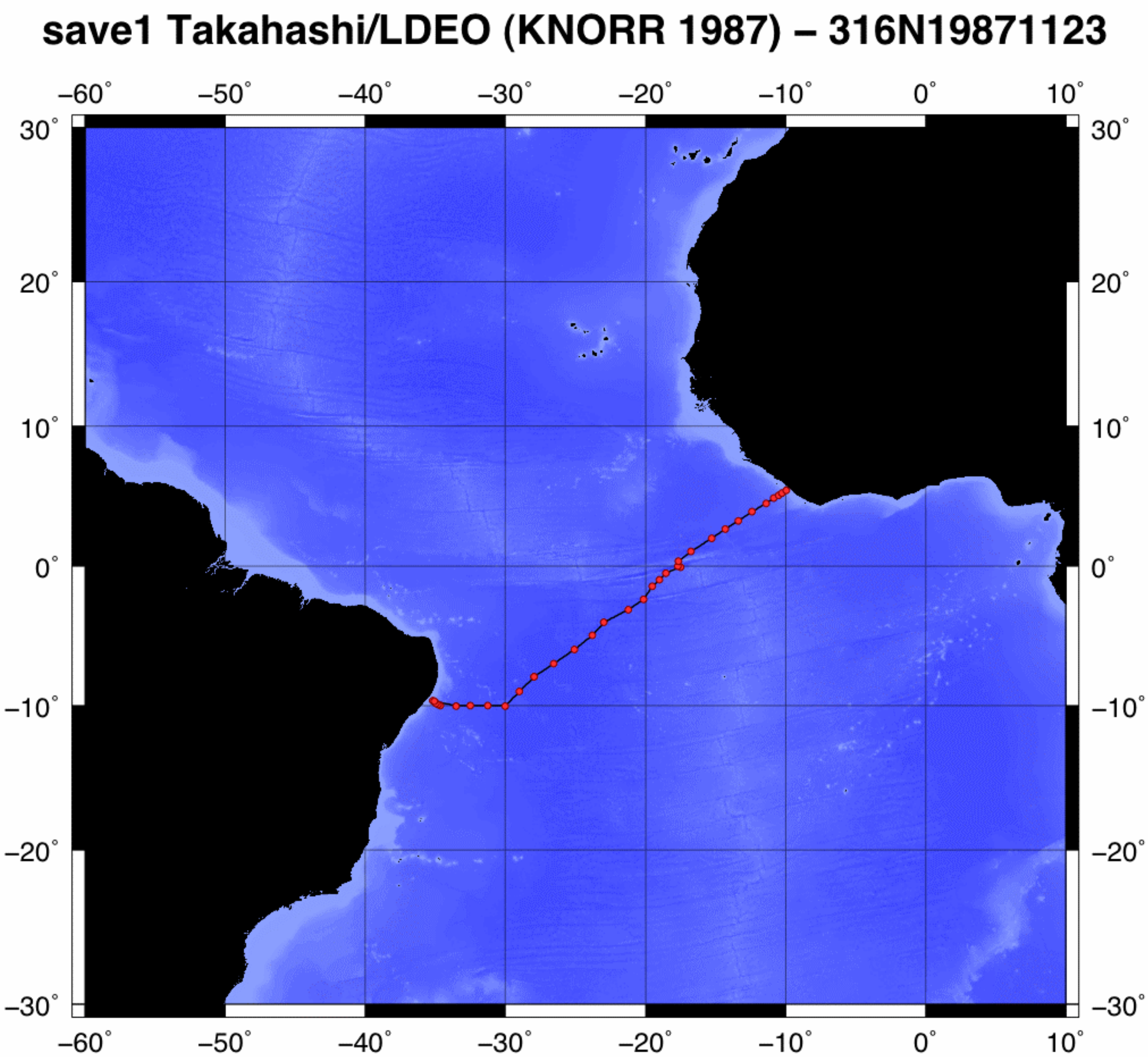
LINKS TO SELECT TOPICS

Shaded sections are not relevant to this cruise or were not available when this report was compiled

Cruise Summary Information	**Hydrographic Measurements**
Description of Scientific Program	**CTD Data:**
Geographic Boundaries	Acquisition
Cruise Track (Figure): PI CCHDO	Processing
Description of Stations	Calibration
Description of Parameters Sampled	Temperature Pressure
Bottle Depth Distributions (Figure)	Salinities Oxygens
Floats and Drifters Deployed	**Bottle Data**
Moorings Deployed or Recovered	Salinity
	Oxygen
Principal Investigators	Nutrients
Cruise Participants	Carbon System Parameters
	CFCs
Problems and Goals Not Achieved	Helium / Tritium
Other Incidents of Note	Radiocarbon
Underway Data Information	**References**
Navigation Bathymetry	
Acoustic Doppler Current Profiler (ADCP)	
Thermosalinograph	
XBT and/or XCTD	
Meteorological Observations	**Acknowledgments**
Atmospheric Chemistry Data	
Data Processing Notes	


save1 Takahashi/LDEO (KNORR 1987) – 316N19871123
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South Atlantic Ventilation Experiment (SAVE) Leg 1

Shipboard Chemical and Physical Data Report

PRELIMINARY

23 November - 13 December 1987

R/V *Knorr*

Data Report Prepared by:

Oceanographic Data Facility
Scripps Institution of Oceanography
University of California, San Diego

April 1988

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ODF Publication No. 224

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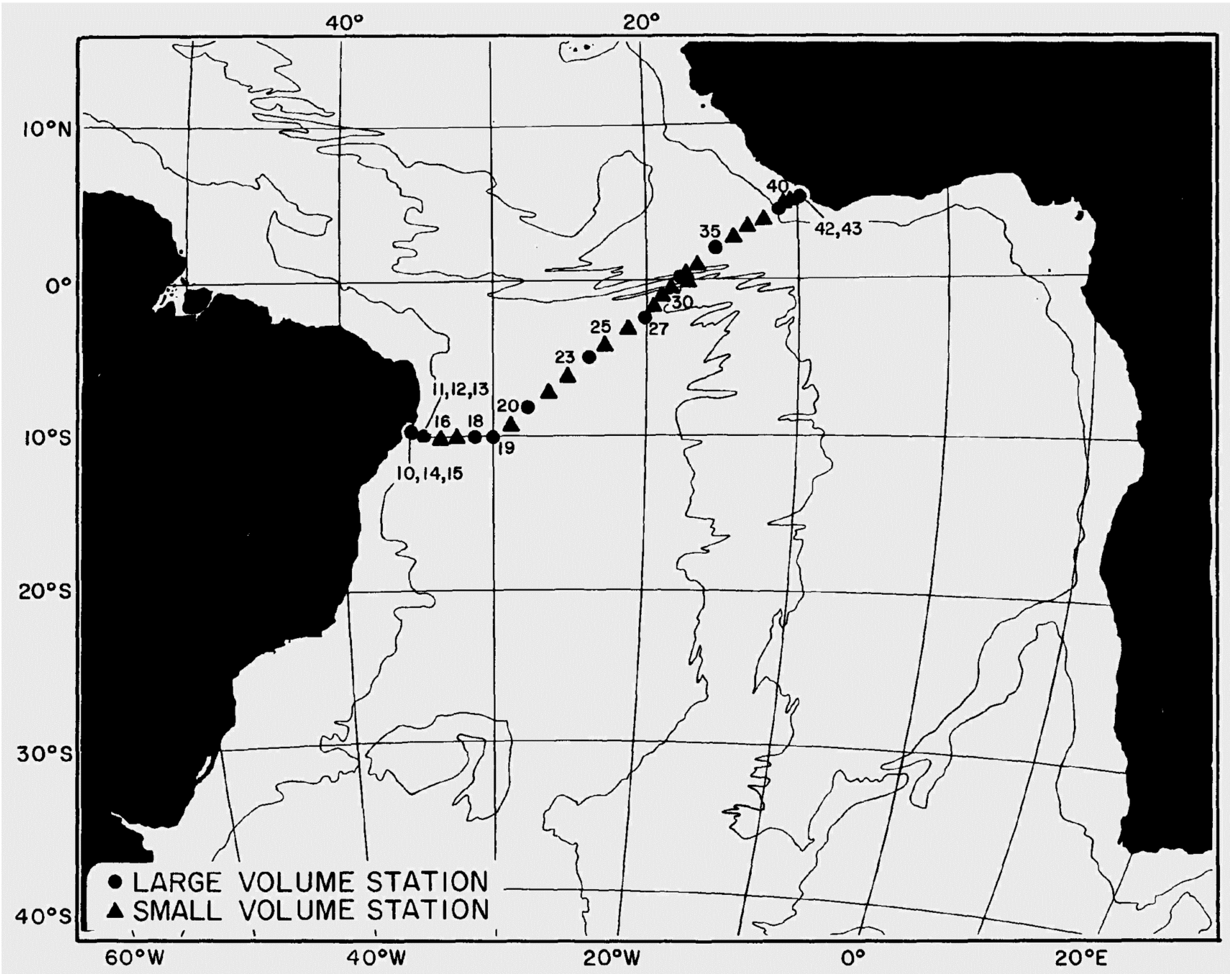

INTRODUCTION

The major objective of the South Atlantic Ventilation Experiment (SAVE) program is to investigate the rates of ocean circulation, mixing, ventilation, inter–ocean exchange and carbon–oxygen–nutrient cycling on an ocean–basin scale in the South Atlantic Ocean. Standard hydrographic measurements (temperature, salinity and the concentrations of dissolved oxygen and nutrient salts) as well as the observations on the distribution of transient and radioactive tracers and CO_2 are made in order to provide strong constraints on time–averaged rates of circulation and mixing and to reveal transport pathways between the air/sea interface and the abyssal ocean.

Leg I of the SAVE program combines some features of a zonal section, such as western and eastern boundary currents, mid-ocean gyres and deep water regimes, with other features of meridional sections, in particular the equatorial crossing. It was ideally suited to look at the legendary bifurcation of water masses that are crossing the equator. Recent dynamical theories have given strength to the idea that water masses driven from high northern latitudes should arrive along a "Kelvin–wave" pathway at the equator, and then split with some fluid passing eastward along the equator and the rest continuing down the western boundary. The data obtained during this and other legs of SAVE and the prior Oceanus 133 sections should yield an increasingly sharper picture of the Brazil Basin water masses. This should tell us whether classical circulation models do or do not account for the interior circulation and tracer balance and the nature of the western boundary currents. This report summarizes shipboard observations and operations made during Leg 1 of the SAVE Program.

OVERVIEW OF THE EXPEDITION

The R/V *Knorr* departed at 11:30, November, 23, 1987, from Recife, Brazil, for Leg 1 of the SAVE program, and arrived Abidjan, Ivory Coast, at noon, December 13, 1987, During the 21–day leg, the following number of measurements were made aboard the ship:

Salinity	1,402
Oxygen dissolved in seawater	1,174
Nutrient salts dissolved in sea water	1,148 for each of nitrate, phosphate and silicate.
Freons dissolved in seawater	723 for each of Freon–11 and –12.
Total CO_2 dissolved in seawater	743
pCO_2 in seawater	640

The following number of samples were collected and processed aboard the ship for the shore–based measurements;

Helium–3 in seawater	360
Tritium in seawater	360
Radium–228 in seawater	155
Carbon–14 in seawater	121
Krypton–85 in seawater	39
Argon–39 in seawater	1

In addition, the atmospheric CO_2 concentration, partial pressures of CO_2, CH_4 and N_2O in surface water and in air were measured continuously throughout the expedition. A set of underway samples, which include an XBT cast and a sample each for the determination of dissolved oxygen, nutrient salts and CO_2 concentrations and CO_2 partial pressure in seawater, was collected twice between two regular stations.

The expedition was generally successful. The 36–bottle Rosette sampler and CTD functioned flawlessly throughout the expedition. However, it was marred by the loss of nine 270–liter Gerard samplers due to a failure of trawl cable at Station 32 located in the Romanche Fracture Zone at the equator and 17 degrees 43 minutes West. The cable failed during the winding–up operation of a Deep Gerard Cast at a point of about 600 meters below the sea surface with a total length of about 5800 meters of cable out. Since the sea was calm during the entire station operation, the cable was not subjected to unusual stress before and at the time of failure. Furthermore, the cable had been used for sampling at depths exceeding 5800 meters at previous stations. Therefore, the break was tentatively judged as a result of metal fatigue after a long use since it was first installed in 1980 or thereabout. Since the Gerard samplers and failed cable fell onto a 6000 meter deep narrow valley floor of the Romanche Fracture Zone, and since the designated tensile strength of the new cable was found to be marginal to lift the weight of the lost cast (5800 meters of cable plus nine Gerard samplers), a recovery operation was not attempted.

A new 9000–meter trawl cable, which had been stored in the ships hold, was put on the winch immediately after the unfortunate cast, so that large–volume sampling operations can be continued using the remaining two Gerard samplers aboard. At the large–volume stations after Station 32, three casts of two Gerard samplers were deployed to collect subsurface samples down to about 1000 meters and a pump to collect surface water samples. Because of the shortage of station time, no large volume sample was obtained below 1000 meters in the Eastern Basin of the South Atlantic during Leg 1.

COMMENTS ON THE SHIPBOARD WATER SAMPLING PROCEDURES

During Leg 1, water samples were drawn from each 10–liter Niskin sampler by 5 to 6 analysts and technicians each assigned to specific properties in the following sequence; Freons, helium–3, oxygen, total CO_2, pCO_2, tritium, nutrients and salinity. During the first half dozen stations, sampling operation of a 36–bottle Rosette took as much as two and a half to three hours due to varied sampling requirements. At Station 16, the sixth but the first daytime station after leaving Recife, an awning was erected over the staging area in order to protect the Rosette and water samples from rapid warming due to the blazing equatorial sun shine. Even under this protection, deep water samples, for example, warmed up by 13°C to about 17°C by the time when the water samples were drawn for chemical analyses of dissolved gases. It was feared that the gas concentration in the water in a Niskin bottle might have been altered by gas exchanges with the air introduced into the head space, and that the sample alteration might also have been exacerbated by increasing water temperature. Therefore, a number of time–series sampling experiments was conducted in order to assess the extent of sample alterations.

Figure 1 shows the results of a time variation of oxygen concentration in the water samples drawn from a low–oxygen water collected at about 300 meters deep by a single 10–liter Niskin bottle wire cast. The wire cast was selected so that the contact time of the sample water with warm near surface waters (up to 30°C) can be minimized. The head space, water temperature and the oxygen concentration in the drawn water samples are plotted as a function of time in Figure 1. At the time of the first draw of water sample for oxygen analysis, the water warmed up only by about 0.5°C from 11.97°C to 12.5°C. It is seen in Figure I that the oxygen concentration increased by about 0.04 mL/L for the first 6 minutes, steadied (or decreased somewhat) at this level for the following 14 minutes, and then increased rapidly for the remaining duration of the experiment. All the oxygen measurements were made by the Winkler titration method immediately after the samples were collected. The observed initial increase appears to be real in view of the precision of ± 0.01 mL/L or better estimated on the basis of the multiplicate determinations made during the expedition. Possible causes for the changes observed during the first 10 minutes will be discussed below. Two extreme cases may be considered. First, if the water in the Niskin sampler is not mixed vertically, the effect of sample alteration should be confined to the upper portion, and hence the water samples drawn from a spigot located near the bottom of the bottle should not show any change in the oxygen concentration until more than a half of the water was drained. Secondly, if the water in the sampler was mixed homogeneously as it was drained and at the same time took up oxygen from the air introduced into the head space, the oxygen concentrations in the water samples should increase with time as shown by the solid curves in the right-hand panel of Figure 1. Three model curves represent the cases for the assumed air–water gas transfer velocity values of 0.01, 0.02 and 0.04 cm/mm respectively. The data appear to be broadly consistent with the middle curve, although they tend to be higher during the first six minutes and lower during the following 20 minutes or so. This behavior suggests that the water column in the cylindrical Niskin sampler might have been convecting as a result of heating through the outer wall, and that the water samples drained from the sampler might represent varying portions of a convective cell or different convective cells formed within the sampler. Convective motion could rapidly transport a parcel of contaminated water from the top of the Niskin sampler down to the bottom where the sampling spigot is attached.

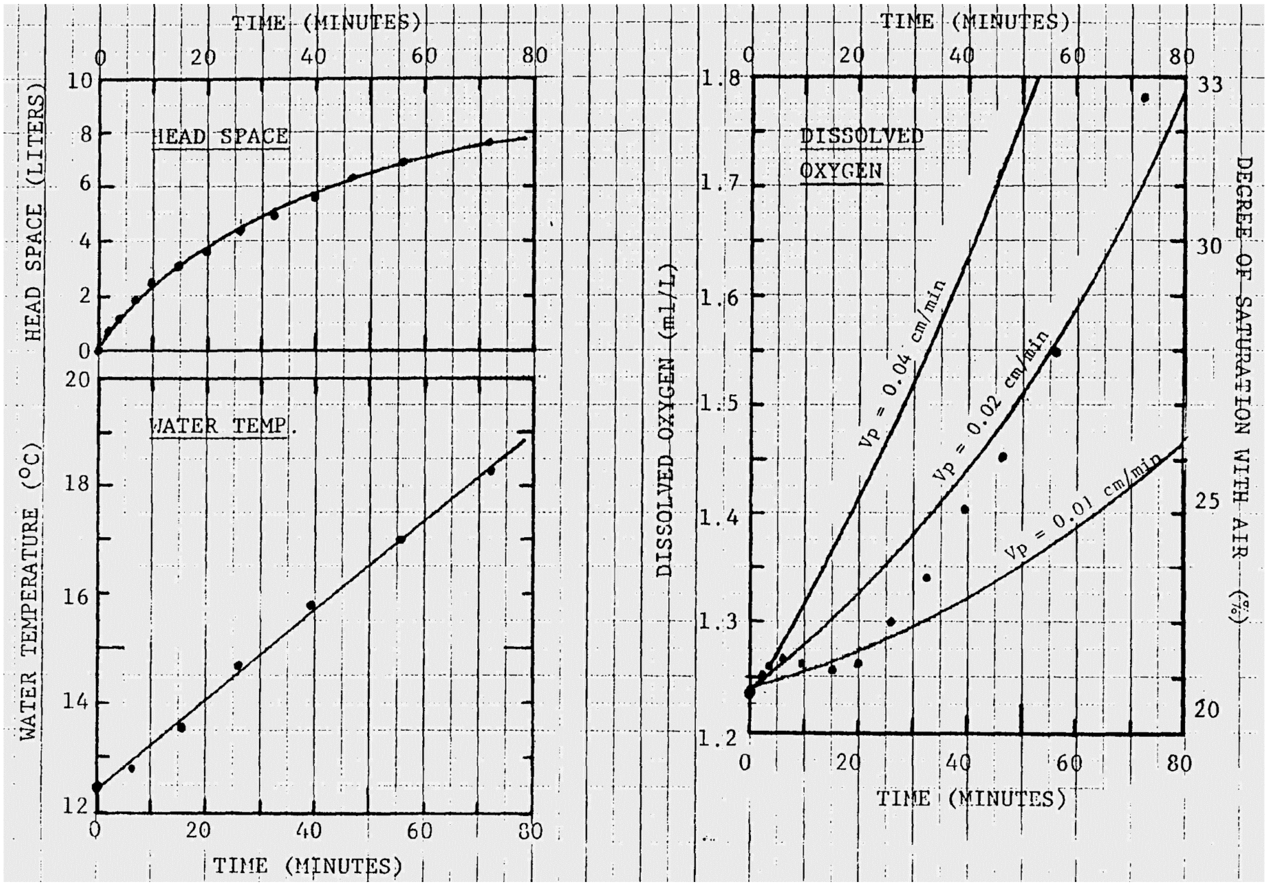

Figure 1: *A time-series study of the temperature and oxygen concentration in the water samples drawn from a 10-liter Niskin sampler. The water was collected at about 300 meters deep off the coast of Liberia within an oxygen minimum layer. The in situ temperature of water was 11.97°C*

We have conducted a number of time-series experiments similar to that described above for oxygen as well as for CO_2 using samples with varying degrees of saturations, and obtained the results consistent with those described above. It was observed that about 2 uM/kg of CO_2 were lost from a deep water sample (about 1300 uatm pCO_2) during the first 30 minutes of water sampling operations. Since the concentrations of nutrient salts were also measured and found to be invariant with time during the duration of experiments, the observed changes in dissolved oxygen and CO_2 were not due to biological activities. We were unable to conduct experiments for Freons, since the Freon measurement system exhibited high backgrounds during Leg 1. Hopefully, a series of Freon time-series experiments will be carried out during the following legs.

Based upon the time-series experiments conducted during Leg 1, the following conclusions and recommendations may be made.

1) When a number of water samples are drawn from a Niskin sampler, the gas concentrations may be altered by gas exchange between the water and the air introduced into the head space. A column of cold water sample in the Niskin sampler may be mixed convectively due to heating through the outer wall during its exposure to warm waters near the sea surface and to warm air. Thus a parcel of altered water near the top of the column may be transported downward to a sampling spigot located near the bottom of the column. Our observations suggest that the magnitude of sample alteration is of an order

of analytical precision for dissolved oxygen and CO_2 determinations, if water samples were collected within 20 minutes after a 10-liter Niskin sampler was brought up onto the deck.

2) The magnitude of sample alteration increases rapidly with increasing contrast in the partial pressures (or concentrations) of a gaseous species between air and water samples. The worst case is Freons, since deep waters contain virtually no Freons, whereas the shipboard air contains sometimes much higher concentrations of Freons than clean marine air due to local sources.

3) We recommend the following drawing order for water samples for gas analyses; Freons, helium-3, oxygen and CO_2. This should be followed by tritium, nutrients and salinity samples.

4) Throughout Leg 1, the water sampling operations were conducted by a half dozen analysts and technicians, who are specialized for collecting specific water samples only for Freons, helium, CO_2 or oxygen. This had not only caused a traffic jam around the Rosette, but also drained the energy of analysts and reduced the time available for chemical analyses. Therefore, we recommend that, during the following legs, the operation should be streamlined by assigning a few technicians exclusively for water sampling, and that the analysts should be kept with their respective analytical instruments without interruptions for water sampling.

5) Since an increasing variety of water samples for gas analyses will be collected in future oceanographic expeditions, we recommend that a development of advanced water samplers is important for preventing sample alterations occurred by contact between the water and the air introduced into the head space while water samples are drained.

DISTRIBUTION OF VARIOUS PROPERTIES

The major oceanographic features observed during the SAVE Leg 1 Expedition will be briefly described below.

Western Boundary Current and Central Water

a) Upper Layers:

We experienced strong southward current near the Brazilian shelf break (10°S, 35°W), even though we were just south of the climatological stagnation point for the upper level circulation. The mean zero wind−curl line runs NW−SE from Capo Blanco just north of Recife toward Walvis Bay, and serves as a crude predictor for the bifurcation point of the zonal equatorial currents between southward and northward flowing boundary currents. Simple Sverdrup theory suggests that the bifurcation point will be shifted poleward by the non−zonal orientation of the zero curl line.

The isopycnals tilt upward toward the western boundary current in the shallow water, as expected from thermal wind balance. But below there is a more marked downtilt toward the boundary with 150 db being the pivot point for sigma theta and most tracers. The isopleths for total CO_2 concentration bend upward above 150 db, whereas they bend sharply downward at greater pressures. The former appears to be the effect of the continental shelf, where CO_2 is released from shelf sediments rich in carbon. The downward bending below about 150 db in part mirrors the tilt of isopycnals, but this is also observed even in density space. The downtiltlng boundary current is characterized by very low nutrients, high oxygen, fresh salinity, high Freons and low CO_2, in plots of constant potential density surfaces as well as level surfaces. The feature is not easy to find in historical maps of properties. This thick region of shear appears to connect with the system of Equatorial countercurrents described by Cochrane et al. (JPU, 1979).

In the northwestern part of the SAVE Leg 1 section, there was a clear shallow salinity maximum, analogous to the Subtropical Underwater of the North Atlantic, a signal of high evaporation in the nearby tropics. There were strong double diffusive staircases visible in the region just below this salinity maximum.

b) Deep Layers:

The distribution of the total CO_2 concentration below 500 meters along the SAVE Leg 1 tracks is shown in Figure 2. The section defined by Stations 11 through 19 (i.e. the right half) represents a zonal section oriented nearly right angles to the Brazilian coast line, whereas that defined by Stations 19 through 27 (i.e. the left half) is oriented diagonally across the tropical South Atlantic in the general direction of SW−NE. A western boundary undercurrent consisting of the North Atlantic Deep Water is clearly depicted by a low CO_2 area (see the 2215 and 2220 uM/L contours) centered around 1800 db near the western margin of the section. This low CO_2 area coincides with the high Freon concentrations observed between 1700 and 1900 db in this area during the 1981 TTO/TAS Expeditions. However, because of high backgrounds in the Freon analysis system during the SAVE Leg 1, the previous observations could not be confirmed. Although signals for the boundary current are visible in the oxygen, nutrient salts and salinity data, the CO_2 data appear to show the boundary current more clearly than other properties.

TCO_2(uM/L), South Atlantic Ocean

SAVE Station No.

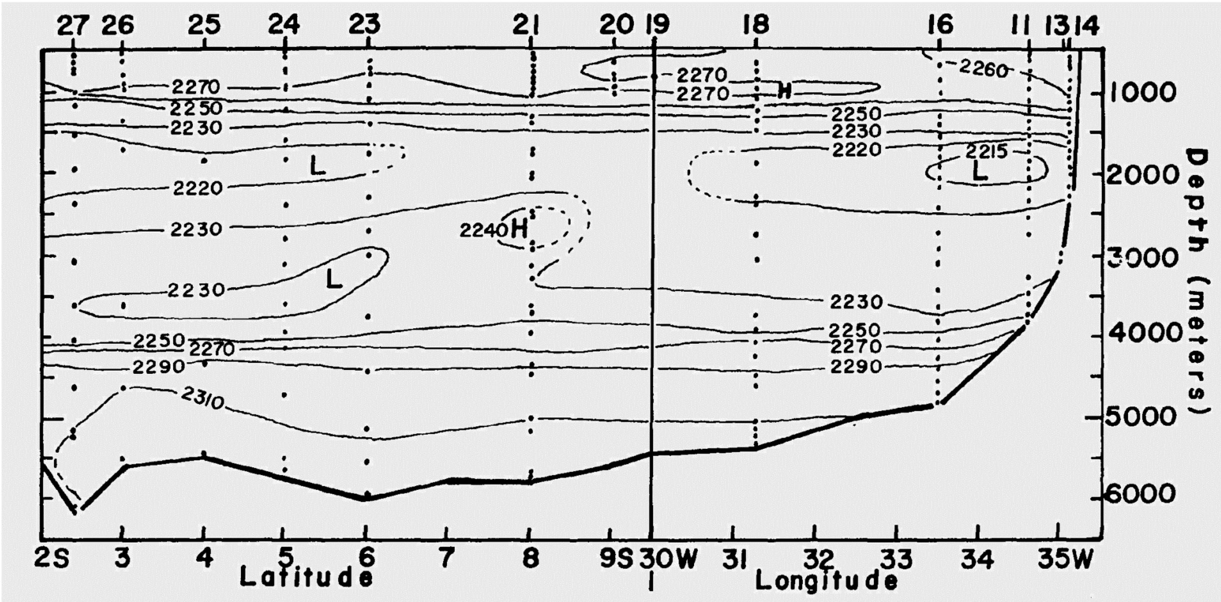

Figure 2: *Distribution of the total CO_2 concentration in the western South Atlantic Basin along the SAVE Leg 1 tracks. The low CO_2 area centered around at 2000 meters near the South American coast (right side of the figure) indicates the western boundary current originated from the high latitude North Atlantic Ocean.*

A low CO_2 layer having similar CO_2 values as those for the boundary current is seen further east in a pressure range of 1500 to 2000 db. This indicates the upper portion of the NADW, whereas another low CO_2 area (defined by the 2230 uM/L contour) observed around 3500 db at Stations 23 through 27 indicates the lower NADW.

There appears to be a small high CO_2 zone depicted by a 2260 uM/L contour near 34°W between 450 and 650 db (see the upper right hand corner of Figure 2). Since this water has high oxygen concentrations, it is suspected that this may represent a boundary current originating in the Southern Ocean.

Equatorial Region

a) Temperature, Salinity and CO_2:

In the upper ocean the high salinity evaporation signal weakens northeastward, and the mixed layer depth decreases along the section. Extremely low salinity values and thin mixed layer were observed near the Liberian coast. Meanwhile, the 10°C isotherm deepens remarkably between Stations 23 and 26. The thermocline at the mixed layer base was very thin and sharp at 3°S. The equatorial zone shows many interesting extrema, but perhaps fewer number of clear "bullets" than expected. Continuous vertical profiles of oxygen, temperature and salinity show rugged structure down to at least 1000 meters deep near the equator and there are strong features in the tracer distributions off the equator. This may corresponds to the subtherrnocline countercurrents observed by Firing and Cochrane et al. (JPO, 1979) off the equator in the Pacific Ocean.

The Equatorial Undercurrent is well resolved by various quantities measured. In Figure 3, the meridional distribution of the total CO_2 concentration in the upper 1000 meters is shown across the equator. 1ie Equatorial Undercurrent centered around 100 db is clearly depicted by a downward bulge of isopleths exceeding 300 db. Below the Undercurrent signals, high CO_2 deep waters are observed as outlined by the mushroom-shaped 2260 uM/L contour. Toward south of the equator, two high CO_2 water masses are observed in a pressure range between 300 and 700 db and between 800 and 1000 db (see 2280 uM/L contour lines). The upper portion of the shallower CO_2 high corresponds to the low oxygen water, and local minimum between the two CO_2 maxima corresponds to the core of AAIW.

b) Oxygen Minimum Layer:

The oxygen minimum layer is observed near a sigma theta value of 26.8 (Figure 4) nearly throughout the SAVE Leg 1 tracks. The minimum strengthens northeastward, ranging from 200 uM/kg near the Brazilian shelf to 60 uM/kg near Liberia. This layer disappears suddenly in the western boundary current, which is protected from this tropical influence.

Antarctic Intermediate Water (AAIW)

The Antarctic Intermediate Water mass is observed in the vicinity of 27.25 sigma-theta density. In the Western Basin of the South Atlantic, the temperature-salinity signals for AAIW is very noisy, indicating interleaving of water layers and hence active erosion of the AAIW. The salinity signal for AAIW weakens eastward, but rather gradually from typically 34.4 to 34.6 ‰, The oxygen field also weakens gradually to the east (Figure 4). The associated nutrient maxima are intriguing: the silica maximum is located at deeper level than the salinity minimum.

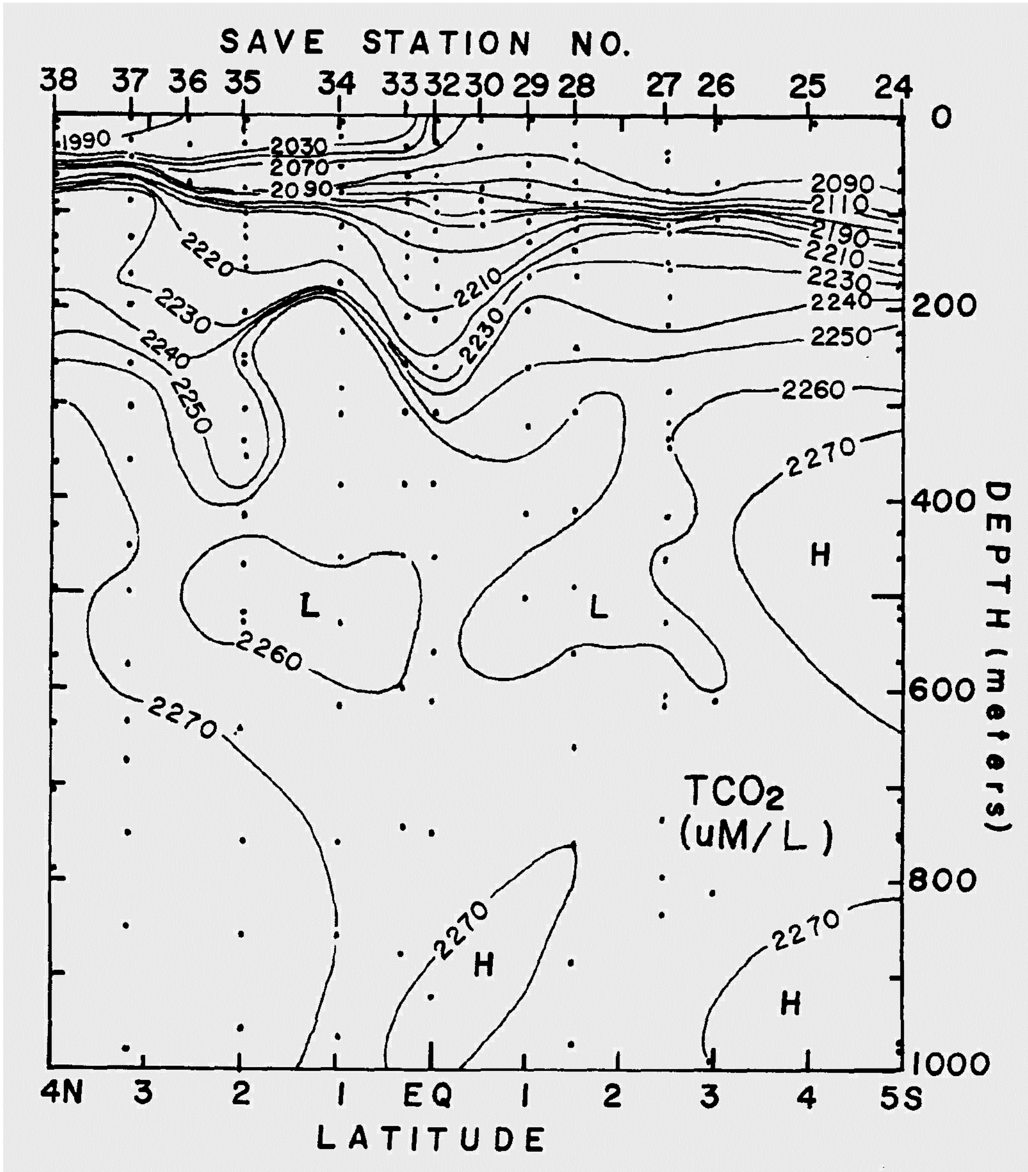

Figure 3: *Distribution of the total CO_2 concentration in seawater in the equatorial Atlantic Ocean along the SAVE Leg 1 tracks. The equator was crossed at 17° 30' W. The downward bulge centered around 150 meters deep at the equator represents the equatorial countercurrent.*

North Atlantic Deep Water (NADW)

Progressing toward the northeast direction, the ledge of nearly uniform potential temperature on the theta–S relationship rotates clockwise, and the AAIW salinity minimum fills in. In the western regions, a distinct inversion of temperature is observed. This temperature maximum (i.e. cold AAIW above warmer NADW) disappears to the east. The salinity maximum associated with the upper NADW is gradually eroded toward east (see Figure 5, the station numbers increase eastward) with noisy interleaving approximately aligned along constant potential density surfaces.

The double oxygen maxima are observed at potential temperatures of about 2.0°C and 3.5°C (Figure 6). This feature is absent near the western boundary and appears toward the middle of the Brazil Basin, suggesting an erosion of NADW by low−oxygen South Atlantic waters. There is a corresponding 'cutout" in the knee of the theta−S plots (located at about 2°C). The nutrients have minima that correspond to the double oxygen maxima, although their depth levels differ substantially. This may be due to the differing background vertical gradient upon which the perturbations lie (e.g. a linear gradient displaces the maximum of a Gaussian perturbation up the gradient). The double oxygen maxima have been noted by Wust, Reid and others, and appear to reflect the intensity of water mass formation at the respective levels of Labrador Sea Water and Denmark Strait Overflow Water.

There is a widespread silicate minimum beneath the AAIW maximum at about 1800 db. Below, at a potential temperature of about 2.4°C, a weak relative maximum occurs that corresponds to the erosive mixing described above. The double−pronged structure of tracers in the tropical and equatorial Atlantic, with extrema appearing along the western boundary and the equator, is familiar as far back as the Meteor Expedition in the mid−1920's. It now has substantial dynamical motivation through the sink−source flows calculated by M. Kawase, F. Bryan and others.

Antarctic Bottom Water (AABW)

In the deeper regions of the Brazil Basin, the AABW appears as a weakly stratified water mass with weak tracer gradients through a depth of 1 km or more. The "lid" is heavily stratified with remarkable linear theta−property signature (see Figure 6). Here, and in the even more homogeneous eastern deep basins, one has a laboratory in which to study diapycnal mixing and vertical motion. Although logistics prevented us from conducting extensive surveys around the Romanche and Chain Fracture Zones, there is a need to know the rate and properties of the flow from the western into the eastern basins. Deep transports of 2 to 5 Sv predicted by box models (Schlitzer, JGR, 1987) would seemingly show intense circulation in these narrow passages, and need to be confirmed by direct observations.

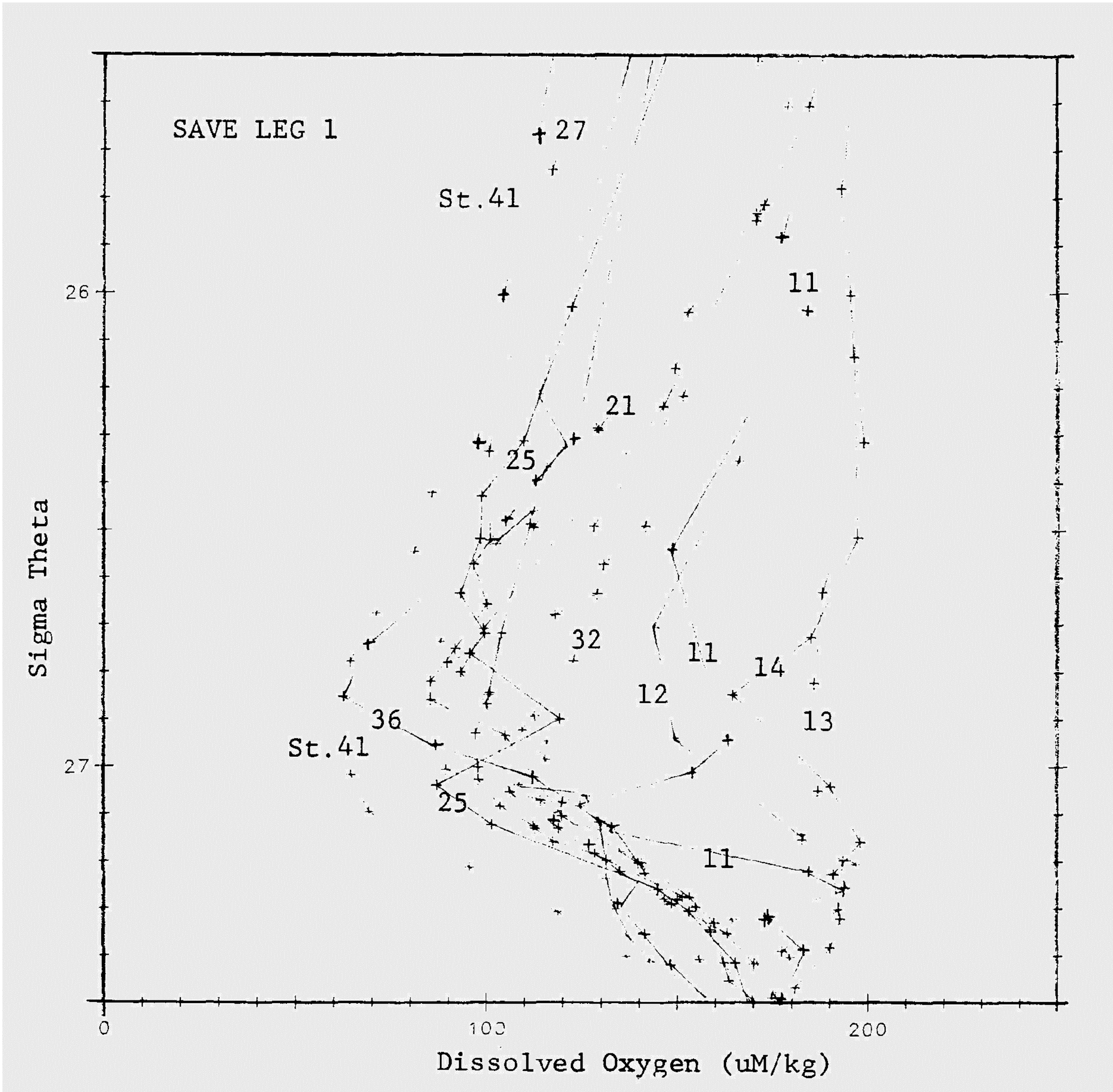

Figure 4: *The concentration of dissolved oxygen versus potential density observed at various stations. The numbers indicate the station numbers. The station numbers increase toward northeast; the stations with numbers lower than 32 are located in the western basin and those with greater than 32 are located in the eastern basin.*

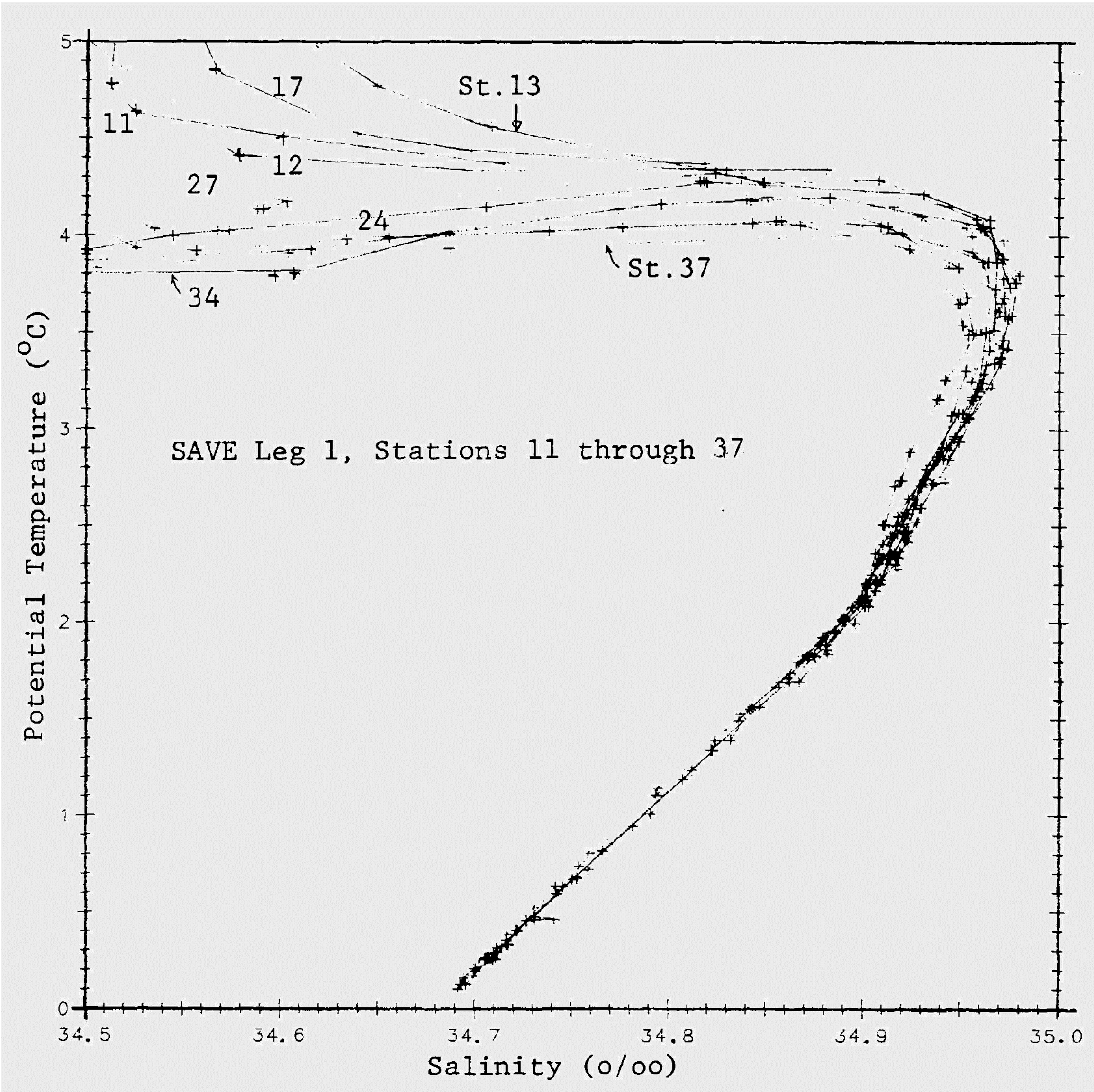

Figure 5: *The theta-salinity relationship observed at the SAVE Leg 1 stations. The numbers attached to the curves indicate the station number. The station numbers increase northeastward, #11 being located near the Brazil coast and #37 near the Liberia coast.*

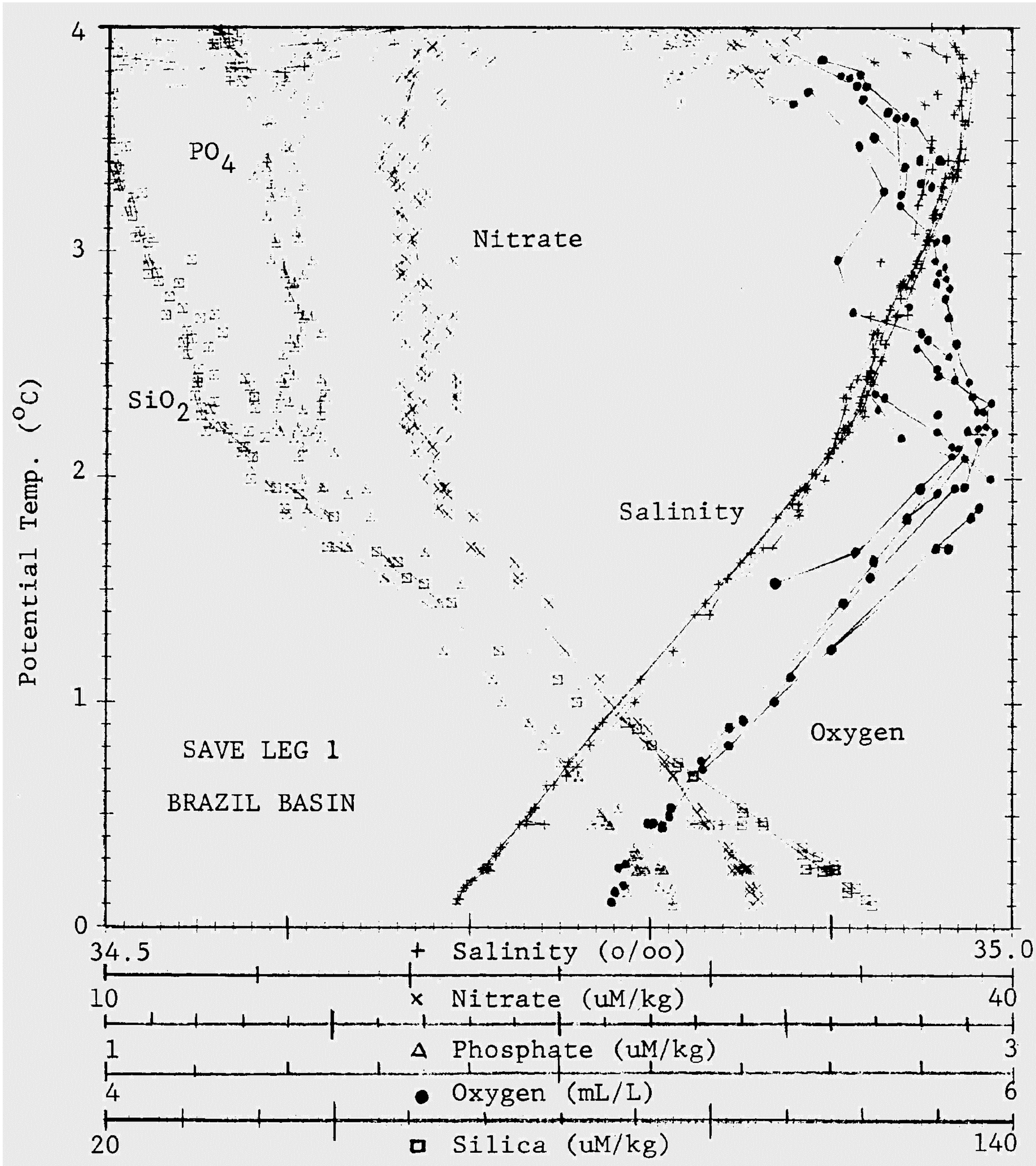

Figure 6: *Potential temperature versus property plots for salinity, oxygen and nutrient salts at the Brazil Basin stations, SAVE Leg 1. Note double maxima features in the distribution of oxygen and nutrient salts at about 2.0 and 3.5°C.*

Data Tables and Plots

(R.T. Williams ODF/STS/SIO)

Most of the users of this preliminary report will be familiar with the techniques and methods used to acquire the data, for the most part identical with those employed in the TTO program. Calculated parameters have been generated from the same equations as used in the TTO final report.

Hydrographic data from Gerard casts is included with the rosette data in the report. The right column of the report gives the difference between the salinity from the 2 liter bottle mounted outside the Gerard barrel and the salinity from within the barrel. At the bottom of the station reports salt, oxygen, and/or nutrient values may occasionally be found without pressure or depth. These values have been considered suspect, and would not normally appear in the report; however, because the users of this report may be concerned with factors affecting the integrity of their shore based samples, the original values are reported. They may be keyed to the other data from the same level by subtracting 9000 from the sample number. There are other cases where missing oxygen and nutrients (and a "D" flag on a salinity) may indicate a bottle which was obviously leaking, a lanyard caught in a bottle lid, sampling error, or other problem about which additional documentation will be made available in the near future.

On the first station of leg 1, station 10 (9 stations were taken for inter-calibration prior to *Knorr's* arrival in Recife), neither the ship's precision depth recorder nor our rosette-mounted altimeter were working, so that bottom depth information is lacking. However, a small depth recorder on the bridge indicated a bottom at about 200 meters at the beginning of the cast. During the cast the bottom began to shoal rapidly, and it is my feeling that the deepest 4 or 5 bottles are all within a few meters of the bottom; that is, we were barely keeping the rosette out of the mud as the cast was brought up. By the end of the cast the depth was about 50 m. On the second station the altimeter was working so that the distance above bottom (dab) at maximum depth could be reported for the rosette cast. Without the ship's 12 kHz equipment, the bottom depth and dab could not be reported for the Gerard casts. On all succeeding stations, the sonic depth and dab are reported for each deep cast in the heading of each station report, unless poor bottom conditions made the trace unreadable.

List of participants

Ship's Captain

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Brazilian Naval Observer

Cpt. Emmanuel Bonfim de Jesus

CCHDO Data Processing Notes

Date	Contact	Date Type	Summary
2011-04-08	*Muus, Dave*	BOT/SUM	Exchange, NetCDF, WOCE files online

Notes on Save Leg 1 rosette sample data. EXPOCODE 316N19871123 110406/dm

1. Temperature, salinities, oxygen and nutrients taken from ODF data, whprpasave1, dated Aug 25, 2005.
2. CFCs and CO2 data merged from file SAVEsv.csv received from R. Key Dec 10, 2010.
   PCO2 values in file but no flags. Added flag 2 for all PCO2s.
3. Station 16, Cast 1, Sample 16 684db: ODF deleted water samples "Lanyard hangup?" Salinity & oxygen high, nutrients low.
   SAVEsv.csv TCARBN 127 low, PCO2 785 low. Deleted.
4. Deleted Station 24 Cast 3 Bottle 9 from SAVEsv.csv file. Cast 3 is Gerard cast, Bottle 9 is rosette bottle. Only sample values are CFCs.
5. CTDTMP units ITS-68 not ITS-90.
6. Station 41, Cast 1, Sample 32 Reversing Pressure 550db low. Other values including Reversing temperature look okay. Changed flag from 2 to 4.