Physical and Chemical Data from the Canadian Arctic Archipelago, August 28 to September 18, 1997

F. McLaughlin, E. Carmack, M. O'Brien, L. Adamson, J. Barwell-Clarke, G. Gatien, M. Hingston, P. Johnston, B. May, H. Melling, M. Poliquin, D. Riedel, D. Sieberg, D. Tuele, B. VanHardenberg, D. Walsh, B. Welch and C. Welch

Fisheries and Oceans
Science Branch, Pacific Region
Institute of Ocean Sciences
9860 West Saanich Road
Sidney, B.C. V8L 4B2

2008

Canadian Data Report of Hydrography and Ocean Sciences 176

Fisheries and Oceans   Pêches et Océans

Canada

Canadian Data Report Of Hydrography and Ocean Sciences

Data reports provide a medium for the documentation and dissemination of data in a form directly useable by the scientific and engineering communities. Generally, the reports contain raw and/or analyzed data but will not contain interpretations of the data. Such compilations commonly will have been prepared in support of work related to the programs and interests of the Ocean Science and Surveys (OSS) sector of the Department of Fisheries and Oceans.

Data reports are not intended for general distribution and the contents must not be referred to in other publications without prior written authorization from the issuing establishment. The correct citation appears above the abstract of each report. Data reports are abstracted in *Aquatic Sciences and Fisheries Abstracts* and indexed in the Department's annual index to scientific and technical publications.

Data reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page. Out of stock reports will be supplied for a fee by commercial agents.

Regional and headquarters establishments of Ocean Science and Surveys ceased publication of their various report series as of December 1981. A complete listing of these publications is published in the *Canadian Journal of Fisheries and Aquatic Sciences*, Volume 39: Index to Publications 1982. The current series, which begins with report number 1, was initiated in January 1982.

Rapport statistique canadien sur l'hydrographie et les sciences océaniques

Les rapports statistiques servent de véhicule pour la compilation et la diffusion des données sous une forme directement utilisable par les scientifiques et les techniciens. En général, les rapports contiennent des données brutes ou analysées, mais ne fournissent pas d'interprétation des données. Ces compilations sont préparées le plus souvent à l'appui de travaux liés aux programmes et intérêts du service des Sciences et levés océaniques (SLO) du ministère des Pêches et des Océans.

Les rapports statistiques ne sont pas destinés à une vaste distribution et leur contenu ne doit pas être mentionné dans une publication sans une autorisation écrite préalable de l'établissement auteur. Le titre exact paraît au-dessus du résumé de chaque rapport. Les rapports statistiques sont résumés dans la revue *Résumés des sciences halieutiques et aquatiques*, et ils sont classés dans l'index annuel des publications scientifiques et techniques du Ministère.

Les rapports statistiques sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre. Les rapports épuisés sont fournis contre rétribution par des agents commerciaux.

Les établissements des Sciences et levés océaniques dans les régions et à l'administration centrale ont cessé de publier leurs diverses séries de rapports en décembre 1981. Une liste complète de ces publications figure dans le volume 39, Index des publications 1982, du *Journal canadien des sciences halieutiques et aquatiques*. La série actuelle a commencé avec la publication du rapport numéro 1 en janvier 1982.

Canadian Data Report of
Hydrography and Ocean Sciences 176

2008

PHYSICAL AND CHEMICAL DATA FROM THE CANADIAN ARCTIC ARCHIPELAGO, AUGUST 28 TO SEPTEMBER 18, 1997

by

F. McLaughlin, E. Carmack, M. O'Brien, L. Adamson, J. Barwell-Clarke,
G. Gatien, M. Hingston, P. Johnston, B. May, H. Melling, M. Poliquin, D. Riedel,
D. Sieberg, D. Tuele, B. VanHardenberg, D. Walsh, B. Welch and C. Welch

Fisheries and Oceans
Science Branch, Pacific Region
Institute of Ocean Sciences
9860 West Saanich Road
Sidney, B.C. V8L 4B2

Cat. No. Fs 97-16/176E ISSN 0711-6721

Correct citation for this publication:

McLaughlin, F., Carmack, E., O'Brien, M., Adamson, L., Barwell-Clarke, J., Gatien, G., Hingston, M., Johnston, P., May, B., Melling, H., Poliquin, M., Riedel, D., Sieberg, D., Tuele, D., VanHardenberg, B., Walsh, D., Welch, B., and Welch, C. 2008. Physical and chemical data from the Canadian Arctic Archipelago, August 28 to September 18, 1997. Can. Data Rep. Hydrogr. Ocean. Sci. 176: vi + 140p.

TABLE OF CONTENTS

ABSTRACT

McLaughlin, F., Carmack, E., O'Brien, M., Adamson, L., Barwell-Clarke, J., Gatien, G., Hingston, M., Johnston, P., May, B., Melling, H., Poliquin, M., Riedel, D., Sieberg, D., Tuele, D., VanHardenberg, B., Walsh, D., Welch, B., and Welch, C. 2008. Physical and chemical data from the Canadian Arctic Archipelago, August 28 to September 18, 1997. Can. Data Rep. Hydrogr. Ocean. Sci. 176: vi + 140p.

The physical and chemical water properties of the Canadian Arctic Archipelago (CAA) were measured during a Joint Ocean Ice Study expedition aboard the *CCGS Louis S. St-Laurent* from 28 August – 18 September, 1997 (Institute of Ocean Sciences Mission Number 1997-22). The program objective was to investigate selective withdrawal and circulation of Arctic outflow waters, examine the long-range transport of contaminants to water and the food chain and study the population ecology of Arctic fish and marine mammals. This report provides a summary of all science activities together with data collected from CTD/rosette casts. The CTD data consists of pressure, temperature and salinity and the bottle data include salinity, oxygen, nutrients, oxygen isotope ratio, barium, alkalinity, dissolved inorganic carbon, halocarbons, chlorophyll-a and hexachlorocyclohexanes. Sampling and analytical methods are described. Other samples collected but not included in this report are also listed.

RÉSUMÉ

McLaughlin, F., Carmack, E., O'Brien, M., Adamson, L., Barwell-Clarke, J., Gatien, G., Hingston, M., Johnston, P., May, B., Melling, H., Poliquin, M., Riedel, D., Sieberg, D., Tuele, D., VanHardenberg, B., Walsh, D., Welch, B., and Welch, C. 2008. Physical and chemical data from the Canadian Arctic Archipelago, August 28 to September 18, 1997. Can. Data Rep. Hydrogr. Ocean. Sci. 176: vi + 140p.

Les propriétés physiques et chimiques de l'eau dans l'archipel Arctique canadien (AAC) ont été mesurées lors d'une expédition menée dans le cadre d'une étude conjointe des glaces de mer (JOIS) à bord du NGCC *Louis S. St-Laurent*, du 28 août au 18 septembre 1997 (mission numéro 1997-22 de l'Institut des sciences de la mer). Le programme visait à étudier les caractéristiques (p. ex. profondeur) des masses d'eau du bassin Canada qui sortent de l'océan Arctique à travers l'archipel Arctique canadien, le transport à longue distance des contaminants jusque dans l'eau et la chaîne alimentaire, et l'écologie des populations de poissons et de mammifères marins de l'Arctique. Ce rapport présente un sommaire de toutes les activités scientifiques ainsi que les données de conductivité-température-profondeur (CTP) d'échantillons prélevés avec système Rosette. Les données de CTP concernent la pression, la température et la salinité, et les données de bouteille de la salinité ainsi que la teneur en oxygène et en nutriments, le ratio des isotopes de l'oxygène, la teneur en baryum, l'alcalinité et les teneurs en carbone inorganique dissous, en hydrocarbures halogénés, en chlorophylle a et en hexachlorocyclohexanes. Les méthodes d'échantillonnage et d'analyse sont décrites. D'autres échantillons prélevés mais non traités dans ce rapport sont également mentionnés.

ACKNOWLEDGEMENTS

The science team would like to express their appreciation to Captain Stephen Gomes, Chief Officer Roy Lockyer and the officers and crew of the *CCGS Louis S. St-Laurent* for their professional expertise and willingness to make our problems their own. We share with them the success and accomplishments of our program. Many thanks are also due to Dave Maloley and the staff at Polar Continental Shelf in Resolute for providing food, lodging and help with locating shipped gear. We also acknowledge the assistance from the pilots of the *CCGS Louis S St-Laurent*, the *CCGS Des Groseilliers* and the *CCGS Sir Wilfred Laurier* for transferring gear and personnel.

This work was supported by Fisheries & Oceans Canada and the Assistant Deputy Minister's High Priority Fund.

1. INTRODUCTION

The transit of the *CCGS Louis S. St-Laurent* through the Canadian Archipelago from 28 August to 18 September, 1997 (Institute of Ocean Sciences Mission Number 1997-22) provided the first opportunity to collect, during a single cruise, physical, geochemical, biological, geological and contaminant samples from Lancaster Sound west to the Canada Basin in the Arctic Ocean. These samples were collected to investigate selective withdrawal and circulation of Arctic outflow waters, examine the long-range transport of contaminants to water and the food chain and study the population ecology of Arctic fish and marine mammals. The scientific team was comprised of 32 researchers from the Institute of Ocean Sciences (IOS), Freshwater Institute (FWI) and Bedford Institute of Oceanography (BIO) as well as researchers from other Canadian and American government departments and universities including the Department of Environment (DOE), Geological Survey of Canada (GSC), Rutgers University and Mystic Marine Aquarium (Appendix 4.1).

<u>Research Program Background – JOIS and SHEBA</u>

Joint **O**cean **I**ce **S**tudies (JOIS) was a joint U.S./Canada effort to build ancillary science programs in climate, contaminant transport, and biology and to make effective use of SHEBA (**S**urface **HE**at **B**udget of the **A**rctic) platform logistics. JOIS included oceanographic work in the Atlantic/Arctic straits and passages, including North Water Polynya and Canadian Arctic Archipelago; and the Canada Basin, and also included data collected from the SHEBA drifting station. SHEBA was predominantly a U.S. program that includes international participants (Canada, Japan and the Netherlands) whose aim was to understand air/sea/ice albedo feedback mechanisms for climate modeling purposes.

The primary objectives of the Canadian component of JOIS were to: (1) carry out physical and geochemical tracer measurements of the Arctic Archipelago through-flow processes (e.g. transports of mass, salt, heat, nutrients, contaminants and tracers) linking the Arctic Ocean and the Labrador Sea; and (2) investigate the relationships among physical, chemical and biological processes in the North Water Polynya, the Canadian Arctic Archipelago and Canada Basin. The diverse programs carried out on the third leg of JOIS, their objectives and accomplishments are reported here.

1.1 FIELD WORK SUMMARY

Mission #1997-22 accomplishments are summarized below. Data presented in this report are outlined in **bold font**. Specific location and time of events are listed in Appendix 4.2.

1) Throughflow program:

- **Conductivity-Temperature-Depth (CTD) data collected at 50 stations**
- **Water samples collected at 28 geochemistry stations for the determination of salinity, dissolved oxygen, nutrients (orthophosphate, silicate, nitrate plus nitrite, nitrite), oxygen isotope ratio ($\delta^{18}O$), barium, alkalinity, dissolved inorganic carbon, halocarbons and chlorophyll-a**
- Samples collected at selected stations for iodine (^{129}I), cesium (^{137}Cs), lead (^{210}Pb), strontium (^{90}Sr) and plutonium (^{239}Pu) for analysis at shore-based laboratory

2) Biological program:

- Zooplankton biomass samples collected from six zooplankton tows
- Arctic fish and macro-invertebrates collected by gill net and longline fishing in Barrow Strait and Viscount Melville Sound and by two Issacs-Kidd trawls in Viscount Melville Sound and the Beaufort Sea
- Observations of marine mammals and birds

3) Contaminant program:

- Five surface water samples and nine air samples were collected for air/sea exchange measurements
- **77 water samples for hexachlorocyclohexane analyses**
- Zooplankton samples from three bongo net vertical casts
- Subsamples from six box cores

4) Geology program:

- Six box cores
- One gravity core
- Three piston and trigger core pairs

5) Sea Ice program:

- Imaging sonar validation at four sites
- Recovery of four moorings at two sites
- Deployment of five moorings at four sites
- Contact with one mooring

6) Beluga Habitat Studies:

- Video of the seafloor taken at three sites
- Acoustic recording of beluga whales feeding in VMS

1.2 STUDY AREA

The science team joined the ship in Resolute Bay on August 29 and disembarked in Tuktoyaktuk on September 18, 2007. The geographical features and location of stations occupied in the Canadian Archipelago during the transit of the *CCGS Louis S. St-Laurent* are shown below in Figures 1 – 6.

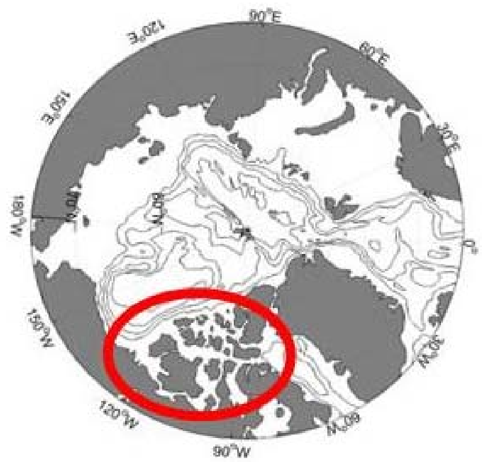


Figure 1. View of the Arctic showing the Canadian Archipelago in the red circle.

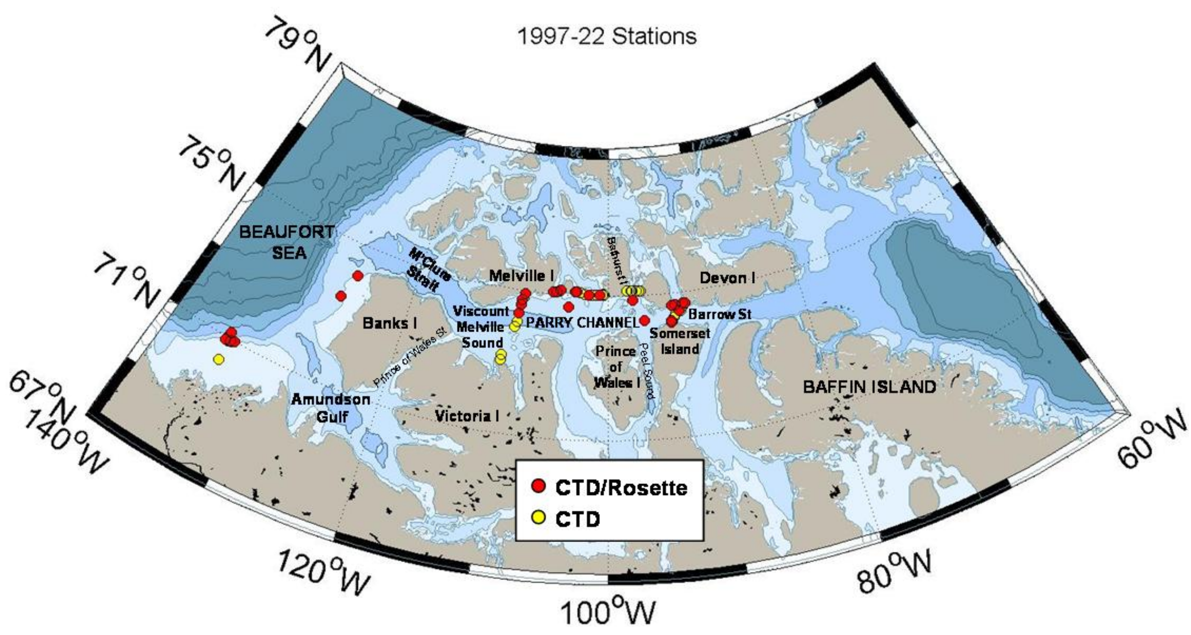


Figure 2. Station locations in the Canadian Arctic Archipelago.

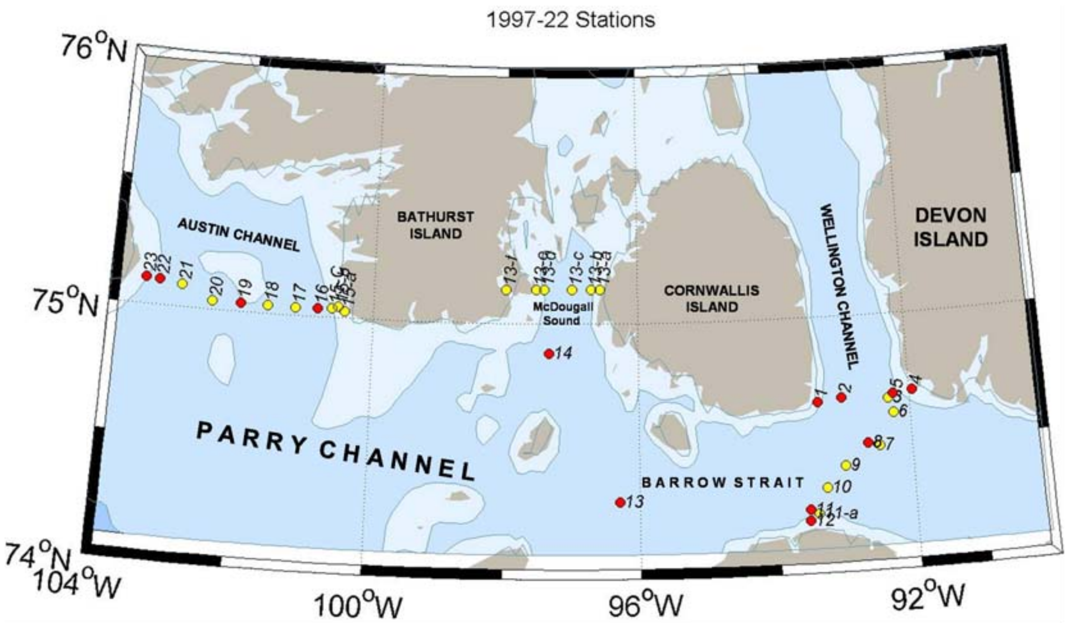


Figure 3. Location of Stations 1 to 23 in the Canadian Arctic Archipelago.

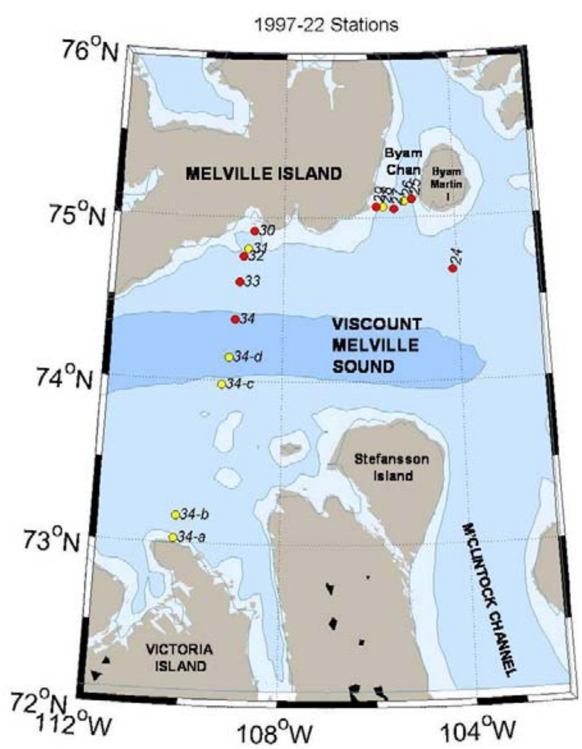


Figure 4. Location of Stations 24 to 35 in the Canadian Arctic Archipelago.

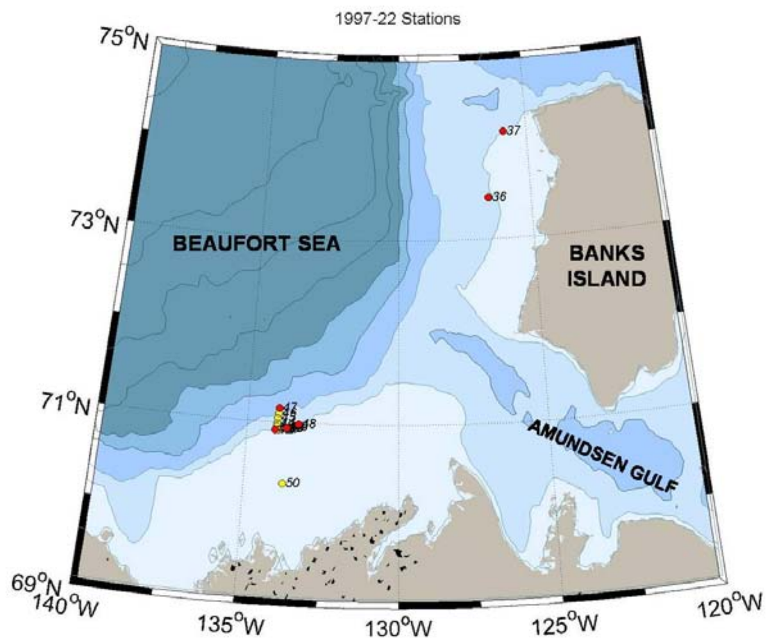


Figure 5. Location of Stations 36 to 50 in the western Beaufort Sea.

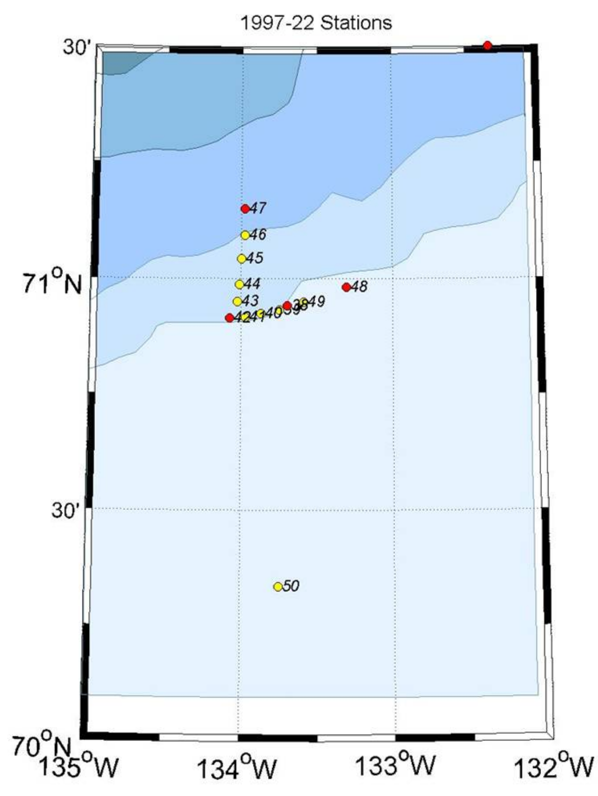


Figure 6. Location of Stations 38 to 50 in the western Beaufort Sea.

Along the 2700 nm transit, samples were collected at 50 stations across Wellington Channel, Barrow Strait, McDougall Sound, Austin Channel, Byam Channel, Parry Channel and half of Viscount Melville Sound in the Canadian Arctic Archipelago and 14 stations in the western Beaufort Sea. The transit between Viscount Melville Sound and Banks Island was via Peel Sound because ice conditions prevented a westward transit through M'Clure Strait or a southward transit through Prince of Wales Strait.

1.2.1 Shipboard Discoveries

Shipboard observations revealed that flow is not channel flow but consists of narrow, focused boundary currents. Water mass properties within the Archipelago suggest the system is comprised of a series of connected basins and not simply a channel connecting the Arctic Ocean with Baffin Bay. One significant finding was waters below 200 m in Viscount Melville Sound are isolated and older than 30 years, therefore renewal of these sub-basin waters occurs on a much longer scale than previously thought. In addition, biology is much richer and more widespread, suggesting that the concept of "hot-spots" requires revision. For example, harp seals were observed farther west and ringed seals (15 to 20) and glaucous gulls were observed feeding near the ice edge off Banks Island - a rare event, according to the biological team. Cod were observed and beluga whales were "heard" feeding at depth in Viscount Melville Sound in September (the first observation this late in the year). There was an abundance of life on the seafloor as seen in the video: many brittle stars, anemones, sponges, worms and cod. One benefit to the multidisciplinary-team approach was the discovery that the video camera was an excellent tool for selecting sites where the box corer could be successfully deployed.

1.3 PROGRAM OBJECTIVES, SAMPLE COLLECTION AND OBSERVATIONS

This report includes a summary of study objectives and sampling completed for each research program. Analytical methods and physical and geochemical data collected for the CTD and water chemistry program (Archipelago Through-flow), conducted primarily by the team from the Institute of Ocean Sciences, are reported below.

1.3.1 Archipelago Through-flow

(PI McLaughlin and Carmack, IOS)

Objective

The program objective was to obtain a high-quality geochemical tracer section through the Canadian Arctic Archipelago in order to understand through-flow processes linking the Arctic Ocean and Labrador Sea. Emphasis was on collecting samples for the study of selective withdrawal, along-channel mixing and scales of motion.

Sampling completed

Continuous CTD profiles and discrete water column samples were collected at 28 stations in the major passageways of the Canadian Archipelago using a Falmouth Scientific Inc. (FSI) integrated CTD (ICTD) attached to a G.O. rosette frame outfitted with 24 niskin-type bottles manufactured by Brook Ocean Technology (BOT). The water column sample locations are shown by section in Appendix 4.3. The CTD/rosette was deployed from the starboard boat deck. Auxiliary sensors (SeaTech transmissometer and SeaTech fluorometer) were attached to the rosette frame to collect continuous profiles of optical transmissivity and chlorophyll fluorescence: see Appendix 4.4 for sensor serial numbers and calibration dates. These data were not archived but are available. Water collected in the BOT bottles was subsampled, in the following order, for the analysis of halocarbons (CFC-11, CFC-12, CFC-113, CCl_4), dissolved oxygen, alkalinity, dissolved inorganic carbon, nutrients (orthophosphate, silicate, nitrate plus nitrite, nitrite), $\delta^{18}O$, barium, chlorophyll and salinity. Samples were also collected for hexachlorocyclohexane (HCH), total organic carbon and alkalinity, iodine (^{129}I), cesium (^{137}Cs), lead (^{210}Pb), strontium (^{90}Sr) and ^{239}Pu at selected stations. Continuous CTD profiles were also collected at 23 stations using a self-recording Micro CTD (MCTD) deployed from the foredeck. This CTD was also used to collect data from an additional 13 CTD stations reached by helicopter.

Team: McLaughlin, Carmack, Sieberg, Van Hardenberg, May, Walsh, O'Brien, Hingston, Barwell-Clarke, Poliquin, Melling, Reidel, Welch and Johnston.

1.3.2 Beluga Habitat Studies: Acoustic and Video

(PI Scheifele, Mystic Marine Aquarium)

Objective

The objective of this study was to determine if pods of beluga whales were found in September in the Canadian High Arctic Archipelago and, if found, why they are there at that time. Based upon numerous researchers' tag data, this species (*Delphinapterus leucas*) has been recorded and Viscount Melville Sound was identified as the location where beluga would most likely be found feeding at or below 300 m depth. The primary objective was to deploy an underwater audio-visual system down to 300 m and record a feeding event taking place. An additional objective was to collect an acoustic signature of the icebreaker CCGS Louis S. St. Laurent which will be added to the current vessel signature and noise assessment catalogue. This research was supported by Mystic Marinelife Aquarium in collaboration with the National Undersea Research Center (NURC-NAGL) at the University of Connecticut.

The work was also planned to provide educational tools. As a result, a great deal of time was spent in the preparation of video, still and digital footage and an accompanying journal and science teaching paper. The latter not only covers the specifics of this mission but relates the roles and vocations of the 33 scientists and technicians and ship's company.

<u>Sampling and tasks completed</u>

Although no video footage was obtained of beluga whales (either underwater or surface), definitive acoustical evidence was acquired during sonar operations over the 500 m trench in the Viscount Melville Sound, an area suspected to be a beluga "hotspot". This event occurred on September 8, 1997, which was later than the beluga were suspected of being at that site. In addition, other video footage and fishing samples taken by DFO biologists indicated the presence of arctic cod in the area.

Three video recordings of the seafloor were obtained with a downward (vertical) and outward (horizontal) looking camera array comprised of Sony XC-999 video cameras. In addition, numerous shots on 35 mm underwater film were taken. In all cases the camera was positioned at the seafloor with the hydrophone located 2 m above the camera. Video recordings were taken at the following stations and observations were:

Station #12: Cobble bottom with almost no sediment; some brittle stars and sponges.

Station #19: Muddy bottom with no rocks, boulders or cobble; many brittle stars, anemones, worms, sponges and arctic cod. The cod were unique to this place at this time and depth.

Station #24: Muddy bottom but very little life; nine arctic cod were counted during 18 minutes of film.

Team: Scheifele, Worobey and Tedeschi.

1.3.3 Biological Sampling

(PI Bergmann and Reist, FWI)

<u>Objectives</u>

The program objective was to: (1) investigate if a trophic gradient exists across the various channels of the Canadian Arctic Archipelago; (2) evaluate the feasibility and logistical considerations of working from an ice-breaker by collecting fish and macro-invertebrates on an opportunity basis; and (3) record bird and mammal distributions. This expedition provided the first opportunity to measure the productivity gradient and distributions across the Canadian Arctic Archipelago from Lancaster Sound westward to the Canada Basin in the Arctic Ocean.

Sampling Completed

(1) Samples for the determination of zooplankton biomass were collected at six sites: Wellington Channel, Barrow Strait, Austin Channel, Parry Channel and Viscount Melville Sound. Samples were collected using a four net 2x2 m frame deployed from the foredeck. Water samples were also collected for chlorophyll analysis.

Team: Bergmann and Welch.

(2) Conducting research programs on arctic fish either directly from or in small boats supported by the *CCGS Louis St. Laurent* is feasible and recommendations are detailed in a separate report. The following list summarizes the different gear deployed and catches obtained.

Passive gear

- Multi-mesh gill net (10-60 mesh x 120 m length Swedish style) was successfully deployed by the ship's Fast Recovery Craft in Resolute Bay. Catch: 55 arctic cod, 1 fourhorn sculpin, 4 large snails, 1 ectoproct.
- Baited (squid) long-line (100 hooks) and baited nylon shrimp trap rigged for bottom set was deployed from the afterdeck approximately 1 nm before arriving on Station 8 (200 m deep). Gear was lost due to drift and ice conditions (lightly drifting ice floes) and the importance of using appropriate locating beacons was learned.
- Multi-mesh gill net (1-60 mesh x 120 m length Swedish style), 100 hook long-line, and baited cloth bags were successfully deployed from afterdeck in waters 160 m deep and very close to ice edge. Catch: one arctic cod, sea spiders (Pycnogonidae), brittle stars, five-armed starfish, tube worms, crinoid.

Active gear

- Jigging: (a) near Station 24 – 2.5 hr effort with surface and bottom gear at >150 m; (b) near Station 34 – 4.5 hr effort from surface to approximately 200 m including a 17 hook long-line 'hung' vertically. Catch: none.
- Small Issacs-Kidd mid-water trawl (6 foot wide plate) was deployed from foredeck starboard crane using IOS winch with kevlar cable to about 50 m depth at Station 23. Two oblique hauls (to the surface) were obtained while ship moved astern for 20 minutes. Catch: amphipods.

Other samples collected

- Surface water samples for strontium analysis obtained from six sites: Resolute Bay, Stations 11, 22, 27, 32 and 36.
- Polychaetes and other invertebrates from engine intake filters.
  Team: Reist, Gyselman and Crawford.

(3) Regular observations of marine mammals and birds were conducted from the ship's 'Monkey's Island' and the boat deck. Harp, ringed and bearded seals were common in the Canadian Arctic Archipelago and in appropriate habitats. Ringed seals were common both in the water and along the new ice fringe of the pack ice west of Banks Island in the Beaufort Sea; occasional bearded seals were also observed here. A number of polar bears or their tracks and in some cases the kills of polar bears were observed from the ship during the westward transit. Concentrations of tracks and sightings occurred in Peel Sound and in the mixed ice at the northern-most station in the Beaufort Sea. In two cases a sow was observed with two cubs. Two unique observations were made: the occurrence of harp seals in open waters along the north side of Viscount Melville Sound and a concentration of ringed seals and gulls feeding near the ice edge in the Beaufort Sea.

Several species of birds were observed relatively consistently and represent more or less the expectations based upon known distributions. Black Guillemots, Black-legged Kittiwakes, Northern Fulmars, Ivory Gulls and some Glaucous Gulls were observed in eastern areas of the transit; Pomarine Jaegers were occasionally sighted in the eastern areas. In heavier ice conditions and in more western areas Ivory Gulls were observed and were often the only species present; two Ross's Gull were observed in the eastern areas.

Three observations were salient. First, in Peel Sound under ice-conditions of 6/10 coverage, arctic cod were exposed when ice was overturned by the ship and a significant flock of gulls gathered to feed. Most of these were Glaucous Gulls (about 60 birds including adults and juveniles of various ages). The presence of significant numbers of arctic cod, mostly small fish, the gulls and other biological activity (e.g. numerous polar bear tracks and seals), indicate this area may have a significant production base. Second, in the Beaufort Sea west of Banks Island, Black-legged Kittiwakes were observed at two separate times (north and southward legs). The initial sighting consisted of two juvenile birds and the latter sighting consisted of five birds, two of which were juveniles. This sighting may represent either (a) the migration west of these birds from the known colony in the central archipelago to wintering areas; or (b) the presence of an unknown-to-observers colony in the area. Third, along the northward leg approximately three nautical miles prior to the point were the ship entered the pack ice for Station 37, numerous gulls (two or three species of unknown identity) and approximately 15 to 20 ringed seals were observed feeding in a restricted area (about 250 x 300 m) immediately adjacent to the ice-edge (new ice along fringe with first-year and multi-year blocks further in). The birds were all on the water actively feeding along with the seals which were repetitively diving. This event likely represents a rarely observed phenomenon, especially in the western Arctic.

Team: Reist, Krajack, Schiefele and bridge personnel.

1.3.4 Contaminant Chemistry

(PI Strachan, DOE; McLaughlin, IOS; Stern, FWI)

<u>Objectives</u>

Air, water column, zooplankton and sediment samples were collected to determine contaminant distributions (both persistent organic pollutants and trace heavy metals), gradients and pathways across the Canadian Arctic Archipelago. Water column samples were analyzed to determine the depth and rate of selective withdrawal from the Canada Basin. The transit represented the first opportunity to collect contaminant samples from Lancaster Sound in the eastern Canadian Arctic Archipelago westward to the Canada Basin.

<u>Sampling completed</u>

(1) Air/sea exchange: Five surface water samples were collected either by surface pump deployed away from the ship by the foredeck port crane or by 100 L Go-Flo bottle using the foredeck starboard A-frame and winch. Four samples were collected in the Archipelago and one sample was collected in the Beaufort Sea. These samples will be paired with air samples collected by passing 300-500 m^3 of air through pre-cleaned polyurethane foam plugs. The air sampler was located at the bow of the ship. Five samples were collected from Lancaster Sound to Viscount Melville Sound, two samples were collected en route from Lancaster Sound to the Beaufort Sea and two samples were collected in the Beaufort Sea.

Team: Strachan and Tuele.

(2) Water column: Seventy seven samples were collected to HCH profiles at seven stations between Lancaster and Viscount Melville sounds. Stations were chosen to collect samples of Arctic outflow water, i.e. stations located on the southern or western side of the channel.

Team: McLaughlin, O'Brien, Barwell-Clarke and Tuele.

(3) Zooplankton: Three zooplankton samples were collected by repeated bongo net vertical casts to about 100 m. Stations were chosen to collect samples from Arctic outflow water as above.

Team: McLaughlin, Tuele and Danell.

(4) Sediment: Samples were collected to determine profiles of contaminant burdens in sediment cores and geographic patterns of contaminants in surficial sediment collected across the Canadian Arctic Archipelago. Data will be

interpreted in the context of contaminant burdens, sediment process affecting contaminant distributions and spatial patterns of contaminant deposition. Six box core samples were collected: in the center of Barrow Strait (203 m); McDougall Sound (264 m); Parry Channel (203 m); Byam Channel (250 m); Viscount Melville Sound (264 m) and on the Beaufort shelf (55 m). In addition, a sample for the analysis of tributyl tin (TBT) was collected by Ponar grab in Resolute Bay harbor.

Team: Hurlbut, Stern, Wilkinson and Danell.

1.3.5 Geology

(PI Hurlbut, GSC)

Objectives

Samples were collected for the analysis of the physical properties of sediment in the Canadian Arctic Archipelago. This data provides information about the depositional history of the area and whether deposition conditions have changed over time. Researchers from GSC, Atlantic Geoscience Centre (AGC) and FWI collected the samples.

Sampling completed

The coring program was guided by pre-selected sites based on previously obtained acoustic data. In total ten cores were collected at six sites: six box cores, one gravity core and three piston and trigger core pairs. Subsamples of the box core were collected for AGC analysis. Two of the piston cores were obtained from the same basin and at similar depths to pre-selected sites and the third was collected at a site in Viscount Melville Sound, an identified area of interest for which no previous data existed.

Team: Hurlbut, Stern, Wilkinson and Danell.

1.3.6 Moorings and Buoys

(PI Melling, IOS)

Objectives

Objectives were: (1) to evaluate a prototype imaging sonar (being developed at IOS) for two-dimensional mapping of various ice types; (2) to retrieve six internally recording sonars deployed in April 1995 at three sites in the Beaufort Sea; and (3) to deploy the six serviced sonars and two additional instruments at four sites in the Beaufort Sea between the Mackenzie River delta and Prince Patrick Island. These moorings are part of a long-term study of the thickness of Arctic sea ice, and its variations, since 1990. At the Banks and Prince Patrick Island locations, the sonars will observe the oldest sea ice and most severe ice conditions anywhere in the world's oceans.

Tasks completed

Sonar imaging observations were acquired at four sites in the Archipelago, where ice conditions ranged from open water, through young pancake and nilas ice forms, to mature first-year and multi-year ice. These measurements will be applied to the design of an imaging sonar, capable of mapping the underside of pack ice from a self-contained moored package during year-long Arctic deployments.

Ice-observing sonars moored in April, 1996, were successfully recovered in open-water conditions at Sites 1 and 2 on the Mackenzie shelf. Preliminary inspection of data stored within the instruments indicated a 100% recovery of high-quality ice data, and an interesting time series of sound backscatter from zooplankton in the water column. Scattering during the summer of 1996 (a year of heavy ice cover) was a factor of ten lower than scattering recorded during the summer of 1997, when the ice-free period was more than three month duration. Two attempts were made on consecutive days to recover the mooring deployed at Site 5 to the west of Banks Island. During this period the site was overlain by a heavy cover of multi-year ice. Although good contact was made with the acoustic transponders on the mooring, the mooring was not released because ice conditions at the surface were too unpredictable to allow a quick and straight-forward retrieval.

Ice measuring sonars were deployed at four sites, three of which were where moorings were retrieved (Table 1). The mooring proposed for deployment to the west of Prince Patrick Island was eventually deployed off the northwest corner of Banks Island, about 120 miles further south. The change in plan was dictated by heavy ice conditions in the area. There was no need to re-deploy the mooring at Site 5 because it was not retrieved.

Table 1. Location of Sonar Moorings in the Beaufort Sea, September 1997.

Site Number	Latitude (N)	Longitude (W)
1	70° 20.2'	133° 42.3'
2	70° 56.5'	133° 41.6'
5	73° 27.1'	126° 36.1'
6	74° 09.1'	125° 54.4'

Team: Melling, Gamble, Johnston and Riedel.

2. METHODS AND ANALYTICAL PROCEDURES

2.1 CTD/ROSETTE CAST OPERATIONS

The *CCGS Louis S. St-Laurent* is a 26,000 HP icebreaker equipped with helicopter and deployable rigid hull boats (Fast Recovery Craft). An ice specialist, a member of the ship's compliment, received Radarsat ice images and weather information from the Canadian Ice Services, made daily ice and weather observations to send back to shore and assisted in navigation and information regarding science station locations. Ships soundings were taken using an ELAC 15 kHz depth sounder displayed on paper charts. No continuous measurements were recorded.

Science operations were dependent on the ship making openings in the ice as required to allow CTD/rosette, net and mooring deployments and recoveries. Mooring, vertical net tow and Issacs-Kidd mid-water trawl operations were performed from the ship's foredeck using the starboard crane, A-frame and hydraulic winch. The self-recording MCTD was also deployed from the foredeck. CTD/Rosette casts were performed on the boat deck, mid-ships, using a starboard A-frame and hydraulic winch. Multi-mesh gill nets, long lines and traps were deployed from the after-deck.

The ship stopped near the pre-determined location to find a position that would keep the wire clear of ice during the CTD/rosette deployment. The ship's bubbler system was also used to blow ice out of the way although the bubblers' location is most suited to clear the foredeck area, forward of the CTD launch area.

Water sampling and CTD casts were conducted with a 24-bottle GO (General Oceanics) rosette sampler outfitted with 24 10 L niskin-type bottles manufactured by Brook Ocean Technology (BOT). The rosette and CTDs were kept in a specially designed heated "hanger" constructed from a pair of 8' x 12' cargo containers until just before the cast when they were rolled out on deck and deployed. The rosette package was lowered over the side using the A-frame and winch. Once back on deck the rosette was placed on a flat trolley and pulled by means of a come-along into the heated container where the BOT bottles were subsampled.

The rosette had a 1016 (intelligent) pylon and was controlled by its own deck unit. Two internal conductors were used for the primary CTD (Falmouth ICTD). Data were collected on an IBM PC located in the CTD/rosette lab by means of a conducting cable. Profiling speed was well controlled at about 1 m/s. The nominal sampling rate of the CTD as configured was 4 Hz (ST = 0). The manual indicates that for this rate of sampling, the sensor outputs are integrals over 105 ms. The actual sampling rate (3.64 Hz) was slower than the nominal value, presumably because the instrument sampled more channels than the primary data stream (pressure, temperature and conductivity). The instrument also recorded data from the following sensors: Sea Tech transmissometer, Sea Tech fluorometer and Sea-Bird touchdown switch. BOT bottles were closed on the up-cast with the rosette stopped for at least 10 s before closure. Previous experience has shown that the water sampled with this procedure actually comes from ~2 m below the stopped position.

Once the CTD/rosette was returned to the hanger, water in the BOT bottles was subsampled, in the following order, for the analysis of halocarbons (CFC-11, CFC-12, CFC-113, CCl_4), dissolved oxygen, alkalinity, dissolved inorganic carbon and alkalinity, nutrients (orthophosphate, silicate, nitrate plus nitite, nitrite), oxygen isotopes ratio ($\delta^{18}O$), barium, chlorophyll and salinity. Samples were also collected at selected stations for hexachlorocyclohexane (HCH), total organic carbon, iodine (^{129}I), cesium (^{137}Cs), lead (^{210}Pb), strontium (^{90}Sr) and plutonium (^{239}Pu). Halocarbons, dissolved oxygen, alkalinity, dissolved inorganic carbon, nutrient and salinity samples were analyzed onboard ship. Samples collected for chlorophyll analysis were filtered within hours of collection on-board ship and the filters were frozen. The remaining samples were stored for analysis upon return to the various shore-based laboratories.

2.2 PROCESSING AND VALIDATION OF CTD DATA

2.2.1 Overview

The steps outlined below were performed as required in processing data from each CTD cast. Derived oceanographic quantities were calculated from the pressure, temperature and salinity data using the algorithms given by Fofonoff and Mallard (1983). See Appendix 4.5 for plots of CTD data and Appendix 4.6 for plots of dynamic height and sections. Processing of the CTD data involved the following general steps:

- verification of calibration coefficients for all sensors
- verification against log sheets of data files produced by the acquisition programs
- checking and editing header information
- conversion of the CTD files from their acquired format into IOS HEADER format
- application of sensor calibrations to the “raw” data
- creation of profile plots throughout the processing
- removal of data spikes and corrupted data
- correction for differences in temperature and conductivity time responses (method used is dependent on CTD type)
- deletion of swells, upcast and unwanted surface records
- removal of salinity spikes
- manual editing of other data problems where required

- reduction of the data to one meter averaged values (data set has only one record per decibar)
- production of final test plots
- data validation by comparing pre- and post-cruise calibrations
- creation of overlay plots and comparison on CTD data with bottle data, other reference data and historical data
- adjustment of the processed CTD data to agree with reference data

2.2.2 Processing of Downcast CTD Data

(H. Melling)

<u>Choosing the Depth and Temperature for Geochemical Samples</u>

Up-cast CTD data provide better numbers for salinity (and presumably for temperature) in relation to water samples. However, the depth to be associated with the water sample is poorly known because the flushing of the bottle is inefficient and a wake engulfs the rosette when it is stopped for bottle closure. The down-cast data suggest that on average the salinity of the sample is best represented by conditions about 2 m below the rosette when it is stopped. The recommendation for choosing values to associate with water samples:

1. Use the salinity and temperature from the CTD when stopped for bottle closure on the upcast.
2. Use the pressure that provides the best average correspondence between the sample salinity and CTD salinity on the downcast, namely that 2-db greater than the CTD indication when the rosette is stopped.
3. Be aware that the sample is actually a mixture of water from a range of depths below where the rosette was stopped. The depth range over which the sample has been 'smeared' is quite large relative to the 2-m average correction and varies from sample to sample.

Data were recorded by the CTD during both the down-cast (continuous descent) and the up-cast (intermittent ascent, with stops of 10 to 30 s for closure of bottles). In general, oceanic profiles derived from up-cast data are 'ugly' because the wake of the rosette catches up with the CTD during stops, and the (un-pumped) CTD sensors are subject to self-heating when motion ceases. Only data from the down-cast were systematically processed for this cruise. However, those short sections of data recorded separately by the logging software at the times of bottle closure on the up-cast were calibrated for comparison of salinity measured with that analyzed for sampled water. Data from the CTD during down-cast were processed through the following stages:

1. FSICNVT, using Config File: w:\ctd\9720\1329.cnf
2. CLEAN, to reset #RECS, MIN & MAX values in header.
3. REMOVECH, to remove Thermistor1, Touch Down, Transmissivity, Chlorophyll from file
4. Edit for de-spiking
5. ICTD-ADJ.bas (non-standard program)
   Original conductivity channel adjusted by weighted running average
   Weights from -9.9 s to 0 s
   Original pressure & supplementary variables delayed by (ms): 811.4
   Original temperature delayed by (ms): 325.0
6. DELETE, using
   Surface Record Removal: OFF, Pressure filtered over width: 9, Swells deleted, Drop rates < 0.50 m/s (calculated over 8 points) deleted
7. CALIB
   1 Pressure:Adj db 10 -0.1100000E+01 0.1000000E+01
   2 Temperature:Adj °Celsius 10 0.2410050E-01 0.9984878E+00
   3 Conductivity:Adj mS/cm 68 0.0000000E+00 0.1000000E+01
8. FILTER, using Boxcar on Salinity referenced to Pressure:Adj:
   Size 9 to 100-m depth, size 13 to 300-m depth, size 23 at greater depths.

2.2.3 Down-cast CTD Values vs. Bottles

Figure 7 displays the differences between bottle and CTD salinity values in relation to the vertical salinity gradient at the level of sampling. Clearly the discrepancy between the two values of salinity is strongly influenced by how rapidly salinity is changing with depth in the ocean.

Figure 8 shows the difference between the bottle salinity and down-cast CTD as histograms and tests two assumptions:
(1) the sample is representative of the bottle location (i.e. 0.6 m **above** the CTD; and (2) the sample is representative of a location 2.0 m **below** the CTD. The “correction to CTD” values are plotted in three depth intervals for all samples. This allows evaluation on the basis of vertical salinity gradient.

The histograms for the +0.6 m assumption are strongly skewed to positive correction, with the skewness decreasing as the gradient decreases. This result confirms that the waters sampled came from below the stopped position of the rosette.

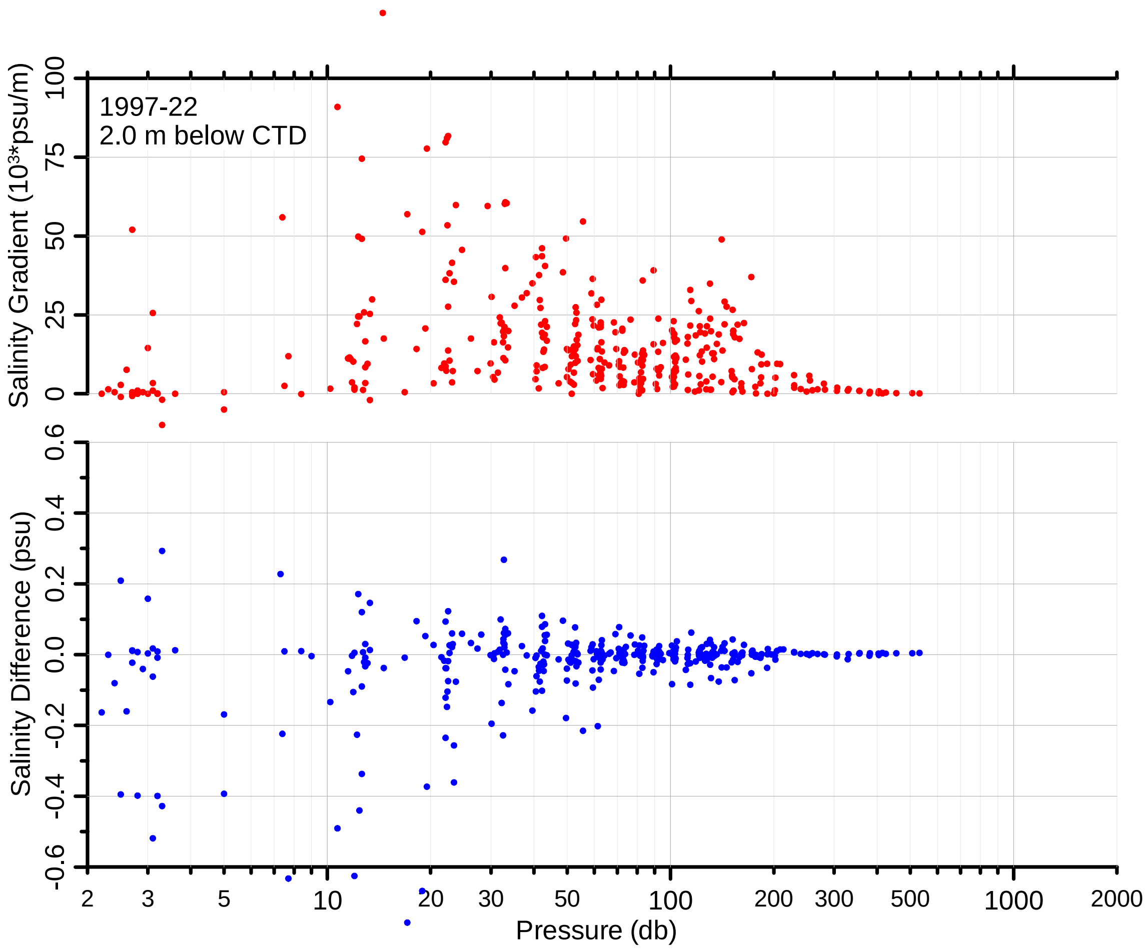


Figure 7. Bottle-salinity minus down-cast-CTD-salinity versus depth.

The histograms for the -2 m assumption are more symmetric. The large width of the histogram (±0.05 in salinity) where the gradient is strong arises from two factors: (1) partially mixed water entrained into the moving wake behind the rosette that catches up when the rosette is stopped for sampling; and (2) changes in the ocean between the time of the down-cast, which provides the CTD data, and the time of the up-cast, when samples were taken for analysis.

The salinity correction is based on deep samples, where the salinity gradient is much less than 1 ppm/m, ranges from -0.002 ppm at 2000 m to +0.002 ppm at 1000 m. Since the variation is congruent to that of temperature, this could be residual temperature dependence in the conductivity circuitry of the ICTD. The change is too large to be associated with thermal contraction of the cell (about 0.0005 over a 2 °C temperature change).

No correction to the conductivity calibration for this cruise was warranted on the basis of the in-situ sampling for salinity. The confidence level for deep salinity values from the CTD is ±0.002.

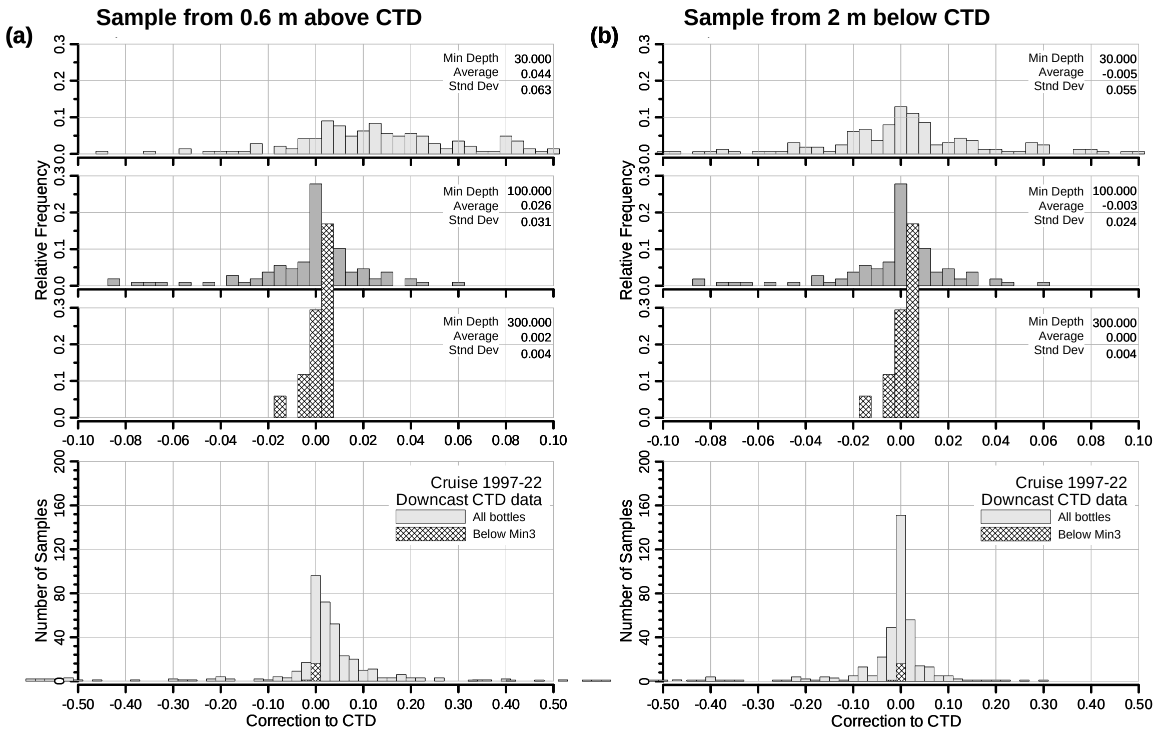


Figure 8. Histograms of salinity difference: bottle salinity minus down-cast CTD salinity, assuming that water in bottle comes from (a) depth of bottle 0.6 m above the CTD and (b) 2.0 m below the CTD.

2.2.4 Up-cast CTD Values vs Bottles

Salinity values from water samples were also compared with the data recorded by the CTD when the rosette was stopped on the up-cast to acquire water samples (Figure 9). In this situation, since the coincidence of CTD and bottle data in both depth and time is very close, one expects an excellent correspondence between values from the two sources of information.

The correspondence is certainly better than that between bottles and down-cast data. In general, the root-mean-square difference is about half that of the former comparison. However, the spread in values (approximately ±0.080 for 95% confidence) is much larger than the analytical precision for salinity samples (±0.001) or the precision (±0.002) of CTD-derived salinity. There is also skewness in the histograms that favours bottle salinity values higher than those measured by the CTD, despite the fact that the bottles were mounted above the CTD. There are also some large differences in salinity between bottles and CTD on the up-cast for this cruise and the prior cruise (IOS Mission # 9720).

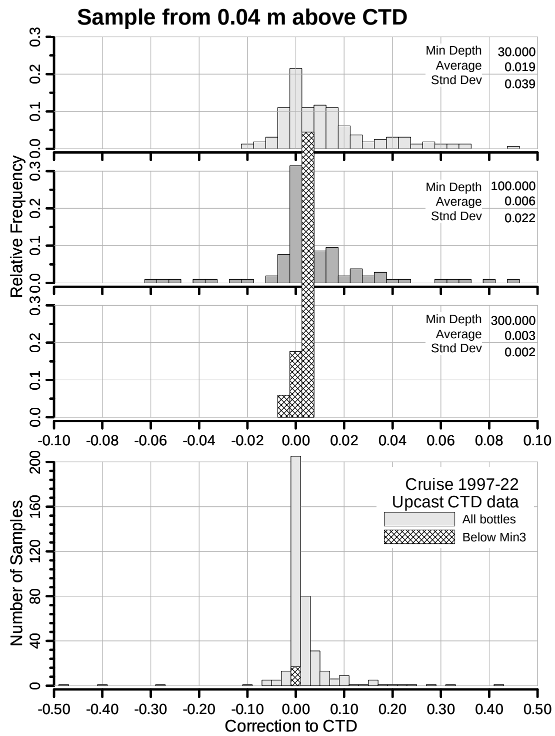


Figure 9. Histograms of difference: bottle minus up-cast CTD, assuming that water in bottle comes from depth of bottle.

There are two issues of concern here: (1) the extent to which samples in the bottles correspond to water in the vicinity of the CTD/rosette on the up-cast; and (2) the extent to which water in the vicinity of the CTD during up-cast corresponds to the water at the same depth as the CTD, but remote from it. The histograms presented in this section reveal significant differences between the water within the bottles and the water in the vicinity of the rosette. Slow flushing of 'old' water from the bottles and inhomogeneity (poor mixing) of water in the wake of the rosette are both implicated as contributors to these differences.

In addition to the slow-flushing and poor-mixing factors, the histograms presented in the preceding section have larger variance because they incorporate two additional effects: (3) entrainment of deeper waters into the wake that follows the rosette and overtakes it at stops; and (4) changes in the ocean between the time of the downcast and that of sampling on the upcast. Factor (3) implies that the water measured by the CTD and collected in bottles on the upcast is not identical to that remote from the rosette.

Factor (4) is not immediately relevant because it is real change, and not an artifact of sampling procedure.

During cruise 2001-16 in the same area as cruise 1997-22, a single wire mounted bottle was lowered repeatedly to acquire bottles at various depths with the winch stopped for the messenger drop. CTD data were taken from the initial downcast. The 2001-16 data set has the same timing problem as the 1997-22 data, in that the sample was not acquired simultaneously with the CTD data, but lacks the problem of the rosette wake encountered in 1997-22. The variance of bottle-CTD differences for 2001-16 is about 1.2 times that of the 1997-22 up-cast differences but only about 0.6 times that of the 1977-22 down-cast differences for the three ranges of depth (30 to 100, 100 to 300 and 300 to 600 db). Therefore, timing mismatch increases the variance by about 20%, while wake effects are probably the cause of an additional increase of almost 50%.

2.2.5 Summary of Quality and Concerns

(G. Gatien)

<u>ICTD</u>

There are uncertainties in the pressure values for the ICTD. For the down-cast, the pressure gauge seems to take a while to equilibrate with values decreasing as the CTD sits near the surface. Sometimes there are no values with zero conductivity so that it is impossible to determine what the pressure gauge would have read at the surface, and where a value can be determined the pressure may still be reading a little high if equilibration is not complete. During 9722 the CTD was lowered to about 30 m for many of the casts and then returned to near the surface for a complete cast; for these casts the pressure is likely to be more reliable. A correction of -1.1 db was made in calibrating the casts.

<u>MCTD</u>

There are similar uncertainties in pressure for the MCTD. For the up-casts the surface varies from -4.9 db to +0.7 db. For the down-casts the surface varies from -1 to -3. A pressure correction of +2.0 dbars was included in calibration. There remains an error bound of ±3 db.

The temperature and salinity data for the MCTD has been recalibrated to match the ICTD; the quality of this adjustment is limited by the configuration of the deployment for the intercalibrations as the two instruments were not sampling at exactly the same depth nor at the same rates.

See Appendix 4.4 for G. Gatien’s processing notes.

2.3 CHEMISTRY SAMPLING AND ANALYSIS

2.3.1 Laboratory Methods

The precision of the methods was estimated by analyzing replicates and expressed as the pooled standard deviation s_p using the equation:

$$s_p = \sqrt{\frac{\Sigma\ (c(1)-c(2))^2}{2n}}$$

where *c*(1) and *c*(2) were the concentrations of duplicate samples and *n* refers to the number of pairs (Table 2).

Table 2. Analytical Accuracy

Chemistry Sample	**Accuracy (s_p)**	**Number of Replicates**
Dissolved Oxygen	0.02 mL/L	35
Nitrate	0.1 mmol/m^3	52
Nitrite	0.01 mmol/m^3	33
Silicate	0.14 mmol/m^3	52
Orthophosphate	0.01 mmol/m^3	52
DIC	1.1 µmol/kg	27
Alkalinity	6.0 µmol/kg	27
Barium	0.75 µmol/m^3	23
CFC12	0.043 nmol/m^3	10
CFC11	0.115 nmol/m^3	10
CFC113	0.010 nmol/m^3	9

See Appendix 4.5 for profiles of chemical data and Appendix 4.6 for oxygen and nitrate sections.

2.3.2 CFC Measurements

CFC analysis was carried out by Michael Hingston using two automated purge and trap systems developed at the Bedford Institute of Oceanography. Separation and detection of the components was achieved using a 60 m, 0.32 mm GasPro Gas separator fused silica column and a Varian Electron Capture Detector. Standardization was done using a gas standard (S36) made at

Brookhaven National Laboratories and standardized at Scripps Institute of Oceanography with concentrations reported on the SIO1993 scale. Analyses for CFC12, CFC11, CFC113 and CCl_4 were carried out on all hydrocast water samples. Air samples were taken at least every day as a further check on the operation of the system. All concentrations are reported in nmol/m^3 with an estimated precision of about two percent. The pooled standard deviation for CFC-12 is s_p = 0.043 nmol/m^3, where n = 10 pairs; CFC-11 s_p = 0.115 nmol/m^3 where n = 10; and CFC-113 s_p = 0.010 nmol/m^3, where n = 9.

2.3.3 Dissolved Oxygen

After the BOT bottle integrity was checked, samples for dissolved oxygen were drawn after the CFCs samples. Water was drawn through rubber tubing into a calibrated volume glass flask with attached stopper. The sample was immediately pickled with 1.0 mL of manganous chloride and 1.0 mL alkaline iodide, the stopper was inserted and the flask was shaken to mix the contents. Dissolved oxygen samples were analyzed on board by Mary O'Brien within 24 hrs of collection using an automated version of the Micro-Winkler Technique as described in Carpenter (1965). The titration was done using a Metrohn Dosimat 665 and the end point was detected using a Brinkmann probe colorimeter PC900. The methodology follows standard IOS protocol described by Minkley & Chase (1997). The pooled standard deviation is s_p = 0.020 mL/L, where n = 35 pairs.

2.3.4 Nutrients

Water samples for nutrient determination were collected into two glass and two polystyrene test tubes after the tube and cap had been rinsed three times with the sample water. All nutrient (silicate, nitrate plus nitrite and orthophosphate) samples collected were analyzed onboard ship by Janet Barwell-Clarke using *Technicon AutoAnalyzer II* components and following the methods described by Barwell-Clarke and Whitney (1996). Replicates were drawn from the same BOT bottle. Archived data is the average of the duplicates. The pooled standard deviation for nitrate is s_p = 0.08 mmol/m^3, where n = 52; silicate s_p = 0.14 mmol/m^3, where n = 52; orthophosphate s_p = 0.01 mmol/m^3, where n = 52 and nitrite s_p = 0.01 mmol/m^3, where n = 33.

Standards and blanks:

Nanopure water was analyzed before the initial standards and after the last standard set to check the chemical blank. Standards (low, medium and high) were made using a freshly prepared 3.2% sodium chloride solution and analyzed at the start and close of each day and every ~ 60 samples. Concentrations of the standards bracket the expected nutrient levels in the samples.

When the nitrate level in surface samples is the same or slightly lower than the 3.2% sodium chloride solution it is reported as zero.

2.3.5 Salinity

Salinity samples were drawn into 200 mL glass salinity bottles after 3 rinses, then tightly capped until analysis onboard ship. Samples were analyzed by Humfrey Melling and Dave Riedel on a Guildline Autosal (Model 8400A*)* after equilibrating to room temperature for at least 12 hrs. Precision was approximately ±0.003 PSU and data are reported in practical salinity units (PSU) (Lewis and Perkin 1978). Pooled standard deviation is not reported as no duplicate samples were collected.

2.3.6 Dissolved Inorganic Carbon

Manon Poliquin used a SOMMA (Single-Operator Multiparameter Metabolic Analyser) - Coulometer system to analyze dissolved inorganic carbon (or total carbon dioxide) in seawater samples. The SOMMA is a sea-going, computer-controlled automated dynamic headspace analyzes, constructed at the University of Rhode Island under the supervision of its manager, David B. Butler, and faculty supervisor, Dr. John King. The current design of the headspace analyzer is based on system UG. It features four independent gas services including a headspace gas (HSG) service, a water-jacket pipette and sample bath, automatic temperature sensing a built-in gas calibration system and an auxiliary carrier gas (AGC) flow route. In addition, a pipette rinsing capability and a protective plastic enclosure with coolant fluid conduits are integrated into the system. SOMMA comes with the electronic components and interface cables for IBM compatible PCs. The SOMMA dispenses and acidifies a known volume of seawater, strips the resultant CO_2 from solution, dries it and delivers it to a coulometric detector. The coulometer is operated in the counts mode. This mode uses the coulometer voltage to frequency converter (VFC) output and constants supplied by the user, via the SOMMA software, to calculate µmol *C* titrated. The pooled standard deviation is s_p = 1.06 µmol/kg, where n = 27 pairs.

2.3.7 Alkalinity

Manon Poliquin used an automated potentiometric titration system to determine the total alkalinity of seawater, defined as the number of moles of hydrogen ion equivalent to the excess of proton acceptors (bases formed from weak acids with dissociation constants of less than $K = 10^{-4.5}$) over proton donors (acids with $K > 10^{-4.5}$) in a one kilogram sample. During the course of the titration the pH is measured using a Ross combination electrode standardized using a Hansson seawater buffer. A known volume (~25 mL) of sample is measured in a calibrated, thermostated pipette and dispensed in to an open cup. The alkalinity of the sample is estimated from its salinity and acid equivalent to 0.7 of this amount is added and the pH measured. A further three aliquots of acids are added to bring the titration to 90% completion. The Gran Function F3 is then applied to these points to obtain a more refined estimate of the alkalinity. Five additional aliquots are then added to complete the titration. The pH values for the last five points of the titration are used to evaluate the Gran Function F1 from which the final estimate of the equivalence point is obtained. Values are reported in units of µmol/kg. The overall precision of the analysis is 1.5 µmol/kg for samples with concentrations in the range of 1900 to 2400 µmol/kg. The pooled standard deviation is s_p = 7.9 µmol/kg, where n = 27 pairs.

2.3.8 ^{18}O

Samples were drawn into ~30 mL glass vials following three rinses of the vials. Once at room temperature, the caps were retightened and wrapped with parafilm for storage. Oxygen isotopes were analyzed initially in 1998 at the University of Calgary (UC). However, there was drift in the UC instrument and there is no means of quantifying this drift because gas pressure operation and other data were not recorded. Reruns relied on the operator identifying a problem. There were also problems due to power fluctuations. A small subset of samples were rerun at Oregon State University in 2003. The rerun data were inconclusive as small leaks in the vials due to storage can move the numbers in a positive direction because the lighter isotope leaks preferentially (Figure 10).

<u>Overview</u>

The $^{18}O/^{16}O$ ratio of natural waters is determined using the common CO_2-H_2O equilibration technique (Epstein 1953; O'Neil et al. 1975) in which millimole quantities of CO_2 are equilibrated with water samples under constant temperatures. Subsequently, the CO_2 is cryogenically purified and analyzed mass spectrometrically for its $^{18}O/^{16}O$ ratio. Note that this technique measures the isotopic activity of ^{18}O and not the actual ^{18}O concentration. For dilute waters, differences between isotopic activity and concentration are negligible. For saline waters and brines, however, supplemental water chemistry data and longer equilibration times are needed to obtain true isotopic compositions (Horita 1993; Sofer 1972).

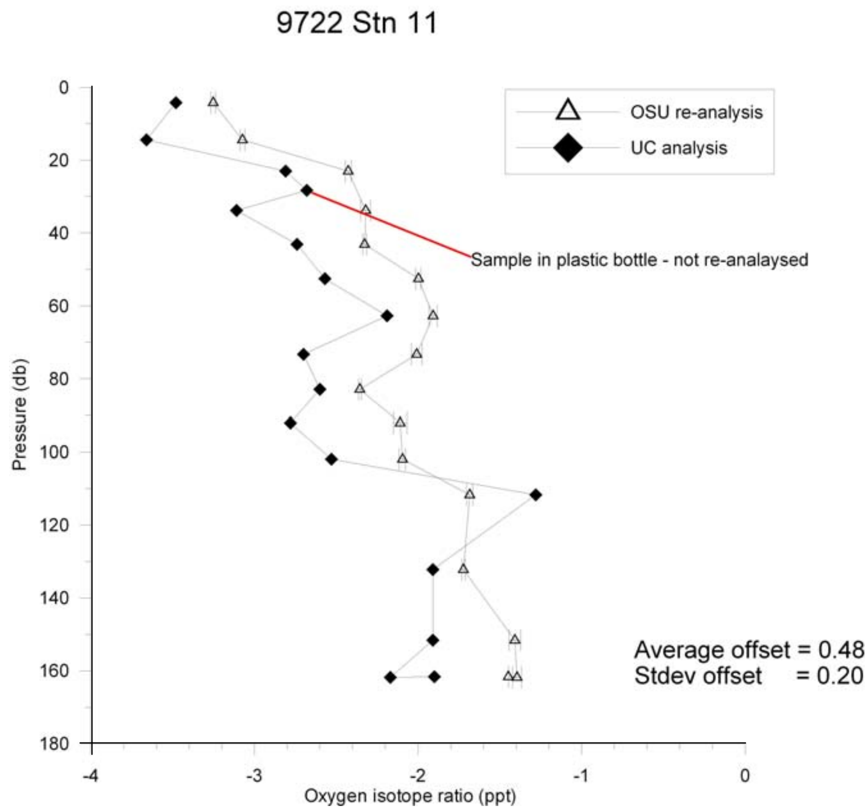


Figure 10. Comparison of oxygen isotope data obtained from samples run at the University of Calgary and Oregon State University.

Details of ^{18}O analysis

1. Aliquots of water samples are equilibrated with CO_2 typically for 18 hours. During the equilibration period, samples are kept at a constant temperature and are shaken gently.
2. Between 0.5 and 5.0 mL water are typically used for analysis.
3. Internal lab standards are analyzed repeatedly within each sample set (one standard per five samples) to guarantee quality control.
4. The pH value of the water samples must be in a range such that H_2CO_3 and HCO_3^- are abundant (pH = 6 to 7). For alkaline waters, anhydrous phosphoric acid may be added to achieve this pH.
5. After 18 hrs of equilibration, the CO_2 gas is cryogenically purified. Subsequently, the $^{18}O/^{16}O$ ratio is analyzed either by dual inlet isotope ratio mass spectrometry (Micomass 903), or by continuous flow isotope ratio mass spectrometer (Gilson sampler + VG Sira 10).

Mass spectrometric measurements

1. The obtained "raw" $\delta^{18}O_{H2O}$ values are drift corrected and normalized using internal laboratory standards.
2. Internal laboratory standards (CW: Calgary water, SW: seawater) are calibrated periodically using international standards [V-SMOW (Vienna-Standard Mean Ocean Water), V-SLAP, V-GISP].
3. Isotopically enriched water samples are calibrated using additional standards with positive $\delta^{18}O$ values provided by the IAEA (e.g. IAEA 302 and 304).
4. Corrected $\delta^{18}O_{H2O}$ values are reported in the per mil (‰) notation relative to V-SMOW.

The oxygen isotope ratio is referenced to Vienna-Standard Mean Ocean Water (V-SMOW) and reported as follows:

$$\text{(V-SMOW):} \quad \delta^{18}O = ((H_2{}^{18}O/H_2{}^{16}O)_{sample} / (H_2{}^{18}O/H_2{}^{16}O)_{VSMOW} - 1) \times 10^3 \quad [‰].$$

Accuracy and precision for $\delta^{18}O$ values of natural waters are generally better than ±0.2‰ (one standard deviation based on n = 50 lab standards).

2.3.9 Barium

Barium samples were drawn into small plastic vials following three rinses of the vials. Once at room temperature the caps were retightened and wrapped with Parafilm for storage. Barium was determined at Oregon State University using isotope-dilution and a VG Thermo Excel Inductively coupled quadrupole mass spectrometer. The method was reported by Falkner et al. (1994) with minor modifications. The pooled standard deviation is s_p = 0.750 µmol/m^3, where n = 23 pairs.

2.3.10 Chlorophyll-a

Total Chlorophyll-a (>0.7 µm) samples were collected into calibrated plastic bottles and filtered by Marty Bergman onto GF/F filters using low vacuum filtration. The filtration castles were rinsed to ensure cells were not left on the castle walls. During filtration and extraction, the samples were kept dark as much as possible. The filters were folded and wrapped in aluminum foil and frozen for shore-based analyses at the FWI.

Analyses were performed at Freshwater Institute and no information about the methods are available. Data are reported in Appendix 4.7 together with concentrations of suspended nitrogen, suspended carbon and suspended phosphorus.

2.3.11 Hexachlorocyclohexane

General handling notes

Hexachlorocyclohexane (HCH) concentrations are higher in ambient air than in subsurface water samples so it is important to minimize air contact. For this reason, the sample bottles were filled with argon prior to sampling. Where possible, the HCH samples were drawn from the Niskin before other non-gas samples were collected, i.e. after CFCs and oxygens and before nutrients or salt. A salinity sample was collected from the same Niskin as the HCH sample. The ends of the specially cleaned (hexane rinsed) tygon tube were kept covered with aluminum foil and in a zip-lock bag between samplings. When handling the tube, fingers were kept away from the end that goes into the bottle.

Sampling

The cleaned tygon tube was connected to the Niskin, then rinsed with sample water and any bubbles were removed from the tube (much like taking an oxygen sample). Then, with the water flowing, the tube was pushed to the bottom of the bottle and the bottle filled up to the top of the shoulder on the bottle (approximately 4" down from the top). Next, 200 mL of dichloromethane was added and the remaining air space flushed with nitrogen (with hydrocarbon trap in line). The teflon liner was replaced and the cap firmly closed. The bottle was inverted three times to provide the initial extraction into the dichloromethane. Samples were stored in the ship's cooler at 4 °C.

Extraction and analysis

At IOS each 4 L sample was spiked with 100 µL of internal standard (200 ng/mL each of tetrachloro-m-xylene and PCB 209) and shaken thoroughly. The sample was transferred to a 4 L separatory funnel, the stopper of which had been wrapped in teflon tape and rinsed with acetone and dichloromethane. The sample was shaken vigorously for five minutes with frequent venting and allowed to settle for approximately 30 minutes before the DCM was drawn off into a 500 mL Erlenmeyer flask. The sample bottle was rinsed with 100 mL of dichloromethane which was transferred to the separatory funnel and the sample was extracted for 5 minutes. The sample was allowed to settle and the DCM added to a second Erlenmeyer flask. The bottle rinse and extraction was repeated a second time with 100 mL DCM. The DCM extracts from one sample were contained in two flasks, each containing ~200 mL of DCM to facilitate drying over sodium sulphate. Sufficient sodium sulphate was added to each flask to remove any residual water and then allowed to stand for approximately 20 minutes with occasional swirling. After drying, the DCM extracts were transferred to a 500 mL Kuderna-Danish (KD) flask and the Erlenmeyer flasks were each rinsed three times with 10 mL of DCM. An aliquot (10 mL) of hexane was then added to each sample together with a few boiling chips, a reflux chimney filled with glass reflux chips was attached to each KD flask and the samples were placed in a hot water bath at approximately 70 °C and allowed to evaporate down to a volume of approximately 2 to 3 mL. The chimneys of each sample flask were rinsed with a small volume of hexane and the sample was allowed to cool before being transferred (with three hexane rinses) to a 15 mL centrifuge tube. The volume is reduced to 1 mL under nitrogen and then put through an 8 gm Florosil (baked, 1.2% deactivated) column, eluted with hexane for F1, 15% DCM in hexane for F2 and 1:1 DCM in hexane for F3 (volumes required were pre-determined per batch of Florosil). For HCH and HCB analysis F1 and F2 were combined and, because the internal standard elutes in F1, 10 µL of the internal standard was added to F3. Solvent volumes were reduced to 2 to 3 mL in a water bath at 75 °C and transferred to centrifuge tubes where they were reduced to 250 µL under nitrogen. A 100 µL aliquot of recovery standard (200 ng/µL each of 4,4' dibromo-octafluorobiphenyl and PCB 204) was added immediately prior to GC analysis. The GC was a HP 5890 with an Electron Capture detector and a 60 m DB-5, 0.25 mm film thickness, column was used. The carrier gas was helium and the make-up gas was argon-methane. A 1 µL aliquot of the sample was injected, splitless for 1 minute. The GC program was as follows:

Oven temperature 100 °C for 2 minutes, heated at 10 °C/m in to 200 °C, heated at 3 °C/min to 300 °C, hold for 5 minutes. The total program was 50 minutes. The injector temperature was 250 °C and the detector temperature 320 °C. Peak areas were quantitated using response factors generated from a linear regression fit to a areas from the standard at different concentrations (~10, 25, 50, 62.5 ng/mL). The standard contained α-HCH, β-HCH, γ-HCH and HCB and was calibrated against a certified reference standard Z-014C-R.

See Appendix 4.5.3 for HCH plots.

3. REFERENCES

Barwell-Clarke, J. and Whitney, F. 1996. Institute of Ocean Sciences Nutrient Methods and Analysis. *Can. Tech. Rep. Hydrogr. Ocean Sci.* 182:vi + 43p.

Carpenter, J.H. 1965. The Chesapeake Bay Institute technique for the Winkler dissolved oxygen method. *Limnol. Oceanogr*. 10:141-3.

Epstein, S. and Mayeda, T. K. 1953. Variation of O^{18} content of waters from natural sources. *Geochimica et Cosmochimica Acta.* 4:213-224.

Falkner, K.K., MacDonald, R.W., Carmack, E.C. and Weingartner, T. 1994. The potential of barium as a tracer of Arctic water masses. p. 63-76. *In:* O.M. Johannessen, R.D. Muench and J.E. Overland [eds.]. The Polar Oceans and Their Role in Shaping the Global Environment: The Nansen Centennial Volume, AGU Geophys. Monograph Series, AGU Books, Washington, D.C.

Fofonoff, N.P. and Mallard, R.C. 1983. Algorithms for computation of fundamental properties of seawater. UNESCO Technical Papers on Marine Science. 44:141-143.

Horita, J., Wesolowski, D. and Cole, D. 1993. The activity-composition relationship of oxygen and hydrogen isotopes in aqueous salt solutions: I. Vapor-liquid water equilibration of single salt solutions from 50 to 100 °C. *Geochimica et Cosmochimica Acta.* 57:2797-2817.

Lewis, E.L. and Perkin, R.G. 1978. The Practical Salinity Scale 1978: conversion of existing data. *Deep Sea Res*. 28A:307-328.

Minkley, B. and Chase, G. 1997. Dissolved Oxygen Determination Methods and Procedures. Institute of Ocean Sciences, July 30, 1997. Internal Document.

O'Neil, J.R., Adami, L.H. and Epstein, S. 1975. Revised value for the ^{18}O fractionation factor between CO_2 and water at 25^{o}C. J. Res. U.S. Geol. Surv. 3:623-624.

4. APPENDIX

4.1 SCIENCE PARTICIPANTS

Table 3. Onboard Science Team

Name	Affiliation	Position
Fiona McLaughlin	IOS	Chief Scientist
Douglas Sieberg	IOS	Chief Technician
Ed Carmack	IOS	CTD Watchleader
Bon VanHardenberg	IOS	CTD Watchstander
David Walsh	IOS	CTD Watchstander
Brian May	IOS	CTD Watchstander
Janet Barwell-Clarke	IOS	Nutrient Analysis
Catherine Welch	FWI	Nutrient Analysis
Darren Tuele	IOS	Contaminant sampling
David Huntley	Contractor	Deck
William Strachan	DOE	Contaminants, Water
Stephen Hurlbut	GSC	Sediment
Gary Stern	FWI	Contaminants, Sediment
Robert Danell	FWI	Sediment
Paul Wilkinson	FWI	Sediment
Harold Welch	FWI	Biomass
Mary O'Brien	IOS	Oxygen Analysis
Marty Bergman	FWI	Chlorophyll-a Analysis
Michael Hingston	BIO	CFCs
Manon Poliquin	BIO	Carbonates
Humfrey Melling	IOS	Mooring Leader
Peter Gamble	IOS	Mooring Technician
Dave Riedel	IOS	Mooring Technician
Paul Johnston	IOS	Mooring/Chemistry
Peter Scheifele	MMA	Bioacoustics
Nick Worobey	MMA	Bioacoustics
Andries Blouw	FWI	Communications
Kevin Krajick		Science Writer

Table 4. Principal Investigators

Name	Affiliation	Program
Fiona McLaughlin	DFO-IOS	Program Leader, CTD and chemistry
Mary O'Brien	DFO-IOS	Chemistry Leader
Kelly Falkner	OSU	Barium
Marty Bergmann	DFO-FWI	Biology Leader
Buster Welch	DFO-FWI	Zooplankton Leader
James Reist	DFO-FWI	Fish Leader
Peter Scheifele	MMA	Bioacoustics Leader
Bill Strachan	DOE	Contaminants, air, water
Gary Stern	DFO-FWI	Contaminants, sediment and biota
Steve Hurlbut	CGS	Coring Leader
Humfrey Melling	DFO-IOS	Mooring Leader

Table 5. Affiliation Abbreviations

BIO	DFO, Bedford Institute of Oceanography, NS
CGS	Canadian Geological Survey
DFO	Department of Fisheries and Oceans, Canada
DOE	Department of the Environment
FWI	Freshwater Institute, MB
IOS	DFO, Institute of Ocean Sciences, BC
MMA	Mystic Marine Aquarium, CT
OSU	Oregon State University, OR

4.2 LOCATION OF SCIENCE STATIONS

Table 6: Station location and sampling/data collection activities conducted.

Station	CTD Cast No.	Date	Time (UTC)	Latitude (N)	Longitude (W)	Depth (m)	Activity
1	100	31/08/97	13:14	74 40.1	93 21.8	101	R
2	101	31/08/97	14:58	74 41.0	93 00.5	140	R
3		31/08/97	19:03	74 40.1	92 18.9	125	C
4	102	31/08/97	20:17	74 41.8	91 57.1	99	R
4		31/08/97	20:51	74 41.5	91 55.9	99	Z
4		31/08/97	20:50	74 41.5	91 55.9	99	LVF
4		31/08/97	21:52	74 40.7	91 54.1	100	G
5	103	01/09/97	13:54	74 41.2	92 14.4	97	R
5		01/09/97	14:43	74 41.5	92 14.2	92	BM
6		01/09/97	16:51	74 36.8	92 14.9	148	C
7		01/09/97	18:32	74 29.3	92 28.3	222	C

Station	CTD Cast No.	Date	Time (UTC)	Latitude (N)	Longitude (W)	Depth (m)	Activity
7		01/09/97	19:09	74 29.8	92 35.6	210	F
8		01/09/97	19:30	74 29.9	92 39.5	210	LVF
8	104	01/09/97	19:41	74 30.3	92 38.0	214	R
8		01/09/97	20:20	74 30.2	92 37.9	214	Z
8		01/09/97	22:41	74 30.0	92 34.8	206	BC
8		01/09/97	23:15	74 29.8	92 34.4	206	PC
9		02/09/97	01:42	74 24.9	93 00.0	158	C
10		02/09/97	13:16	74 20.0	93 16.6	166	C
10		02/09/97	13:33	74 20.0	93 15.6	170	BM
10		02/09/97	14:02	74 19.9	93 14.2	170	P
10		02/09/97	14:23	74 19.7	93 12.8	171	BA
10		02/09/97	14:51	74 19.6	93 10.7	170	SS
11	105	02/09/97	17:36	74 15.1	93 32.5	170	R
11		02/09/97	17:36	74 15.1	93 32.5	170	LVF
11		02/09/97	18:09	74 14.6	93 28.3	170	Z
11		02/09/97	19:32	74 14.2	93 28.0	170	SN
11		02/09/97	19:46	74 14.2	93 27.8	171	SS
11		02/09/97	19:53	74 14.0	93 25.3	169	C
11		02/09/97	20:15	74 14.0	93 27.6	170	R
11		02/09/97	20:40	74 13.5	93 21.6	170	G
12	107	02/09/97	22:15	74 12.3	93 32.8	139	R
12		02/09/97	22:38	74 12.2	93 32.0	132	BA
13	108	03/09/97	14:33	74 18.1	96 17.6	179	R
13-a		03/09/97	17:27	75 08.0	96 34.0	18	C-H
13-b		03/09/97	17:33	75 08.0	96 42.0	45	C-H
13-c		03/09/97	17:44	75 08.0	97 00.0	91	C-H
13-d		03/09/97	17:57	75 08.0	97 25.0	70	C-H
13-e		03/09/97	18:06	75 08.0	97 32.0	9	C-H
13-f		03/09/97	18:16	75 08.0	98 00.0	27	C-H
14	109	03/09/97	20:29	74 53.1	97 20.2	175	R
14		03/09/97	22:00	74 48.8	97 11.1	272	BC
14		04/09/97	00:35	74 48.0	97 06.0	267	PC
15		04/09/97	14:30	74 52.9	99 22.4	49	SS
15-a		05/09/97	01:00	75 01.6	100 25.7	22	C-H
15-b		05/09/97	01:07	75 02.6	100 31.9	48	C-H
15-c		05/09/97	01:16	75 02.1	100 37.4	88	C-H
15-d		04/09/97	14:29	74 44.9	99 57.5		BA-H
16	110	04/09/97	22:29	75 02.0	100 50.0	207	R
17		04/09/97	23:26	75.01.8	101 10.6	121	C
18		05/09/95	00:22	75 01.8	101 35.8	95	C
19	111	05/09/95	01:14	75 01.8	102 00.9	141	R
19		05/09/95	01:27	75 02.0	101 59.9	149	BA
20		05/09/95	03:01	75 01.9	102 25.8	139	C
21		05/09/95	13:11	75 05.1	102 54.9	112	C
21		05/09/97	13:27	75 05.3	102 55.2	110	SS
22	112	05/09/97	14:32	75 05.9	103 15.6	162	R
22		05/09/97	15:01	75 06.0	103 15.6	170	BM
22		05/09/97	15:32	75 06.2	103 16.0	199	P

Station	CTD Cast No.	Date	Time (UTC)	Latitude (N)	Longitude (W)	Depth (m)	Activity
23	113	05/09/97	18:23	75 06.2	103 27.2	146	R
23		05/09/97	19:00	75 06.1	103 27.7	150	T
24	114	05/09/97	23:19	74 40.6	104 05.5	201	R
24		05/09/97	23:45	74 40.5	104 04.9	201	BM
24		06/09/97	00:42	74 40.1	104 04.7	199	BC
24		06/09/97	01:19	74 39.9	104 04.3	203	BA
25	115	06/09/97	13:31	75 07.0	105 00.4	101	R
26		06/09/97	14:19	75 05.9	105 10.7	223	C
27		06/09/97	15:00	75 04.9	105 25.1	242	BM
27		06/09/97	15:37	75 04.4	105 24.2	252	SN
27		06/09/97	15:37	75 03.4	105 25.3	221	SN
27	116	06/09/97	16:54	75 03.3	105 25.5	217	R
27		06/09/97	18:12	75 04.0	105 20.8	258	BC
27		06/09/97	19:49	75 03.8	105 20.6	250	PC
28		06/09/97	21:02	75 04.0	105 40.3	130	C
29	117	06/09/97	21:34	75 04.0	105 50.0	97	R
30	118	07/09/97	13:22	74 55.0	108 40.9	140	R
31		07/09/97	14:37	74 48.4	108 48.8	86	C
32		07/09/97	15:09	74 46.6	108 51.9	162	LL
32	119	07/09/97	15:35	74 45.6	108 55.6	155	R
32		07/09/97	15:38	74 45.6	108 55.6	155	P
32		07/09/97	18:35	74 46.1	108 51.9	160	T
33	120	07/09/97	21:45	74 36.1	109 00.4	274	R
34		08/09/97	01:07	74 21.6	109 08.5	449	BM
34	121	08/09/97	13:17	74 22.4	109 04.5	429	R
34		08/09/97	14:30	74 22.6	109 05.08	428	BC
34		08/09/97	16:26	74 22.8	109 04.2	427	PC
34		08/09/97	17:50	74 23.07	109 03.9	425	SS
34-d		08/09/97	17:42	74 08.6	109 11.0	556	C-H, SN, BA
34-c		08/09/97	16:43	73 58.7	109 19.9	307	C-H
34-b		09/09/97	02:13	73 09.9	110 12.6	250	C-H
34-a		09/09/97	01:34	73 01.6	110 14.1	72	C-H
36		14/09/95	13:00	73 27.0	126 36.1	240	MA
36	122	14/09/97	14:23	73 27.0	126 35.8	108	R
36		14/09/97	15:18	73 26.0	126 35.7	91	SN
36		14/09/97	15:35	73 26.7	126 35.6	108	SN
37	123	14/09/97	23:17	74 09.1	125 54.5	92	R
37		14/09/97	23:48	74 09.1	125 54.3	88	MD
36		15/09/97		74 27.0	126 35.0	107	MA
38		16/09/97	14:53	70 56.8	133 41.9	78	MR
38		16/09/97	15:09	70 56.5	133 41.3	82	MR
38	124	16/09/97	15:46	70 56.5	133 41.6	82	R
38		16/09/97	16:30	70 56.4	133 43.8	81	LL
39		16/09/97	16:47	70 55.9	133 44.9	80	C
40		16/09/97	17:15	70 55.4	133 52.1	86	C
41		16/09/97	17:40	70 55.0	133 58.1	79	C
42	125	16/09/97	18:10	70 55.0	133 04.6	96	R

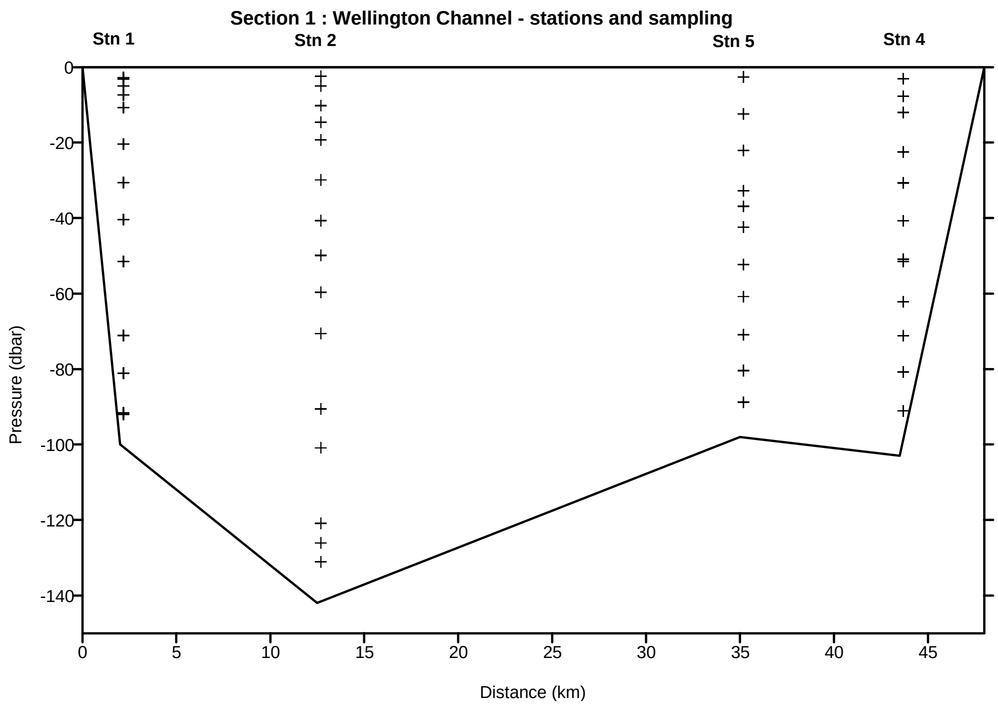
Station	CTD Cast No.	Date	Time (UTC)	Latitude (N)	Longitude (W)	Depth (m)	Activity
43		16/09/97	19:29	70 57.1	134 01.9	105	C
44		16/09/97	19:54	70 59.2	134 00.7	214	C
43		16/09/97	20:30	70 56.9	134 01.5	103	C
45		16/09/97	21:18	71 02.6	134 00.0	324	C
46		16/09/97	22:00	71 05.4	133 59.1	388	C
47	126	16/09/97	22:35	71 09.0	133 59.0	82	R
47		17/09/97	00:48	71 02.4	133 34.1	184	T
48	127	17/09/97	02:04	70 58.9	133 18.2	74	R
49		17/09/97	02:55	70 57.0	133 35.2	86	C
38		17/09/97	04:22	70 56.5	133 41.8	80	MD
38		17/09/97	04:45	70 56.6	133 41.6	80	MD
50		17/09/97	14:57	70 20.2	133 42.3	57	MR
50		17/09/97	15:40	70 20.1	133 42.4	57	MR
50		17/09/97	16:13	70 20.1	133 44.9	56	C
50		17/09/97	17:08	70 20.9	133 48.8	54	BC
50		17/09/97	19:21	70 23.1	133 56.9	54	GC
50		18/09/97	02:50	70 20.0	133 41.8	58	MD
50		18/09/97	03:11	70 20.0	133 41.5	58	MD

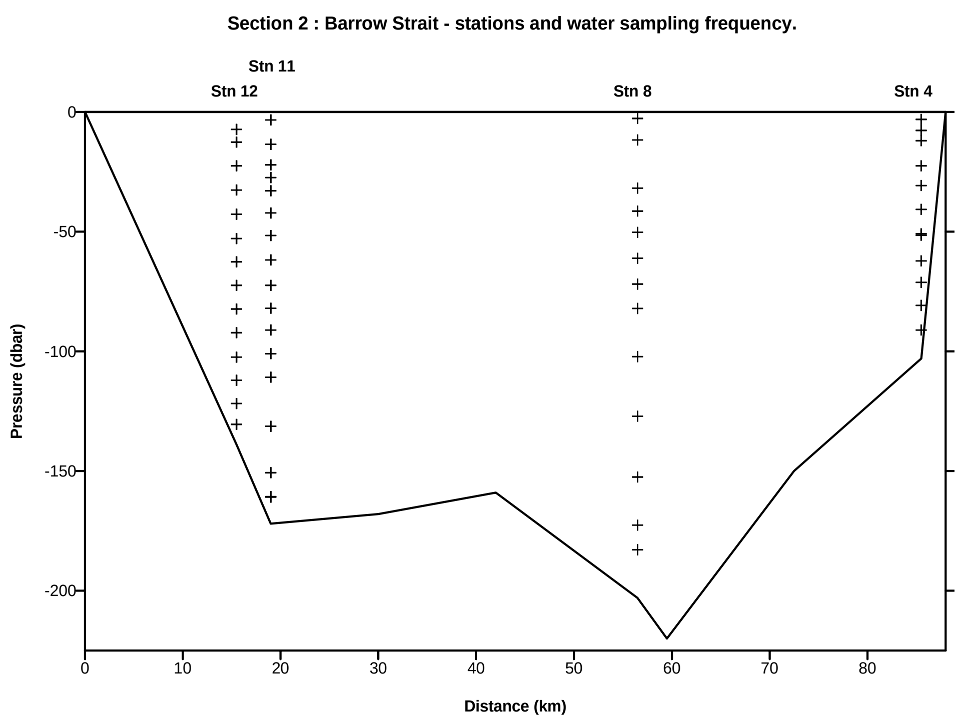
Key:

R: Rosette
C: CTD
C-H: CTD by helicopter
Z: Zooplankton
LVF: Large volume filter
G: Grab
BC: Box core
PC: Piston core
GC: Gravity core
BM: Biomass

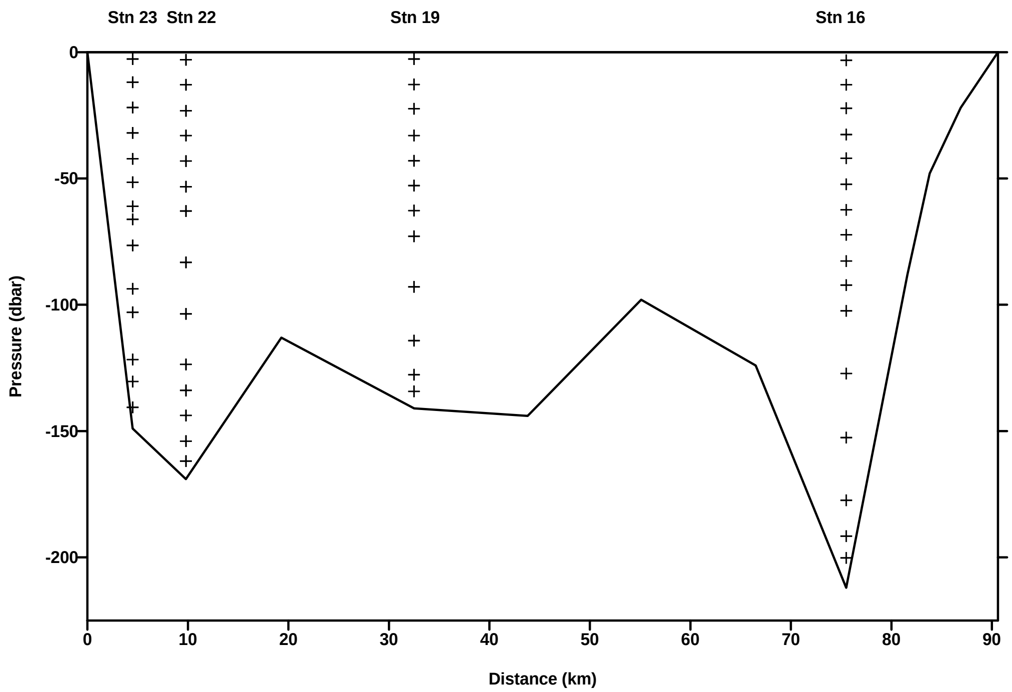
P: Surface pump
SN: Surface niskin
MA: Mooring acoustic/location
MR: Mooring recovery
MD: Mooring deployment
SS: Side scan sonar
F: Fish
LL: Long line
T: Trawl
BA Bioacoustic

4.3 STATION AND WATER COLUMN SAMPLE LOCATIONS

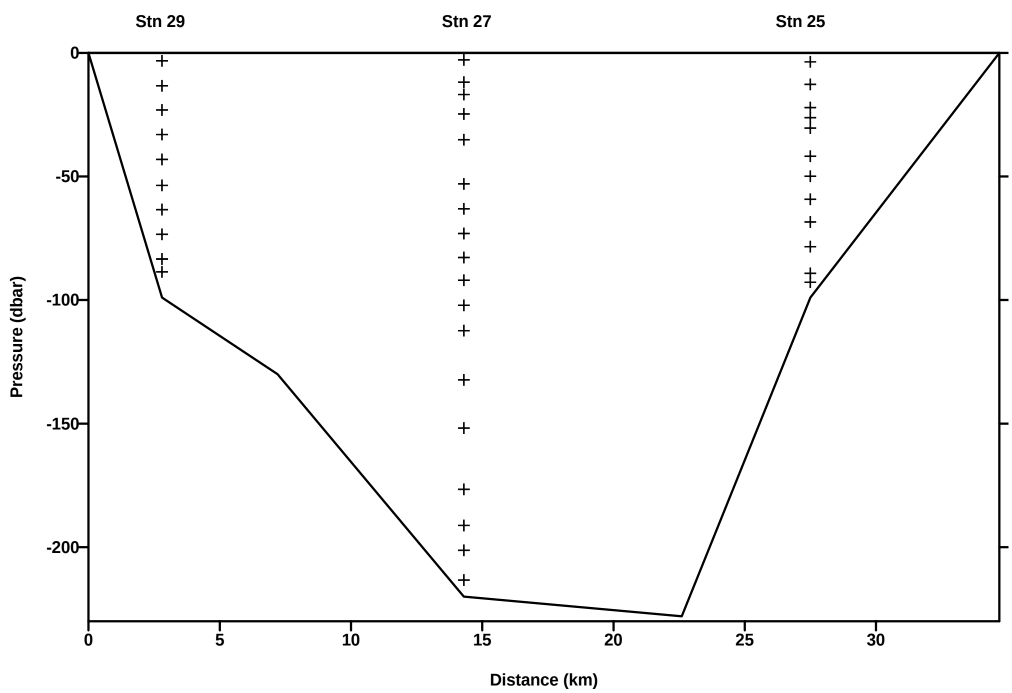




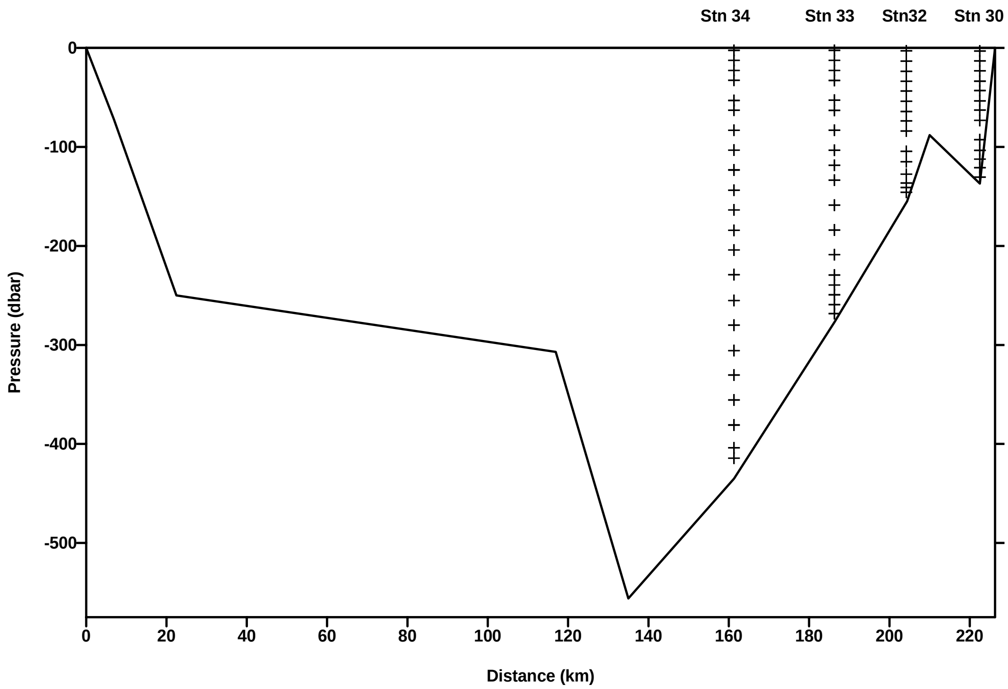
Section 4 : Austin Channel - stations and sampling frequency.



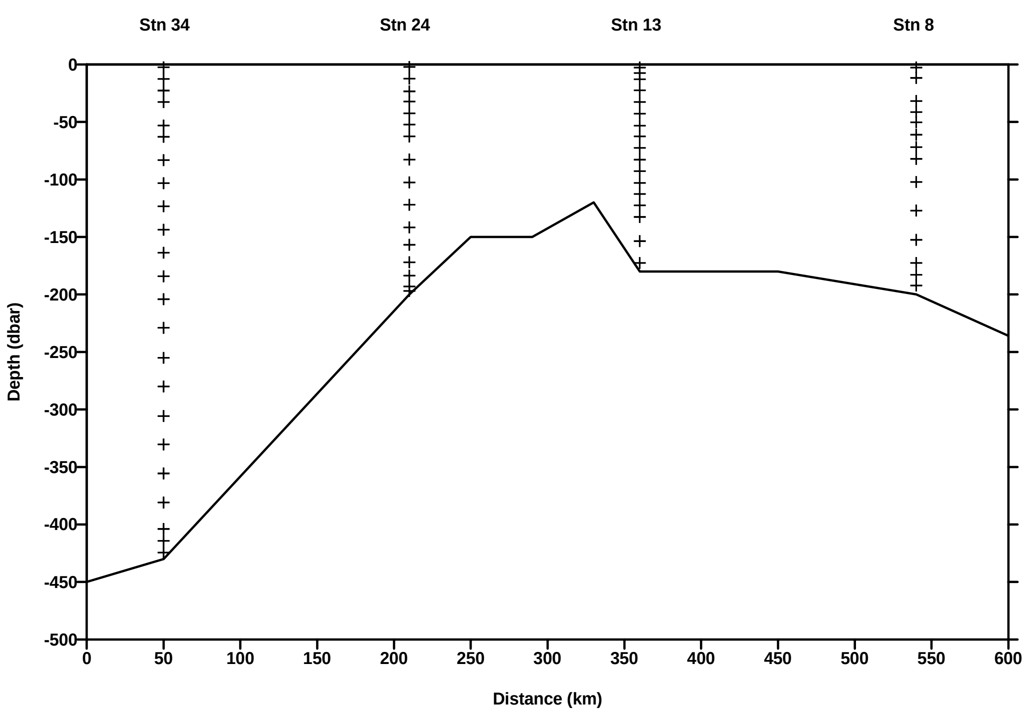
Section 5 : Byam Channel - stations and sampling frequency.



Section 6 : Viscount Melville Sound - station and sampling frequency.



Section 7 : Along Parry Channel - station and sample frequency.



4.4 CTD CALIBRATION AND PROCESSING SUMMARY

4.4.1 ICTD Calibration

Table 7: Calibration Information for FSI ICTD/1329.

Sensor		Pre-Cruise		Post-Cruise	
Name	**Serial No.**	**Date**	**Location**	**Date**	**Location**
Pressure	1329	21 May 1996	*factory		
Temperature	1329	21 May 1996	*factory	Jan 1998	**IOS
Conductivity	1329	21 May 1996	*factory		
Transmissometer	598	13 Feb 1996	lab – Bernard Minkley		
Fluorometer	93S				

* The FSI ICTD was calibrated at the factory on May 21, 1996. The calibration coefficients are stored internally and the output of T, C and P is calibrated.
** A post-cruise temperature calibration was done for the ICTD by Bon van Hardenberg at IOS.

Table 8: Calibration Coefficients for FSI ICTD/1329.

Channel Name	Formula Number	Coefficients	
		C1	**C2**
Temperature: Post-cruise	10	- 0.0241006	1.001510
Transmissometer	10	- 0.08	1.008654

<u>Sensor Calibration Notes</u>

Note the log incorrectly stated that the transmissometer was #234. The transmissivity output from the ICTD is a 14-bit number which has been converted from the analog signal. The raw values have not been converted to %TR. (This can be done by dividing by 16383 (2**14 – 1) and multiplying by 100. The results imply that the 25 cm path length has been accounted for in the conversion.)

The transmissometer coefficents were derived from the measurements made by Bernard Minkley at IOS as follows:

Trans (actual) = 20* Voltage (actual)
= 20* [*A*/*B* *(Voltage measured – Blank Voltage)]
= *A*/*B* * Trans (measured) – 0.08
= 1.008654 * Trans (measured) – 0.08

where *A* = Air Voltage measured at the factory (4.6620); *B* = Lab calibration (4.6220); Blank voltage = 0.0040.

4.4.2 MCTD Calibration

Table 9: Calibration Information for FSI MCTD/1534.

Sensor		Pre-Cruise		Post-Cruise	
Name	**Serial No.**	**Date**	**Location**	**Date**	**Location**
Pressure	1534	May 1996	*factory	—	—
Temperature	1534	May 1996	*factory	Jan 1998	**IOS
Conductivity	1534	May 1996	*factory	—	—

* The FSI MCTD was calibrated at the factory in May, 1996. The calibration coefficients are stored internally and the output of T, C and P is calibrated.
** A post-cruise temperature calibration was done for the MCTD by Bon van Hardenberg.

Table 10: Calibration Coefficients for FSI MCTD/1534.

Channel Name	Formula Number	Coefficients	
		C1	**C2**
Temperature: Post-cruise	10	-0.0241006	0.999785

4.4.3 CTD Processing Summary

Processed by: Germaine Gatien
Date of Original Processing: 6 March – 31 March 1998
Date of Reprocessing: 18 January 2002 – 22 March 2002
Number of original casts: 167
Number of casts processed: 165 (88 ICTD, 77 MCTD)

This data was reprocessed in February/March 2002. The preliminary steps from the original processing were reused.

4.4.3.1 Preliminary Steps

These preliminary steps were completed in March of 1998. The Log Books were not available. Spreadsheets detailing times and positions of casts and salinity bottle data were obtained. The cruise summary sheet was completed.

The cast numbers were changed to IOS format. Casts using the ICTD used designations such as D3; these were renamed 97**00**.raw. Casts using the MCTD used designations such as M5; these were renamed 97**10**.raw. Thus, the fifth position in the cast number indicates which CTD was used. Consecutive numbers were assigned to each instrument independently, so you can not determine from the numbers when two instruments were deployed on the same cast. There was a problem using the page plot routine in IOSSHELL as it would not print the reference number properly if there was a number other than 0 in the 5th position. The cast numbers were written by hand on those plots. Two raw files named D111NG and M110B were named 97223111 and 97223110, and processed to determine what was in them; they proved to be repeats of other casts and somewhat noisier so were deleted.

For the ICTD the data (*.raw and *.bt1) was converted to IOS Headers in IOSSHELL using "CONVERT FSI RAW FILES" with 1329.cnf as configuration file. There were many errors in headers (Lat and Long format) which had to be fixed before this conversion was successful. Comments about data quality found on spreadsheets were entered in the IOS Headers. Station names were entered into the headers after conversion. (The station names are entered correctly in the IOS Headers, but in the header summary and header checks only 4 digits are printed, so the last number or letter is dropped from casts #8 and #36-42 of leg 1). Header Check and Header Summary were run after calibration since the converted files do not contain depth information.

Before conversion of MCTD files to IOS HEADERS, the first line of many of the *.raw files had to be removed. Many files required further editing before conversion was successful. The first line of data frequently contained only zeros and the last line was often blank; such lines had to be removed. Corrupted data points were replaced by interpolation. Frequently there was an opening section with an incorrect time, followed by several zero lines and then the data with the correct time began. Such opening sections had to be removed, but no useful data was lost because those sorts of records occurred while the instrument was kept near the surface for equilibration. The configuration file used was 1534.cnf. Station names were added as part of the conversion which was done using "CONVERT FSI MICRO CTD FILES".

4.4.3.2 Preliminary Editing and Despiking

This work and all that follows was completed from January to March, 2002. The calibrations of P, T and C are done internally by the FSI CTDs. Conversion to IOS HEADER format was done and record numbers were added using ADD TIME CHANNEL to enable time series plotting. Time series plots were produced for all casts and were reviewed to guide editing.

<u>ICTD</u>

A text editor was used to remove initial partial downcast records before the full cast as follows:

9722: 103-110,112-121.

The despike routine in Viewedit was used to remove spikes in the following casts:

9722: 104.105,113,114,119,121,123,125

For most casts the despiking was only applied to the conductivity channel, but for cast 97200019 all channels contained spikes.

MCTD

Before plotting, a text editor was used to remove initial partial downcast records and a few records with near-zero conductivity records at the beginning or end of the cast. Reviewing the plots led to further editing of 3 casts. More records were removed from the beginning of cast #101 to eliminate a spike, and the up-cast sections of casts #116 and 129 were removed to avoid spikes at the bottom of the casts.

The times shown in the headers for casts #1 through #7 are in UTC in some places and UTC – 7 hours in others (although in all entries they are said to be in UTC). The times were corrected to UTC as required. VIEWEDIT was used to remove a few spikes mostly at the beginning and end of casts. In running program DELETE (see section *4.3.5* below) it was found that there were sudden drops in pressure values too fast to be real; the temperature and conductivity varied smoothly at these points. These casts were revisited in VIEWEDIT and interpolation was used to smooth the pressure.

4.4.3.3 Pressure Study

ICTD

The end of the up-cast section, each ICTD cast was examined to find the first pressure for which the CTD appeared to be at the surface. The surface was judged to be where conductivity fell suddenly to low values. The average value for the 3 legs was 1.1 db and for the individual legs the averages were 0.9, 0.8 and 1.4 db, respectively. The range was from 0.1 to 2.6 db.

MCTD

For the MCTD casts the average for the three legs were -1.3 db with the range from +0.7 to -4.9 db. There is an obvious dependence on the maximum pressure of the cast with an average of -0.3 db (values of from -1.2 db to +0.2 db) for casts deeper than 400 m. The surface pressure for downcasts is generally about -3.6 db with no obvious dependence on air or surface water temperatures. Were the pressure dependence of the up-cast surface pressures due to hysteresis then we would expect that the change would increase with maximum pressure. The change does increase until the casts reach a depth of about 600 m. But casts deeper than 600 m do not show any further increase; if anything there is a slight decrease with deeper casts. There is no obvious temporal variation. Since the error is gradually changing through each cast (from -3.6 db to -0.3 db for a deep cast) recalibration requires either an extremely complicated scheme or a compromise. It was decided to pick a value that might be considered typical of the mid-depth of the downcast section of a 200 to 400 m-deep cast. The MCTD pressure will be recalibrated by adding 2 db to all values, but it should be noted that the uncertainty in pressure will be ±3 db.

4.4.3.4 Time Compensation

<u>a) Development of the Routine</u>

Various problems with the design and operating configuration of the FSI CTD conspire to yield measured sequences of ocean temperature and conductivity that are asynchronous and have different bandwidths. If these are combined directly in the computation of salinity, the precision of the result is low and there are large systematic errors.

An ad hoc (but only partial) solution to this problem was implemented in the processing of these data. The bandwidth of the conductivity channel was reduced by convolving the data series with an impulse response function that had been designed to make the time response characteristic for conductivity the same as that for the slower temperature sensor. The impulse response function, determined empirically via plunge trials, is not a simple analytic function. It is available only as a 10 s sequence of discrete values at intervals of 5 ms (ICTD-ImR.lis, for the ICTD). For use with field data, the function was sub-sampled to the sampling interval of the CTD using the ad hoc programme ICTD-Adj.exe.

Following convolution of the conductivity time series with the sub-sampled impulse response (C-Wgts.lis), the time series of temperature and salinity are optimally matched for the calculation of salinity. The match is not perfect for three reasons: (a) the conductivity signal is aliased because the sampling frequency (approximately 4 Hz) is much lower than the Nyqvist frequency (20 Hz) of the signal; (b) spatial averaging over the sampling volume for conductivity is ignored; and (c) differences in fall speed are ignored.

Because of differing sensor-response characteristics, the pressure, temperature and conductivity time series are not synchronous. Moreover, the numerical convolution introduces an additional delay in the conductivity response, which can be calculated from the impulse response for all CTD variables except temperature. The relative timing of conductivity and temperature outputs were determined by trial and error to achieve best results in computing salinity.

A QuickBasic45 programme (ICTDelay.exe) was used to determine the delay in temperature that was optimal for salinity calculation. We use the platinum sensor as the source of temperature data, since the output of the fast-response thermistor drifts badly (> 30 m°C) over times measured in tens of minutes. The programme works from the file ICTDImR.lis that contains the empirical impulse response correction sampled at 5 ms intervals. The programme calculates salinity for four different delays in temperature. Delays for temperature in the range of 100 to 500 ms are suggested. A graphical examination of the salinity series is the easiest route to choice of the 'best' delay.

Because of aliasing during sampling, processing with the 'best' delay will not in general provide a useable profile of salinity. The computed profile must be smoothed using a running average. Near the surface where vertical gradients in salinity are steep, an average over about two seconds will generally produce the desired monotonic increase in salinity (typical of Arctic waters) without flattening the gradient. At greater depth, where the salinity gradient is weaker, the computational noise in salinity dominates the background gradients and a longer averaging period is desirable. Using the output of ICTDelay.exe, various running averages of the salinity time series were examined graphically, to determine the 'best' filter length. Averaging intervals may range from 9 points (2.5 s) near the surface to 23 points (6.3 s) at depth.

Data from the MCTD were adjusted for optimal congruence in response to changing temperature and conductivity using an analogous procedure. Because the two models of CTD have different temperature sensors, the convolution functions for the two instruments are different.

b) Application of the Time Compensation Routines

The edited files from step *4.3.2* were used for the time compensation step. Programs ICTD-ADJ and MCTD-ADJ were applied to the conductivity to match the time response of the temperature sensors. For the ICTD the sample interval was set to 0.275 s and the time response to 0.325 s; for the MCTD the values were 0.616 s and 0.275 s.

CLEAN was run to fix the headers.

For the ICTD the IOSSHELL routine REMOVE was used to create two sets of files containing:

- adjusted Pressure, adjusted Temperature and adjusted Conductivity
- adjusted Pressure, adjusted Transmissivity and adjusted Fluorescence

The latter set of files will be left unprocessed and a note should be made that the values are nominal, raw values.

For the MCTD, REMOVE was used to create only one set of files containing:

- adjusted Pressure, adjusted Temperature and adjusted Conductivity

4.4.3.5 DELETE

ICTD

Before running DELETE the Padj,Tadj,Cadj files output from the TIME COMPENSATION program were edited to remove initial records as follows:

- records with zero conductivity, and
- the first 36 records with non-zero conductivity.

This editing was not necessary for the casts that had been edited in Step 2.
A few bad records were removed from the end of the up-cast of cast #32.
Then DELETE was run using the following parameters:

- Surface Record Removal: None
- Pressure filtered over width: 9 (9 x 0.275 s = 2.48 s)
- Swells deleted. Warning message if pressure difference of 2.00
- Delete Slow Drop Rate: Yes

- Min Drop Rate (m/sec): 0.5
- Drop Rate Width (samples): 8
- Sample interval = 0.275 s

Reviewing the DELETE log indicated no problems. The LAST DEPTH in the DEL files was checked against the maximum sampling depth from the header files and found to be reasonably close for all casts. Where bottle records existed the depth of the deepest bottles were found to be less than the LAST DEPTH except for casts #97200042, 97220104, 97220108, 97220112, 97220114 and 97220127. In those cases the descent rate was very low in the bottom few meters and DELETE operated correctly in removing the data.

<u>MCTD</u>
DELETE was run using the following parameters:

- Surface Record Removal: None
- Pressure filtered over width: 5 (5 x 0.616 s = 3.08 s)
- Swells deleted. Warning message if pressure difference of 2.00
- Delete Slow Drop Rate: Yes
- Min Drop Rate (m/s): 0.5
- Drop Rate Width (samples): 5
- Sample interval = 0.616 s

Reviewing the warnings led to the conclusion that there were problems in the pressure channel for three casts (97201005, 97201018 and 97221138); those casts were put through VIEWEDIT again to repair the pressure and then put through steps *4.3.4* and *4.3.5* again. The only warnings remaining pertain to surface, bottom, up-casts or areas of low descent rate.

4.4.3.6 Calibration of the ICTD files

The instrument was calibrated at Falmouth Scientific on 23 May 1996, and internal coefficients have not been changed since that time. The instrument converts observations to scientific units through use of a calibration table stored within the instrument. These values are scaled for recording as hex integers. The temperature and pressure sensors were calibrated at Scripps (Bon van Hardenberg) in December, 1998. At this time, it was noted that the output from the fast thermistor was unstable, drifting as much as 30 m°C in 45 minutes. German users of the I-CTD have noted the same problem. This sensor is judged unusable.

Calibration with file 1997new.ccf was used on the ICTD files to convert conductivity to conductivity ratio and correct conductivity for effects of *P* and *T* on the dimensions of the C cell, to apply the post-cruise calibration of temperature, to apply a -1.1 db offset to the pressure and to calculate salinity. The BOT files were calibrated using 1997bot.ccf (like the ICTD CCF file except that these files have not been through the time compensation step). Plots were made of the data but no editing was found necessary. The files were bin averaged on bottle number and named RAC.

The header summary was run after calibration to check depths.

4.4.3.7 Initial Calibration of the MCTD Files

Calibration with file 1997mctd.ccf was used on the MCTD files to convert conductivity to conductivity ratio and correct conductivity for effects of P and T on the dimensions of the C cell, to apply the post-cruise calibration of temperature, to apply a +2db offset to the pressure and to calculate salinity.

4.4.3.8 Filtering of ICTD Files

For the ICTD salinity was run through a box car filter for all casts using the following parameters:

Name of filter size reference channel: Pressure:Adj

Filter sizes:

up to: 0.100000E+03 : 9 (2.58s)
up to: 0.300000E+03 : 13 (3.58s)
up to: 0.500000E+04 : 23 (6.32s)
up to: 0.600000E+04 : 23 (6.32s)
up to: 0.700000E+04 : 23 (6.32s)

HEADER EDIT was run to correct the time increment in the RAW section of the headers to reflect the value found in section 4, namely 0.275 s.

Multi-cast T-S plots were produced to compare deep sections of nearby casts as a quality control check. The variations are within the range expected for this instrument. The ICTD data was then analyzed by Humfrey Melling to compare it with that from bottles; he determined that no correction to conductivity was needed. For details see the following files prepared by H. Melling:

- •1997-20-22 ICTD conductivity calibration bottle levels.doc.
- •ICTD Conductivity Calibration.doc.

4.4.3.9 MCTD vs ICTD - Recalibration of MCTD Data

There were 20 casts during which the ICTD *and* MCTD were used simultaneously. COMPARE was run using thinned ICTD and MCTD files (9720COM1.xls) for the 11 of those casts which sampled below 200 db. Large differences were found in the salinity, but there are also differences in temperature which varied in sign and magnitude. To quantify the temperature differences the maxima or minima of features were compared at a few casts. This again showed that the differences vary in sign. A study was made of the differences at 6 casts in regions of low temperature gradient and at the bottom of another 18 casts. Plotting differences against cast #, pressure, temperature and temperature gradient suggests that it is temperature that is the controlling factor. A trendline was found from the fit of temperature difference vs temperature in 9720com1.xls and used to recalibrate the MCTD temperature (MCTDtemp.ccf); salinity was recalculated.

After this step COMPARE was rerun (9720com2.xls) and show that the MCTD salinity is too high by 0.0665 psu using data from below 500 db. The salinity was recalibrated using MCTDsal.ccf and COMPARE was run again (9720com3.xls) and the results were found to be satisfactory.

4.4.3.10 Filtering of MCTD Data

For the MCTD salinity was run through a box car filter for all casts using the following parameters:

Name of filter size reference channel: Pressure:Adj

Filter sizes:

up to: 0.100000E+03 : 5 (3.08s)
up to: 0.300000E+03 : 7 (4.62s)
up to: 0.500000E+04 : 11 (6.78s)
up to: 0.600000E+04 : 11 (6.78s)
up to: 0.700000E+04 : 11 (6.78s)

HEADER EDIT was run to correct the time increment in the RAW section of the headers to reflect the value found in section 4, namely 0.616 s, to add the name of the chief scientists and the ship name to the headers and to add a warning that the pressures are to be considered ±3 db.

Multi-cast T-S plots were produced to compare deep sections of nearby casts as a quality control check. The variations are within the range expected for this instrument.

4.4.3.11 Graphical Editing

The page plots were used to decide which casts needed hand editing using CTDEDIT.

<u>ICTD</u>

Salinity was cleaned for most ICTD casts in the top 20 m. For a few casts records were removed and temperature was cleaned near the surface. Deeper instabilities were left unedited as there was no clear spiking or shed wakes to justify editing. The only casts that were not edited were:

9722: 109,111,116,118,124,126

<u>MCTD</u>

For the MCTD about half the casts needed editing. The following casts were edited near the surface (above 20 m) or at the bottom:

9722: 101,102,103,105-109,113-115,118-122,130,134,139,140.

More extensive editing was done for the following casts:

9722: none

Notes of any editing done were made in the individual files.

4.4.3.12 Final Plots

DERIVED QUANTITIES was run to calculate Theta, Depth, SVA, Gamma and Sound Speed. THIN was then run to obtain values at standard depths. Using edited files and the thinned files final page plots were produced and checked to ensure that the editing was satisfactory.

4.4.3.13 Remove Channels

The following channels were removed from the ICTD and MCTD casts: Conductivity:Adj.

4.4.3.14 Produce Final File

HEADER EDIT was used to add to the headers of all ICTD files:
- the chief scientist's name
- the ship name

4.4.3.15 Particulars

<u>ICTD</u>

97200001 - fluorometer on high sensitivity setting.
- instability near the bottom indicated in T-S plot, also found by MCTD.

File D111NG.raw was renamed 97203111. It has no bottle file and contains down, up and down sections. It is at the same site as 97201111 and was deleted.

97200032 - An error was found in position and time in the header for this cast after processing was underway. It was fixed in all files.

<u>MCTD</u>

97201013 - no data

File MCTD was renamed 97211050 because it should have been M50 originally.

File M110B was named 97223110 and converted to determine its content. It contained repeated up and down casts apparently at the same site as 97221110 and was deleted.

97201030 had a data line that was corrupted. The temperature and pressure were missing and were replaced by interpolated values.

97221108 had a data line that was corrupted. The pressure was replaced by an interpolated value.

97221118 is missing the first 1000 m of down-cast.

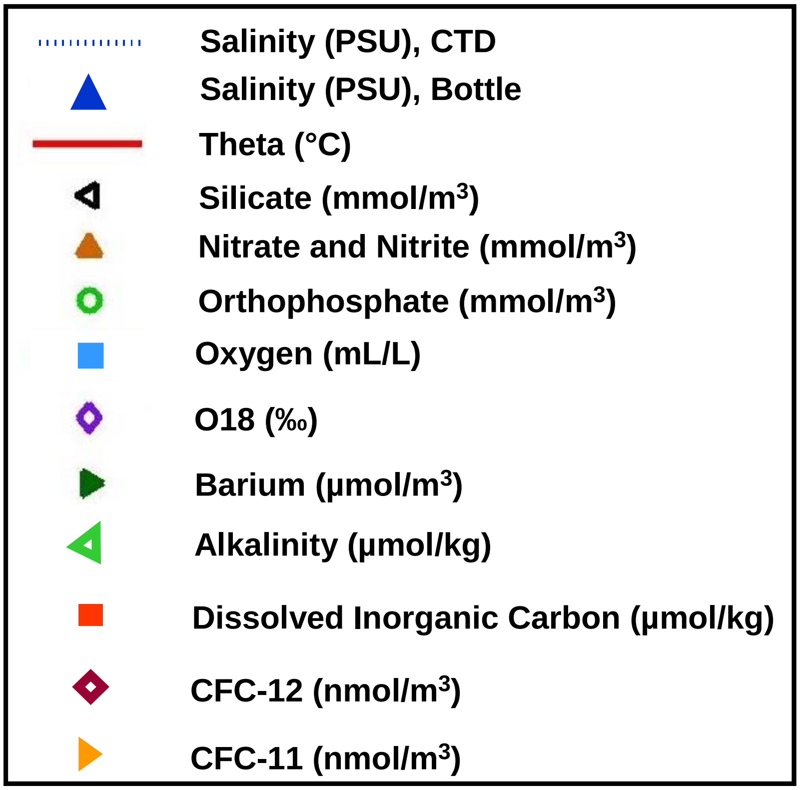
4.4.3.16 Recommendations

When using the FSI CTDs it is important to choose a consistent way of writing the latitude and longitude in the header. The IOSSHELL routine for converting to IOS headers could be edited to reflect whatever choice is made. Similarly, if a decision is made to enter the station identifier in a field (ex. Operator or Direct) the conversion program could be used to read this into the IOS headers. These changes would make the processing of the data more efficient.

Establishing the surface pressure appears to require that the CTD be held in water below the surface for a few minutes and then be raised until a conductivity of value 0 is achieved. The pressure gauge seems to require some time to equilibrate.

4.5 INDIVIDUAL STATION PLOTS

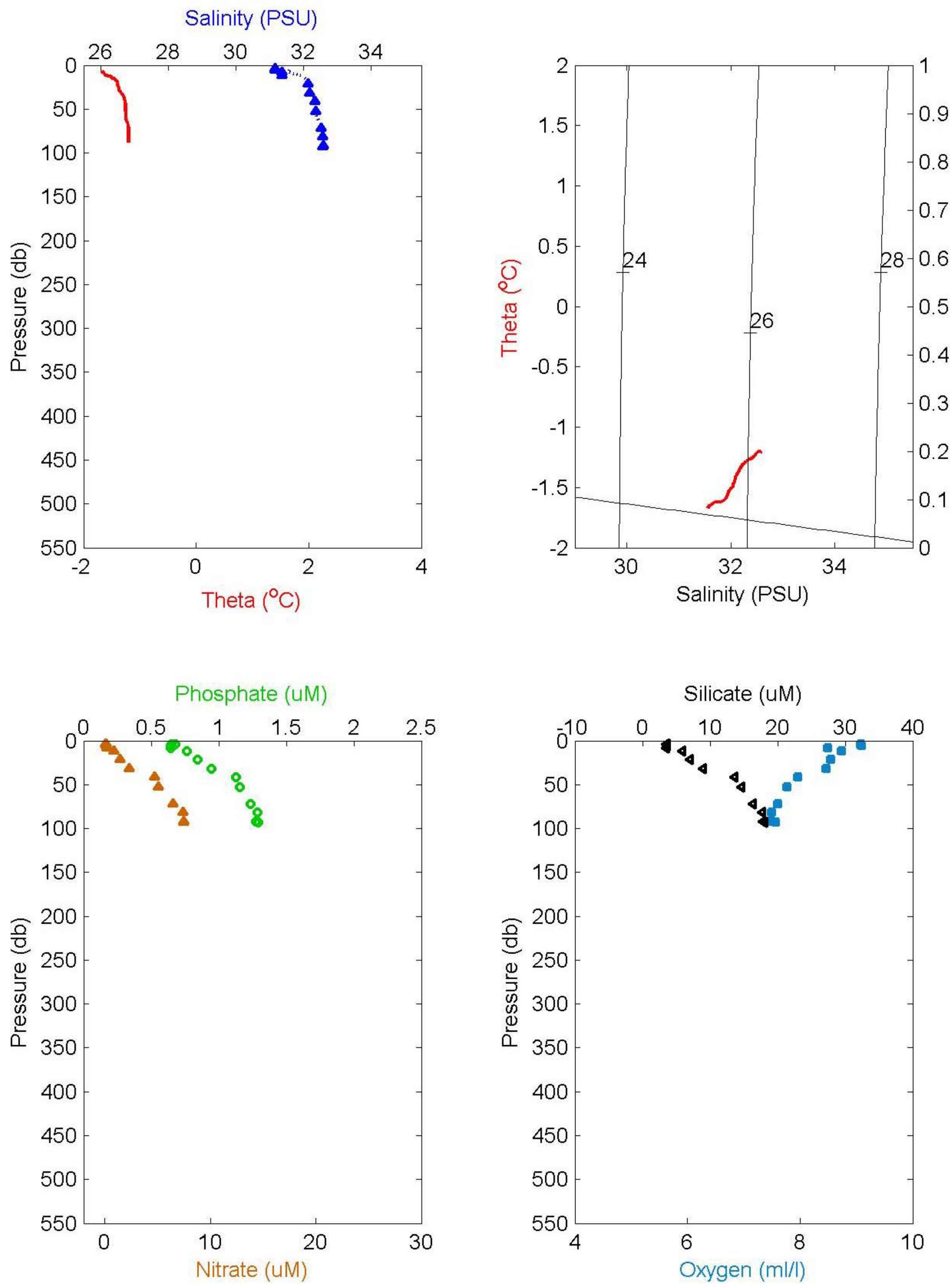
The following section contains data plots for each CTD cast taken on Cruise # 9722. See below for property legend for the individual station plots.



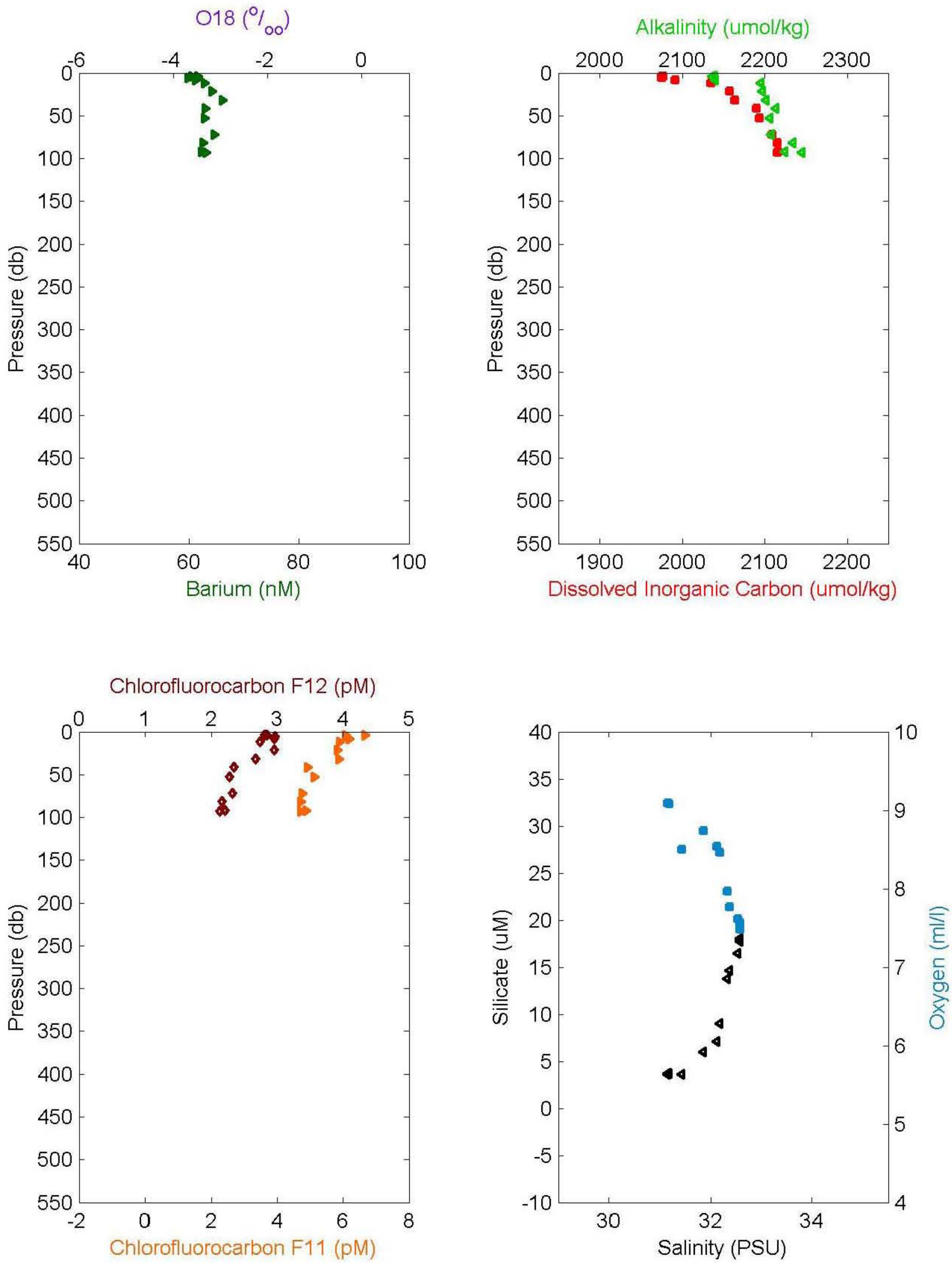
Note: mmol/m^3 is equivalent to uM and nmol/m^3 is equivalent to pM

4.5.1 CTD/Rosette

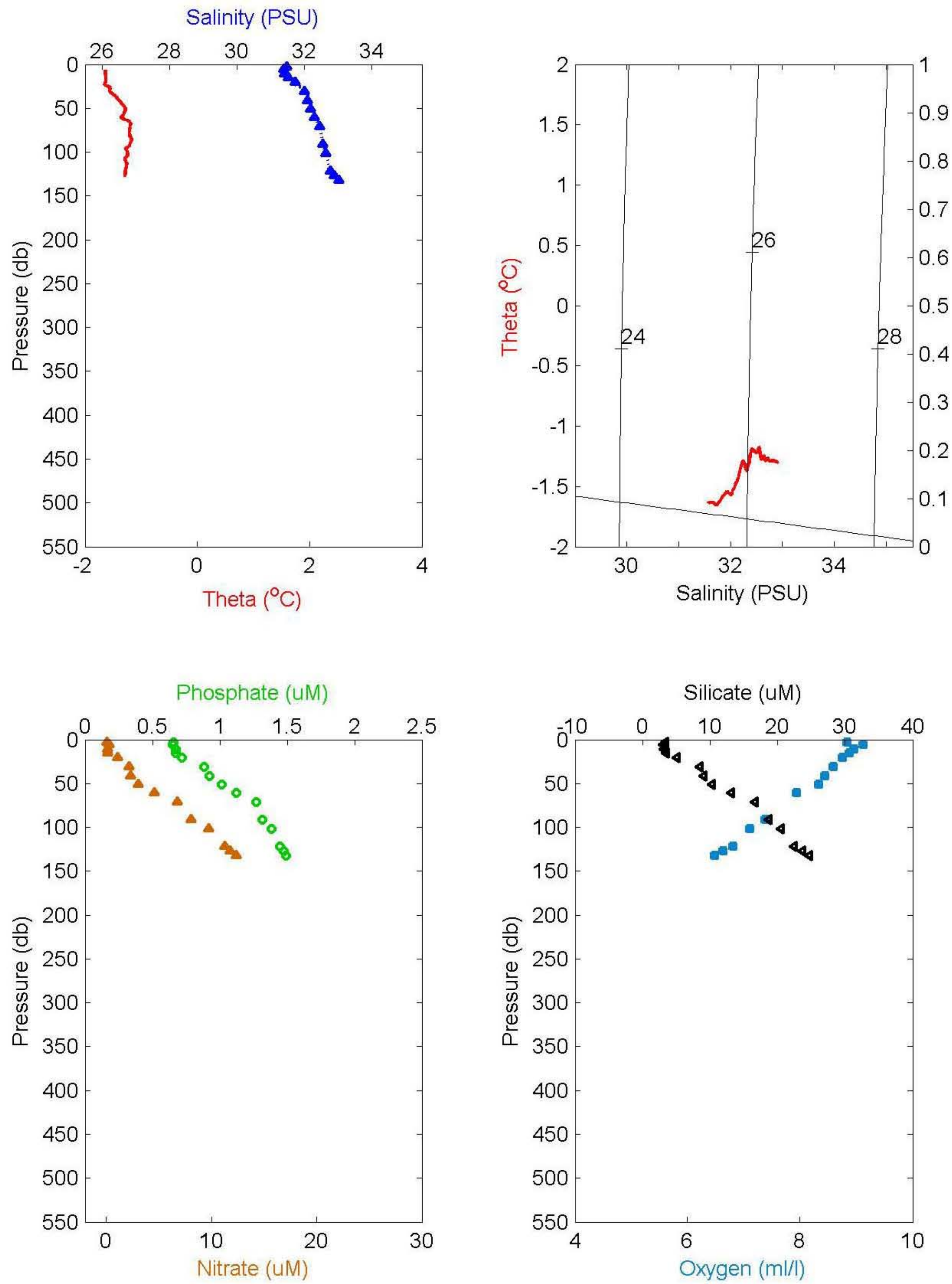
1997-22: Cast 100 Station 1



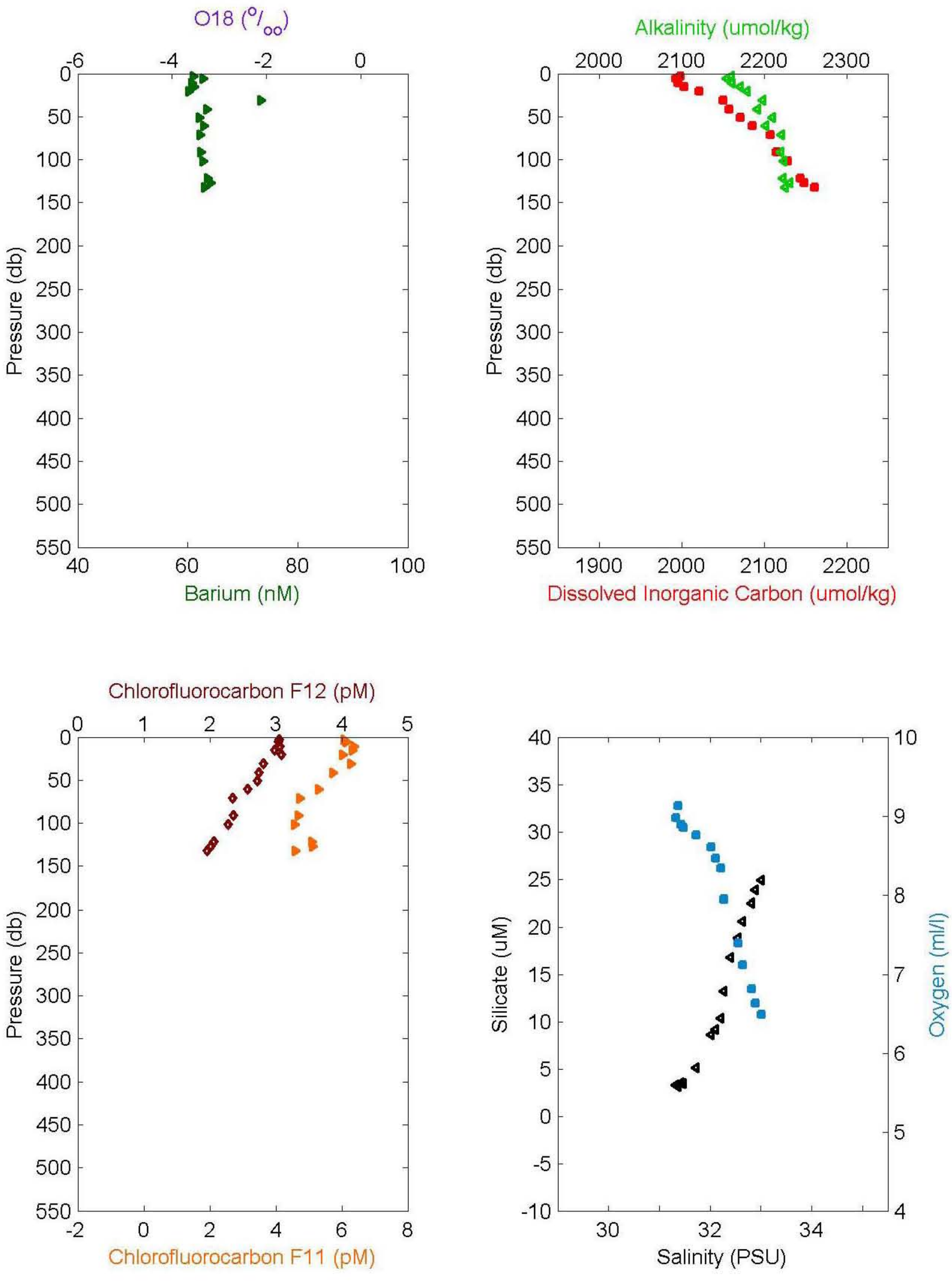
1997-22: Cast 100 Station 1



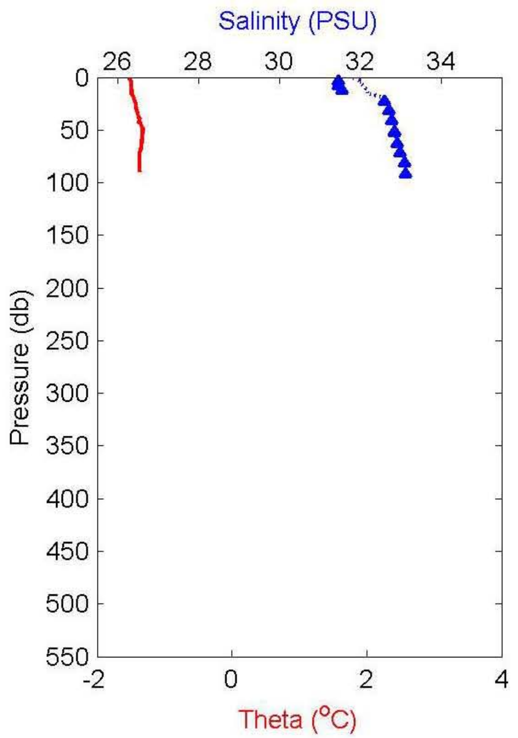
1997-22: Cast 101 Station 2

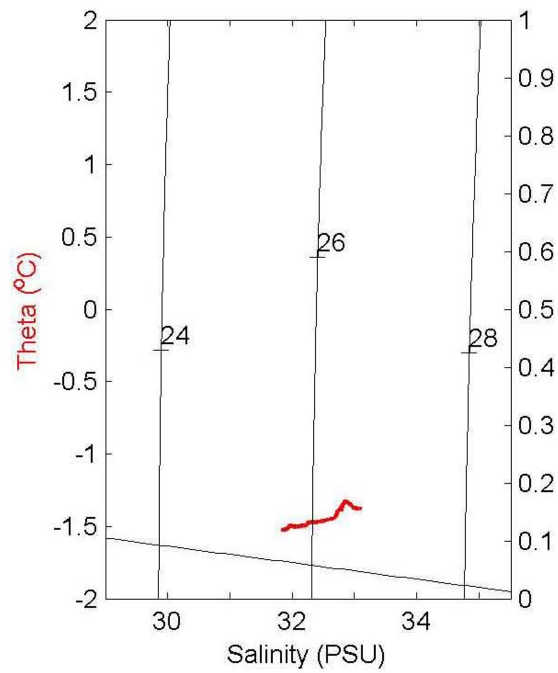


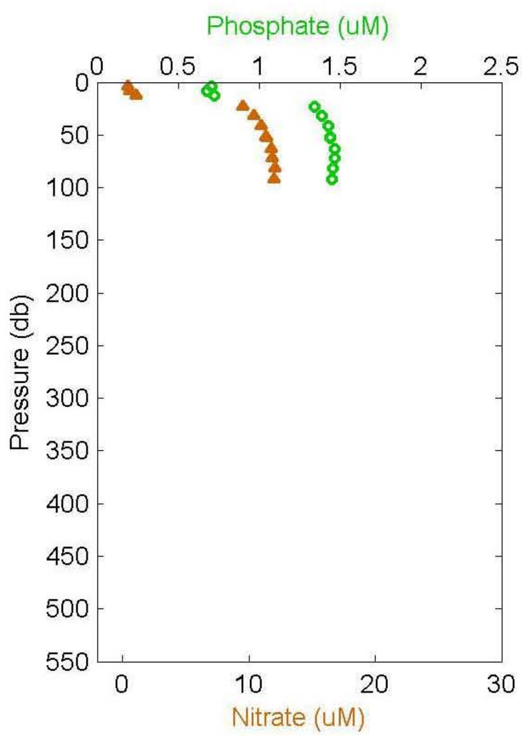
1997-22: Cast 101 Station 2

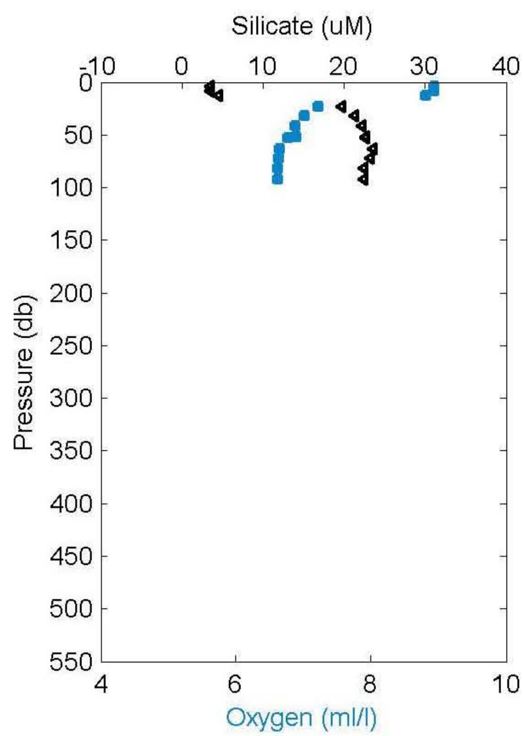


1997-22: Cast 102 Station 4

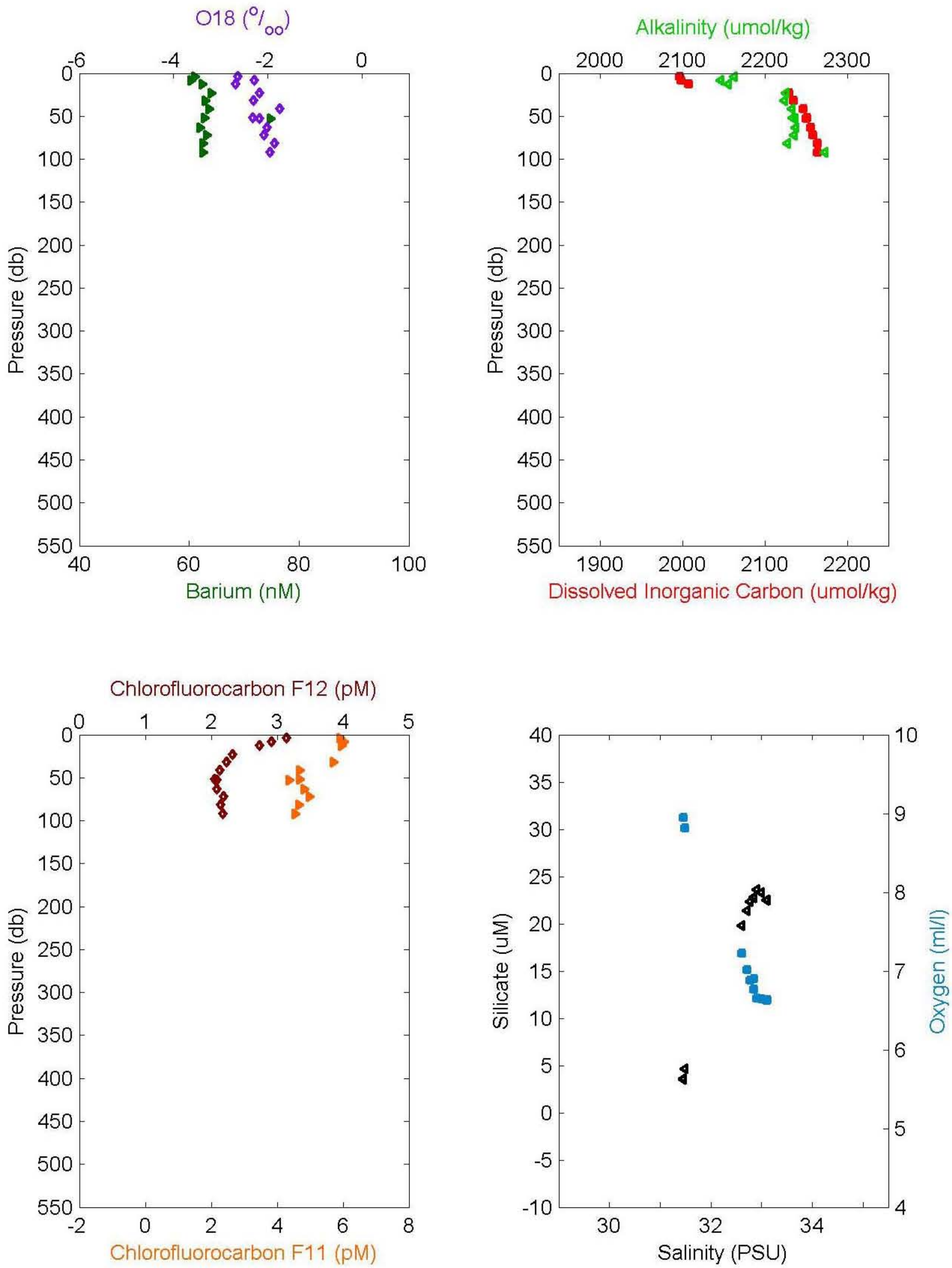




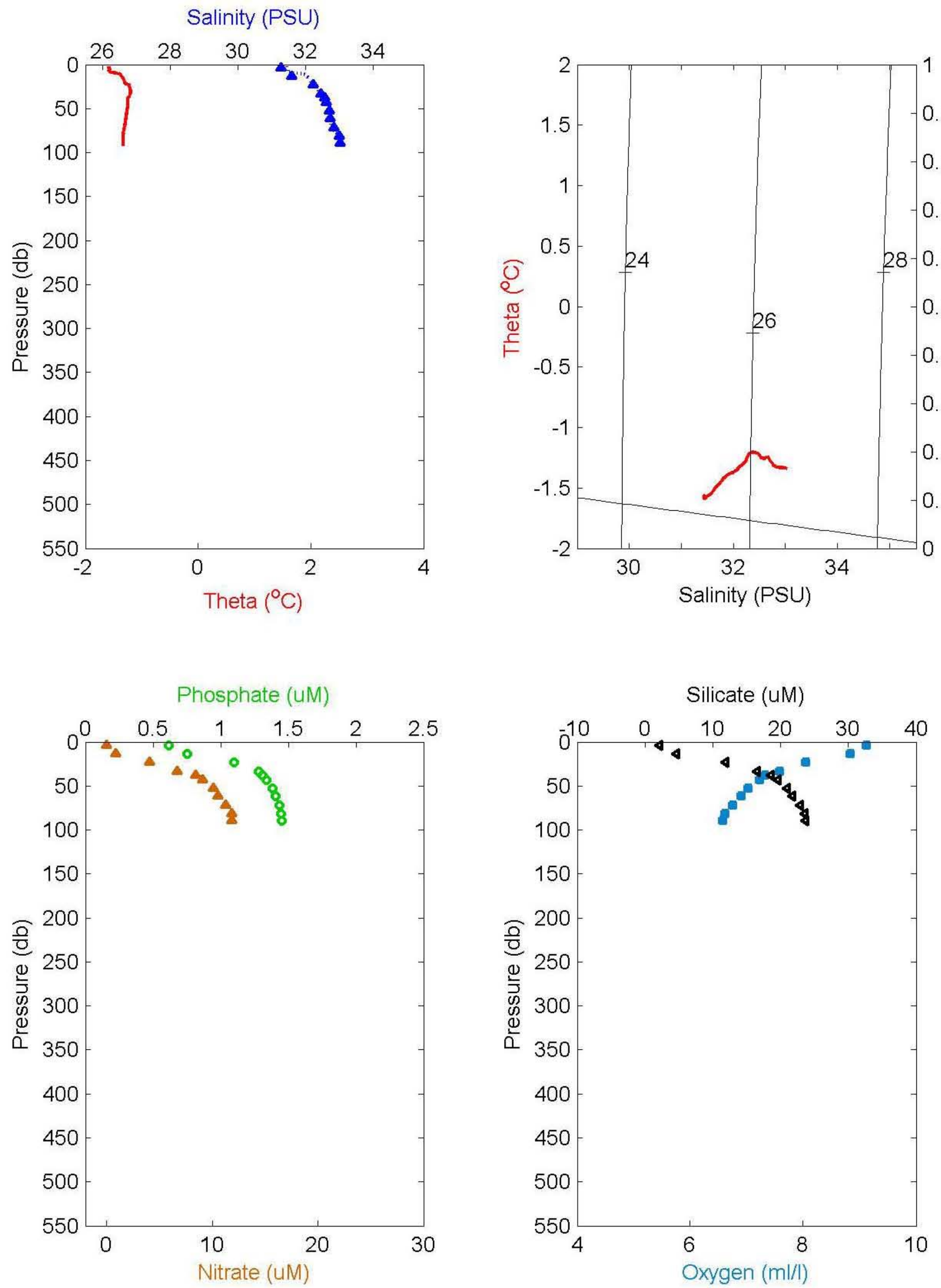




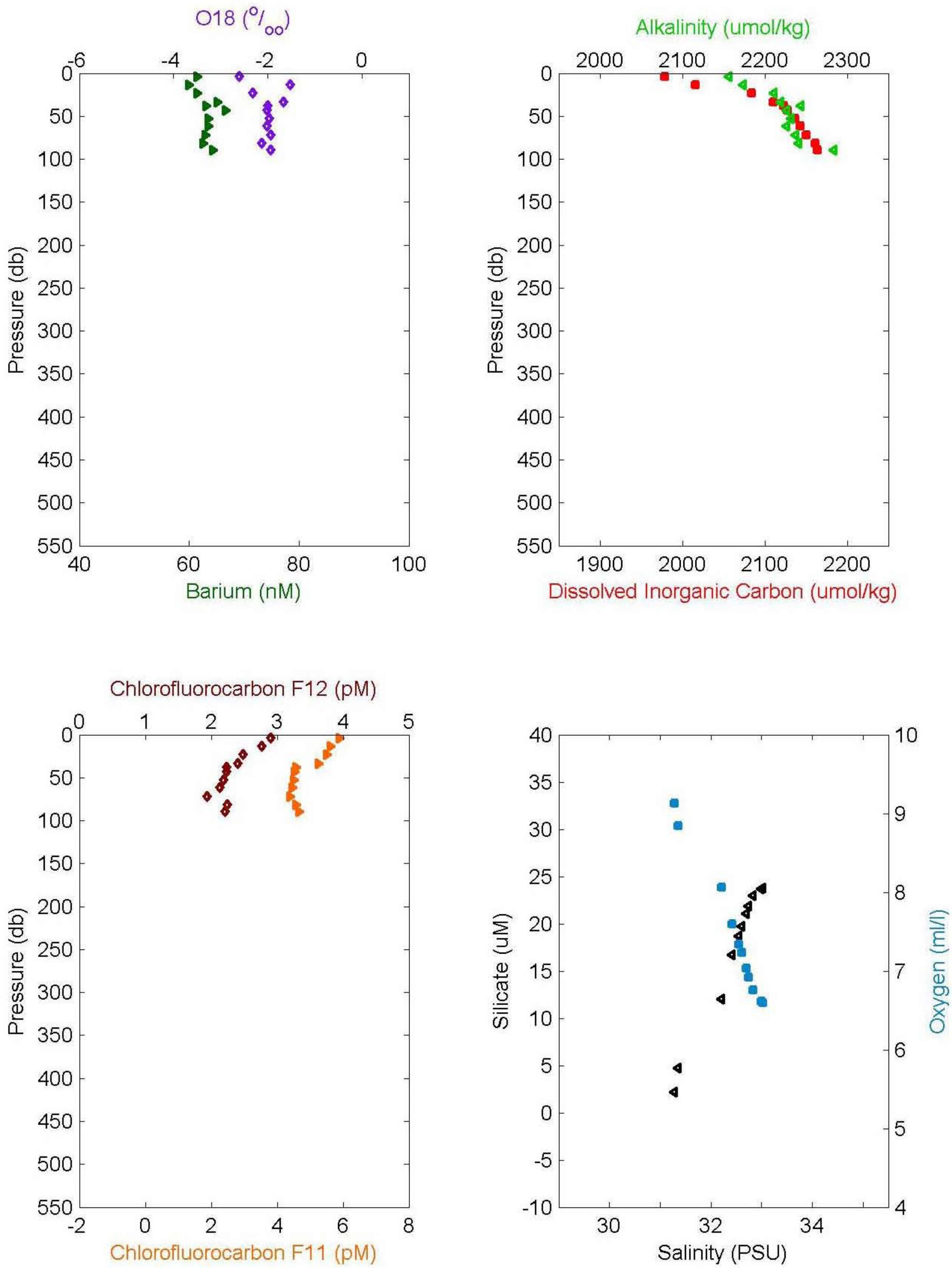
1997-22: Cast 102 Station 4



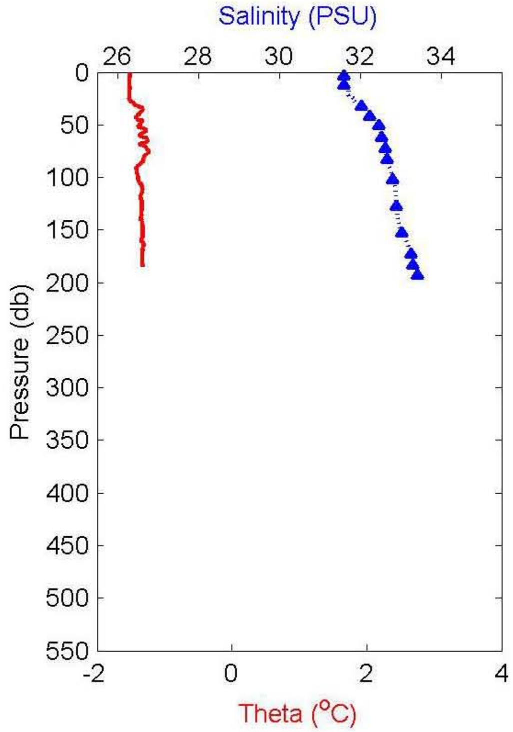
1997-22: Cast 103 Station 5

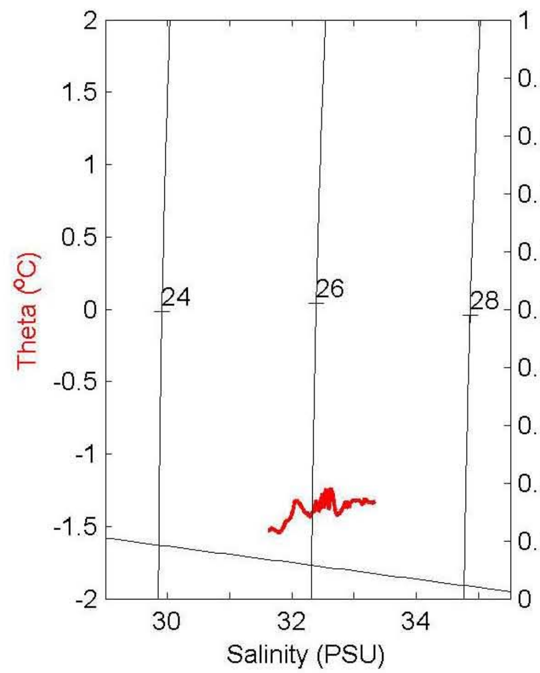


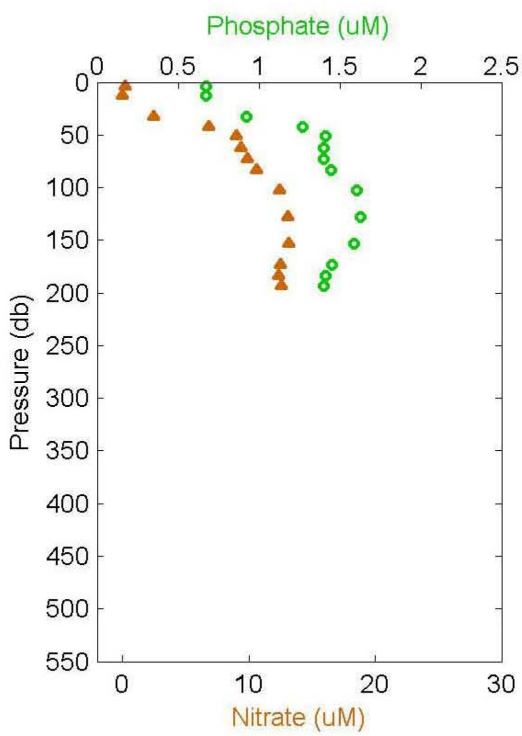
1997-22: Cast 103 Station 5

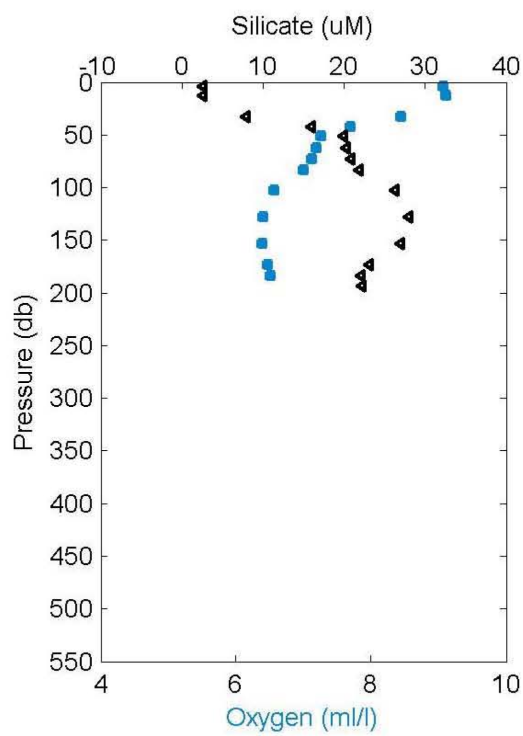


1997-22: Cast 104 Station 8

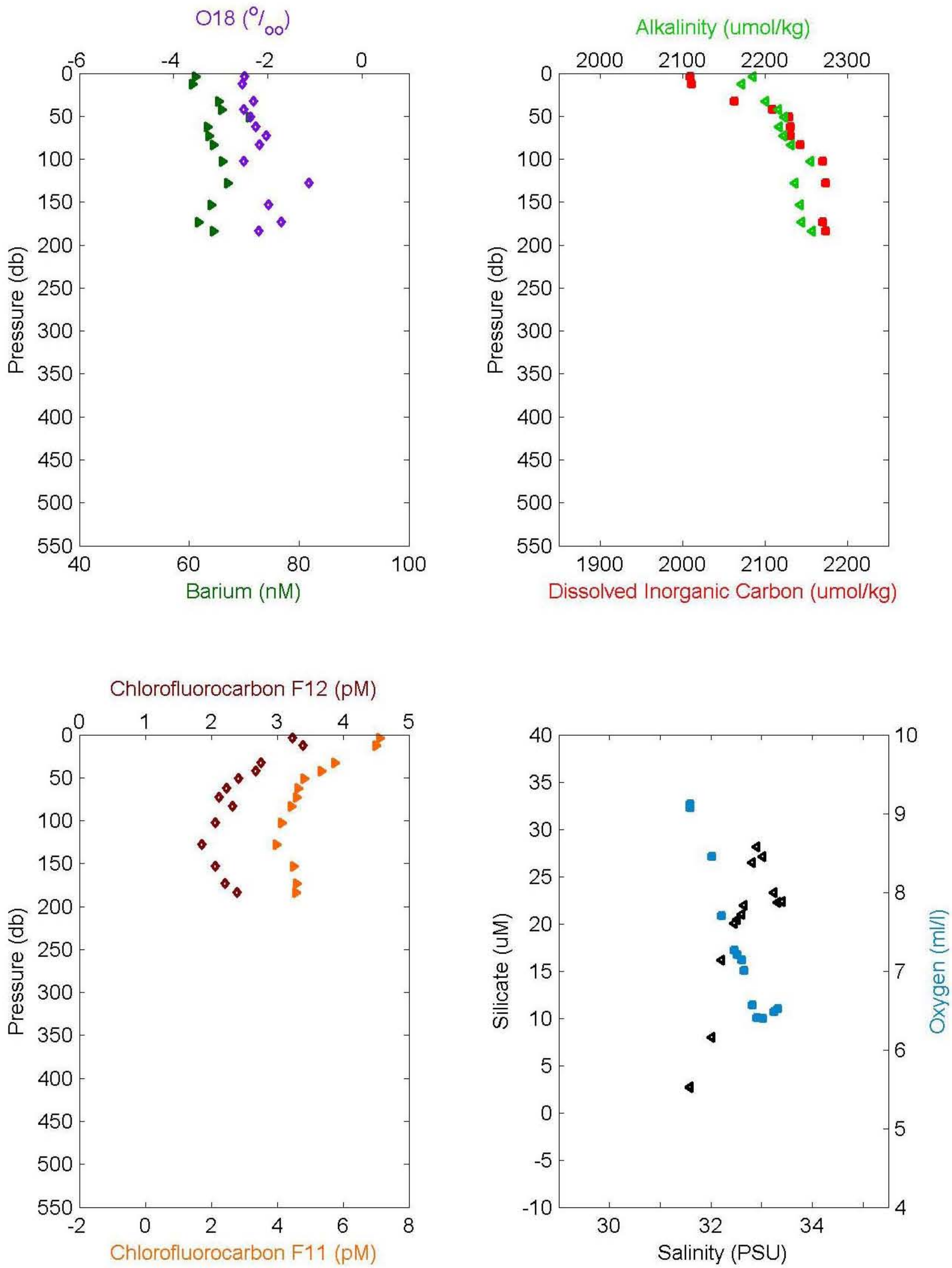




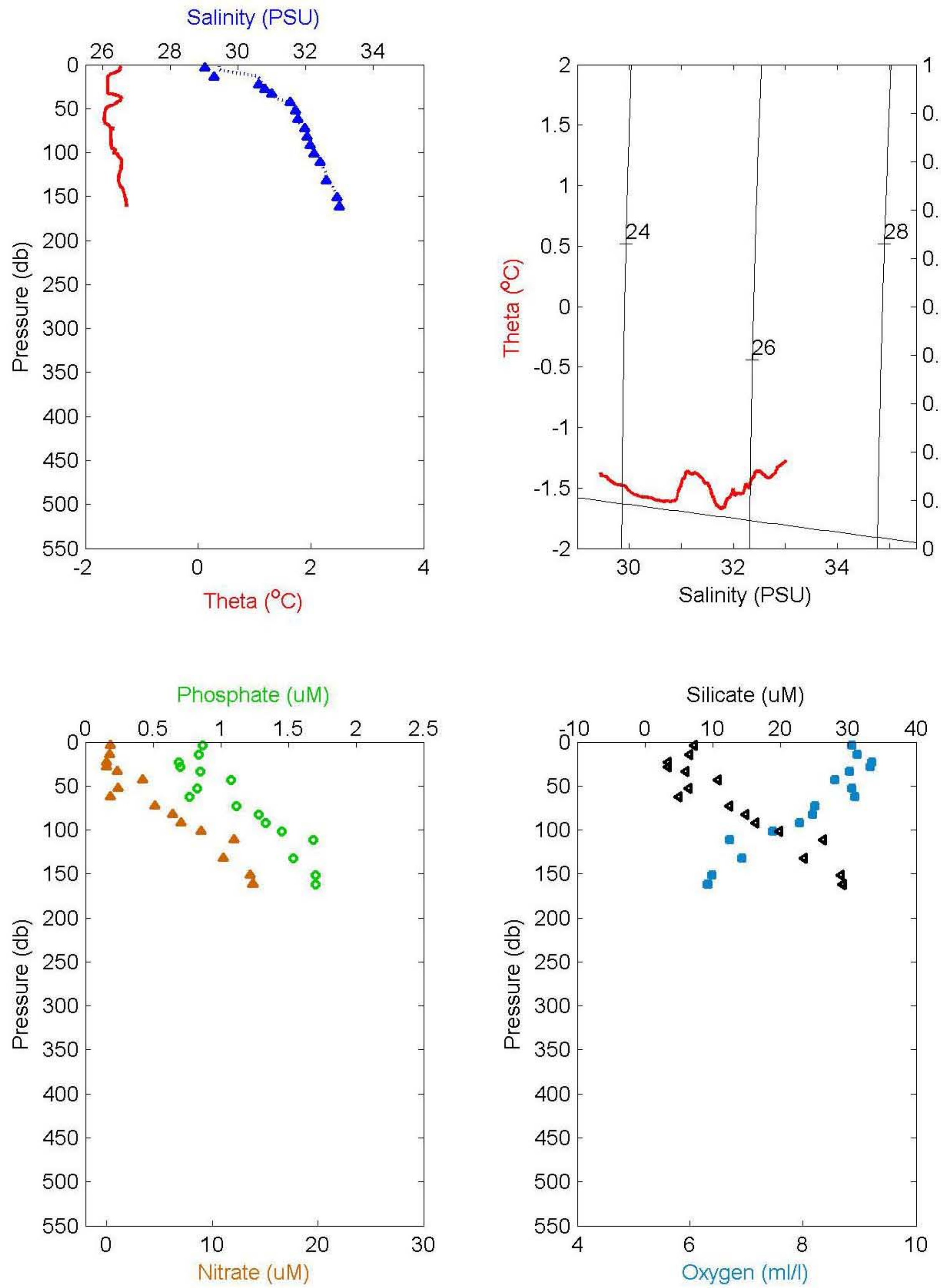




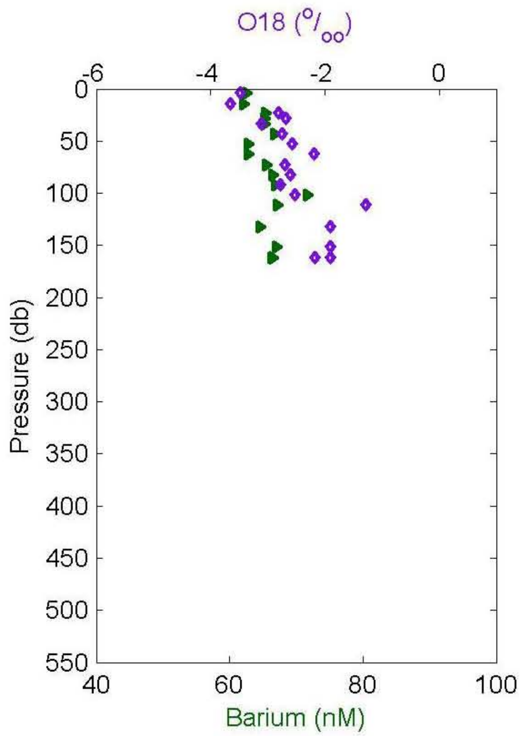
1997-22: Cast 104 Station 8

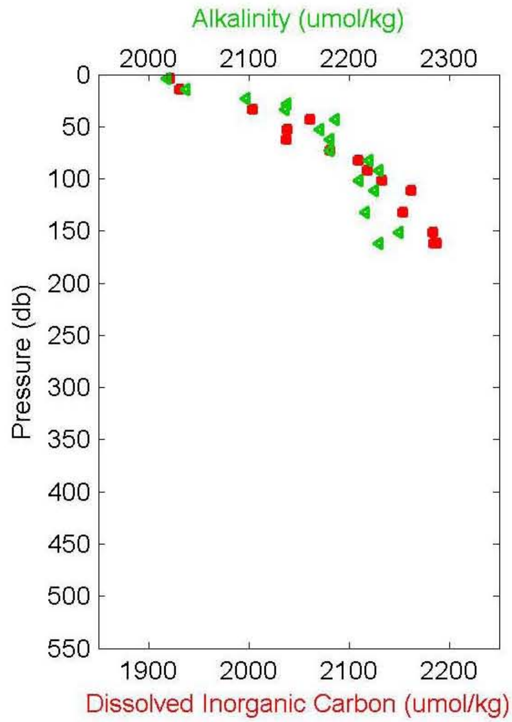


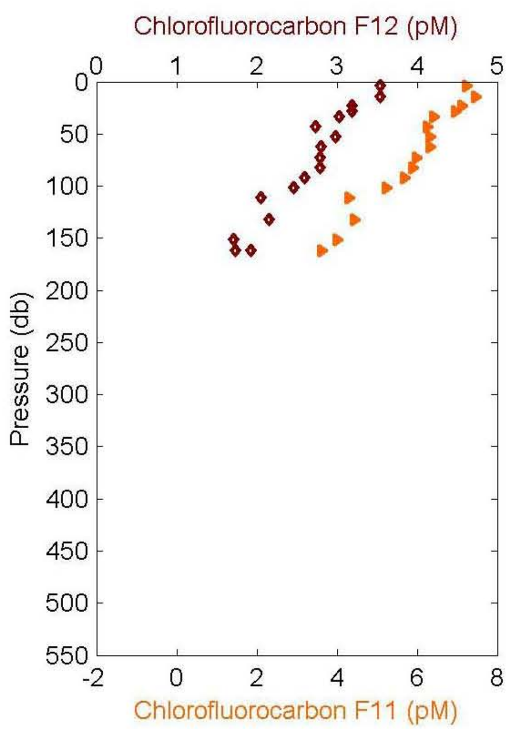
1997-22: Cast 105 Station 11

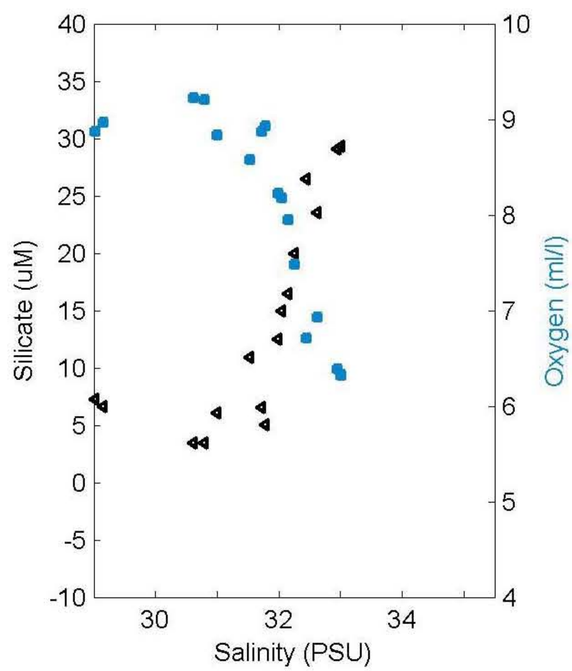


1997-22: Cast 105 Station 11

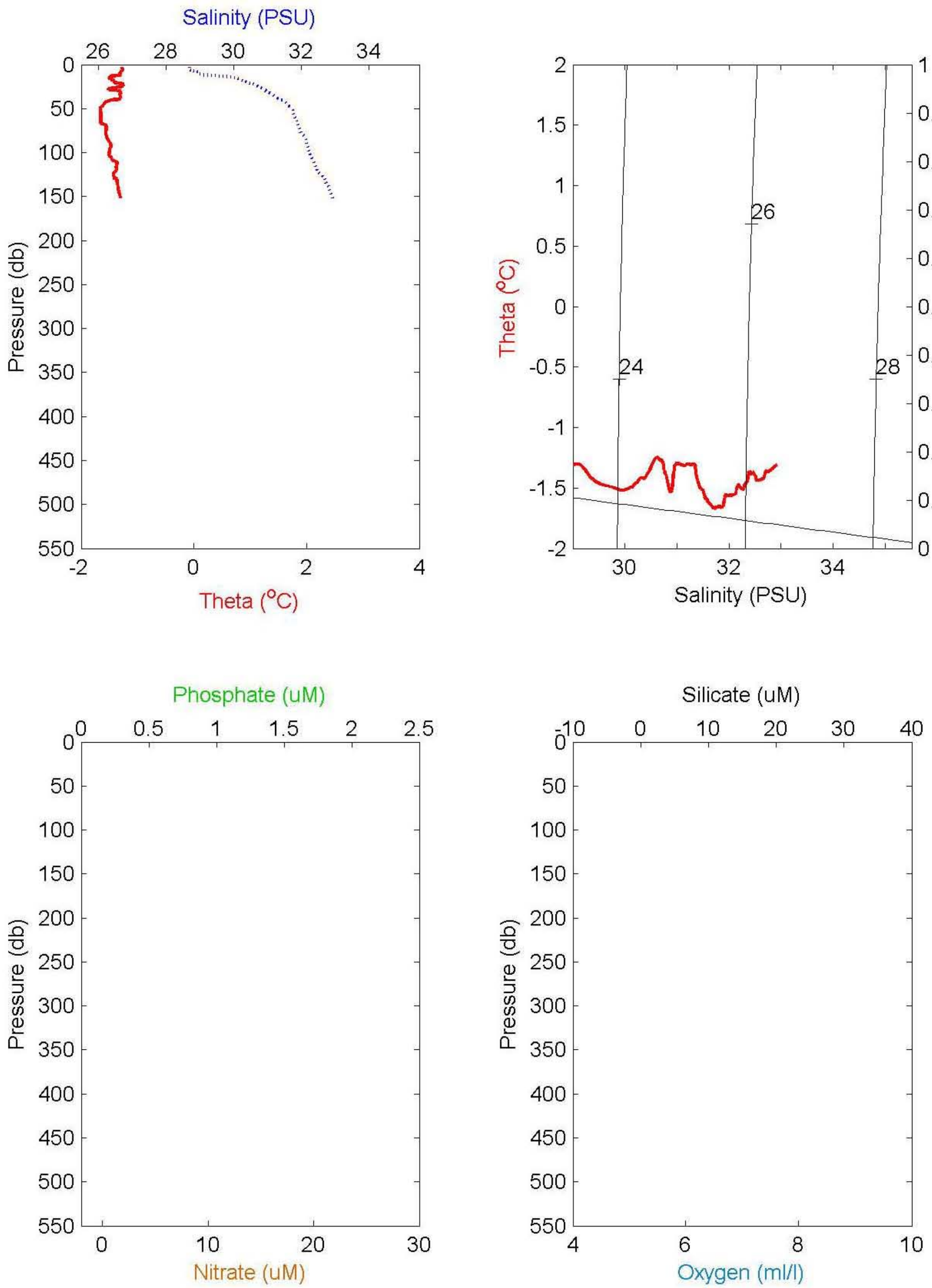




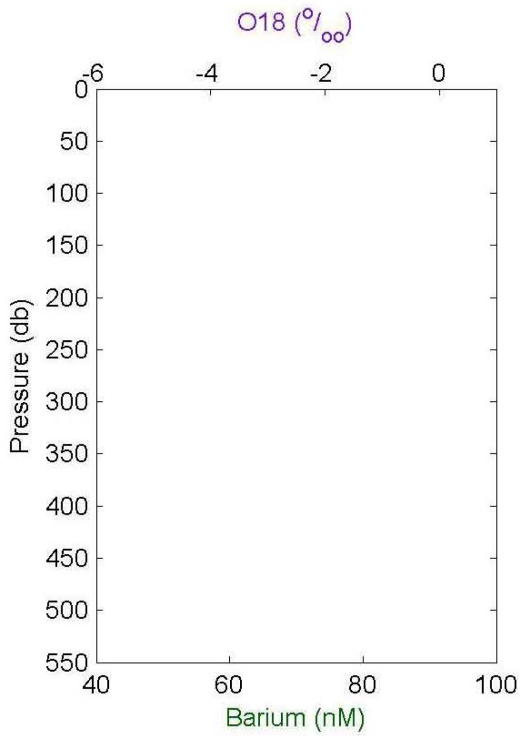


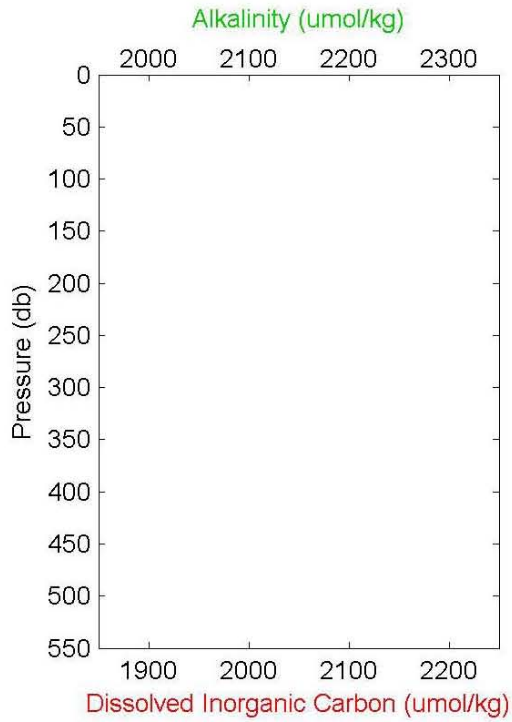


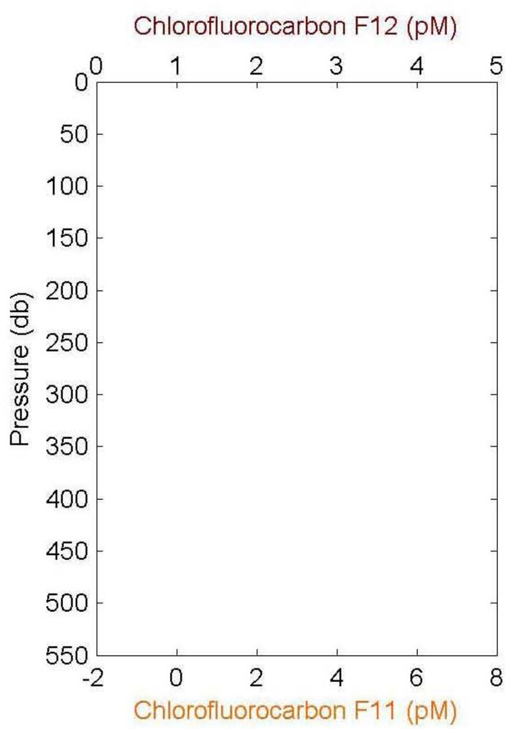
1997-22: Cast 106 Station 11-a

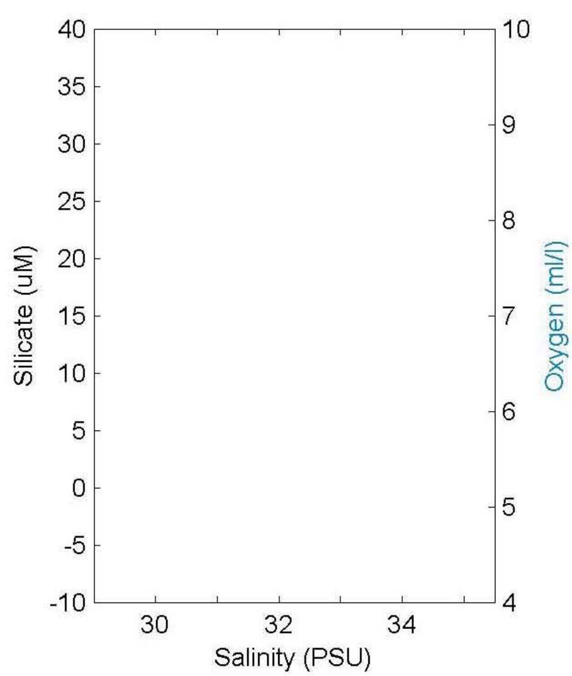


1997-22: Cast 106 Station 11-a

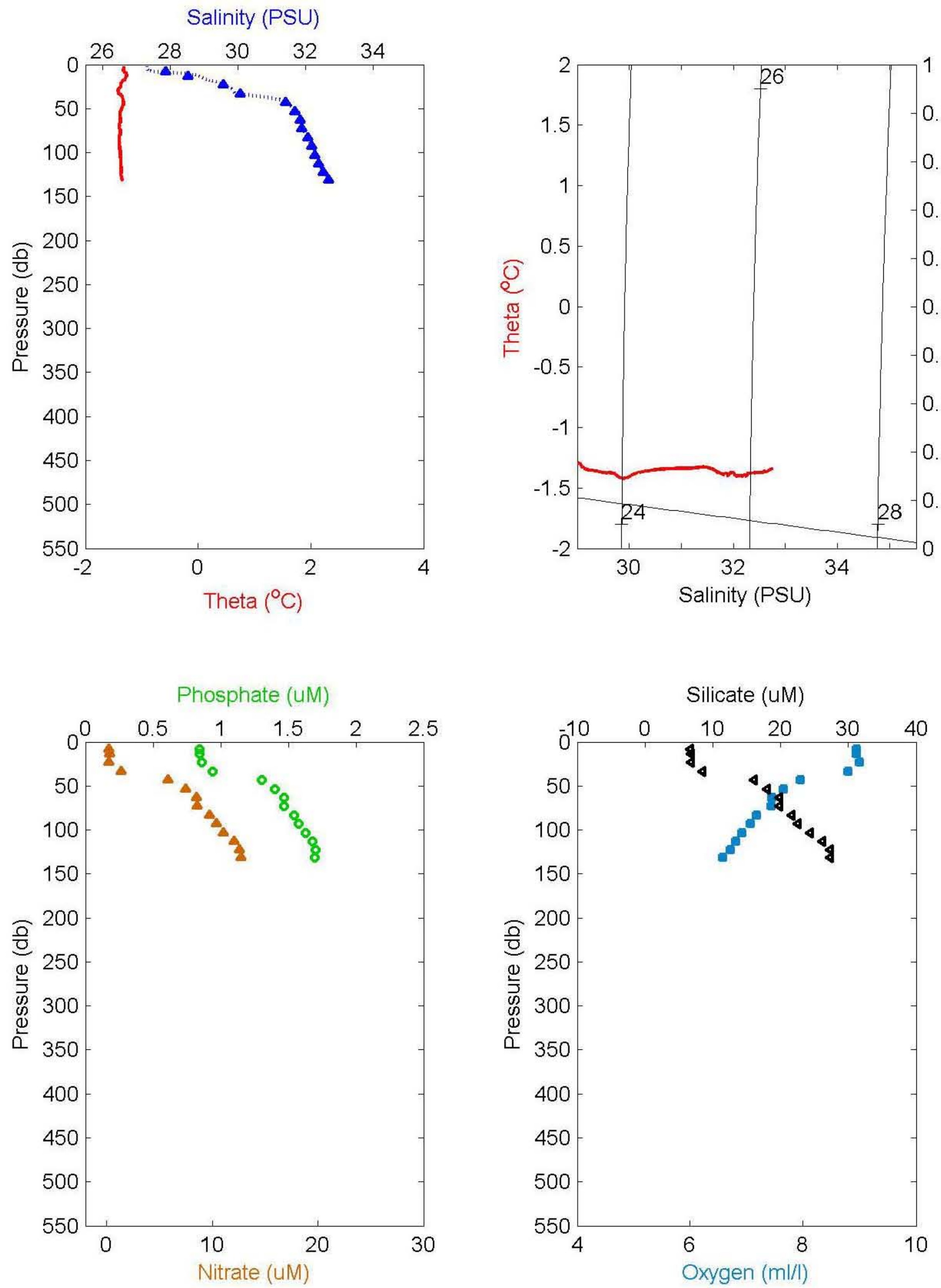




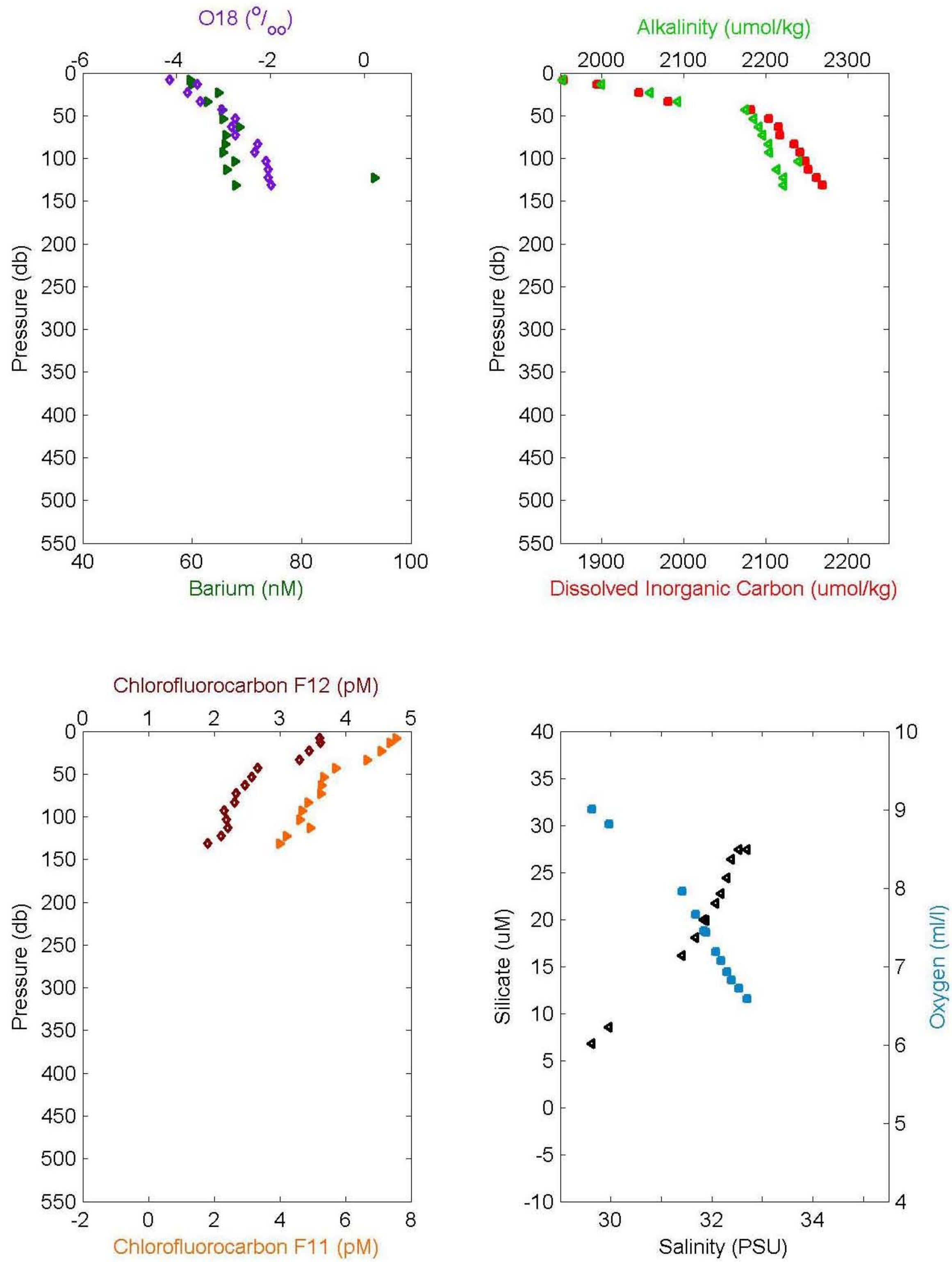




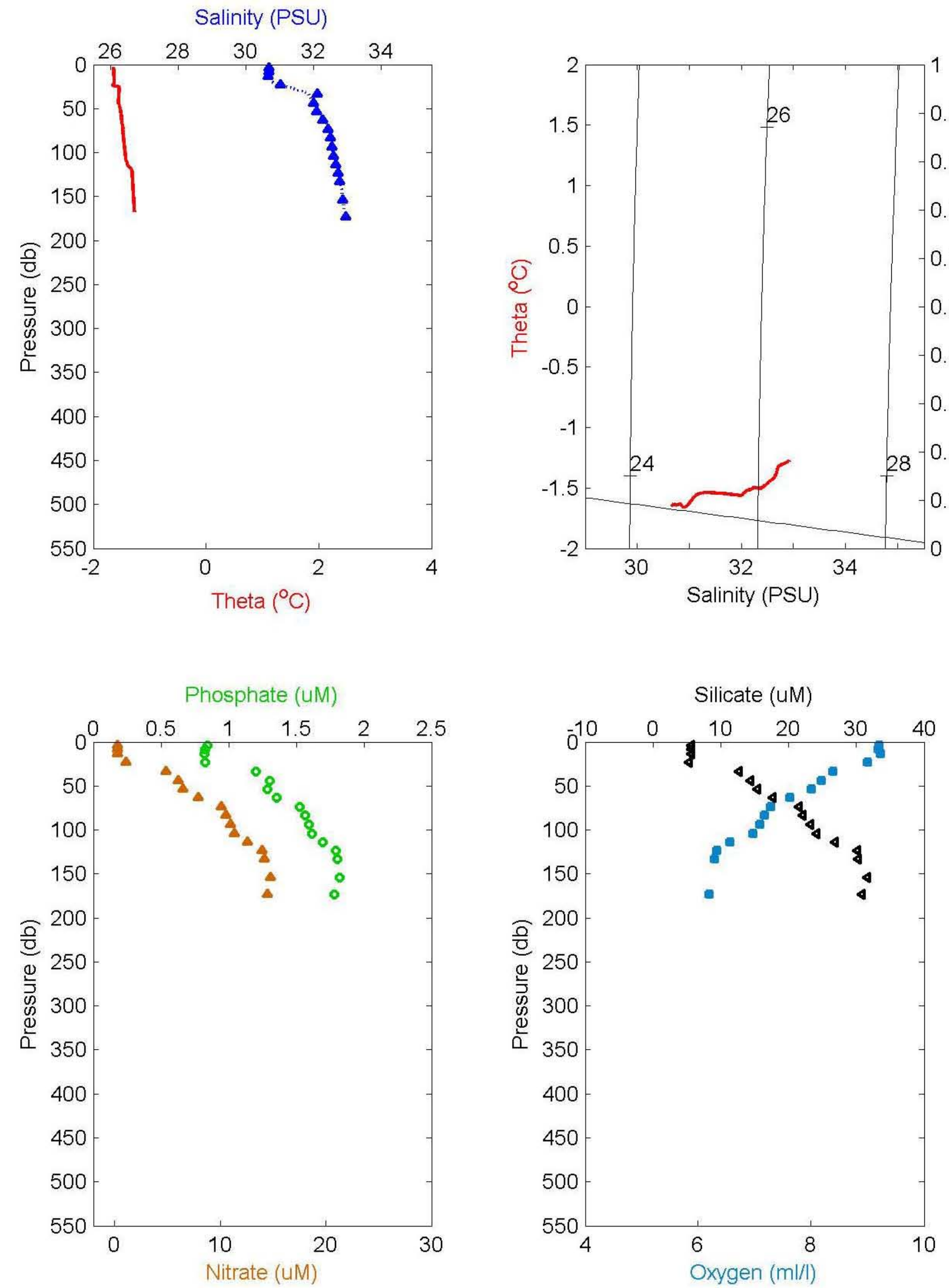
1997-22: Cast 107 Station 12



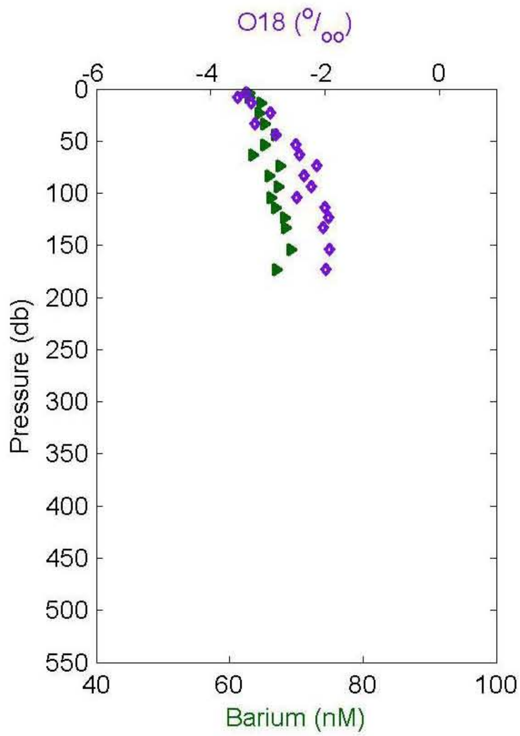
1997-22: Cast 107 Station 12

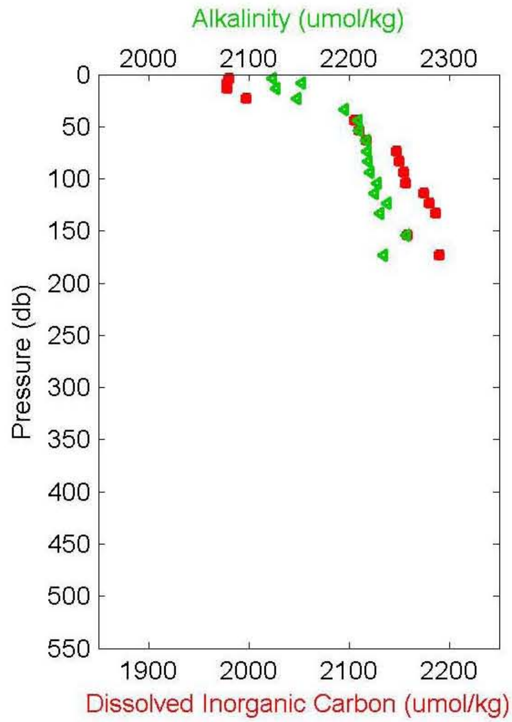


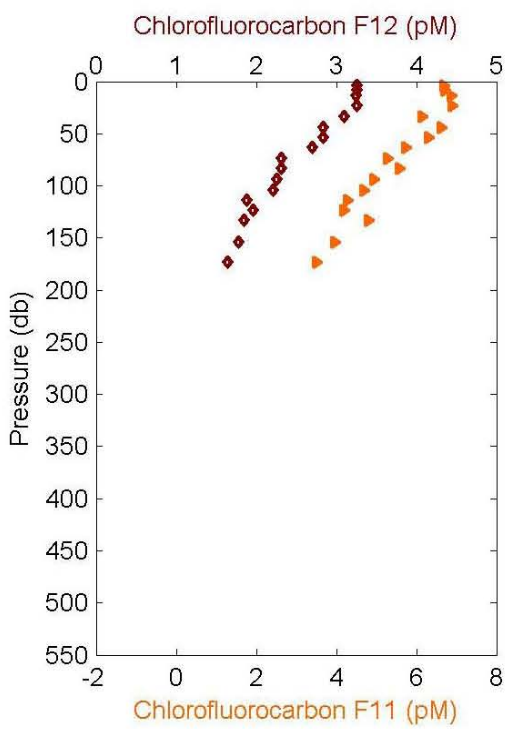
1997-22: Cast 108 Station 13

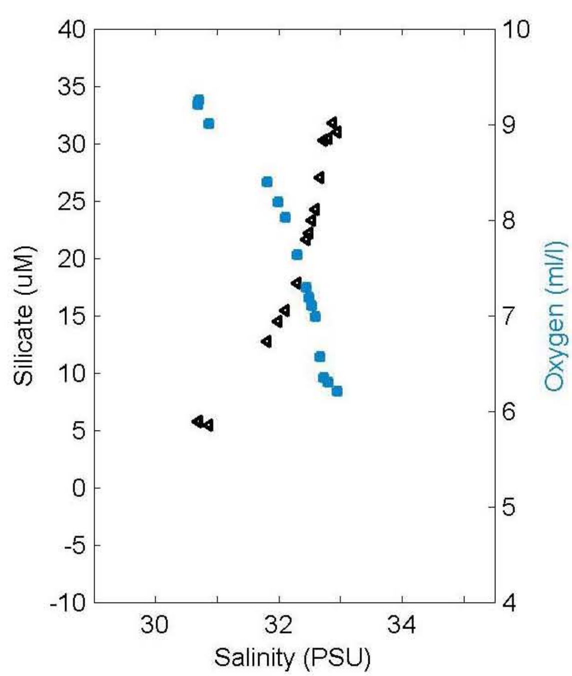


1997-22: Cast 108 Station 13

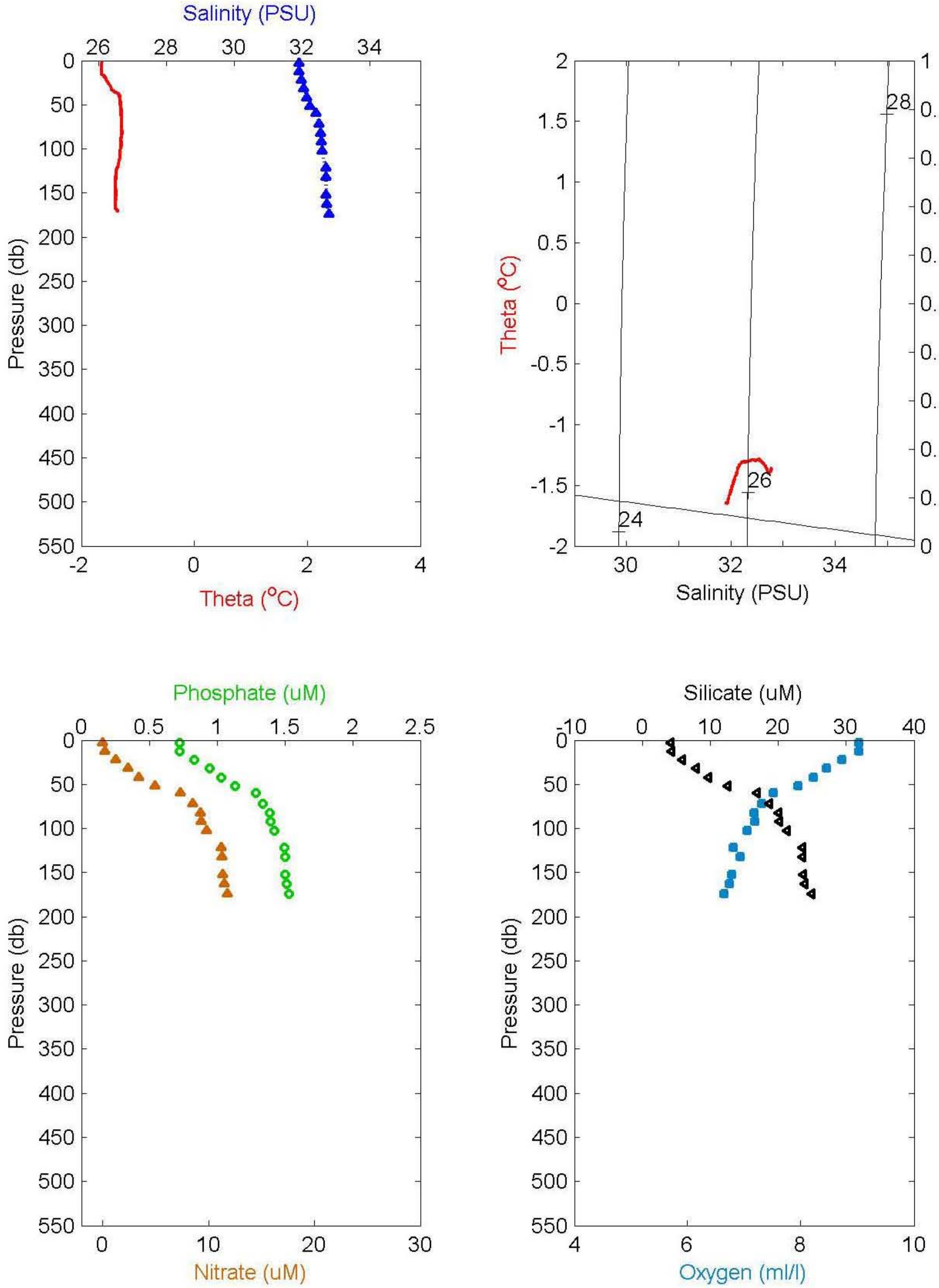




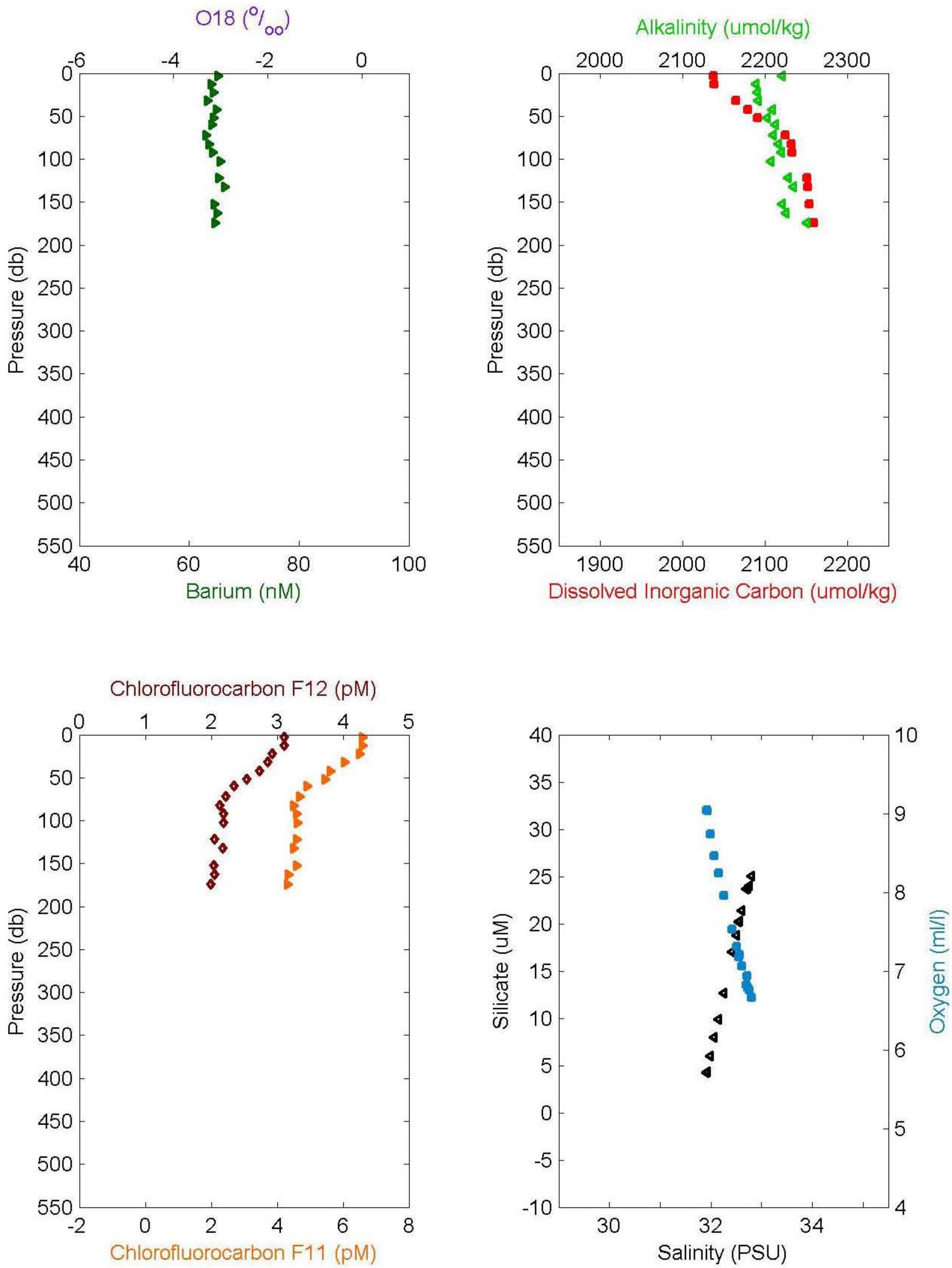




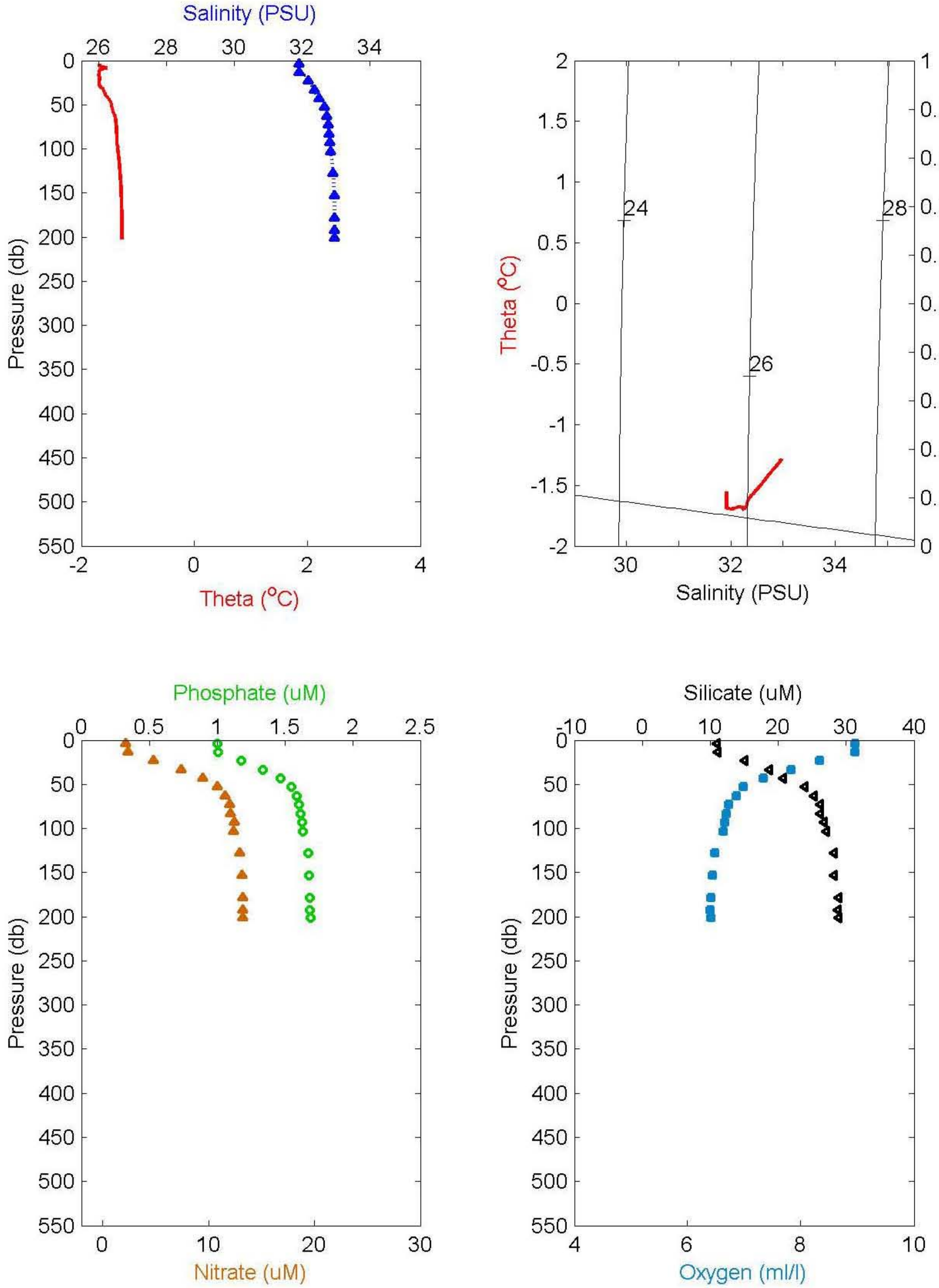
1997-22: Cast 109 Station 14



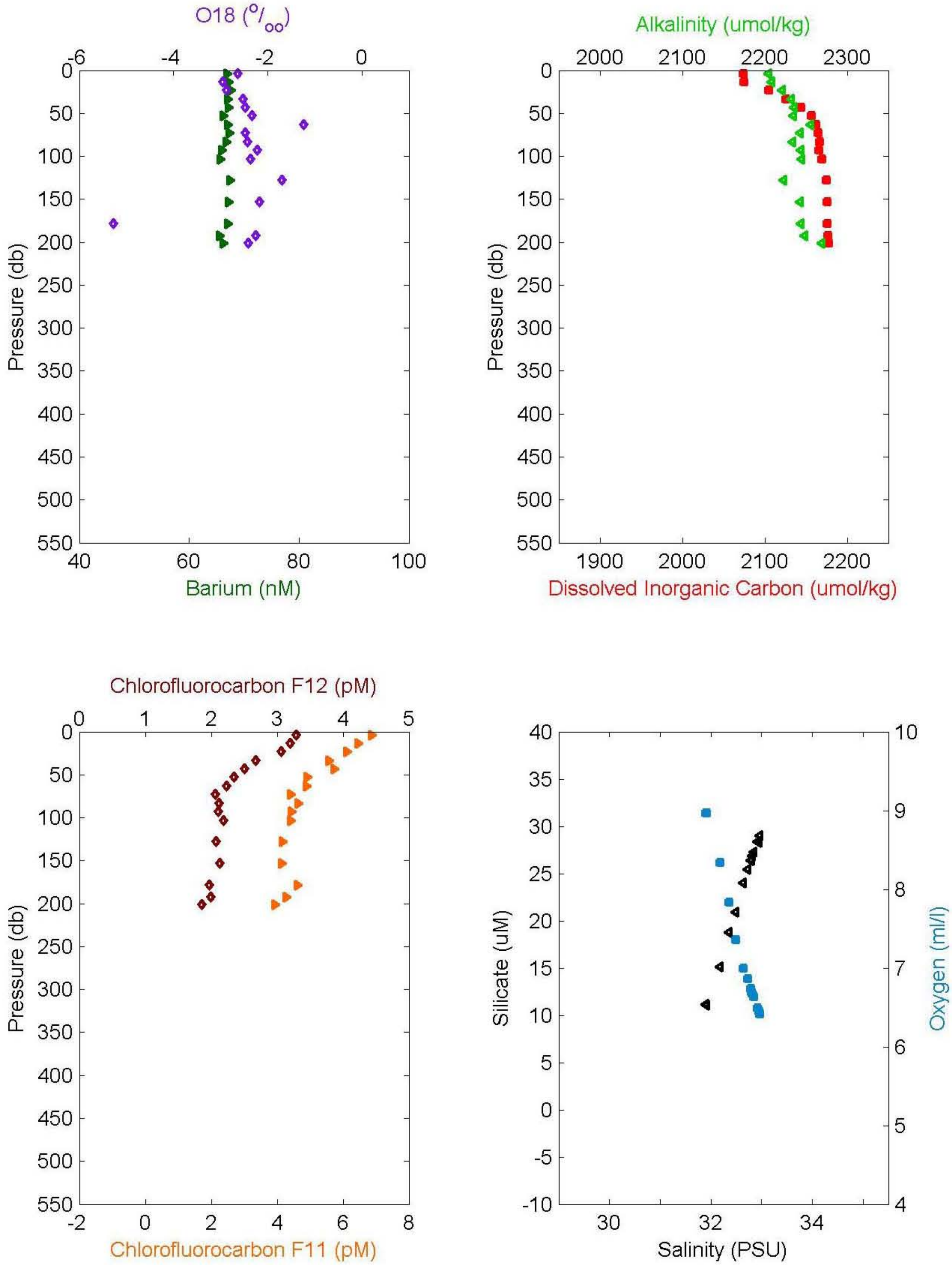
1997-22: Cast 109 Station 14



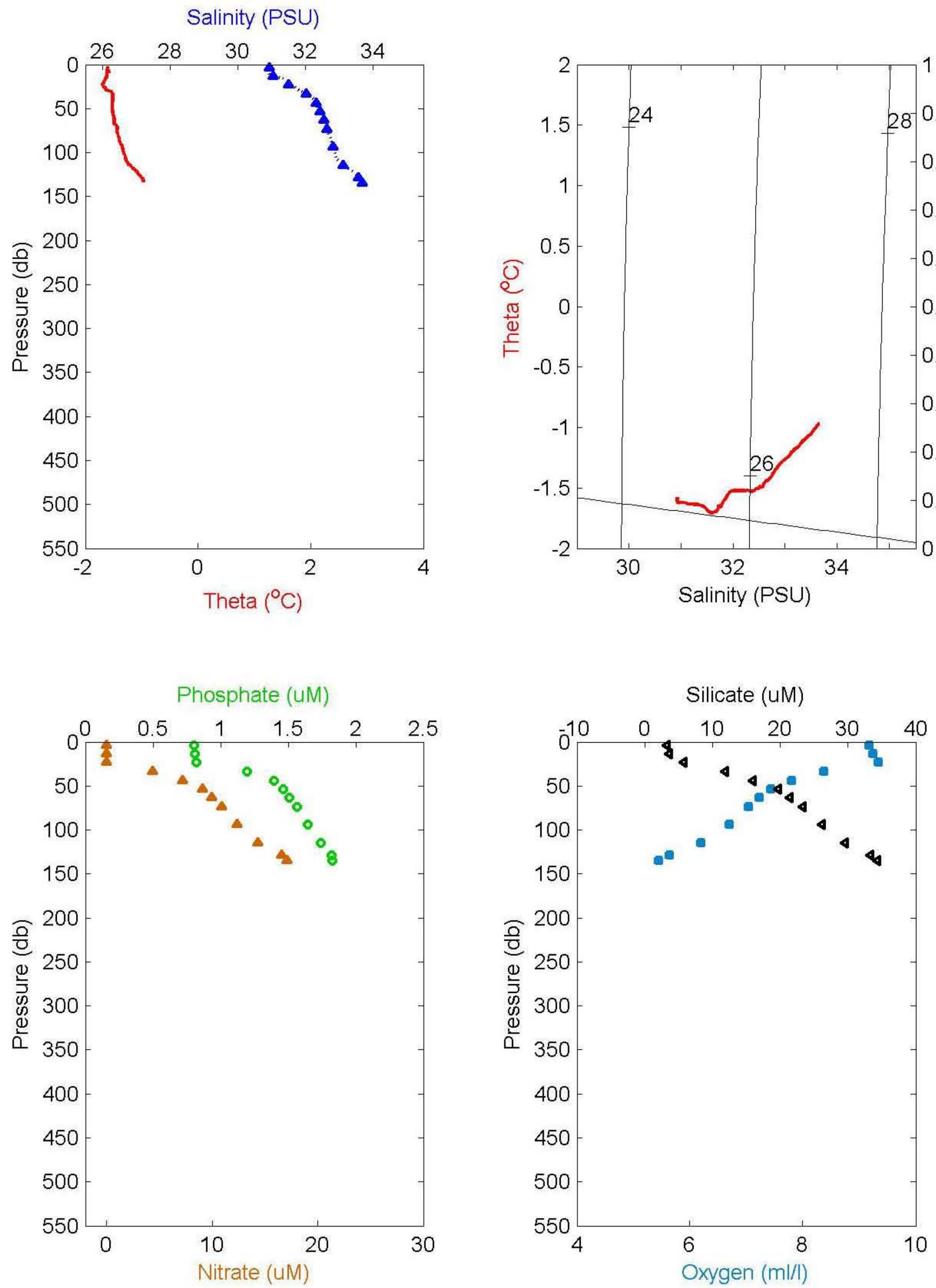
1997-22: Cast 110 Station 16



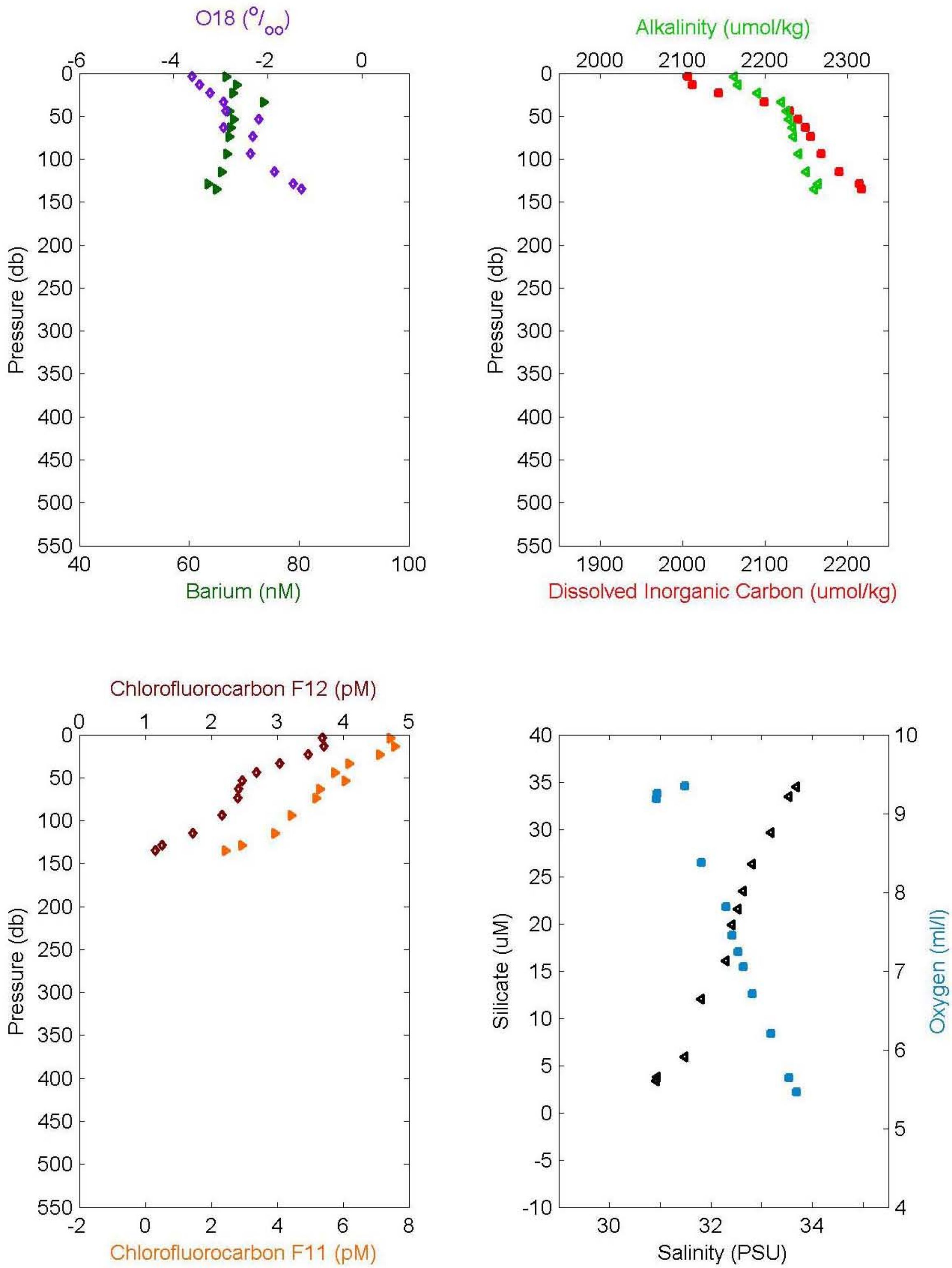
1997-22: Cast 110 Station 16



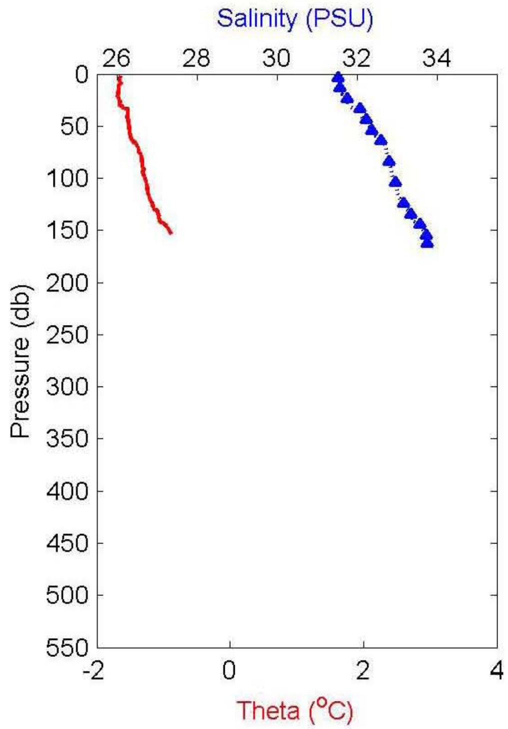
1997-22: Cast 111 Station 19

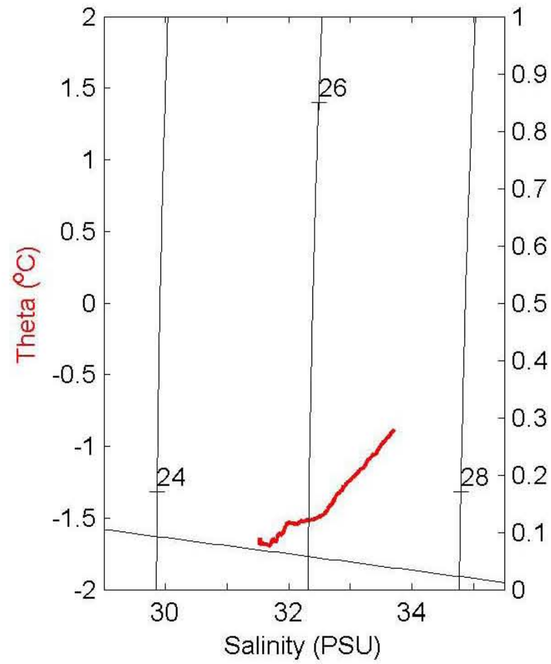


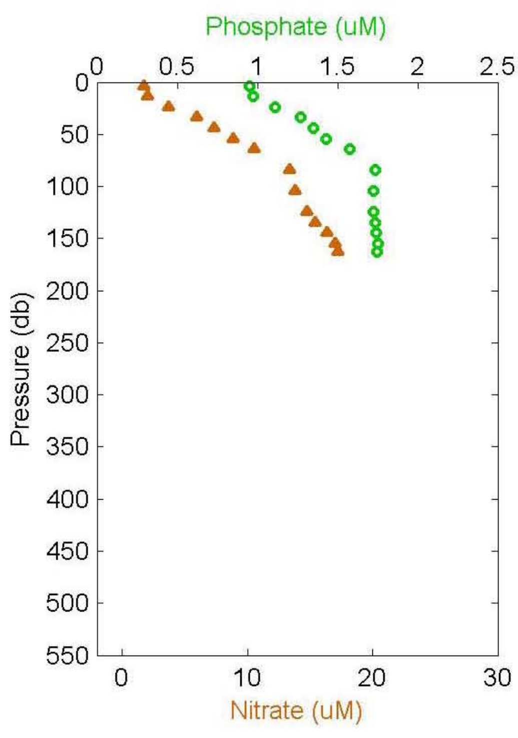
1997-22: Cast 111 Station 19

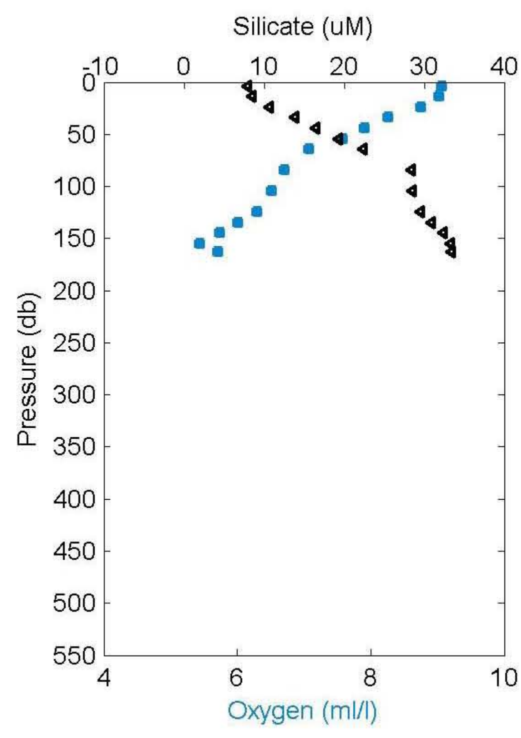


1997-22: Cast 112 Station 22

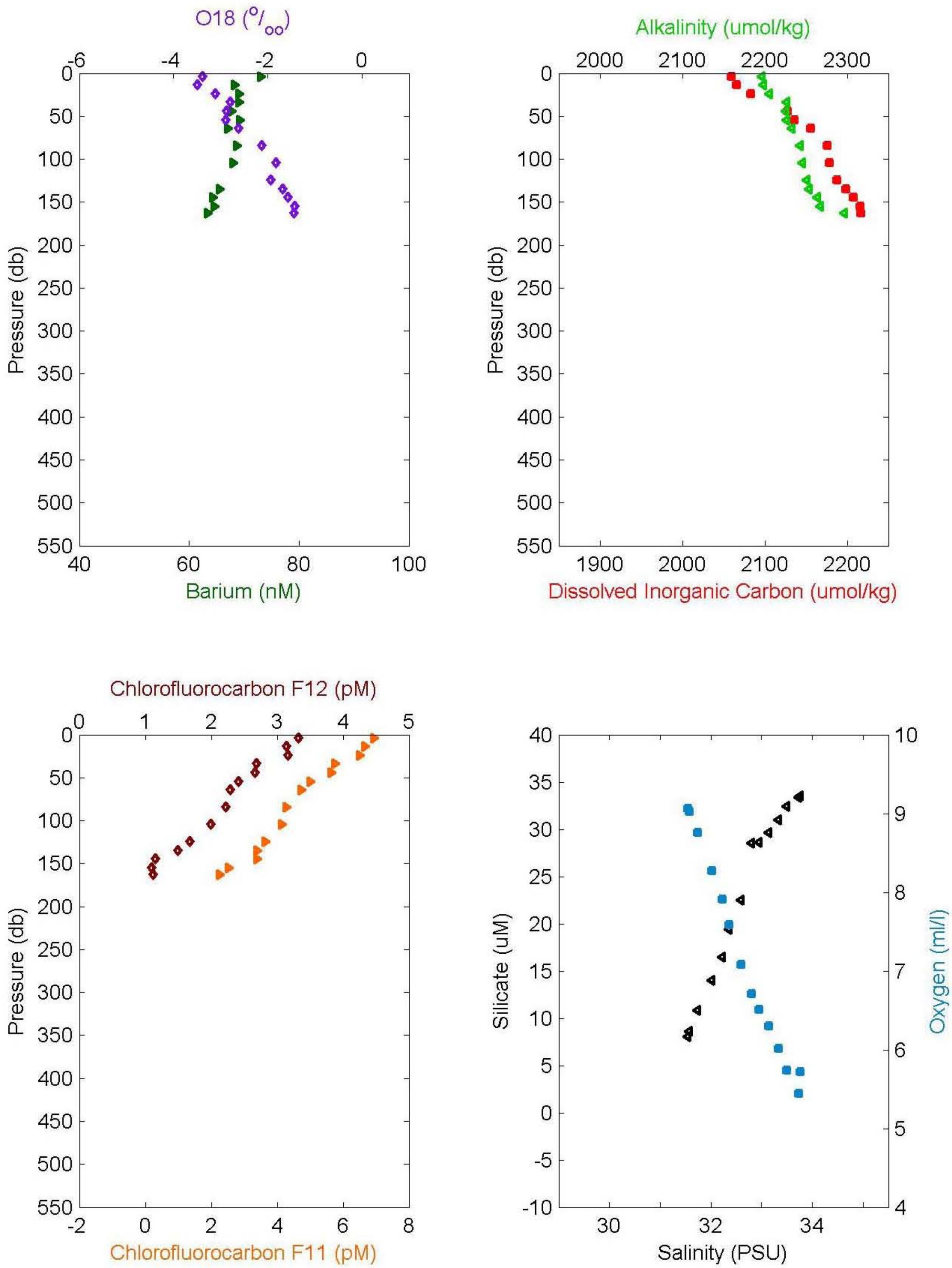




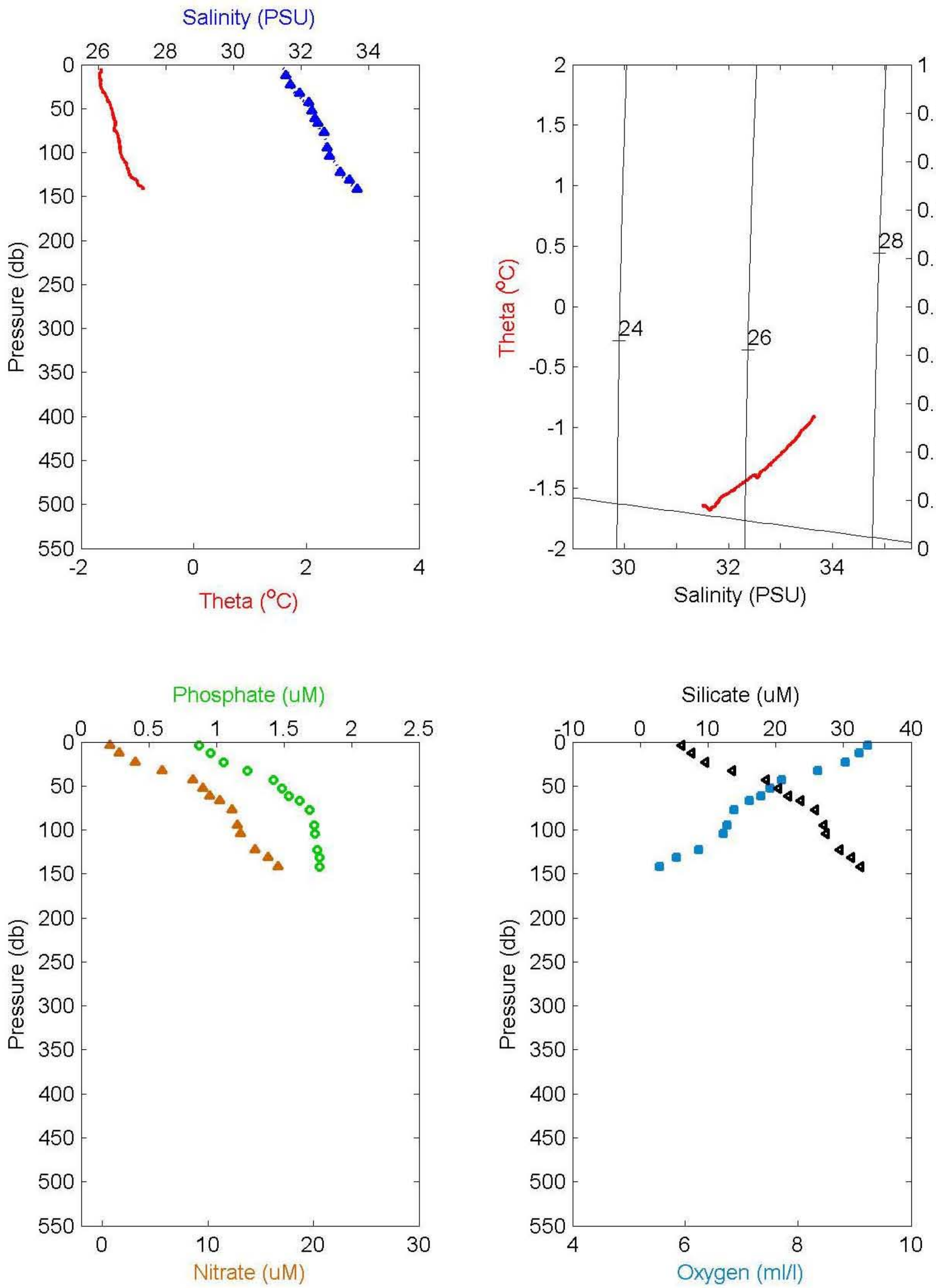




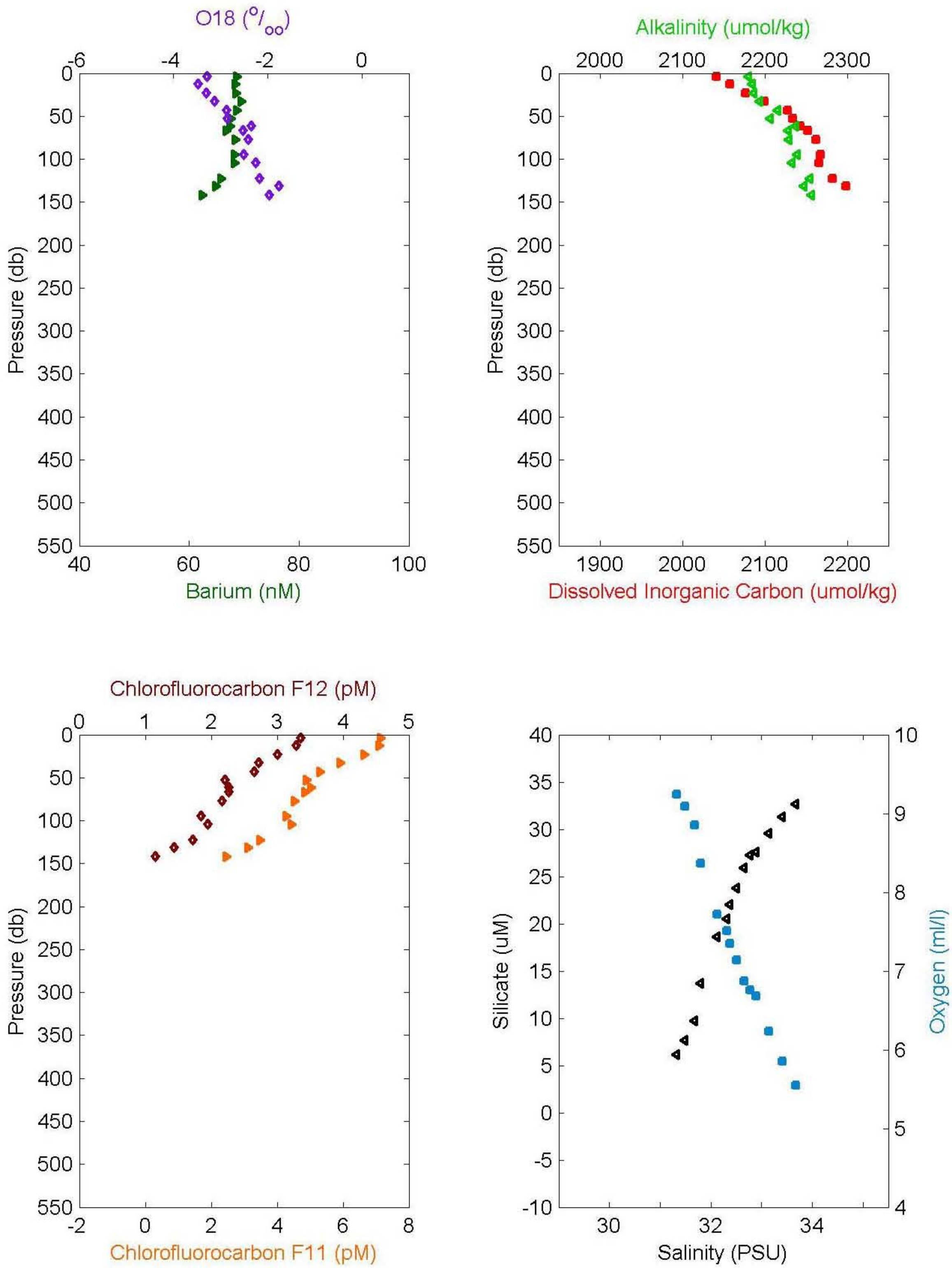
1997-22: Cast 112 Station 22



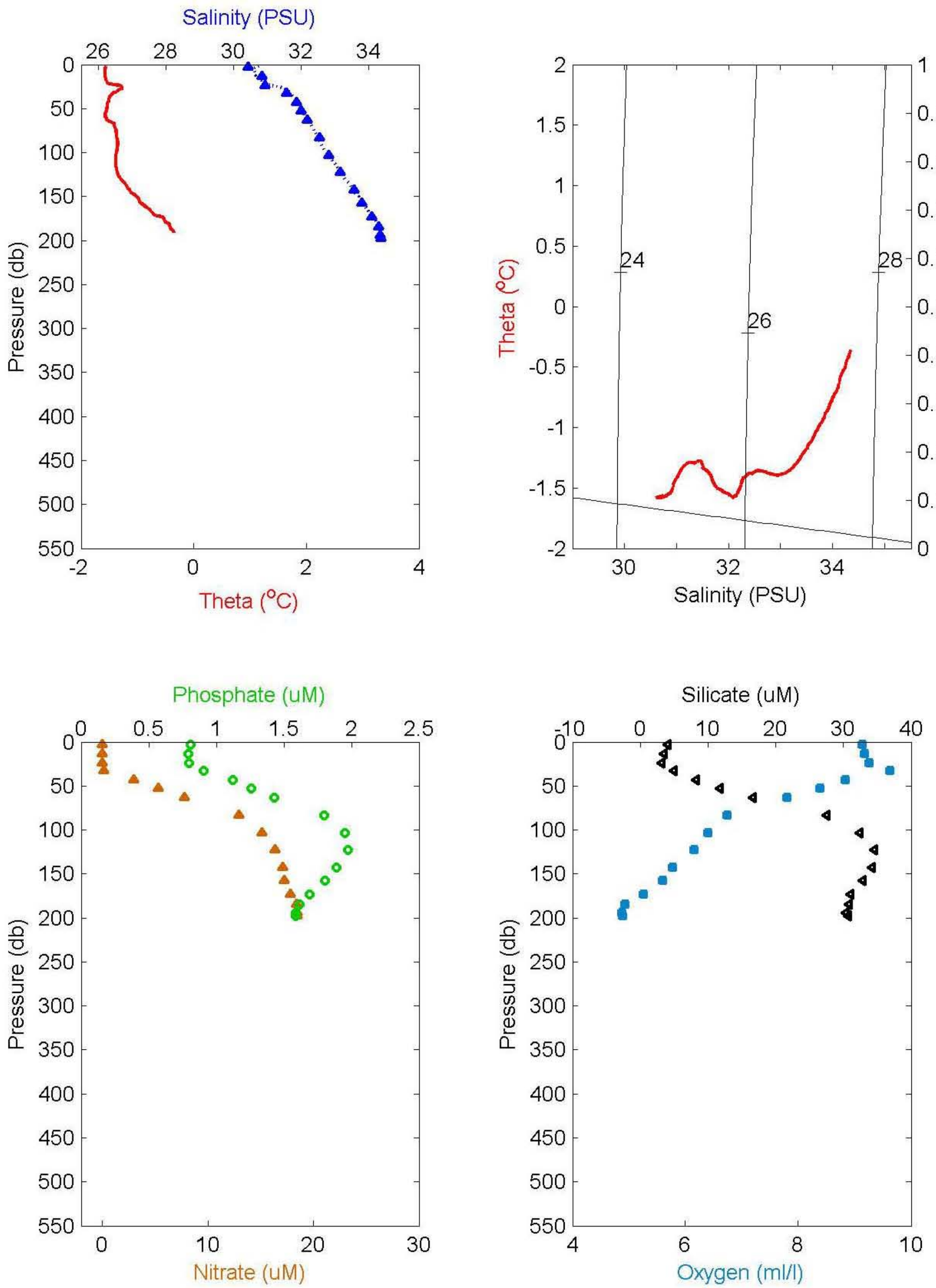
1997-22: Cast 113 Station 23



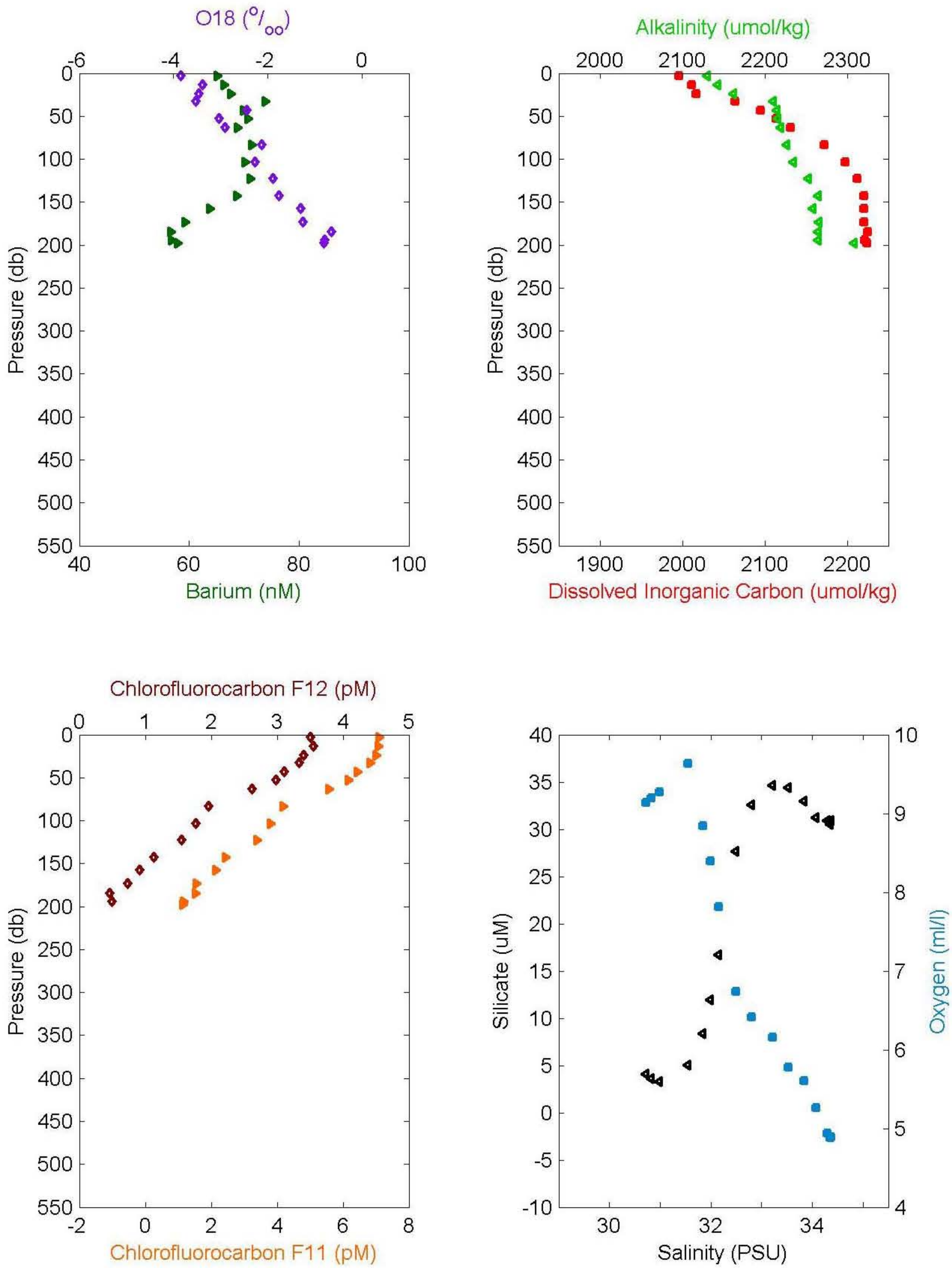
1997-22: Cast 113 Station 23



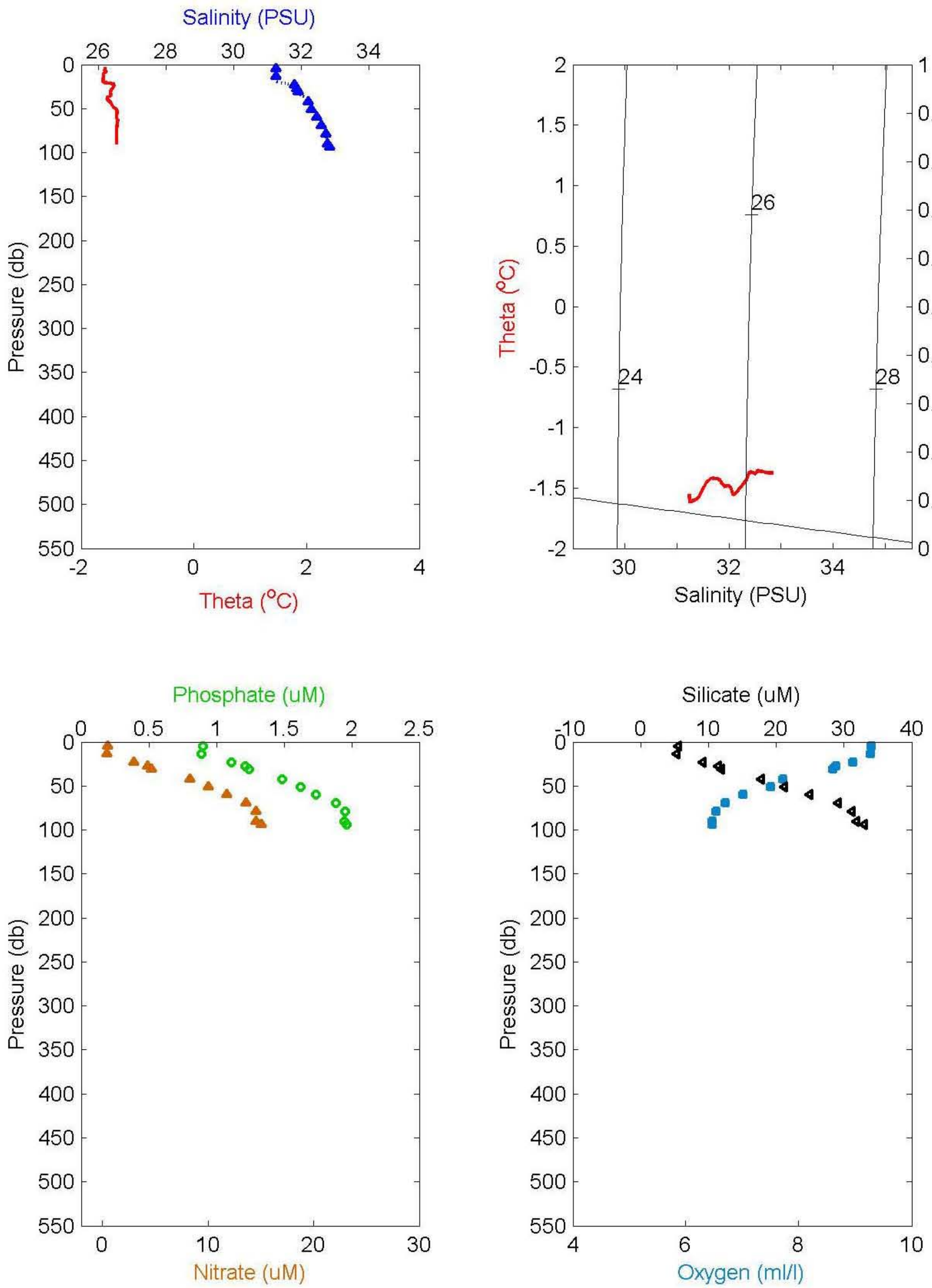
1997-22: Cast 114 Station 24



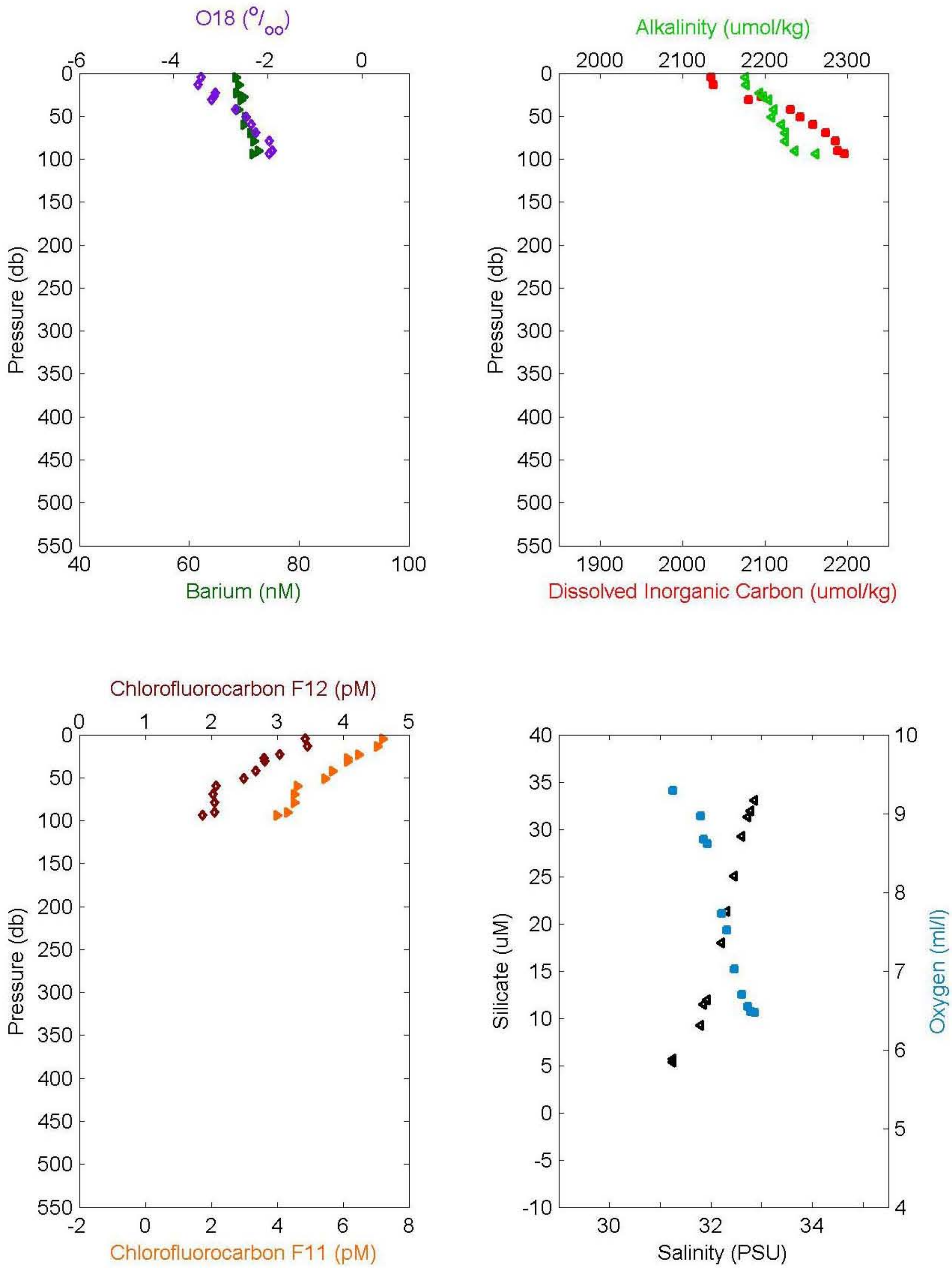
1997-22: Cast 114 Station 24



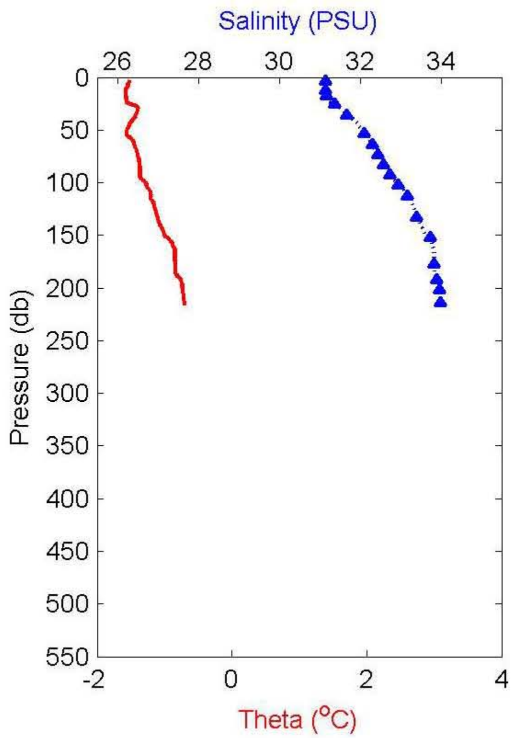
1997-22: Cast 115 Station 25

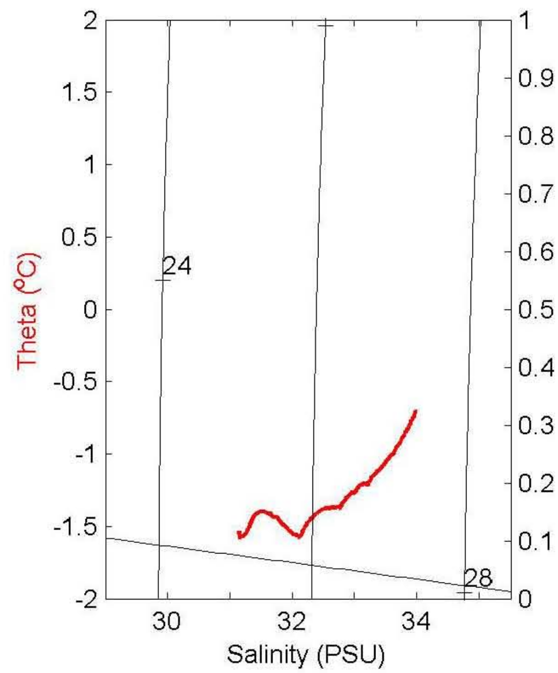


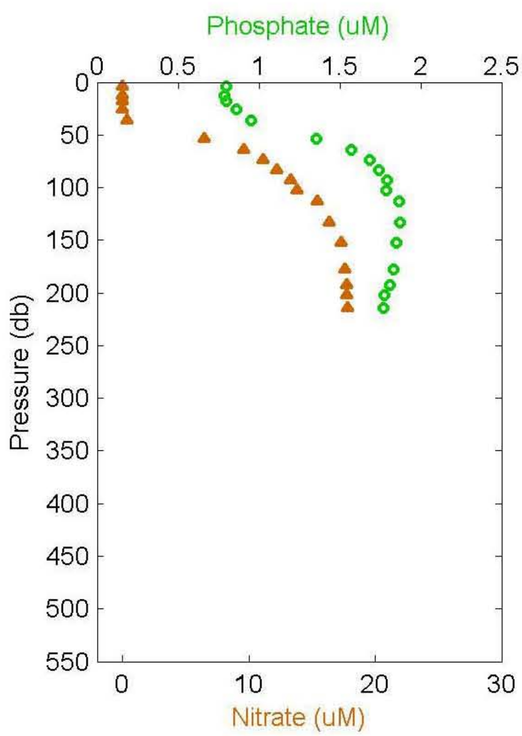
1997-22: Cast 115 Station 25

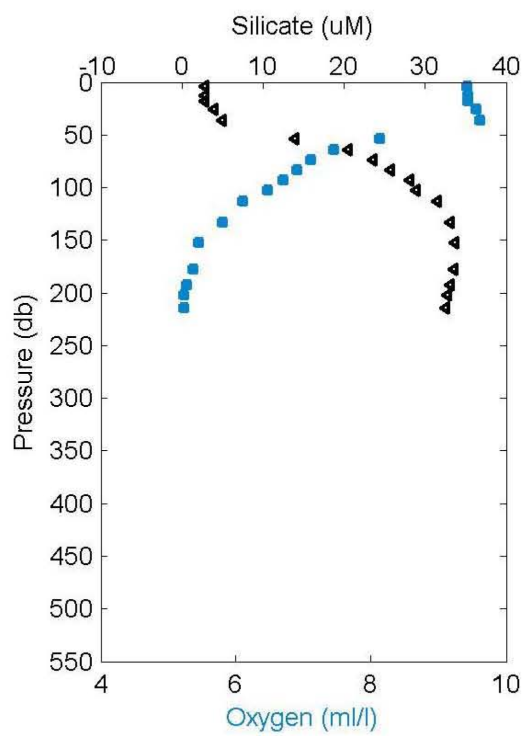


1997-22: Cast 116 Station 27

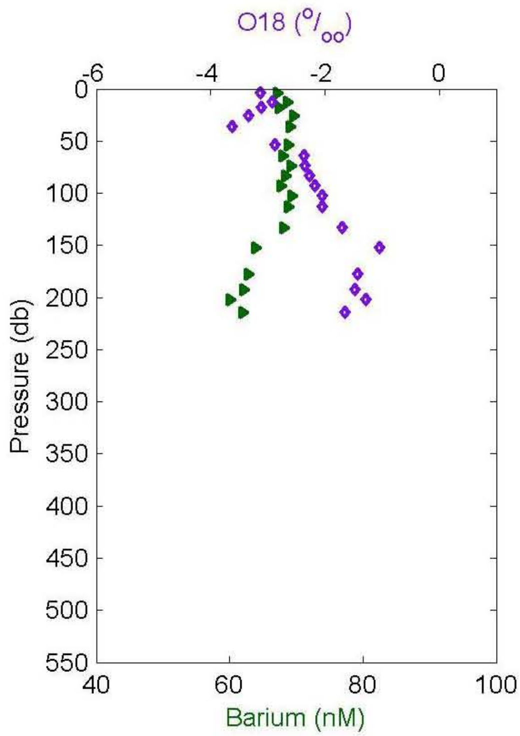


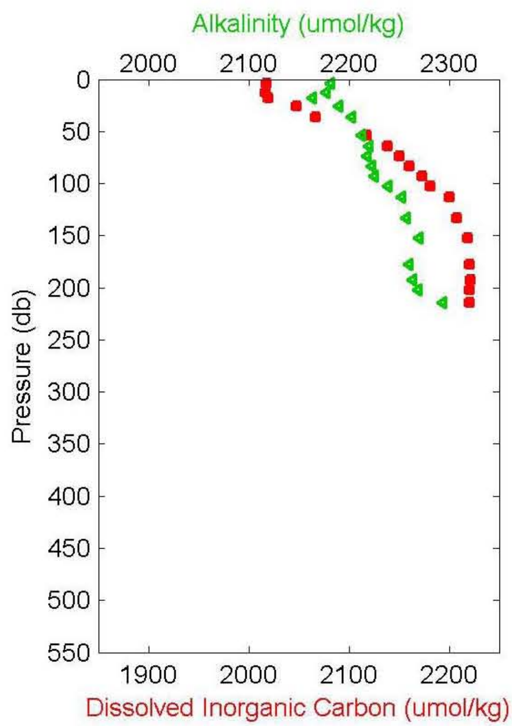


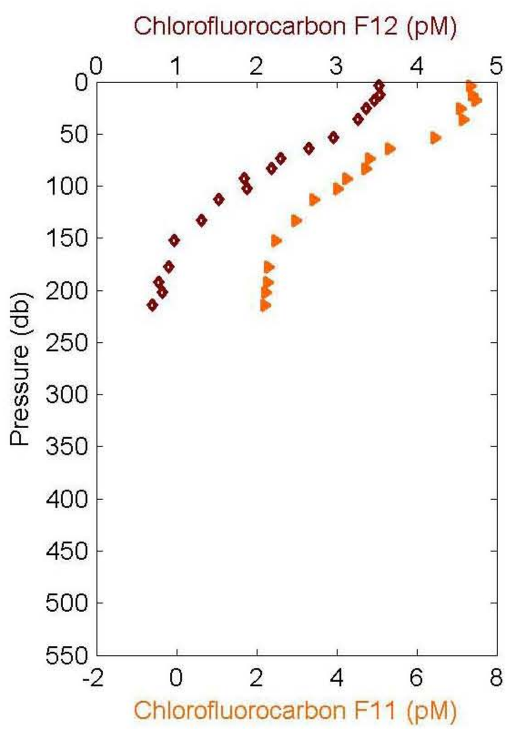


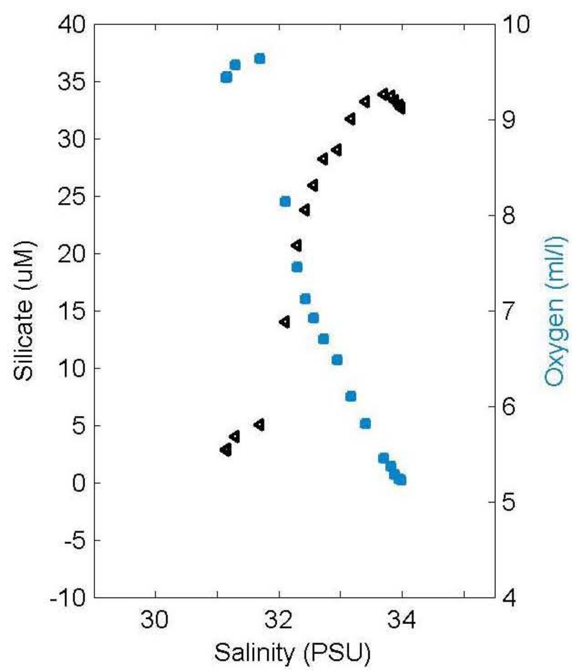


1997-22: Cast 116 Station 27

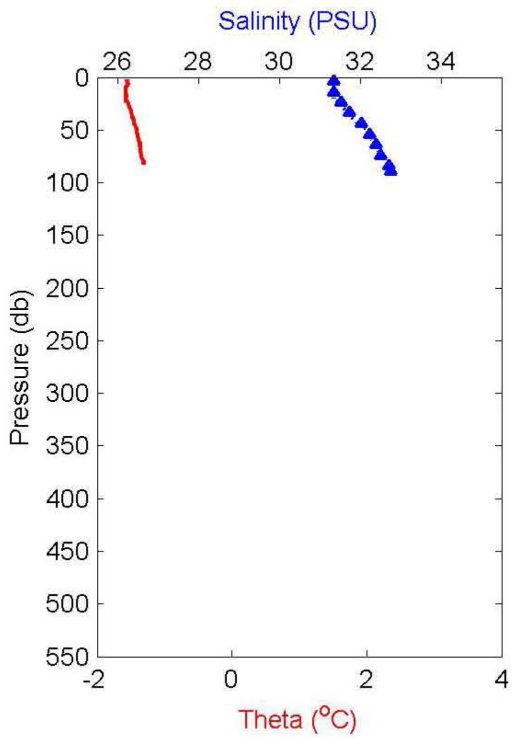


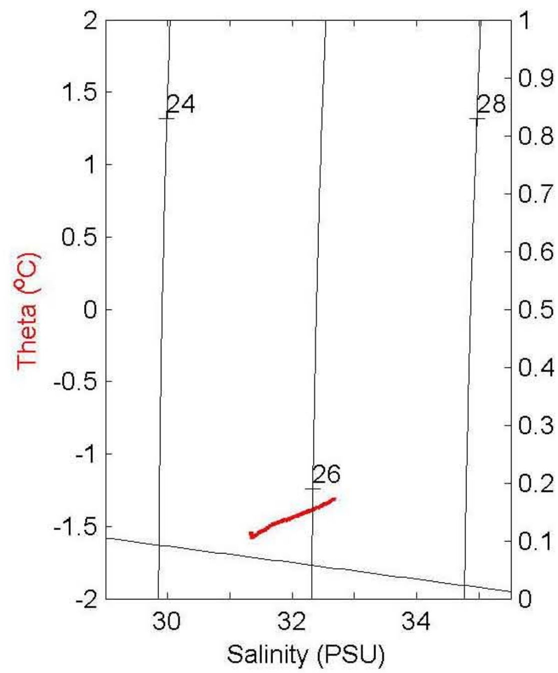


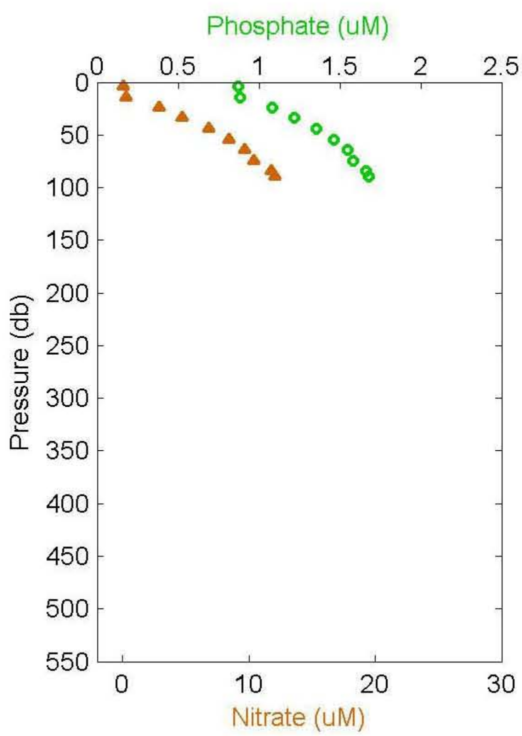


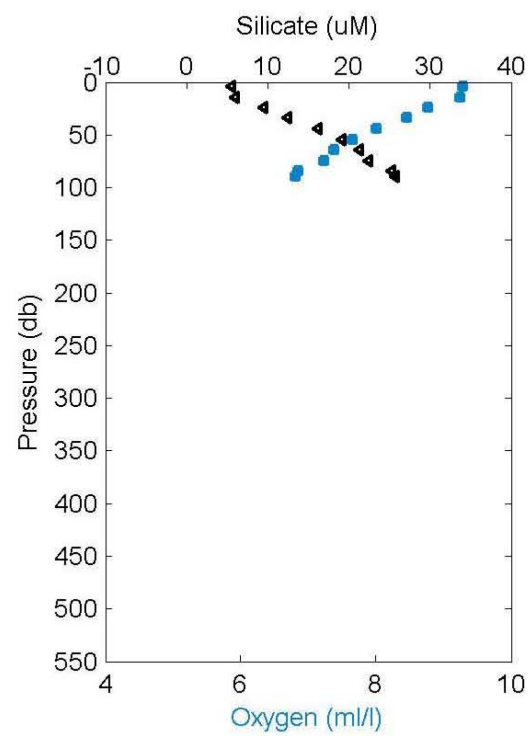


1997-22: Cast 117 Station 29

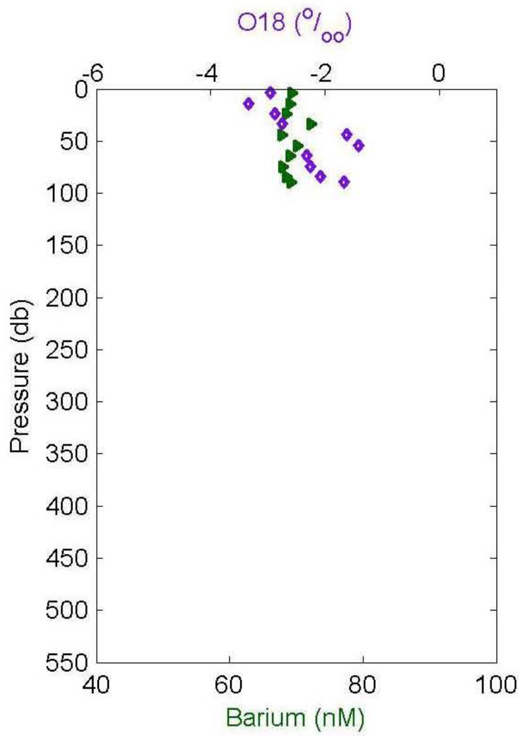


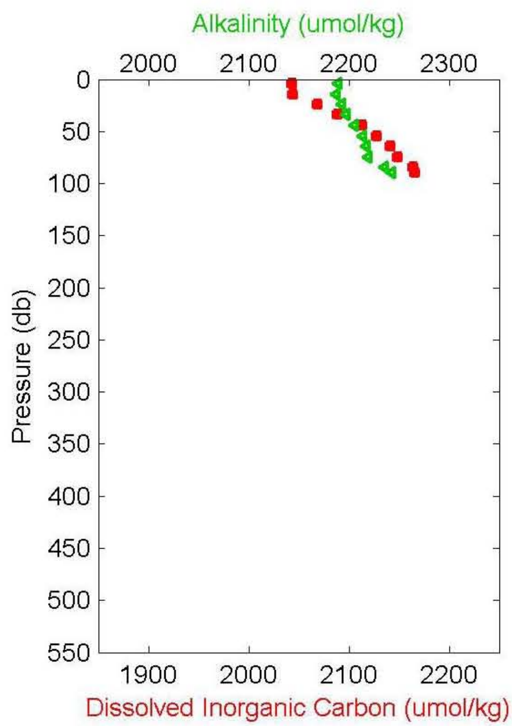


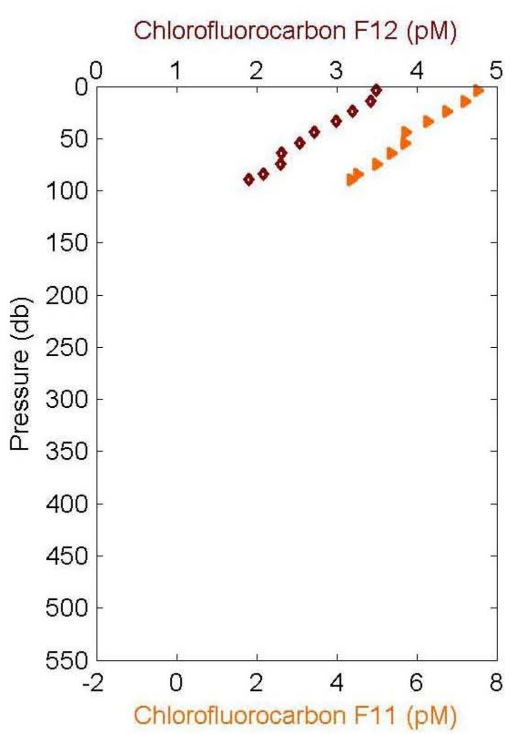


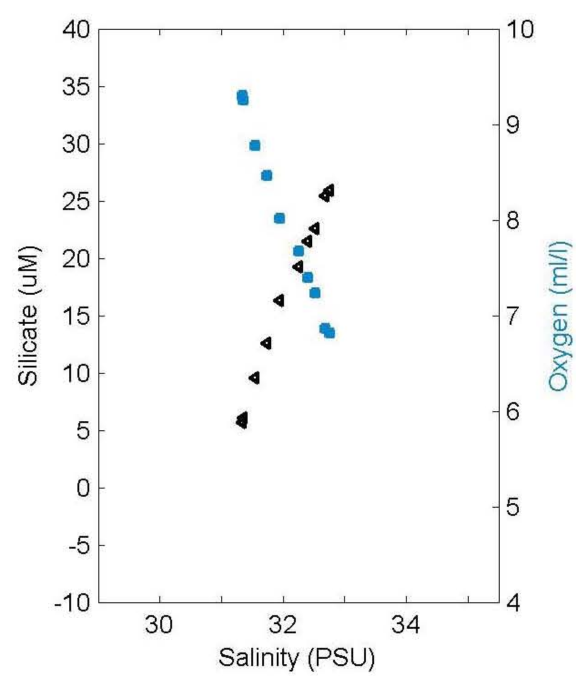


1997-22: Cast 117 Station 29

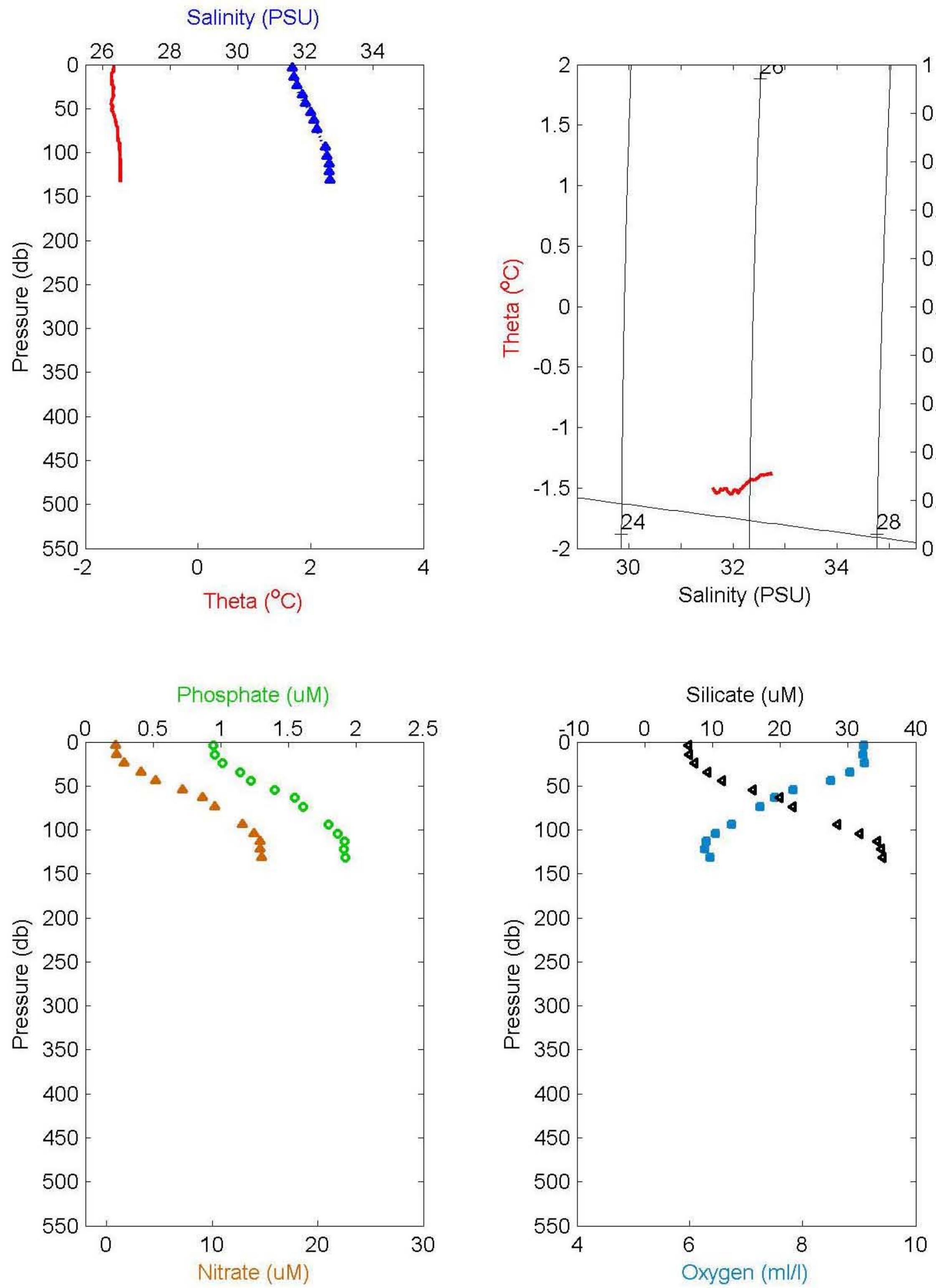




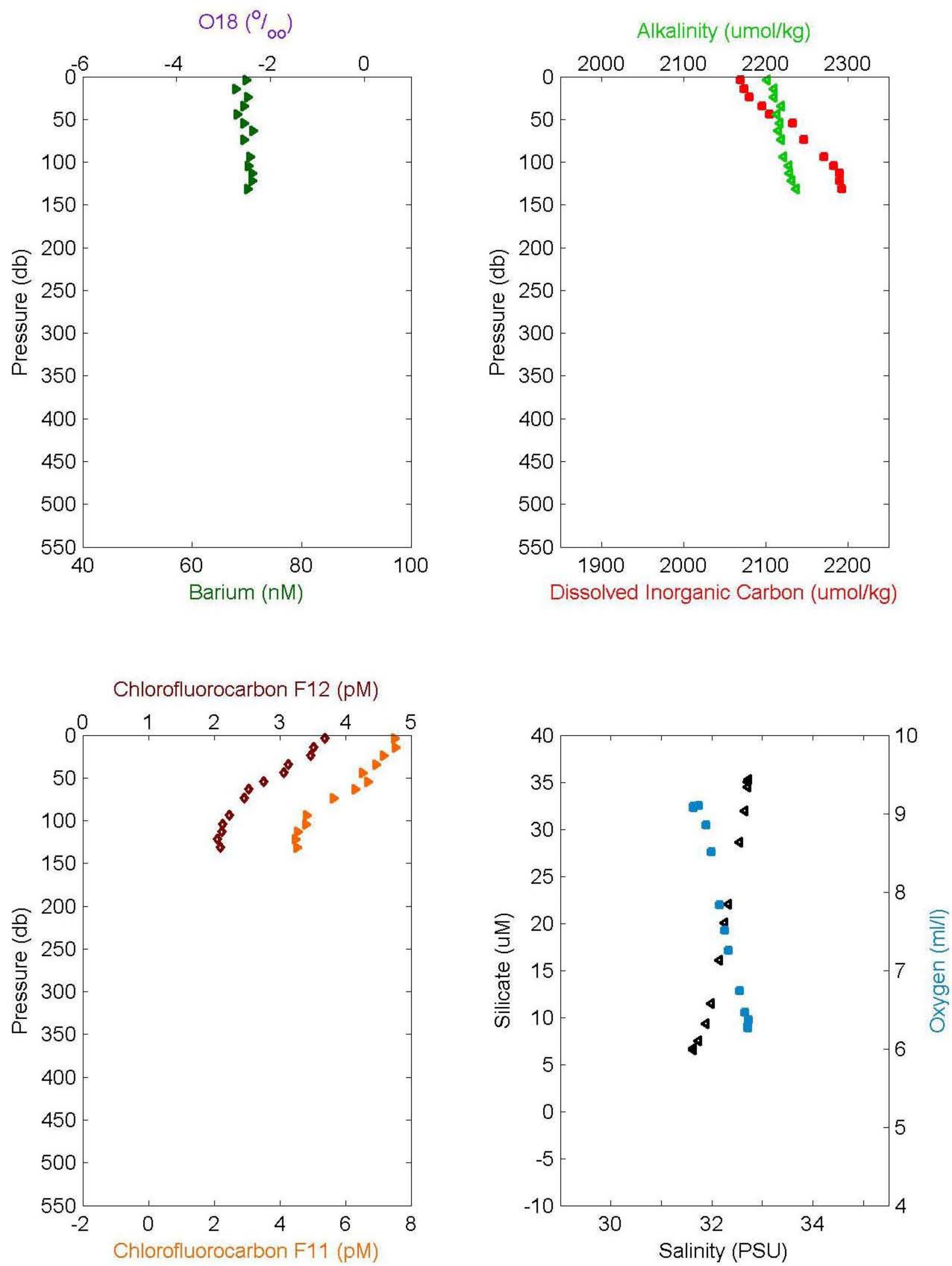




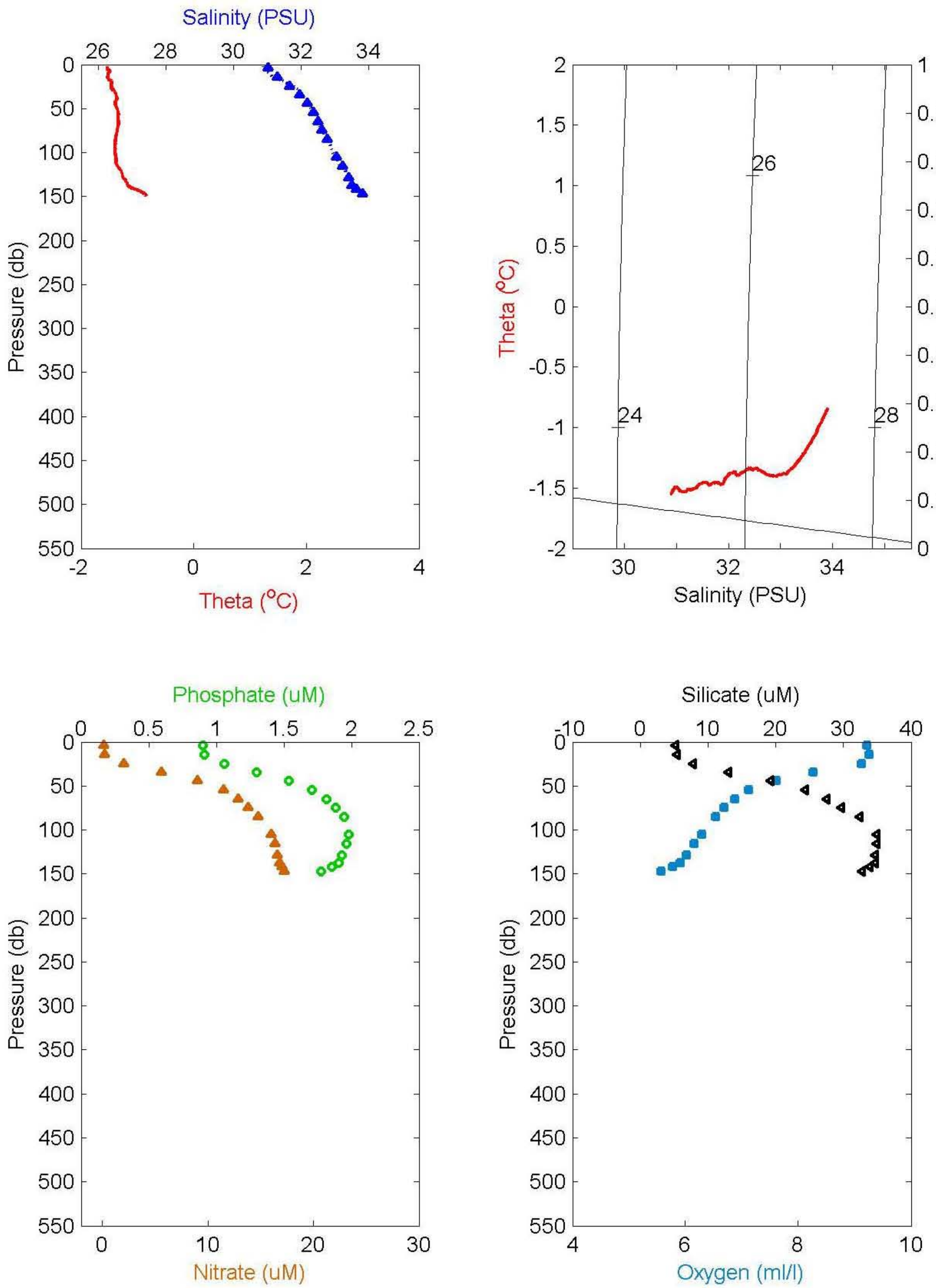
1997-22: Cast 118 Station 30



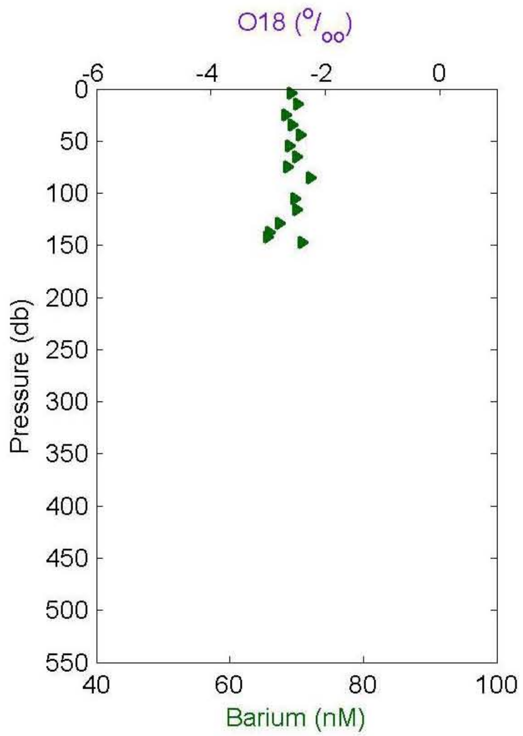
1997-22: Cast 118 Station 30

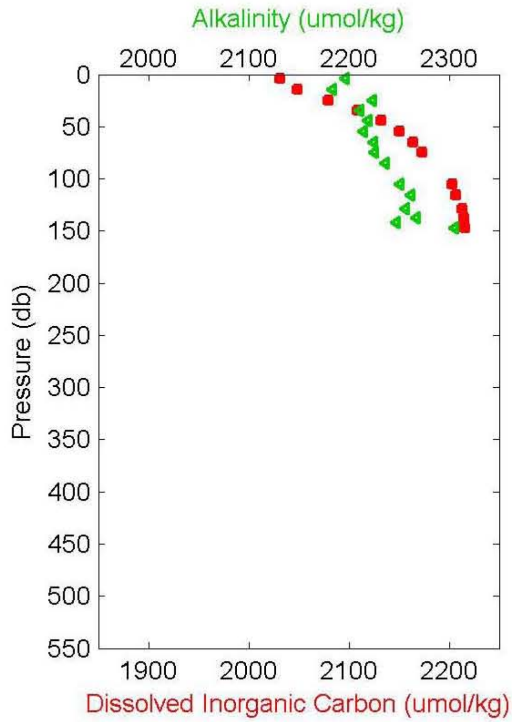


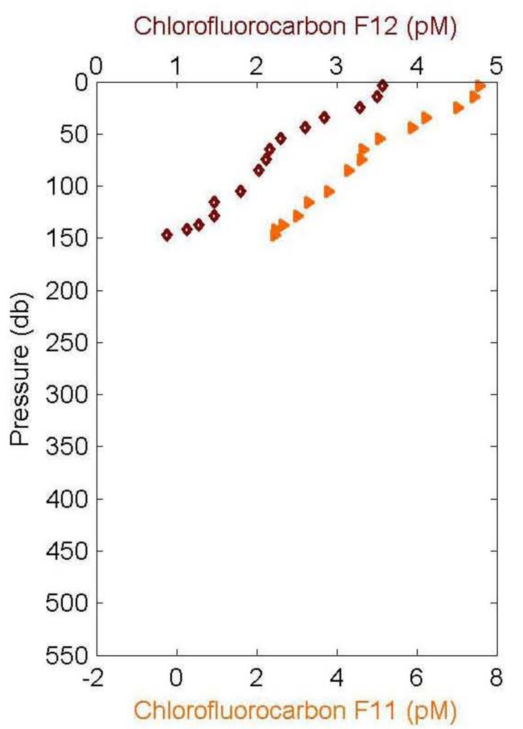
1997-22: Cast 119 Station 32

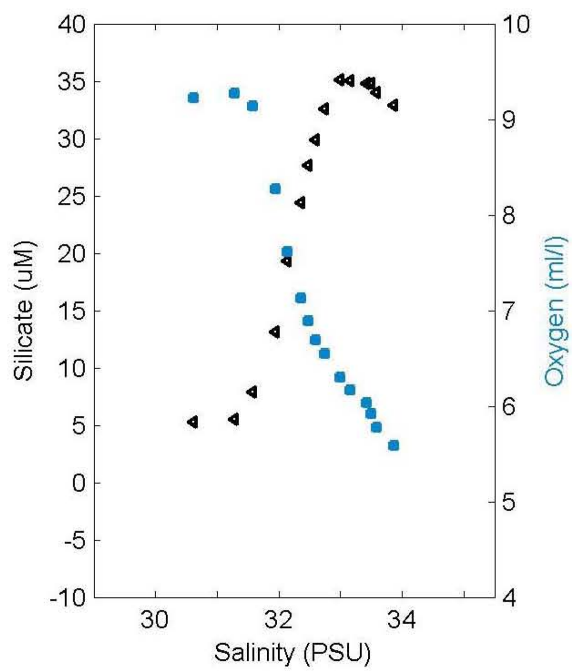


1997-22: Cast 119 Station 32

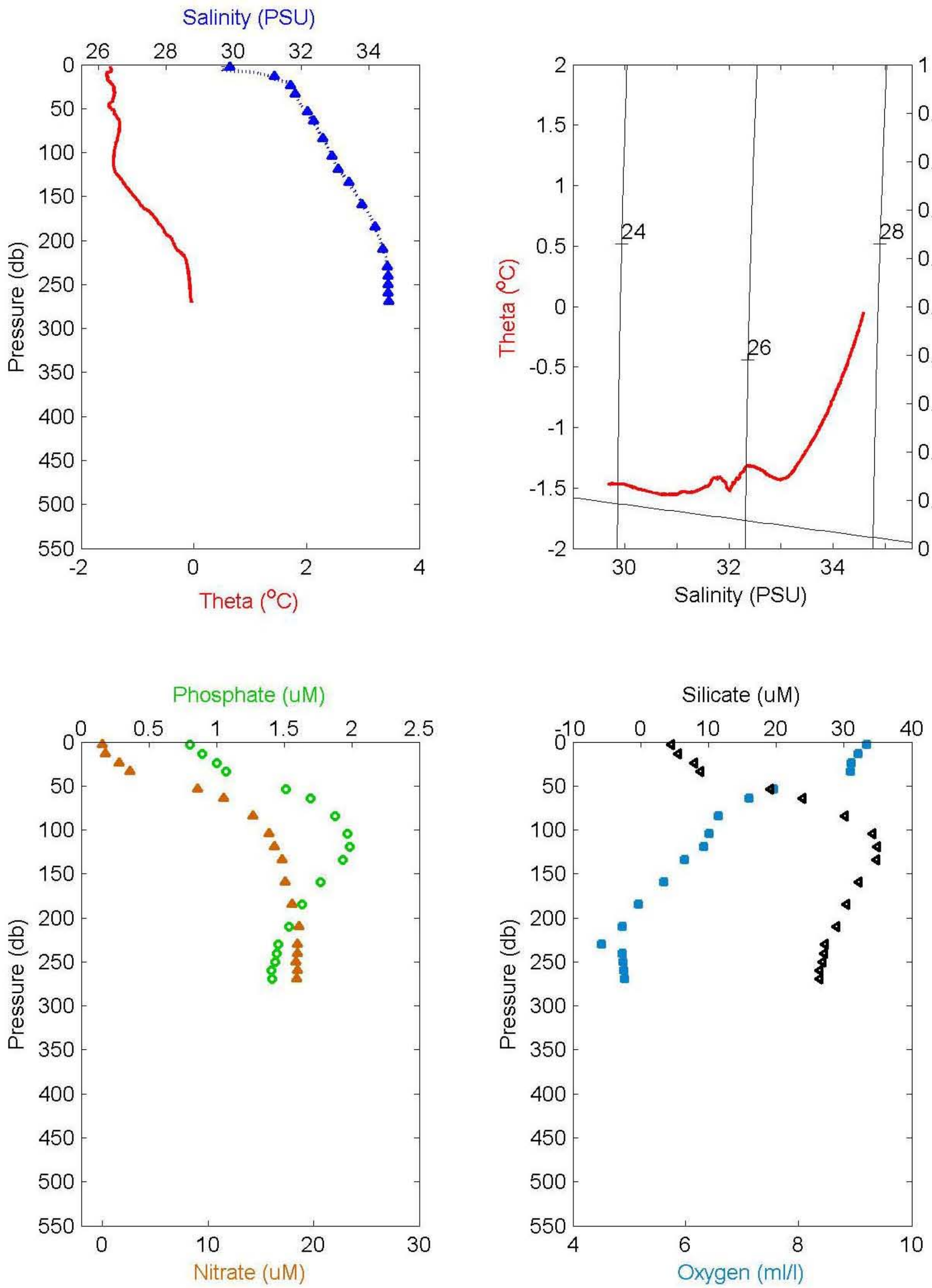




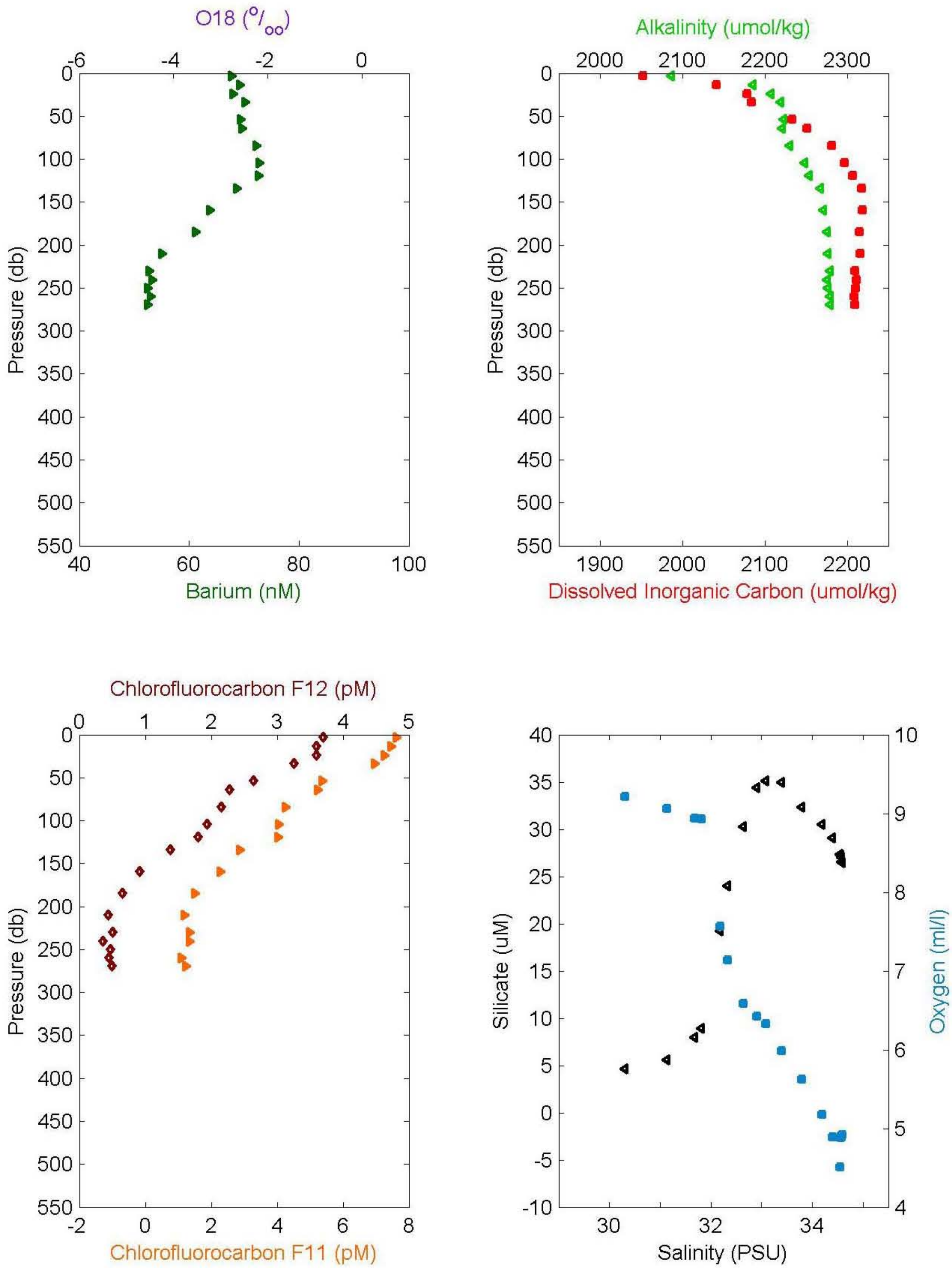




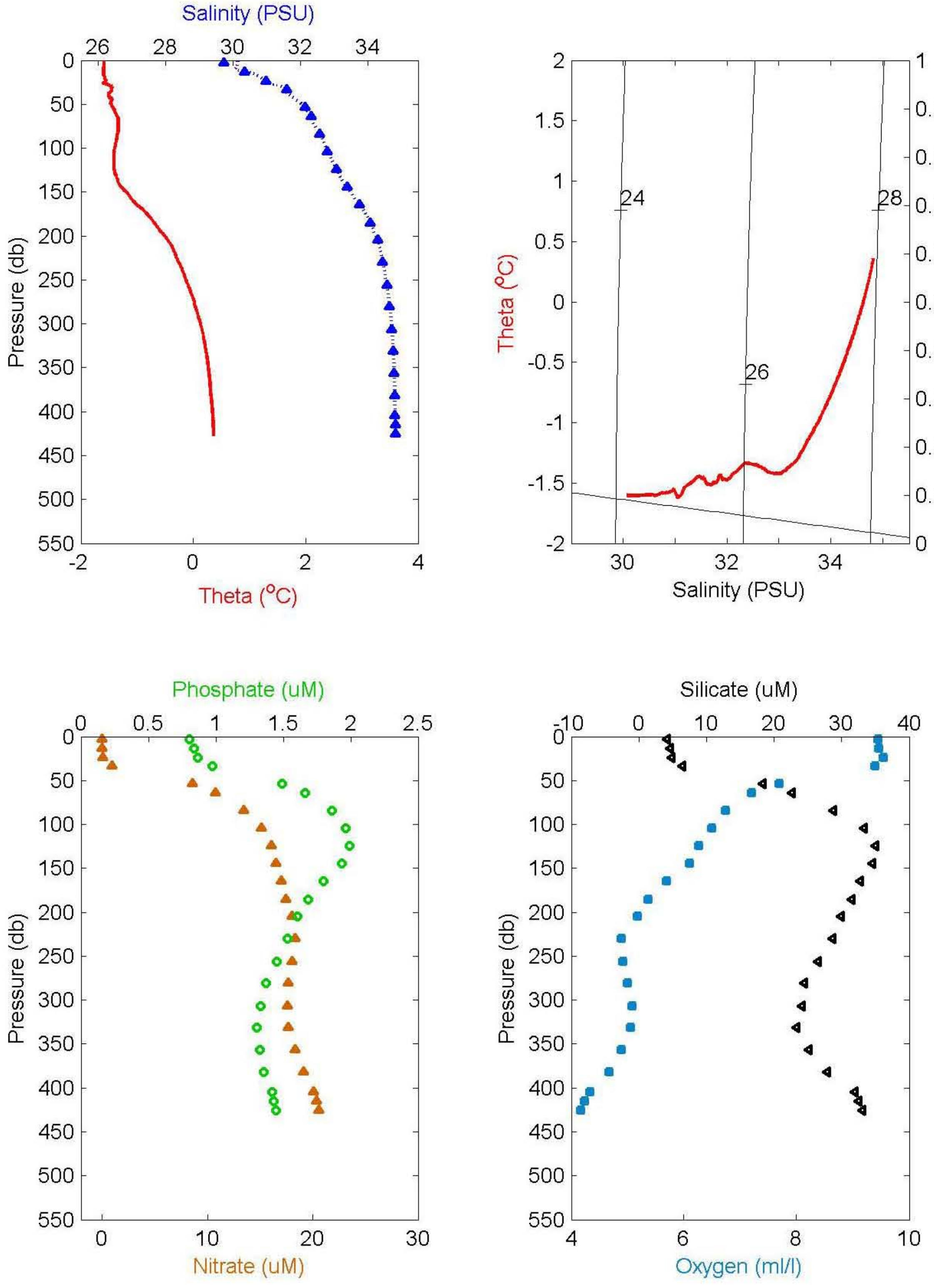
1997-22: Cast 120 Station 33



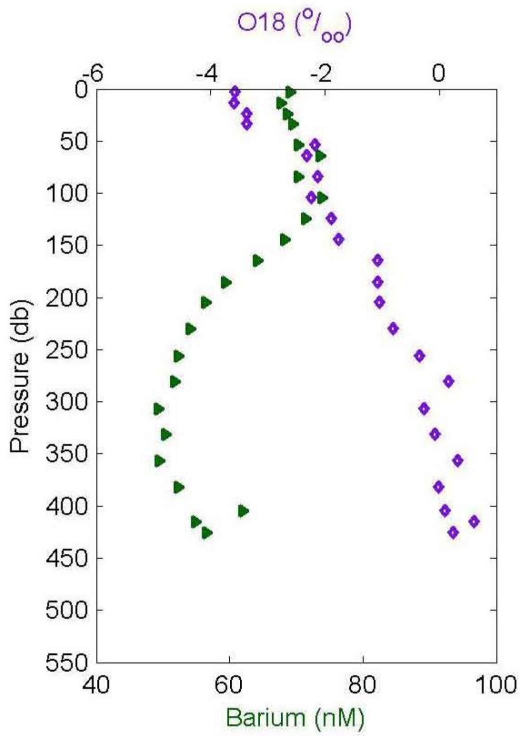
1997-22: Cast 120 Station 33

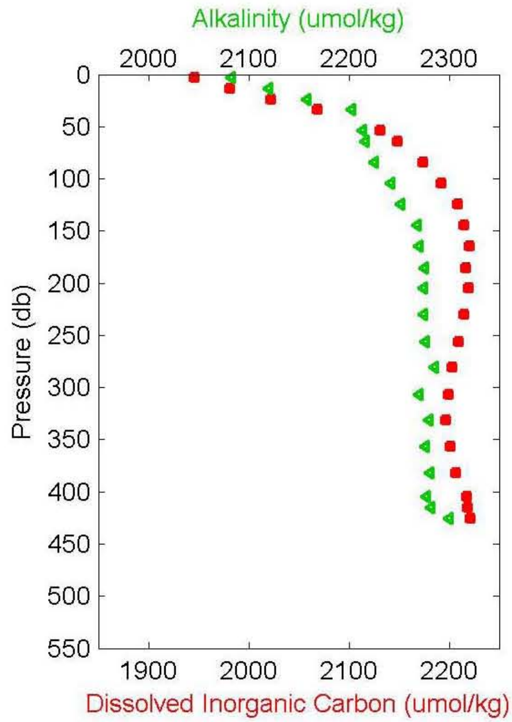


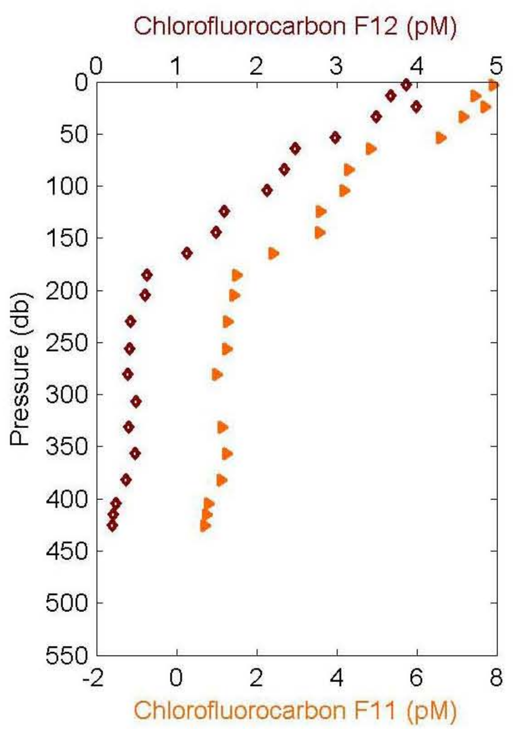
1997-22: Cast 121 Station 34

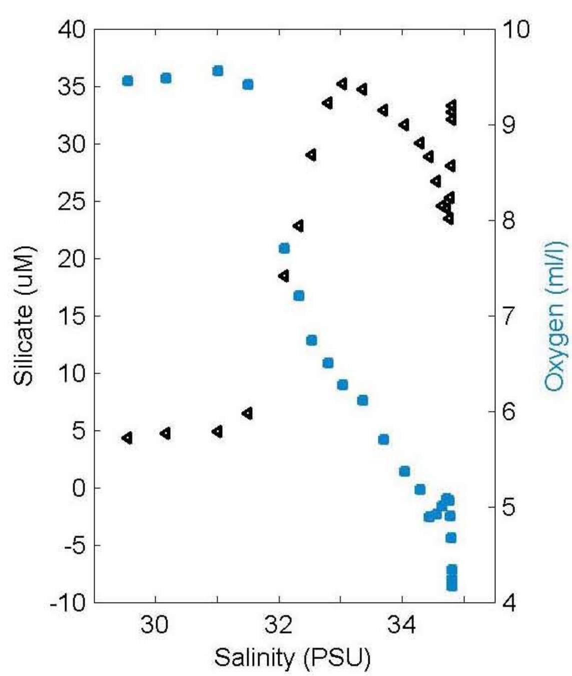


1997-22: Cast 121 Station 34

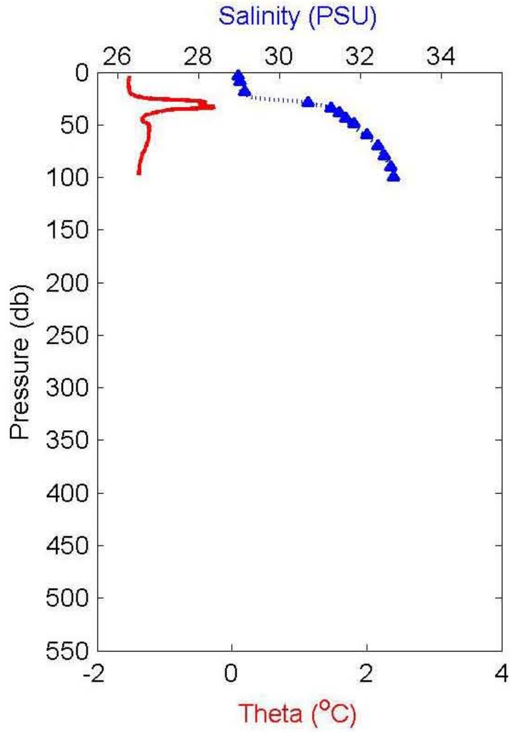


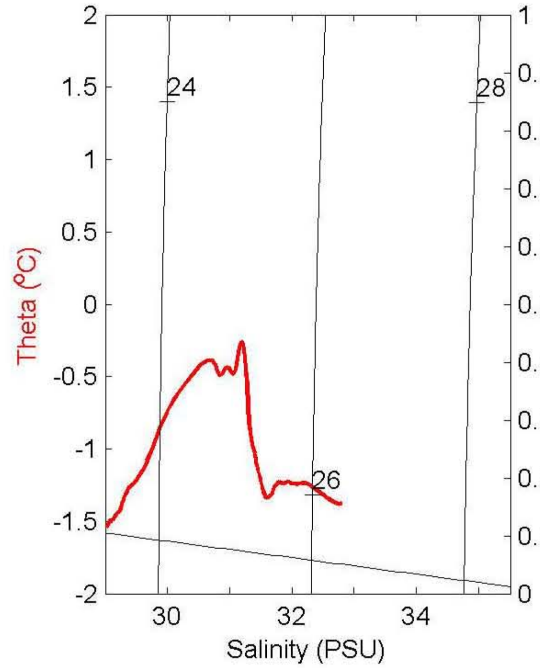


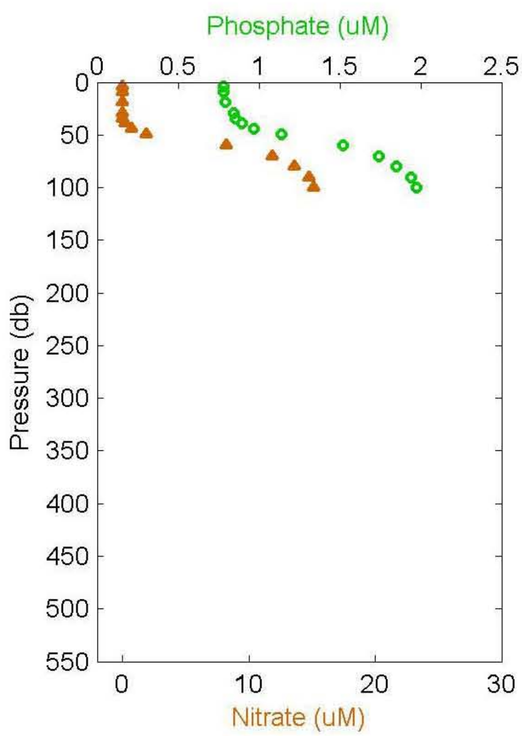


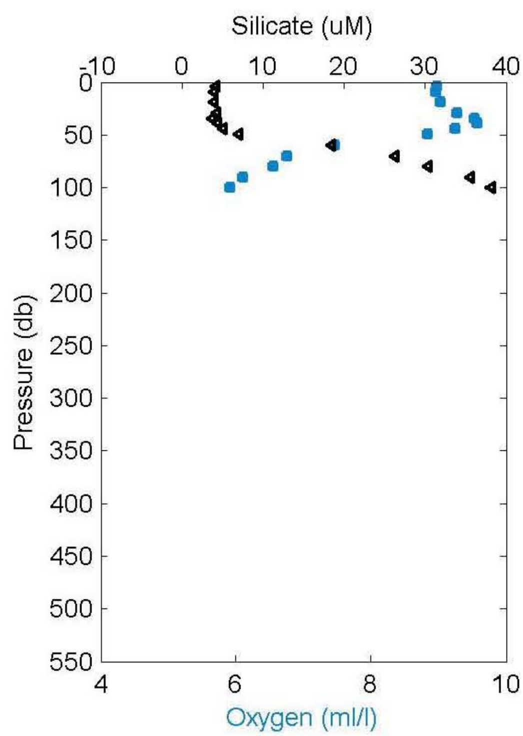


1997-22: Cast 122 Station 36

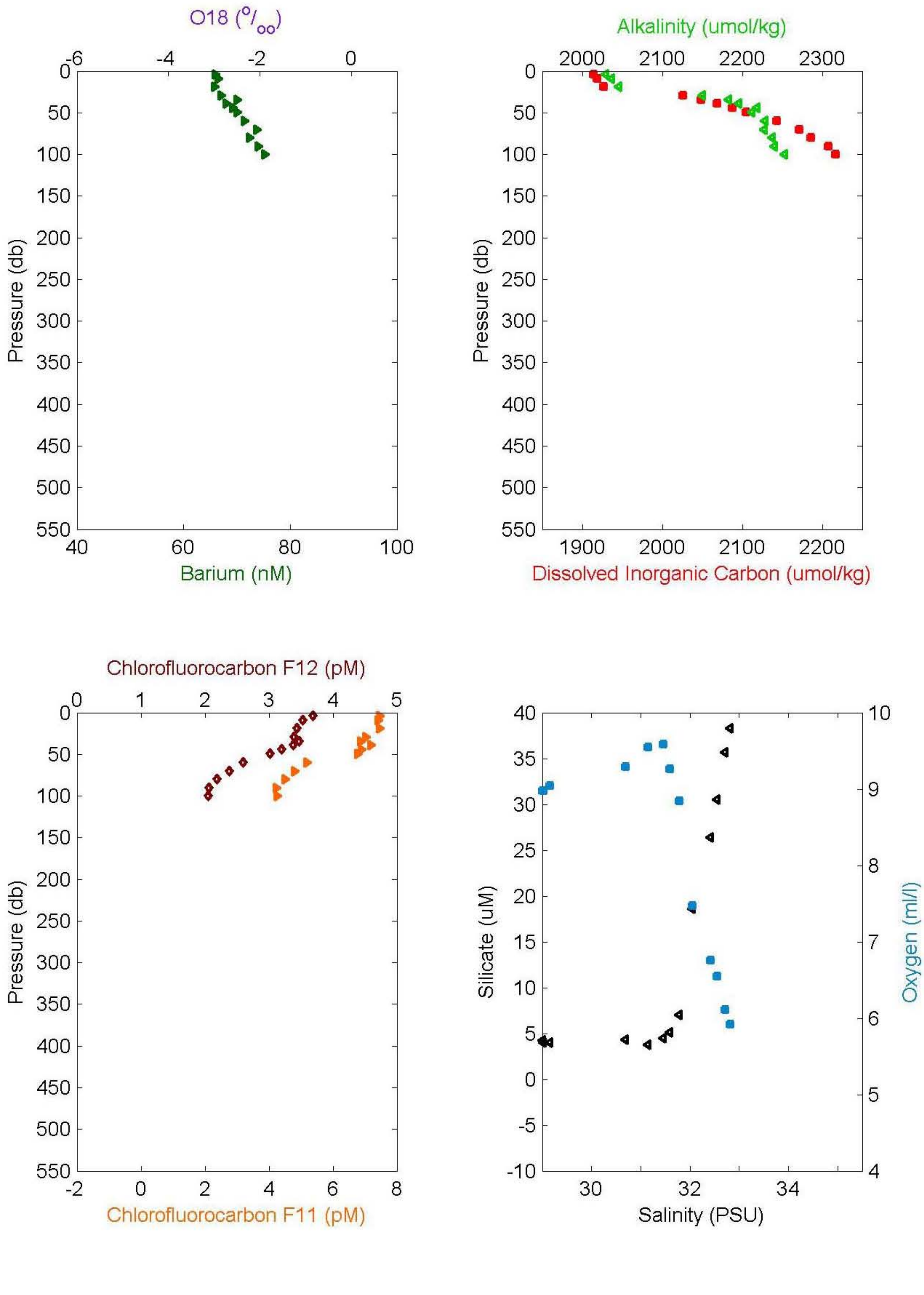




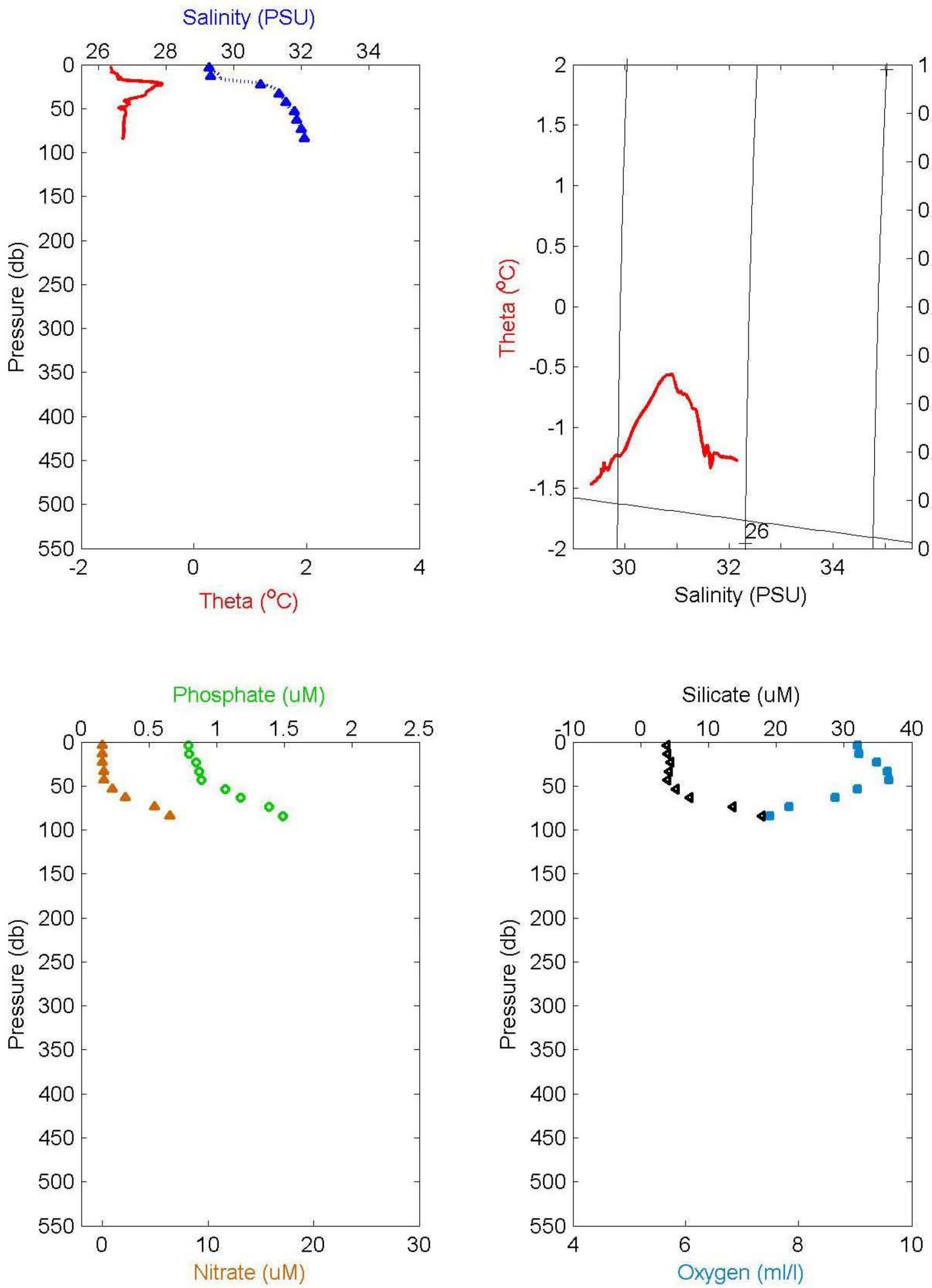




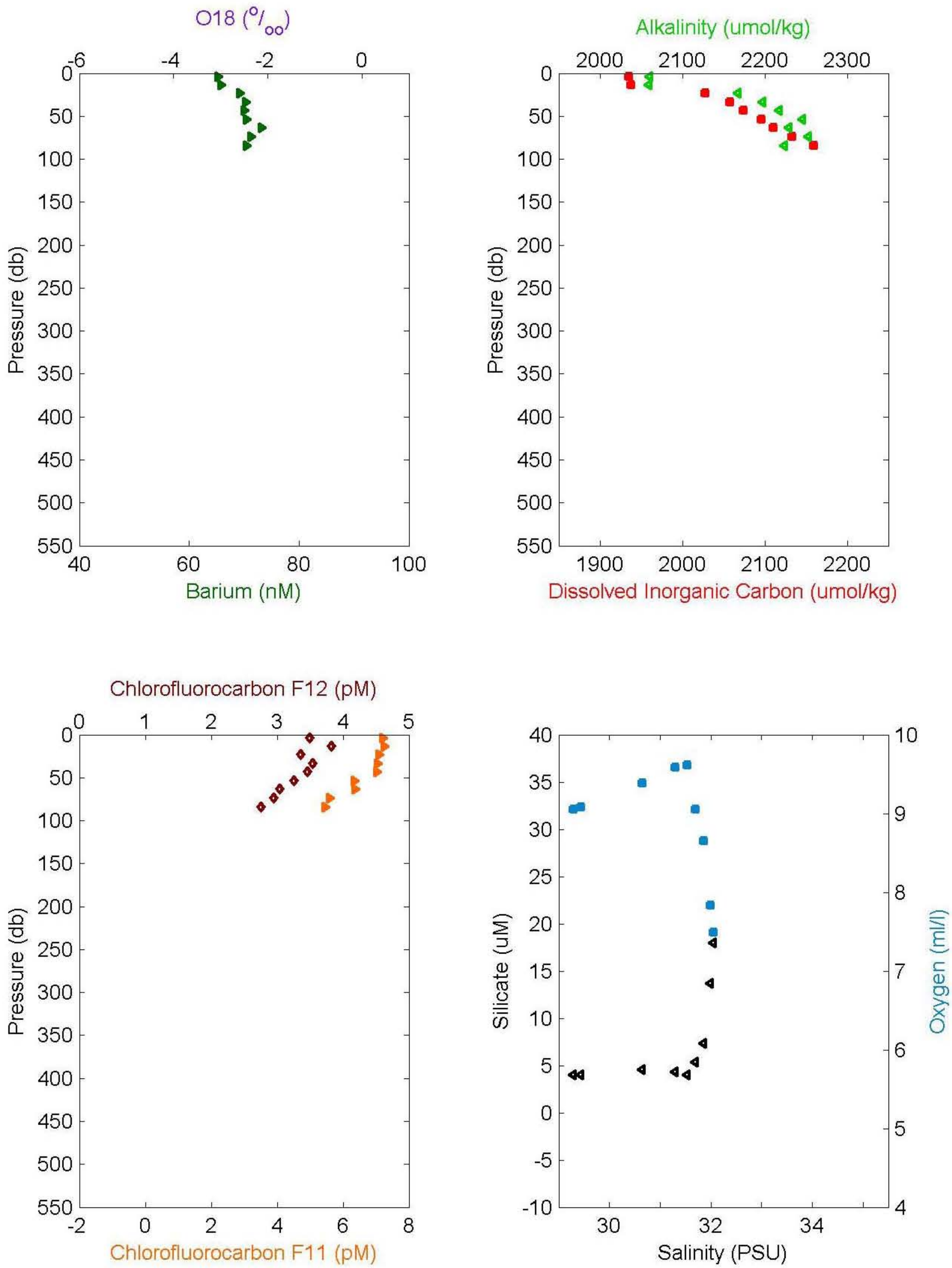
1997-22: Cast 122 Station 36



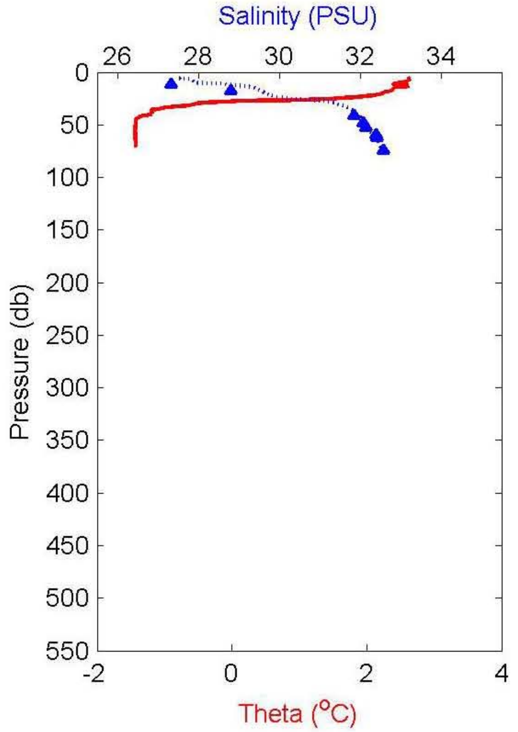
1997-22: Cast 123 Station 37

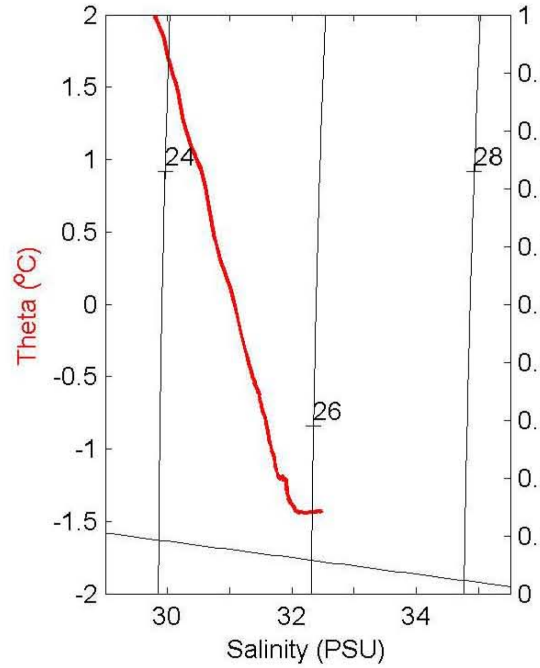


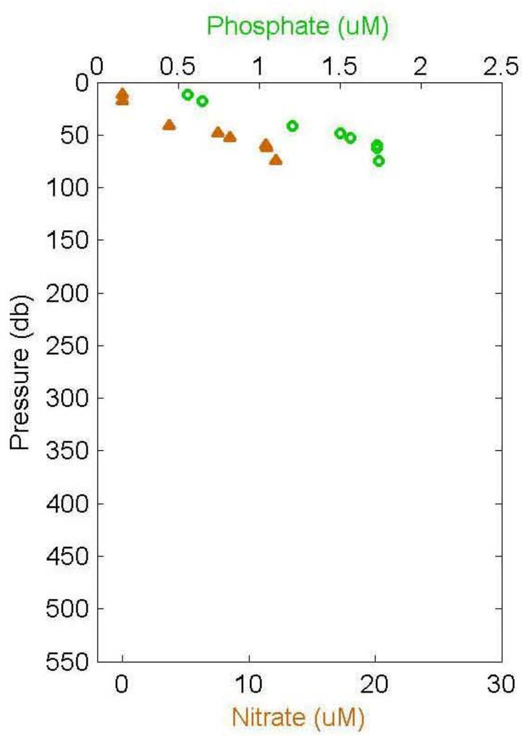
1997-22: Cast 123 Station 37

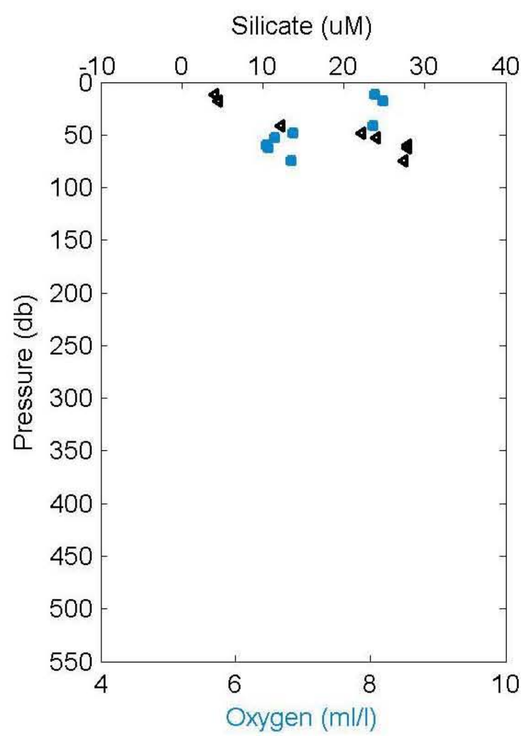


1997-22: Cast 124 Station 38

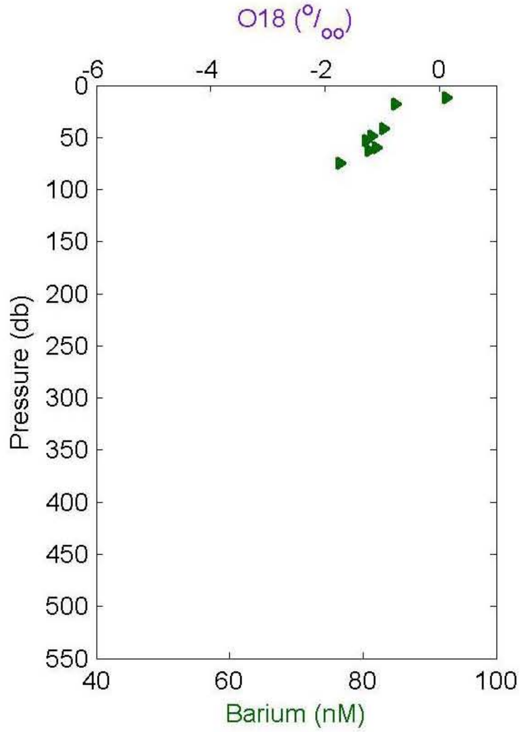


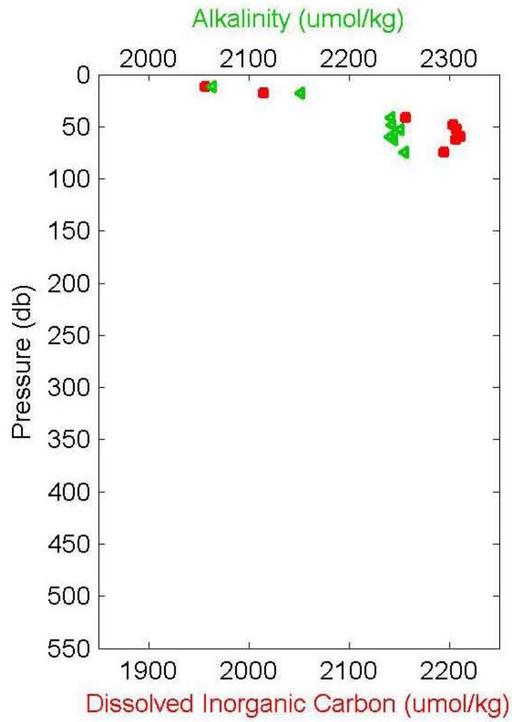


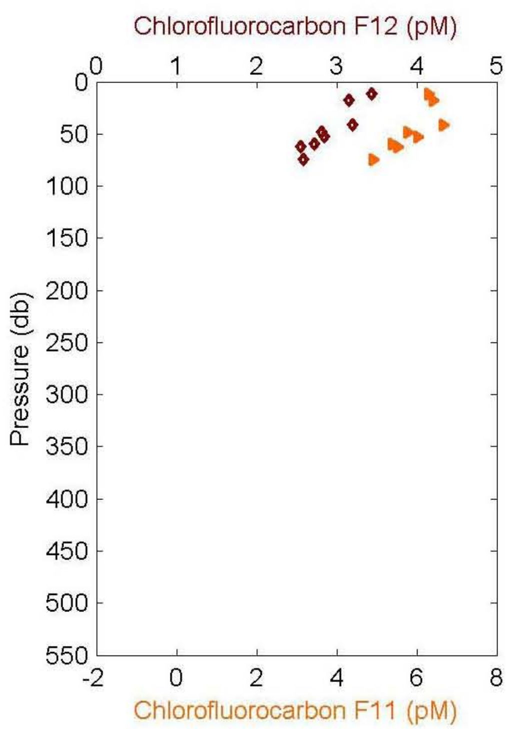


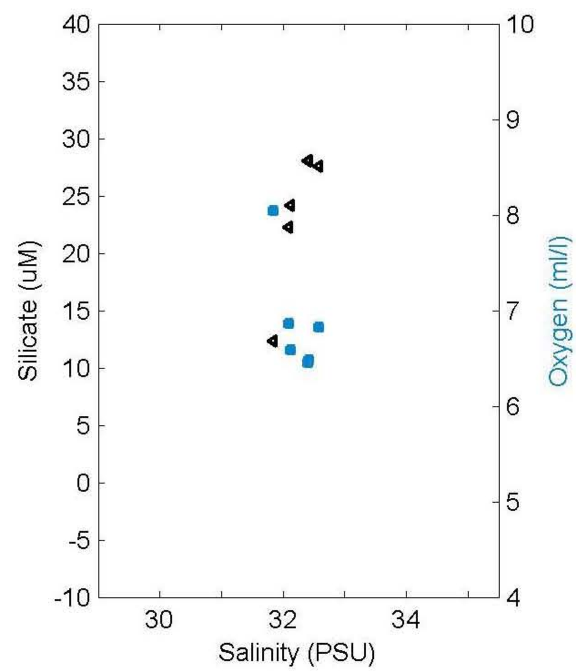


1997-22: Cast 124 Station 38

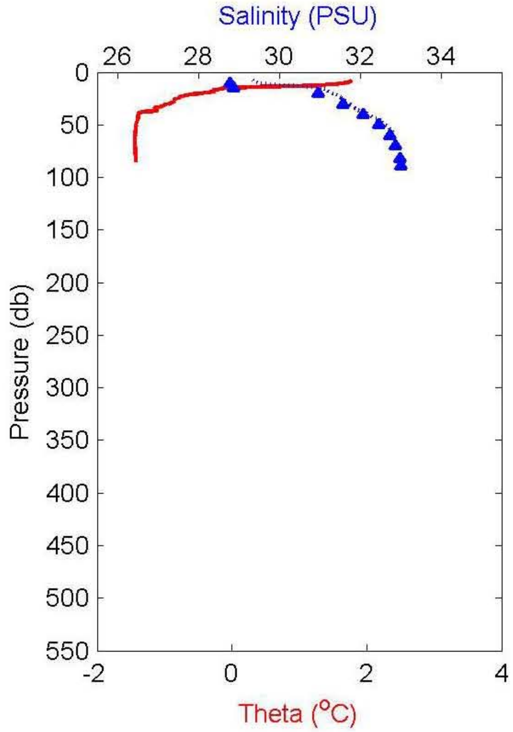


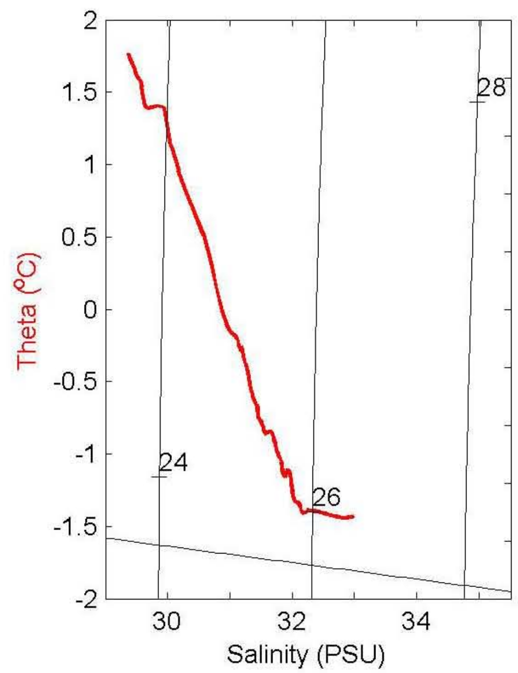


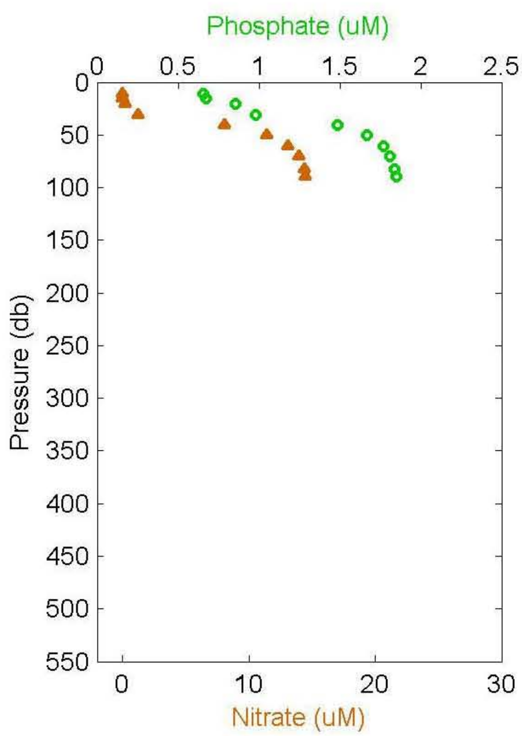


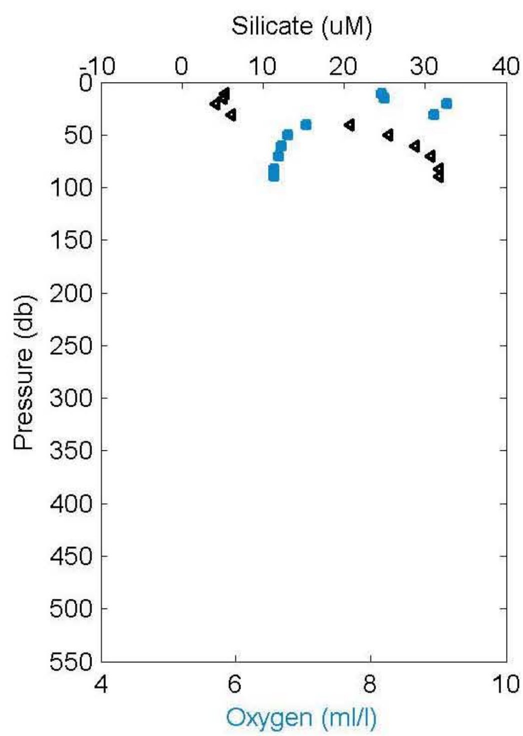


1997-22: Cast 125 Station 42

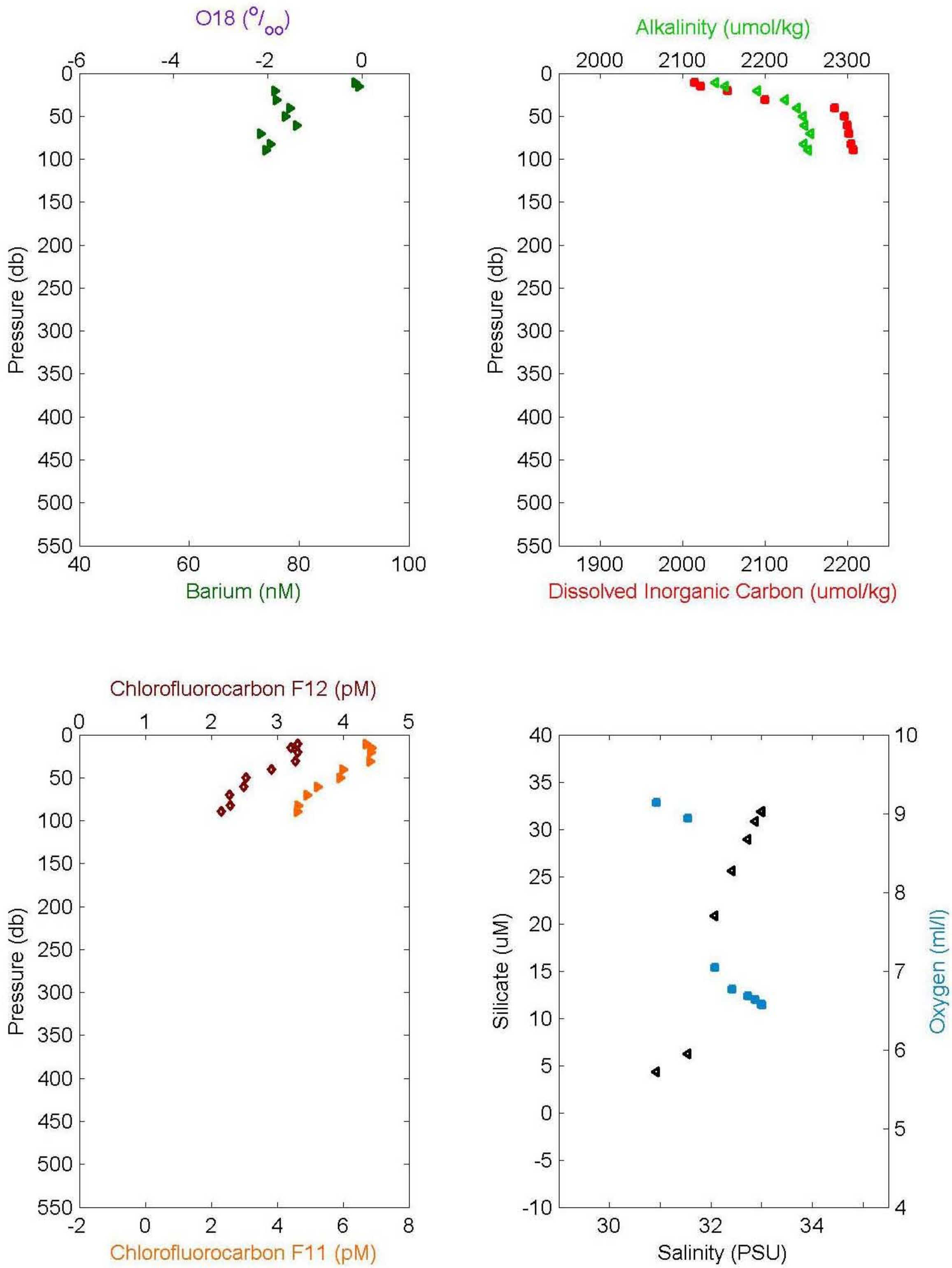




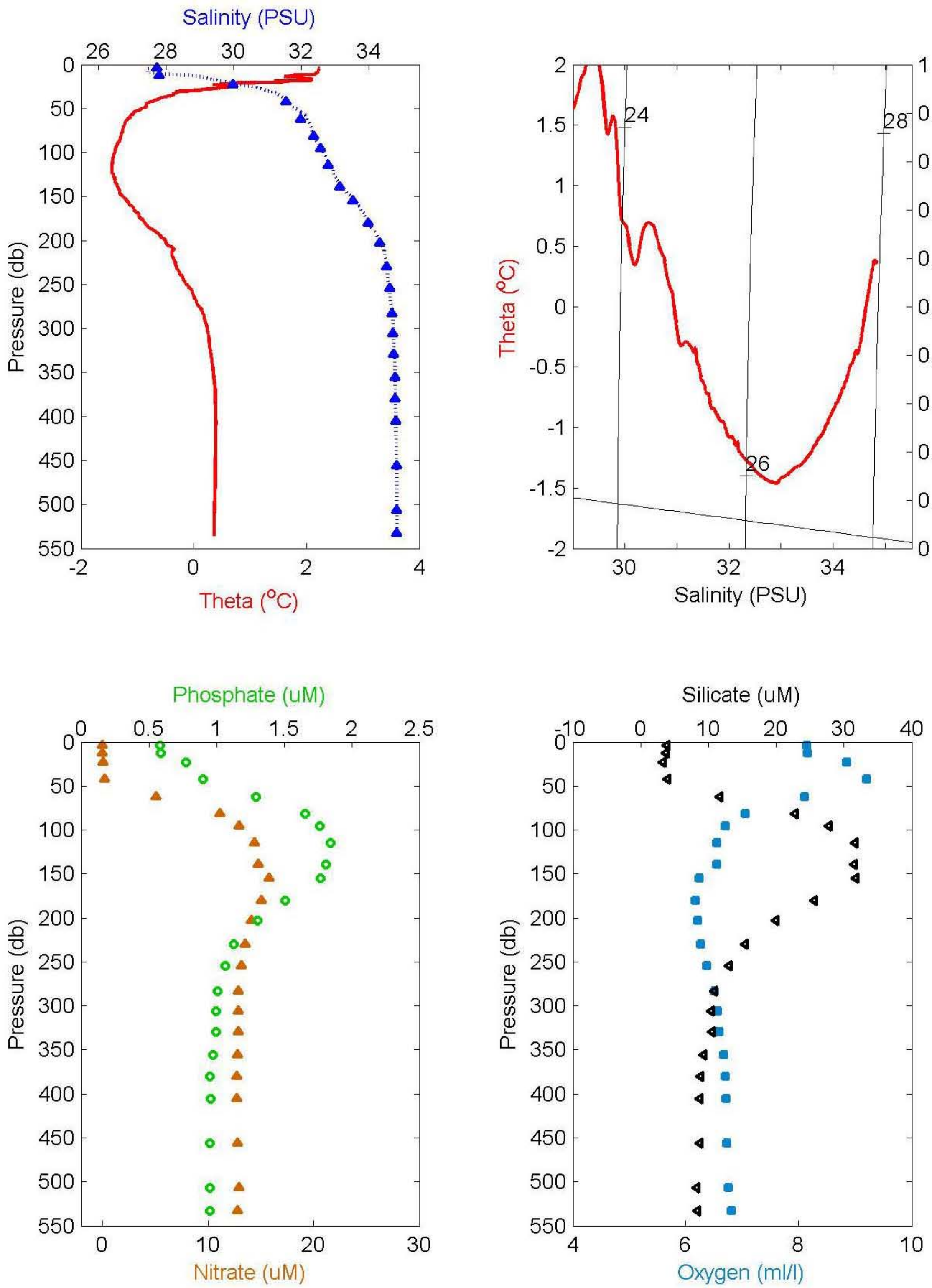




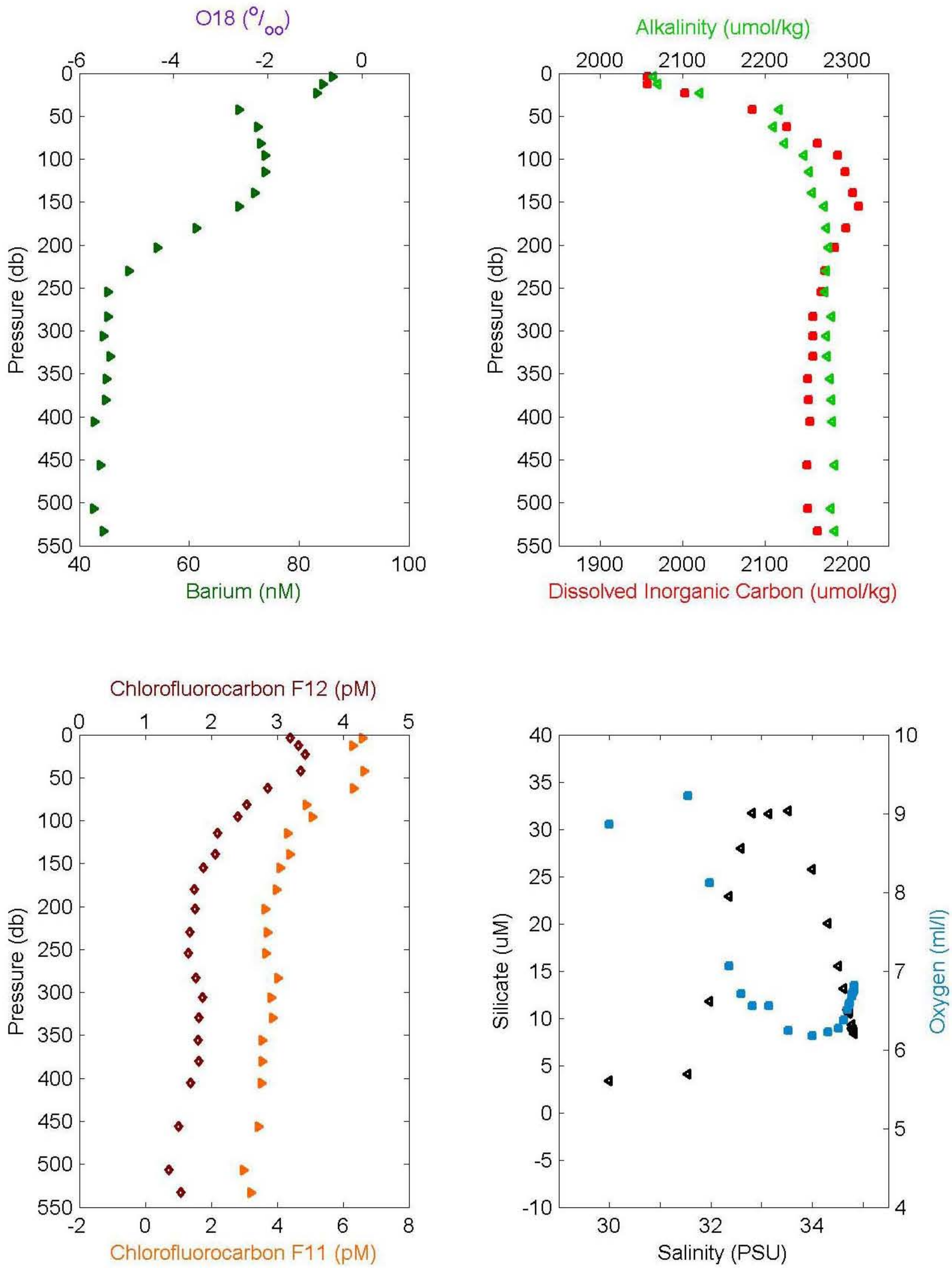
1997-22: Cast 125 Station 42



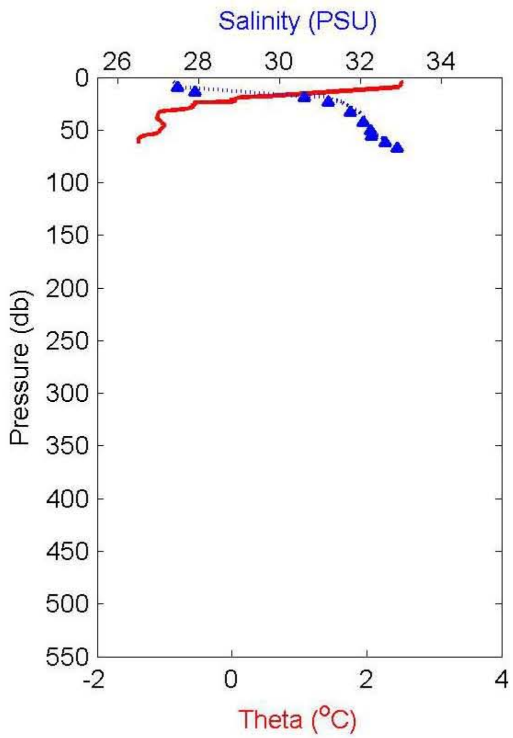
1997-22: Cast 126 Station 47

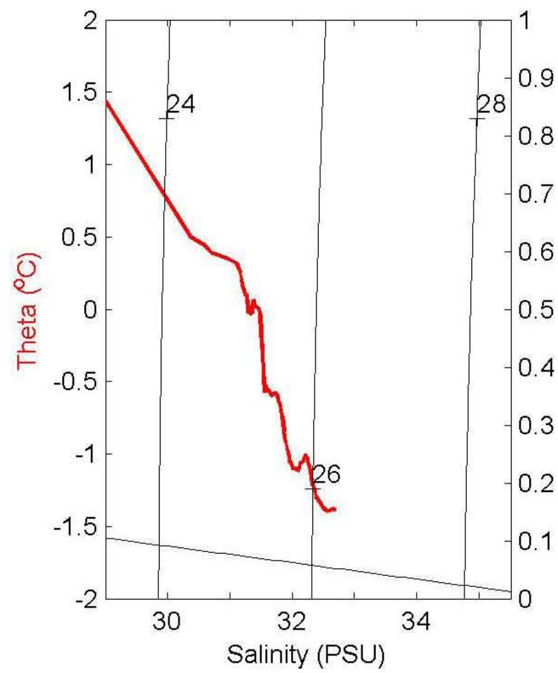


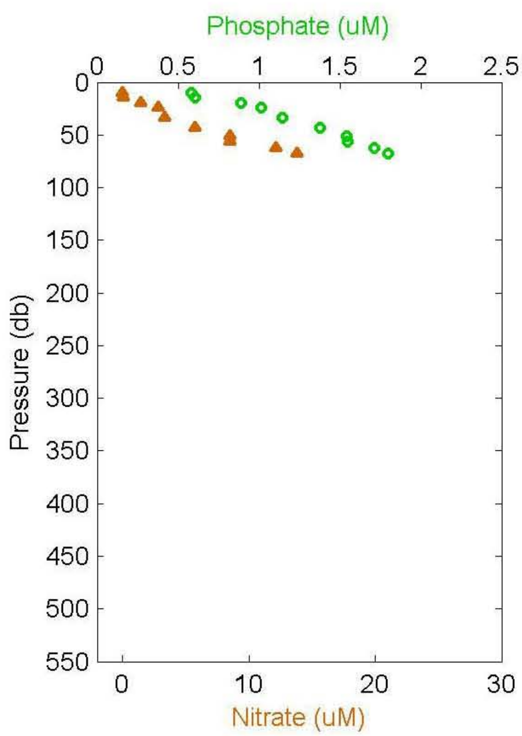
1997-22: Cast 126 Station 47

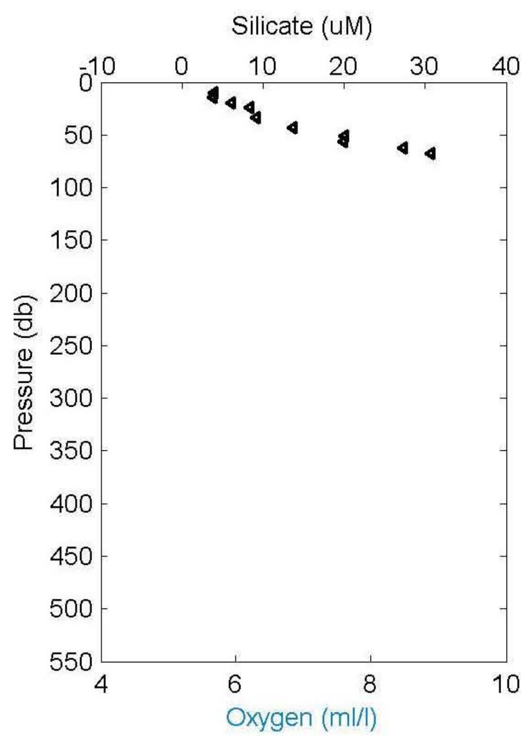


1997-22: Cast 127 Station 48

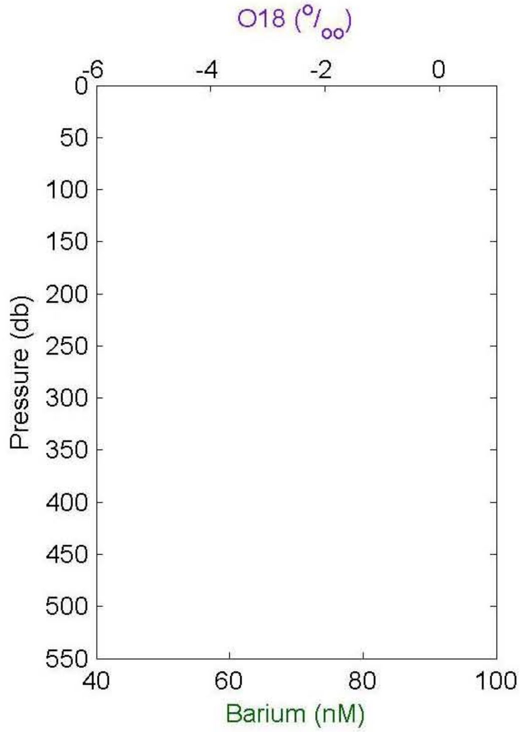


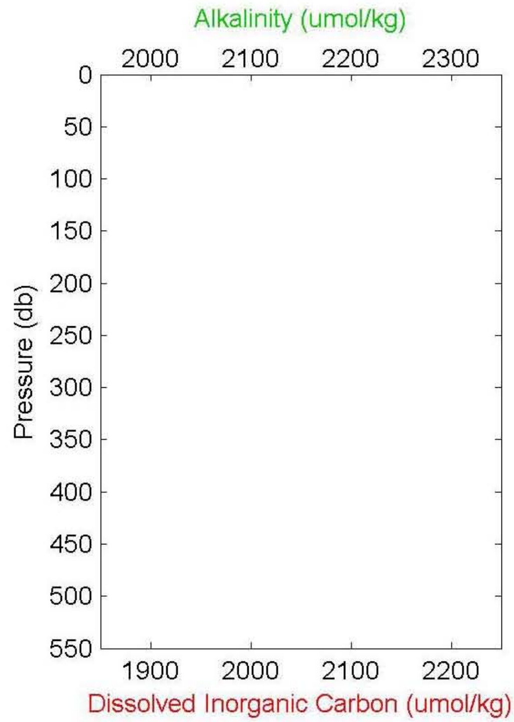


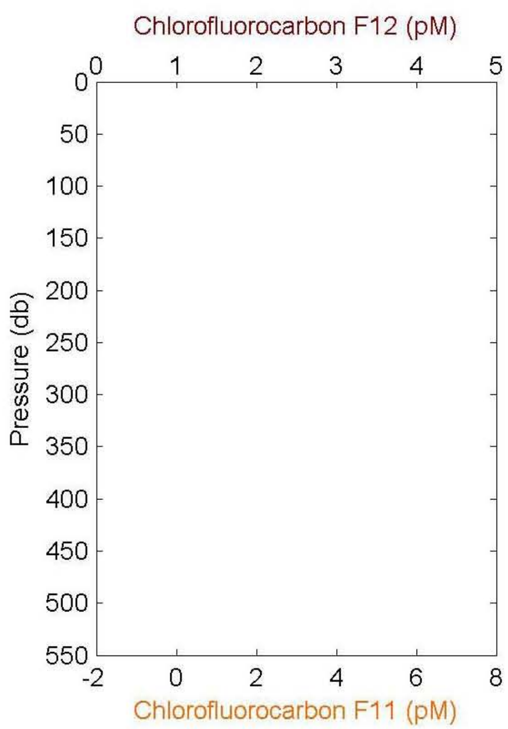


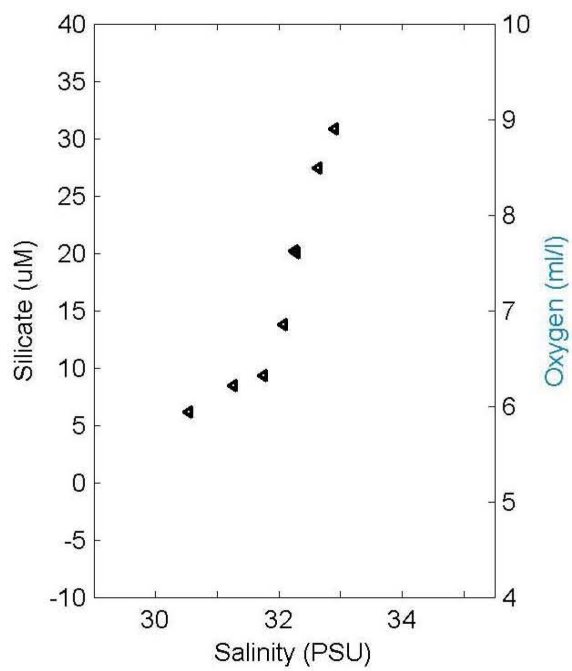


1997-22: Cast 127 Station 48



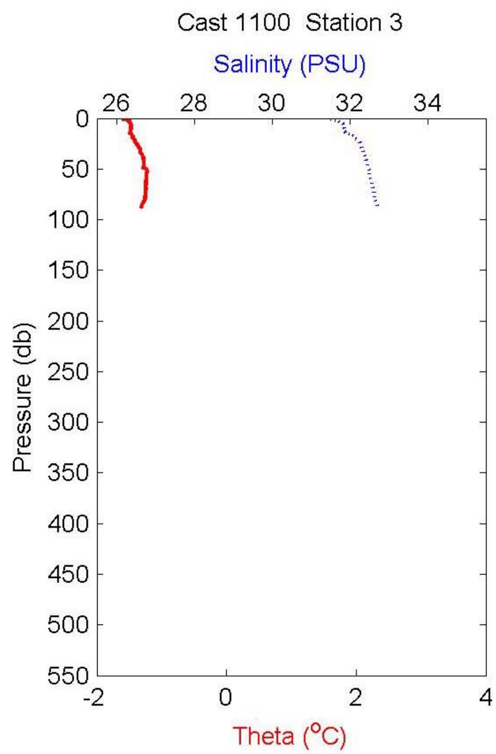


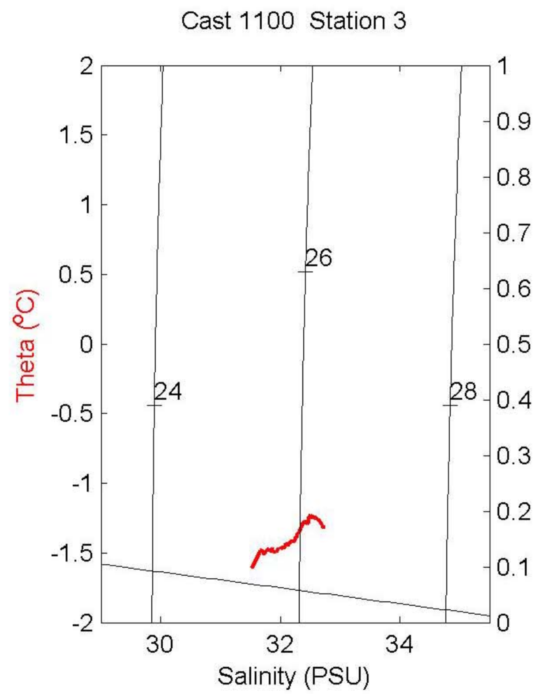


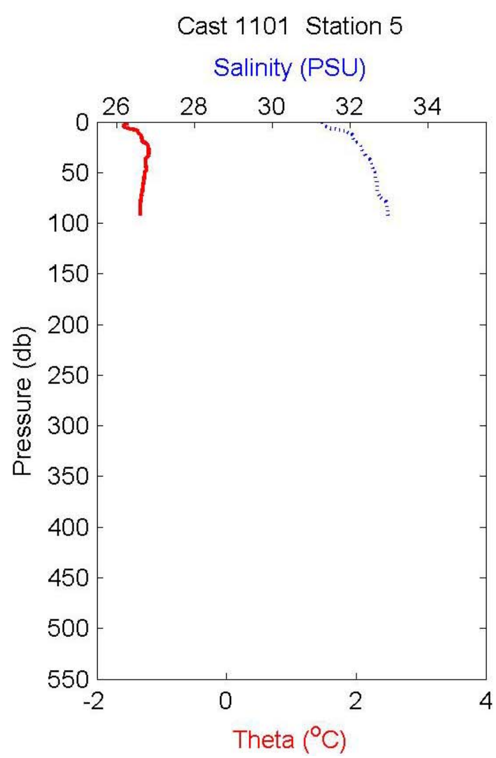


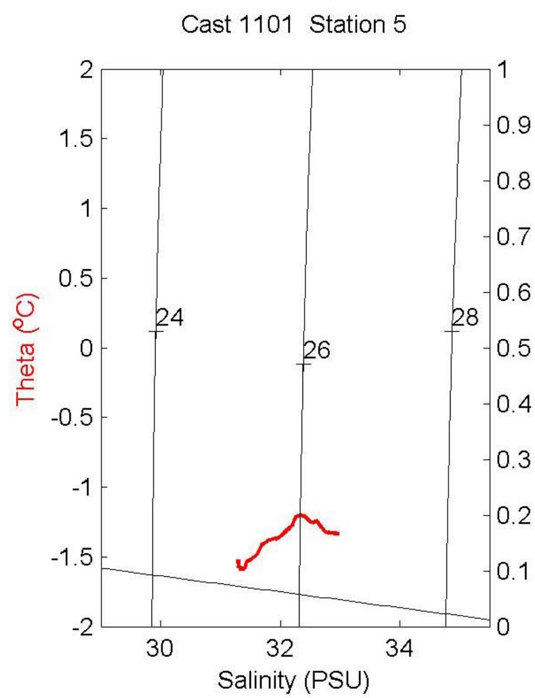
4.5.2 CTD Only

1997-22: CTD-only Casts

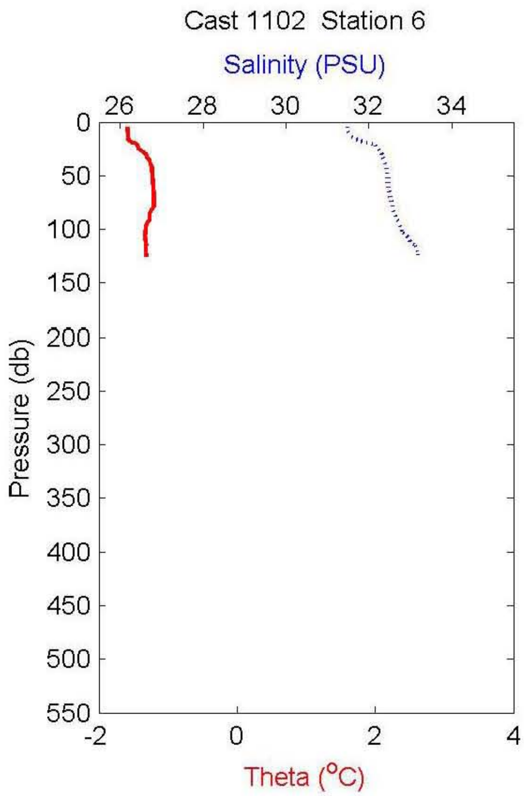


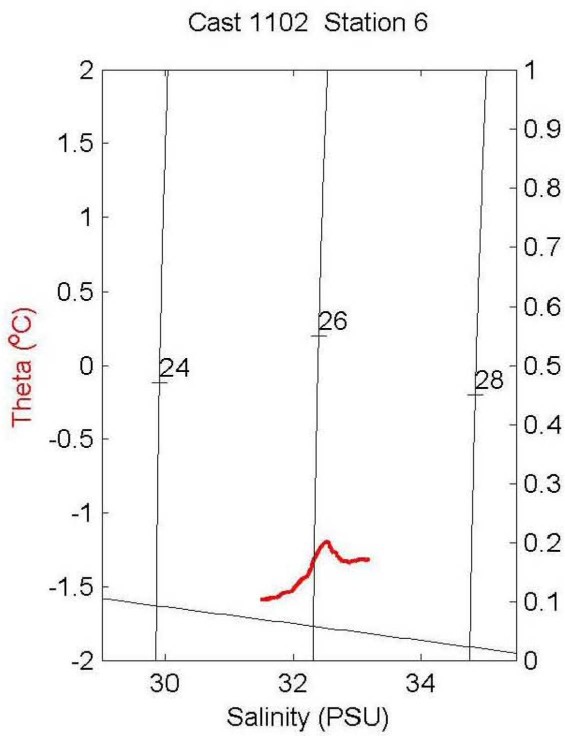


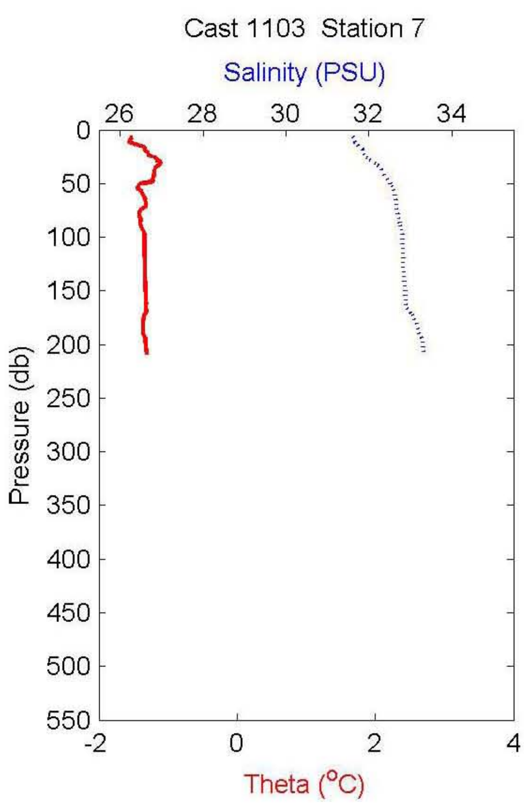


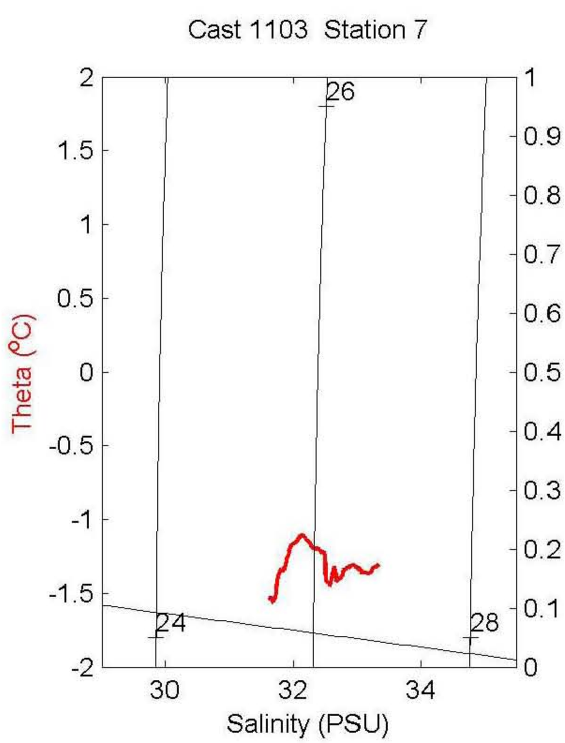


1997-22: CTD-only Casts

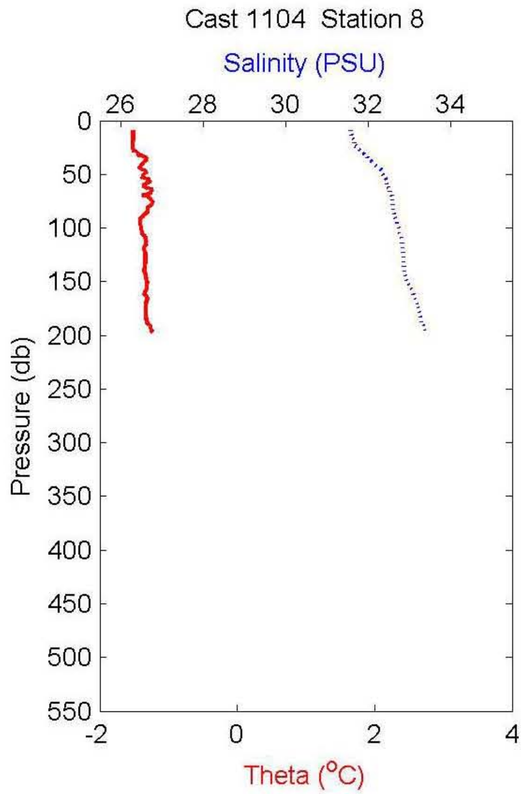


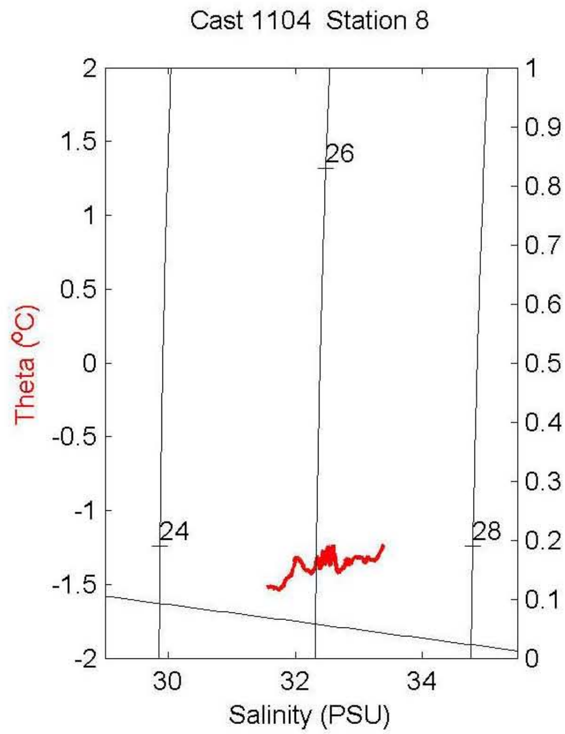


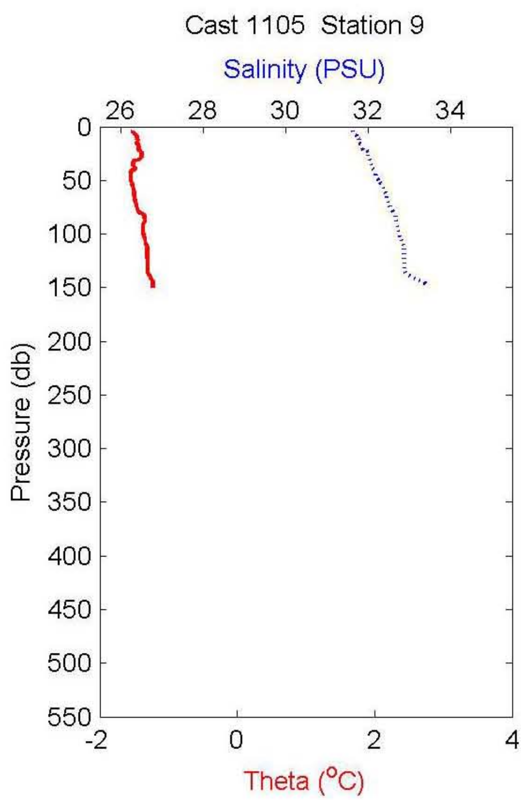


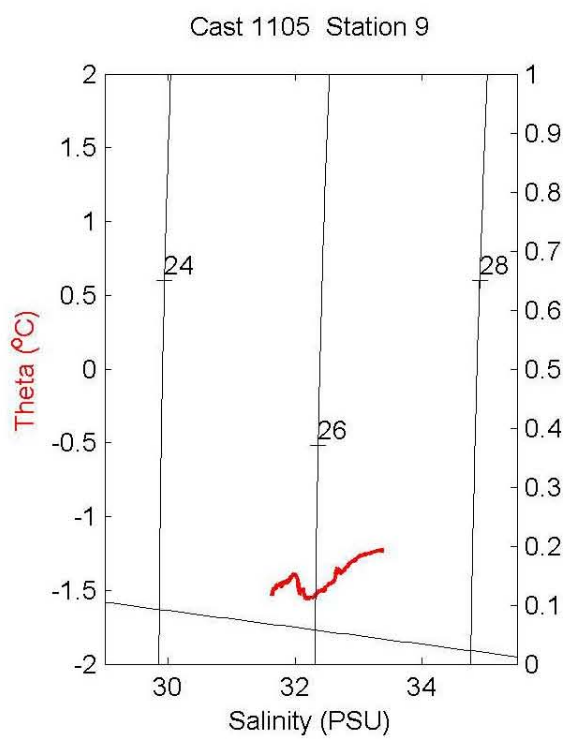


1997-22: CTD-only Casts

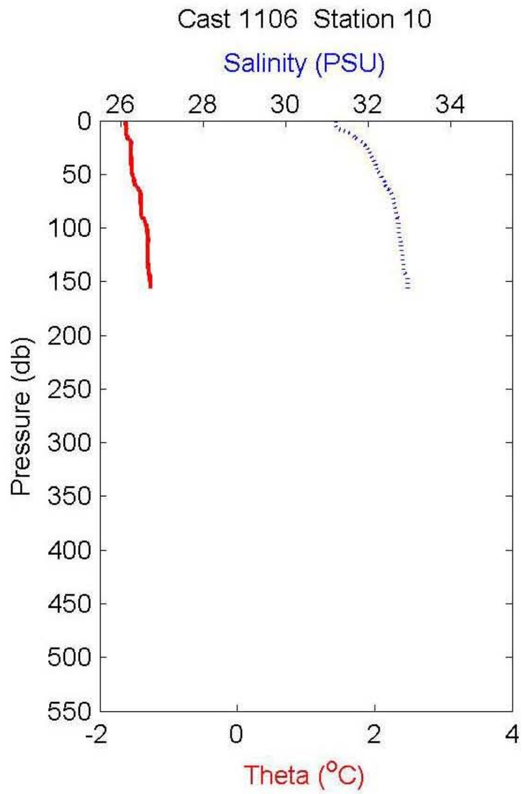


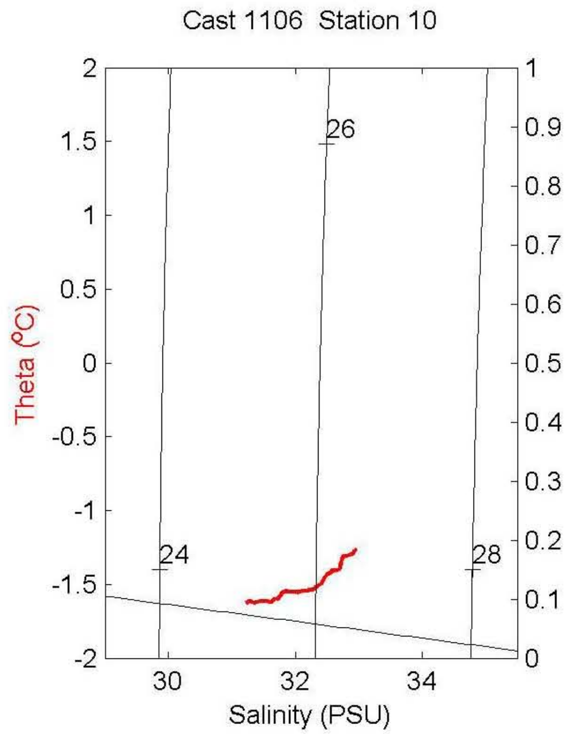


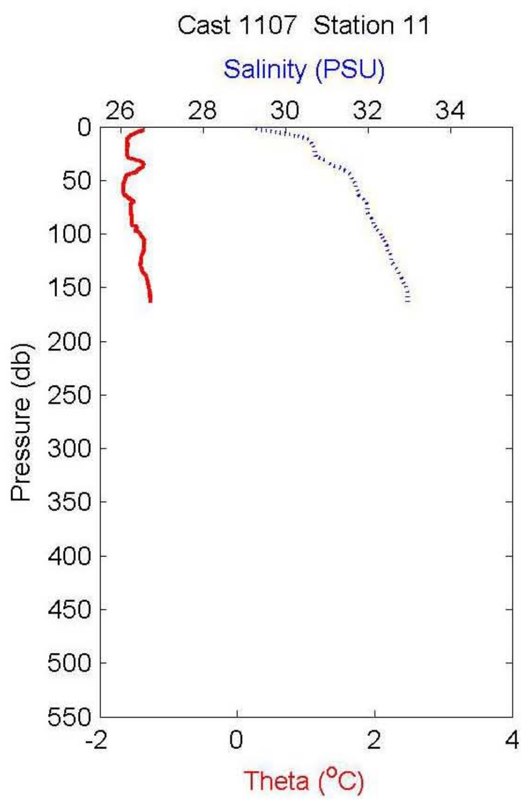


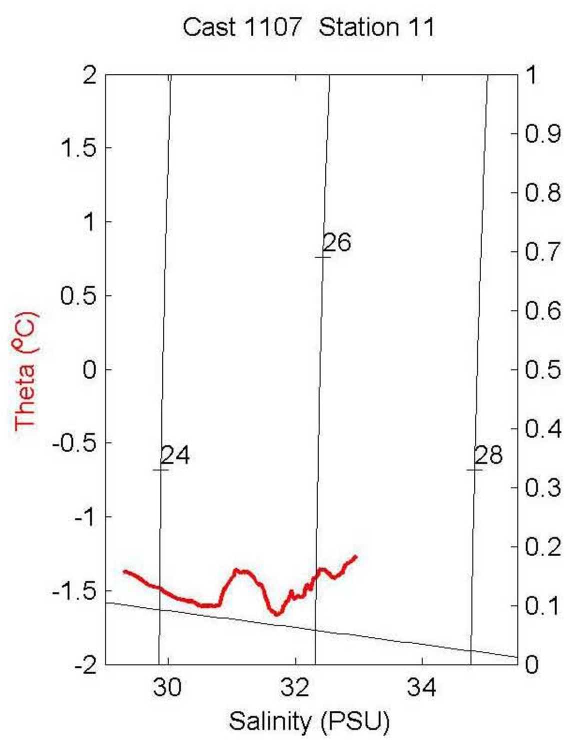


1997-22: CTD-only Casts

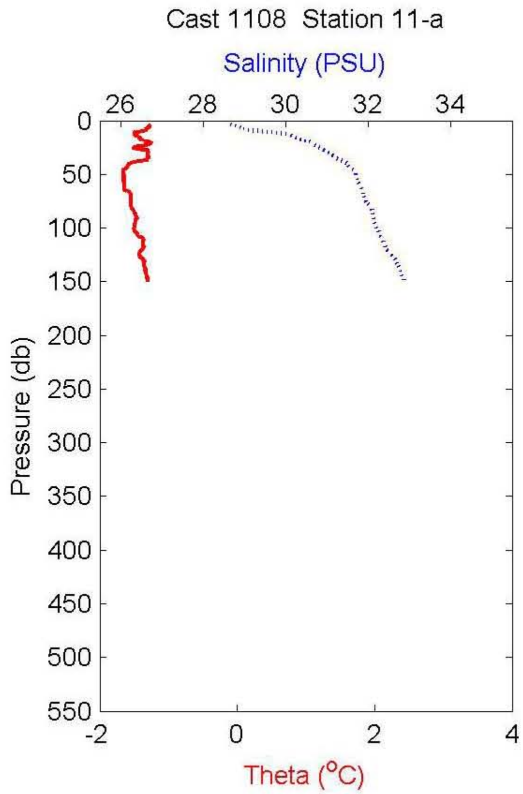


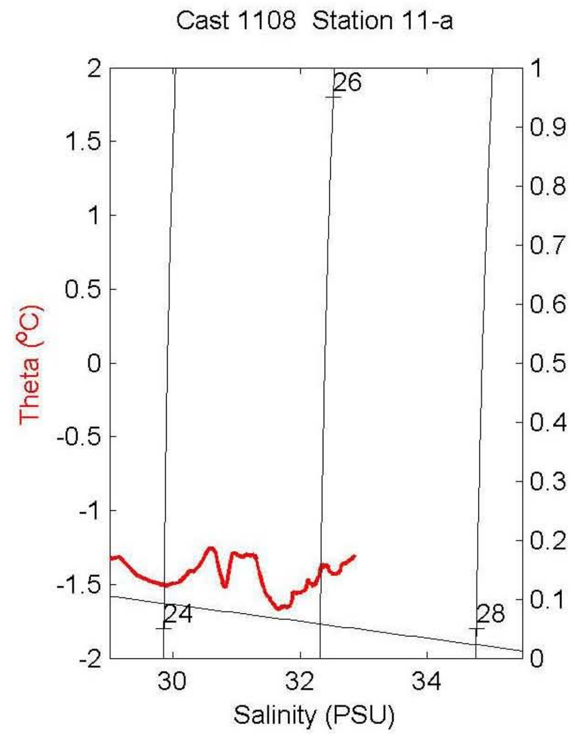


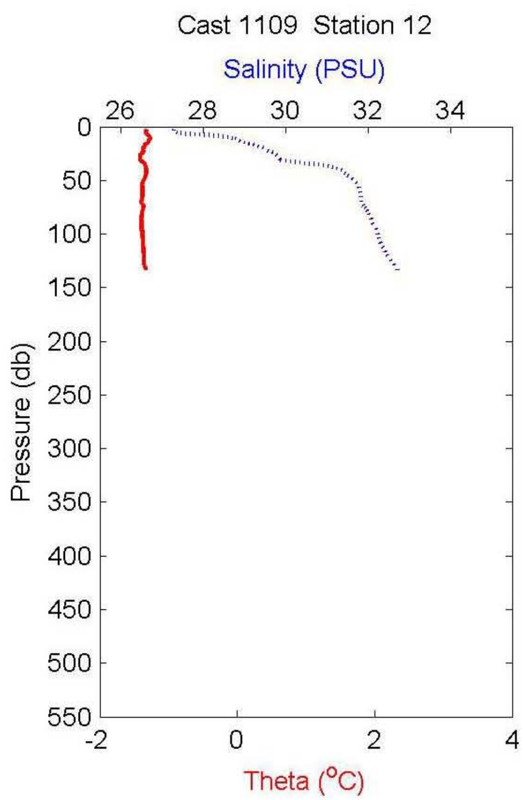


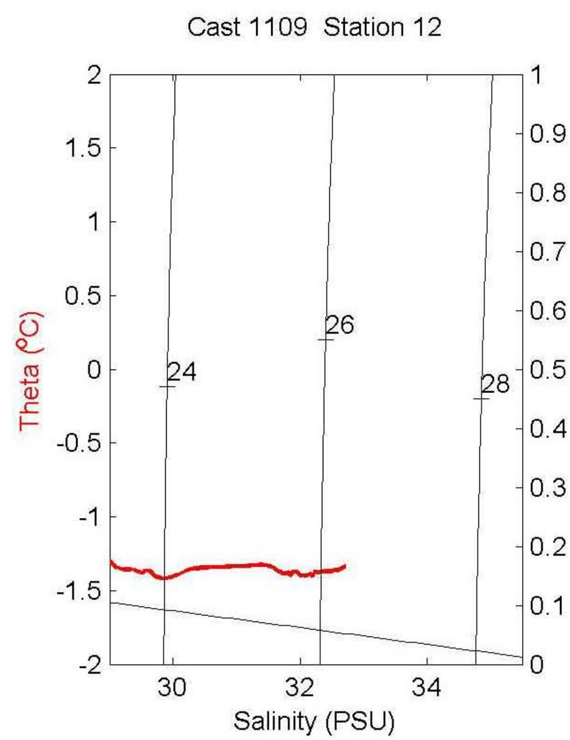


1997-22: CTD-only Casts

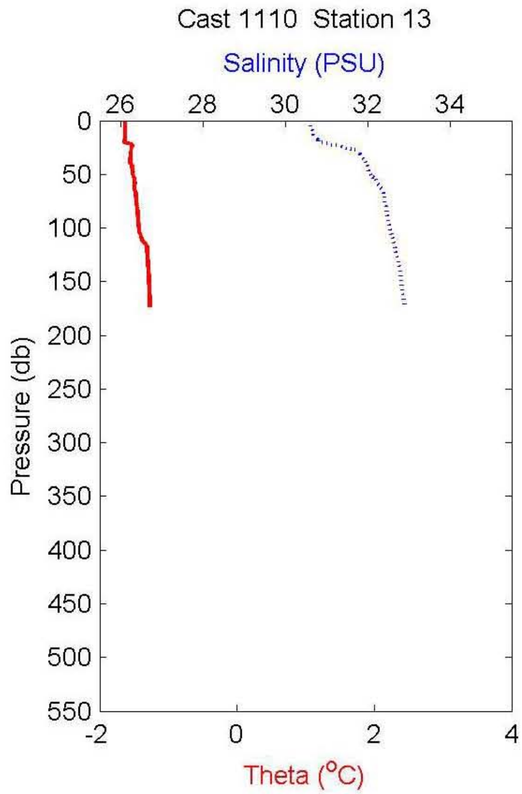


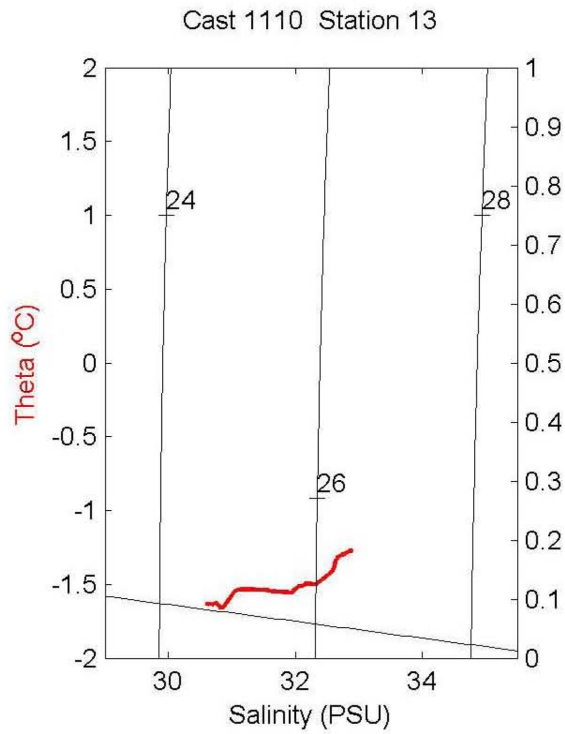


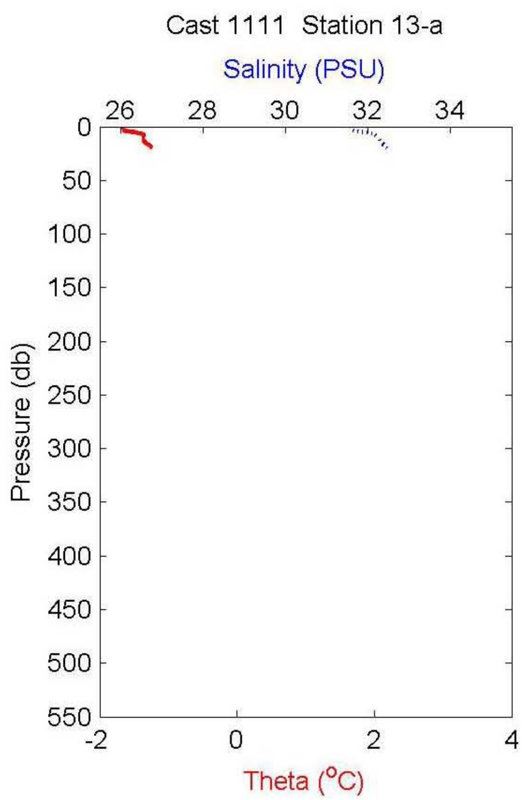


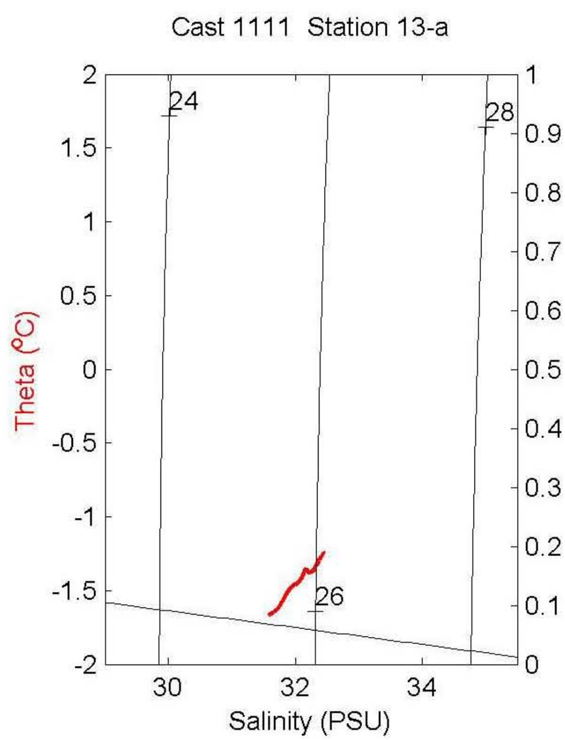


1997-22: CTD-only Casts

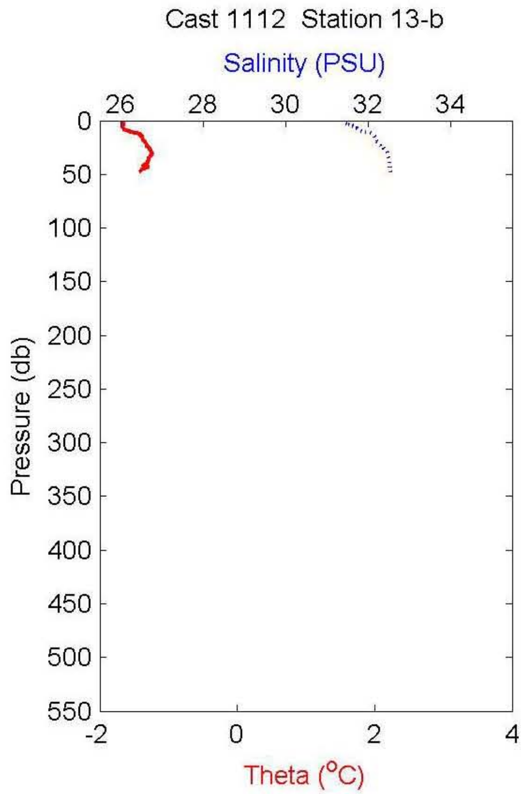


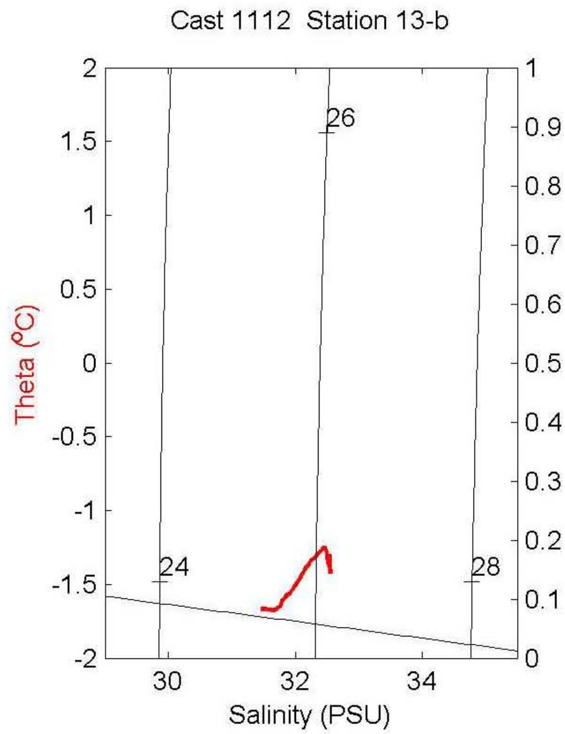


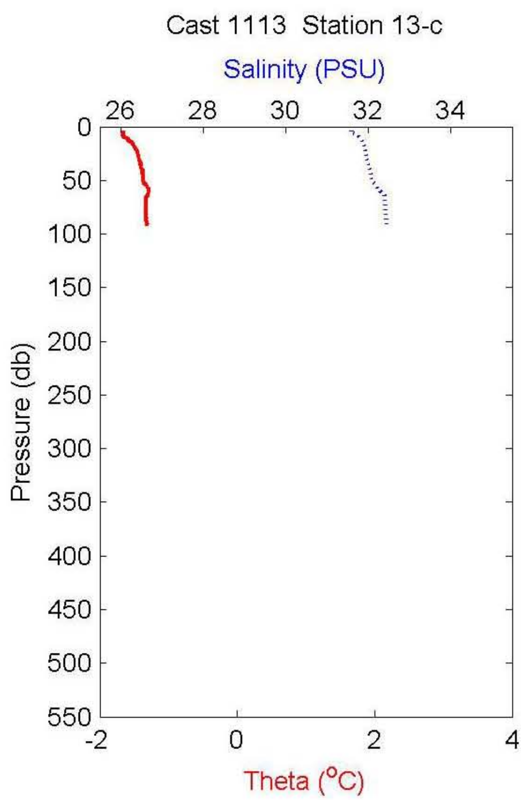


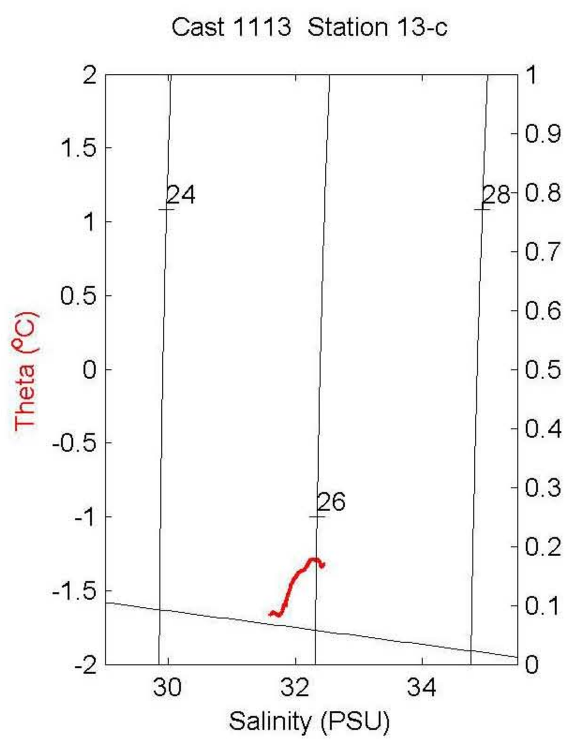


1997-22: CTD-only Casts

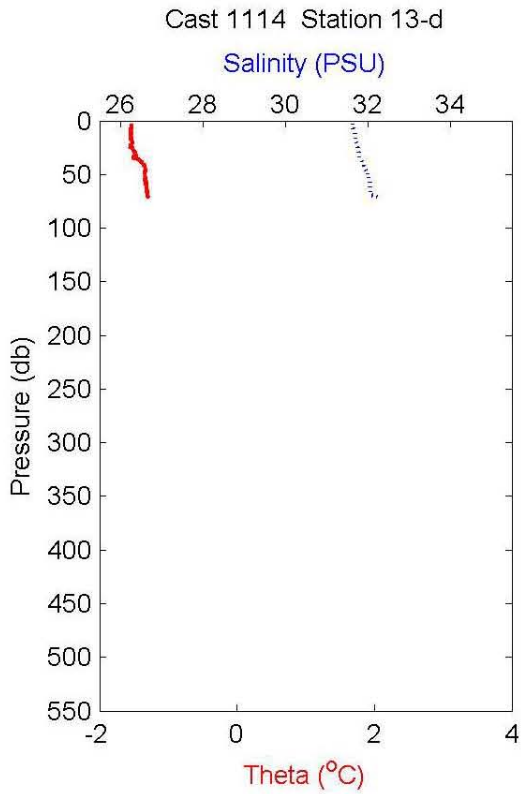


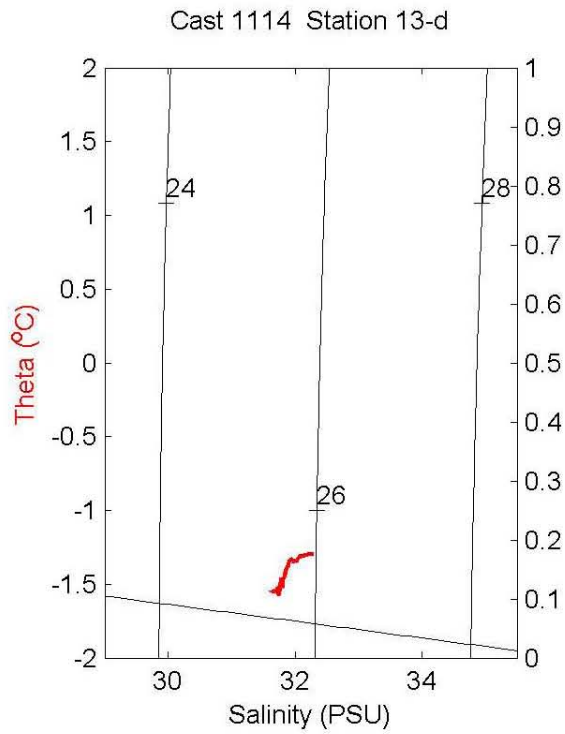


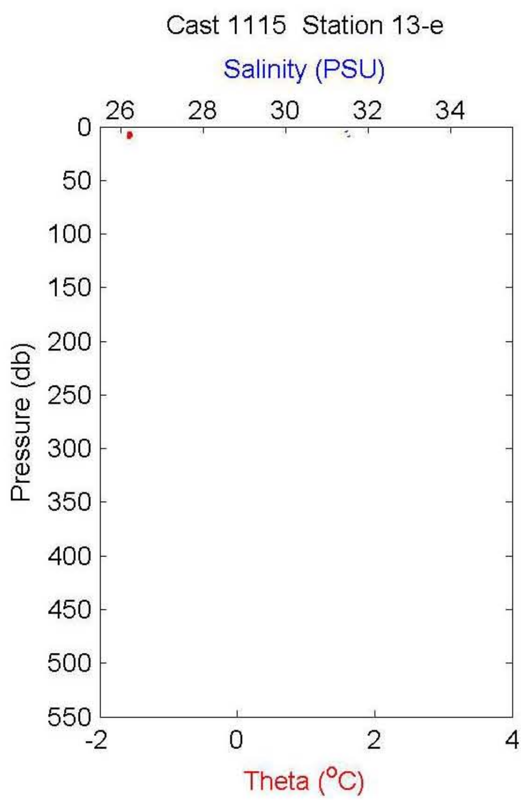


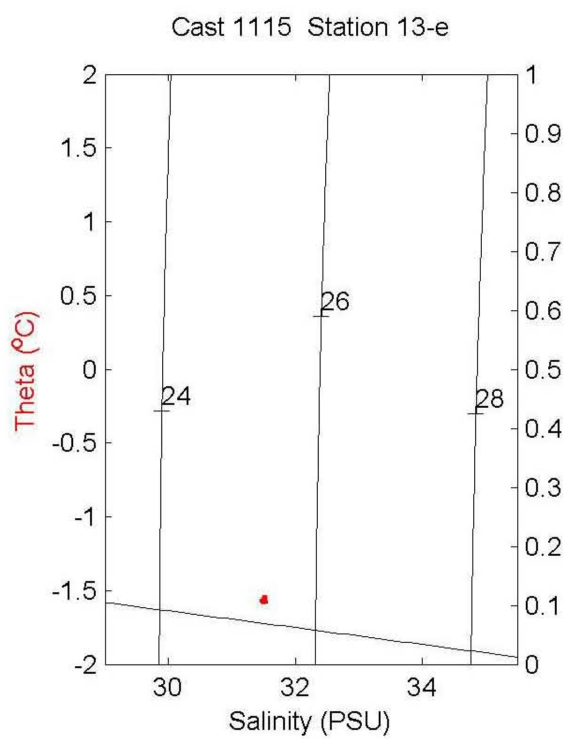


1997-22: CTD-only Casts

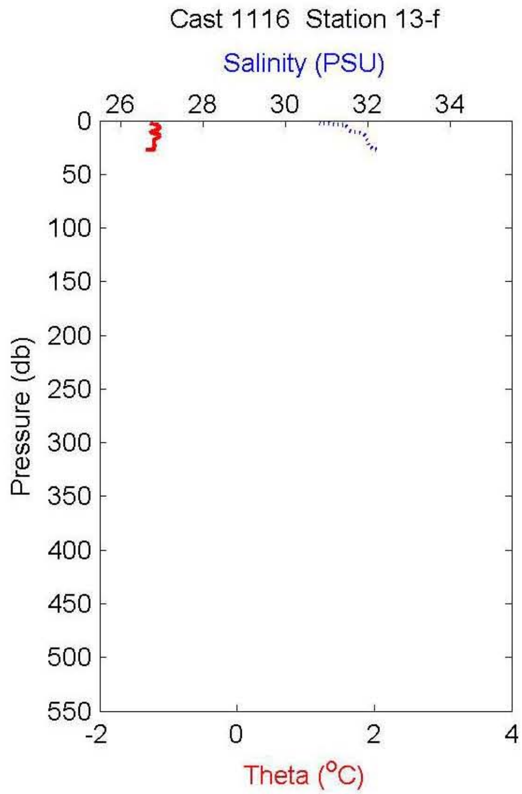


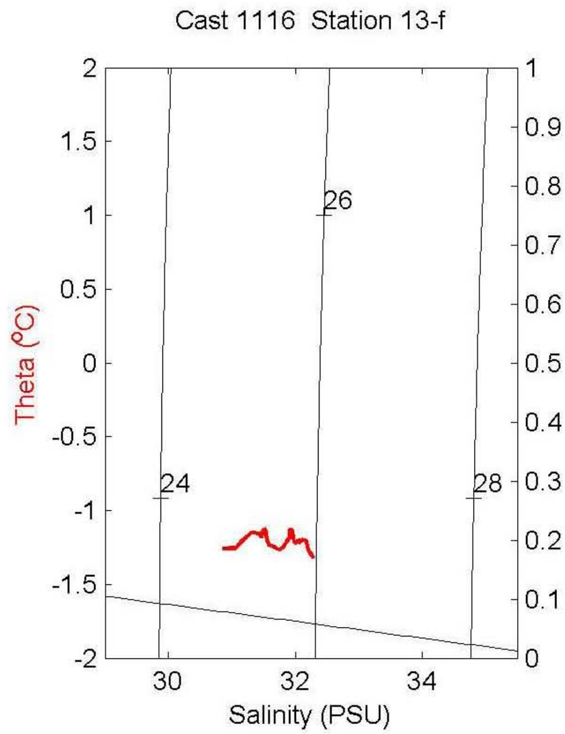


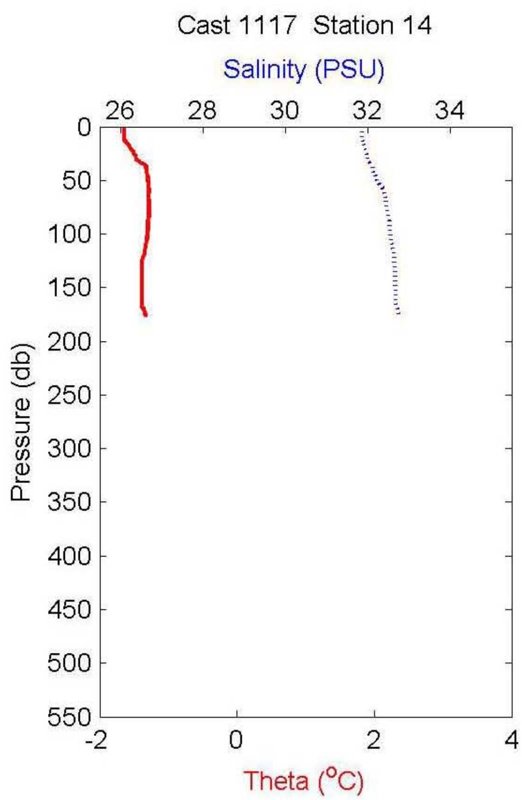


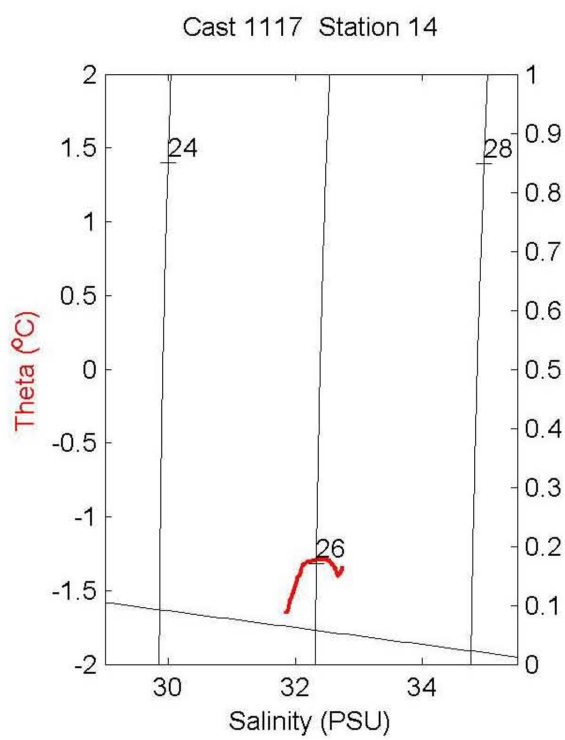


1997-22: CTD-only Casts



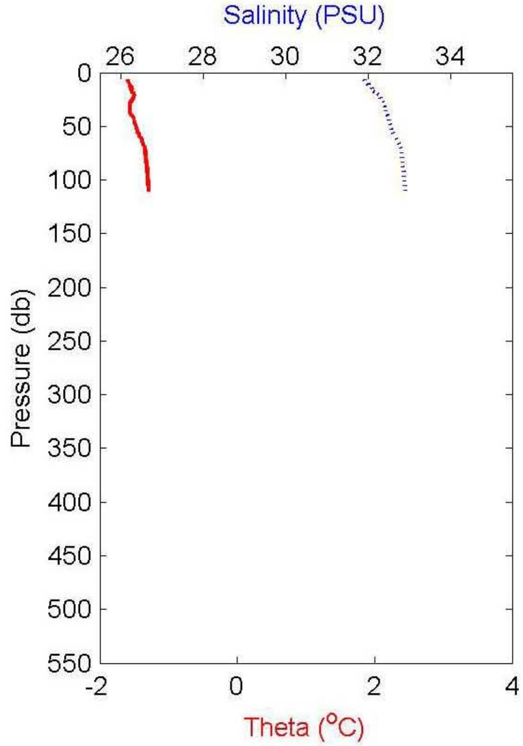




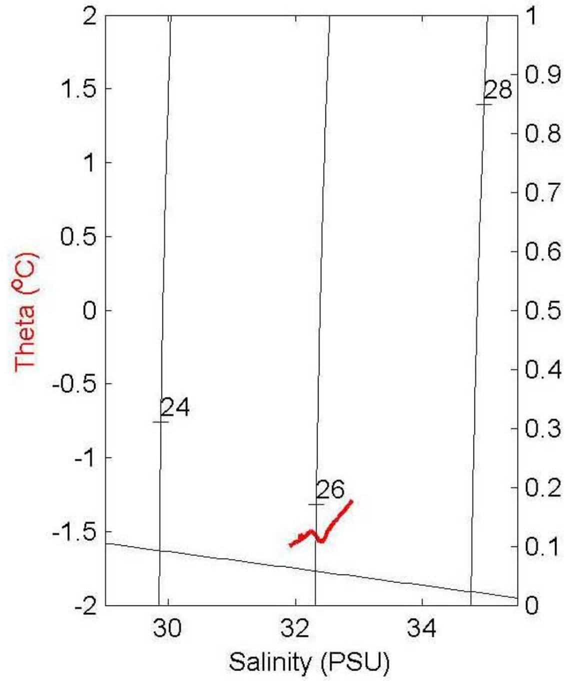


1997-22: CTD-only Casts

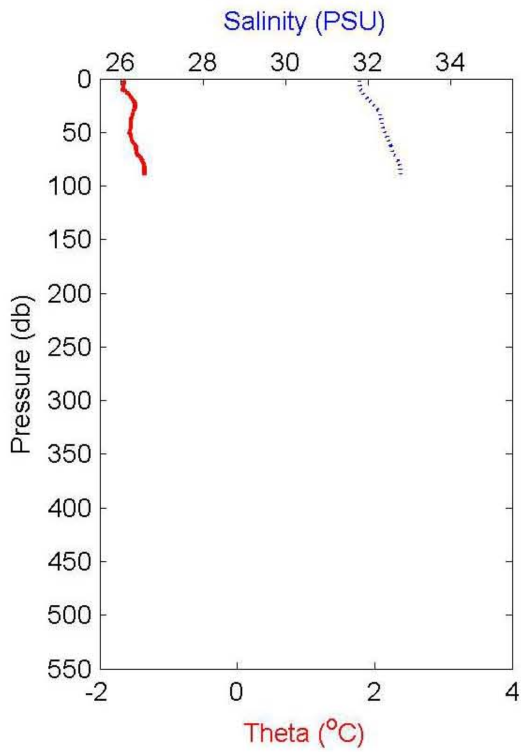
Cast 1118 Station 17



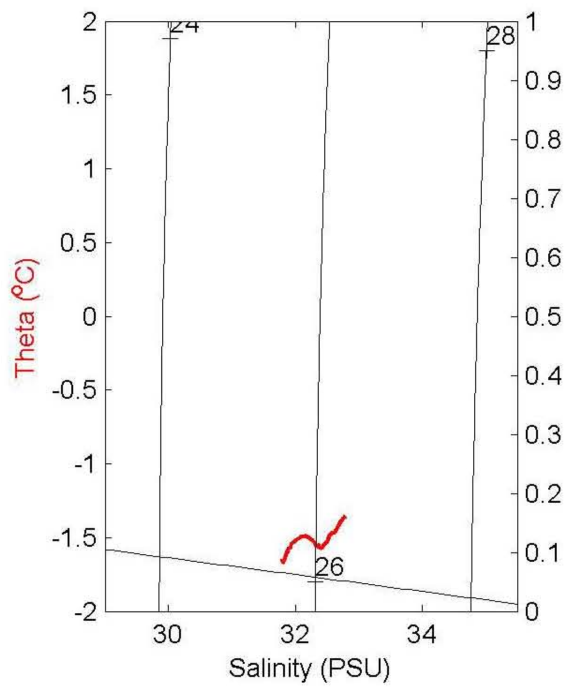
Cast 1118 Station 17



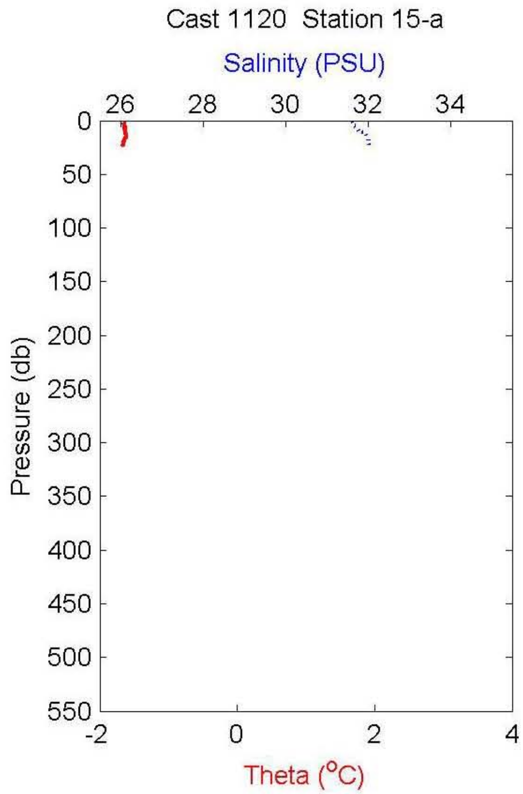
Cast 1119 Station 18

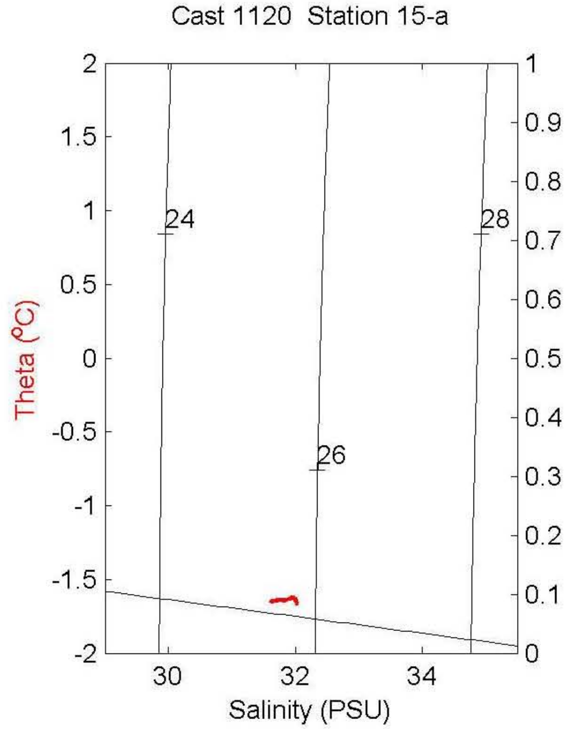


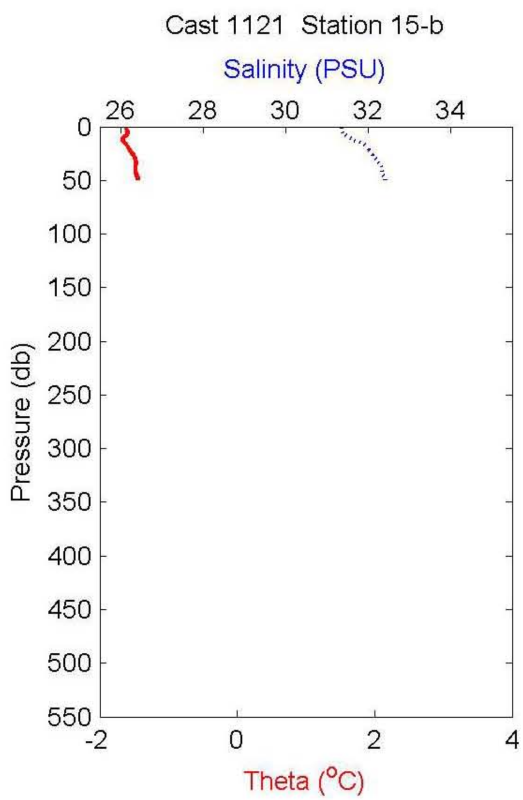
Cast 1119 Station 18

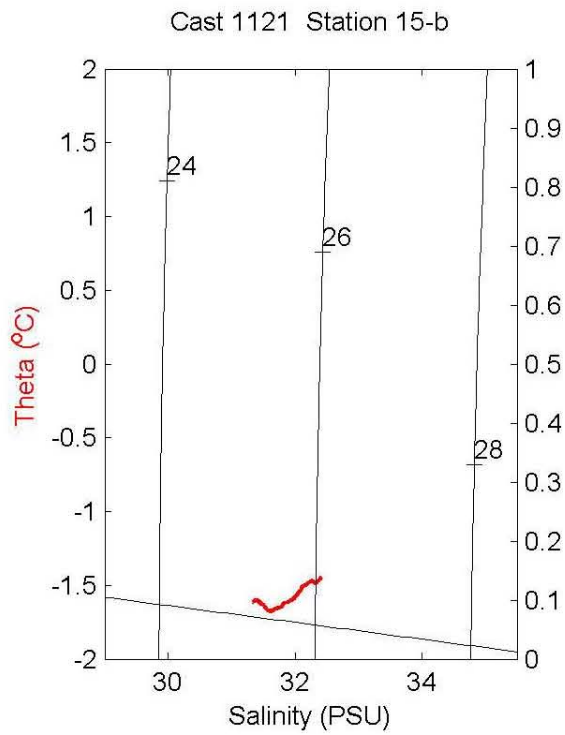


1997-22: CTD-only Casts



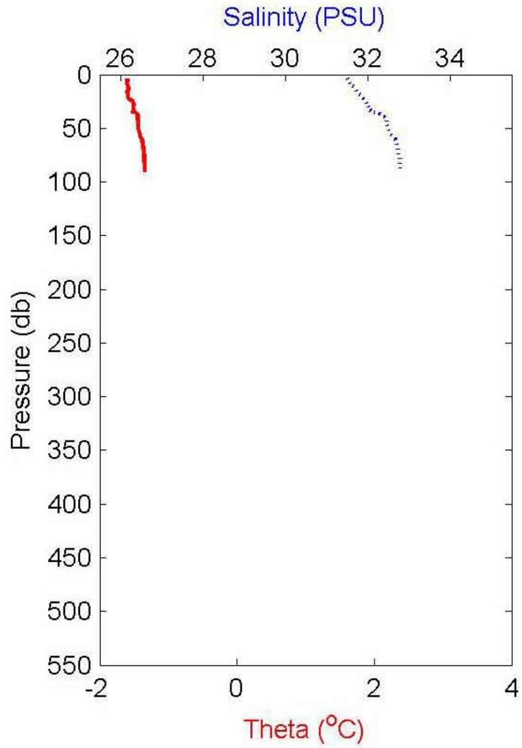




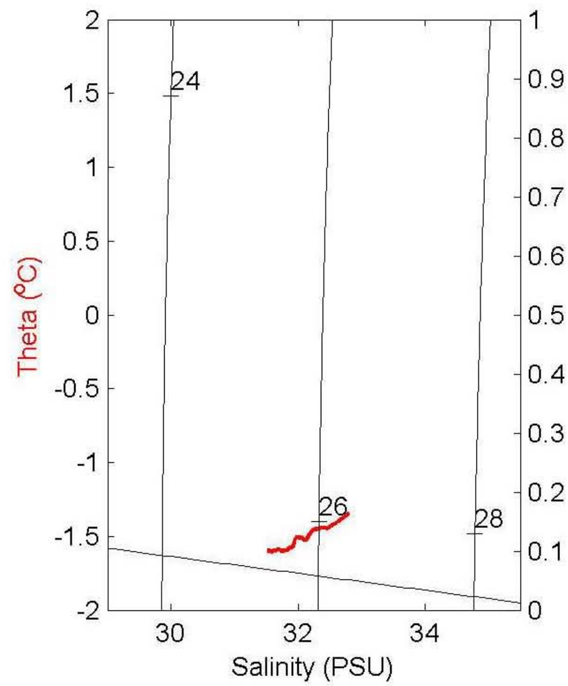


1997-22: CTD-only Casts

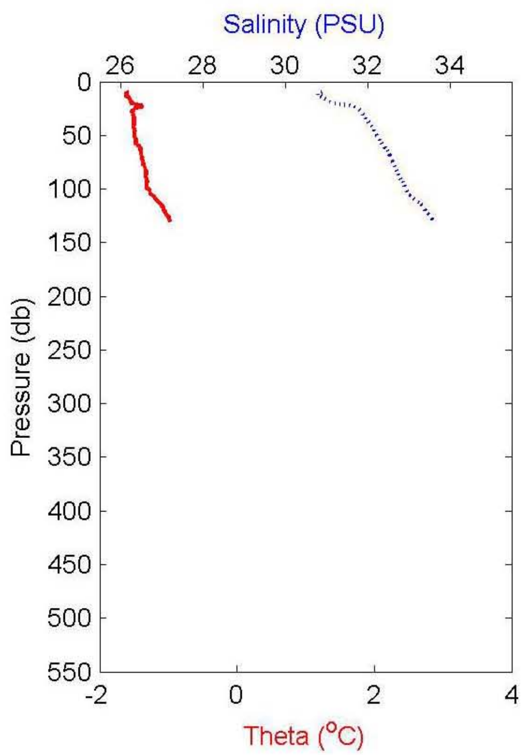
Cast 1122 Station 15-C



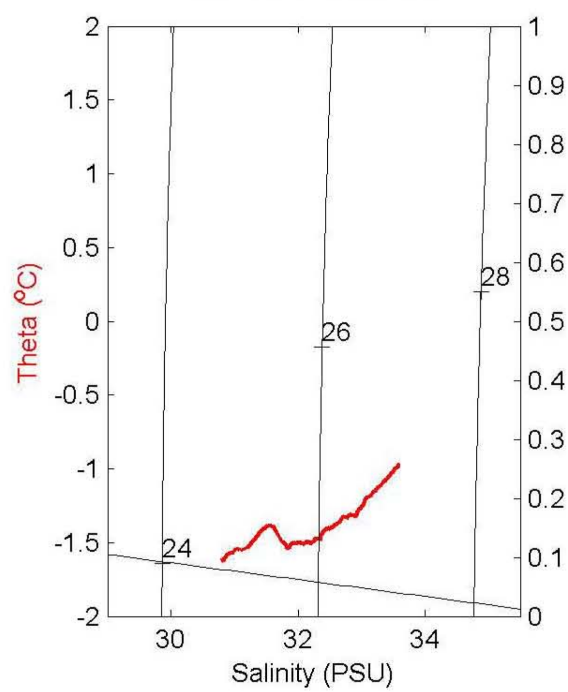
Cast 1122 Station 15-C



Cast 1123 Station 20

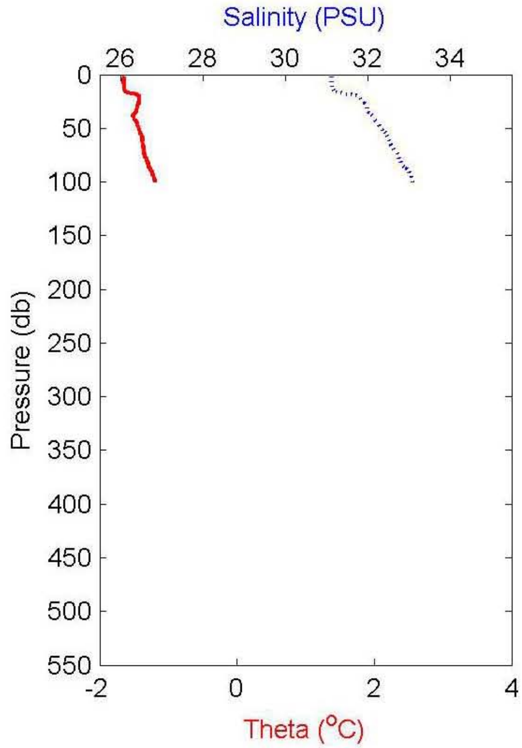


Cast 1123 Station 20

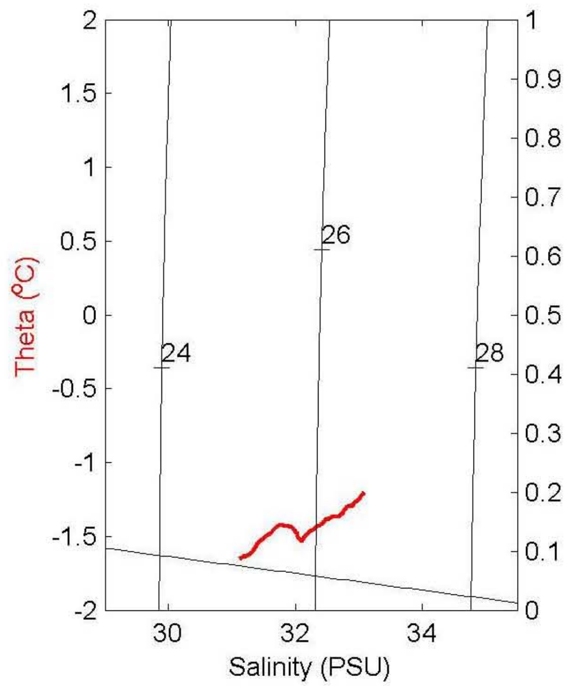


1997-22: CTD-only Casts

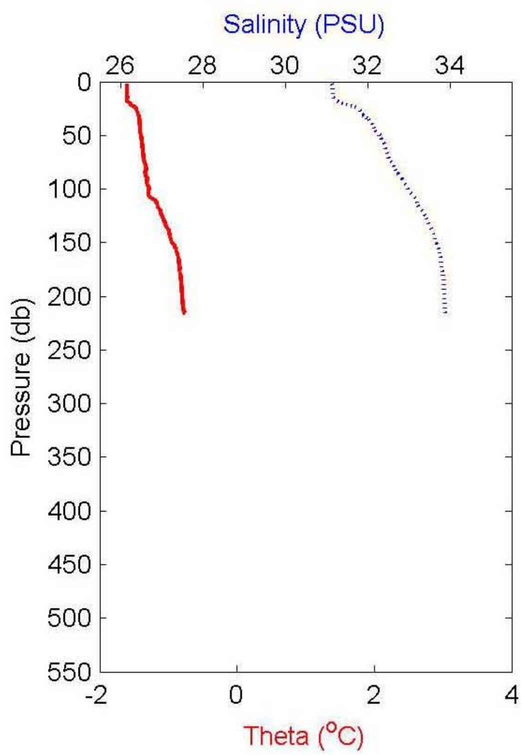
Cast 1124 Station 21



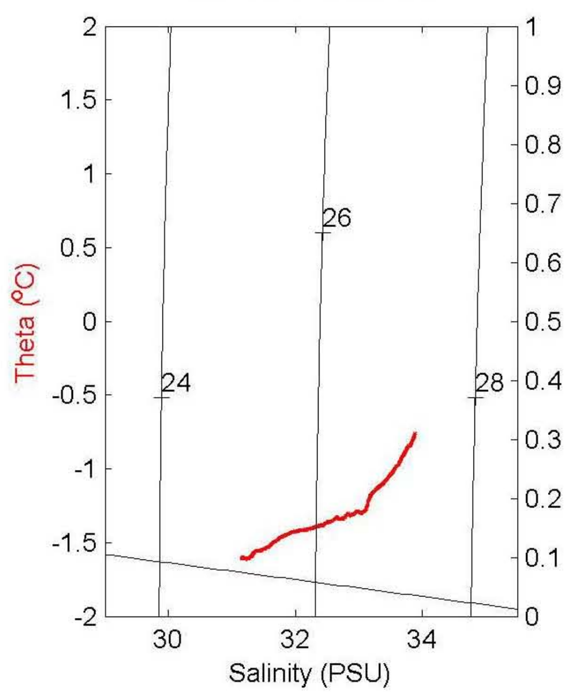
Cast 1124 Station 21



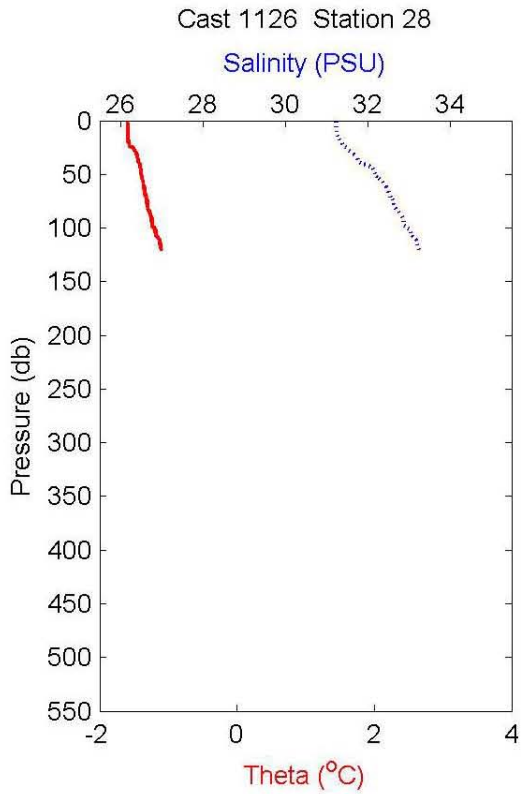
Cast 1125 Station 26

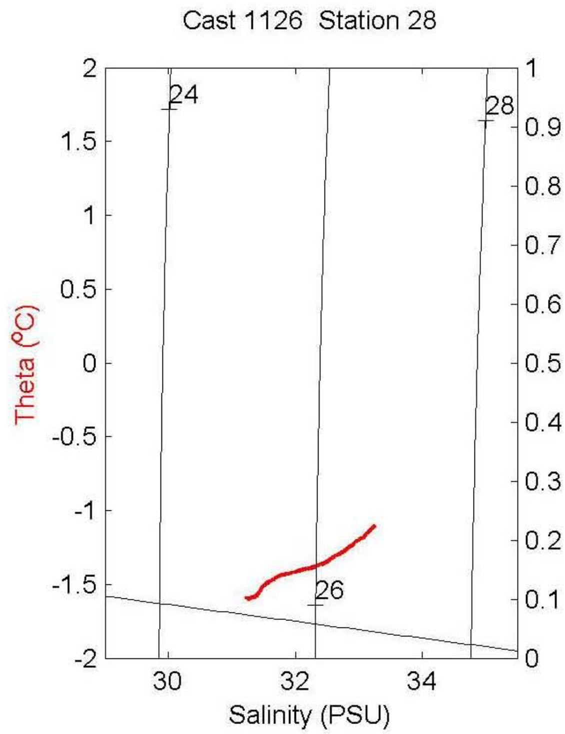


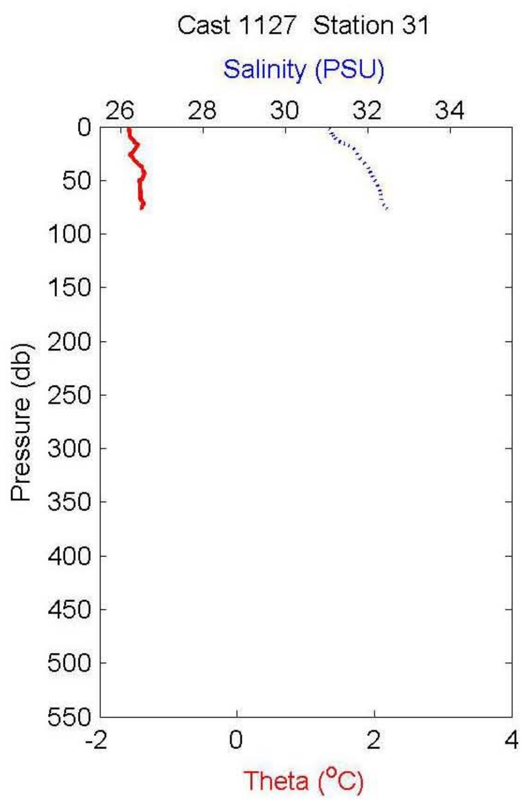
Cast 1125 Station 26

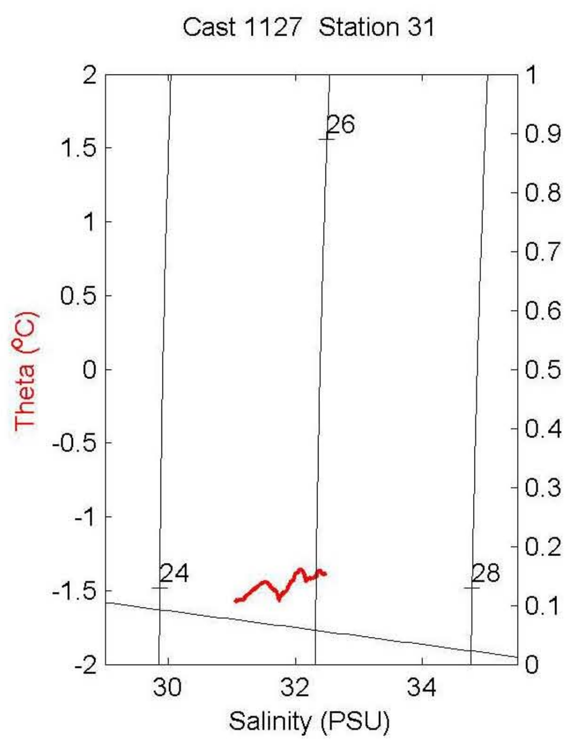


1997-22: CTD-only Casts



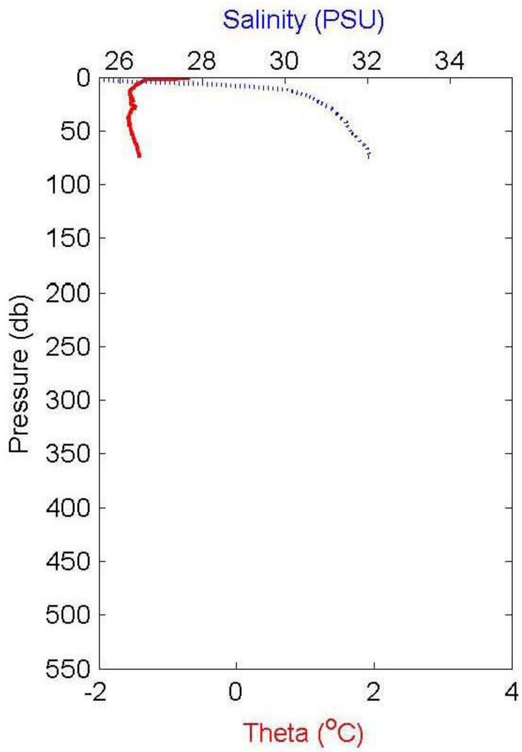




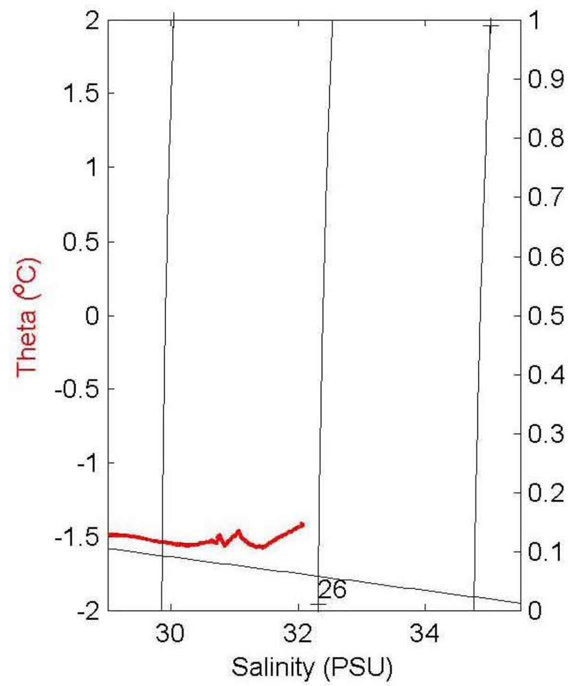


1997-22: CTD-only Casts

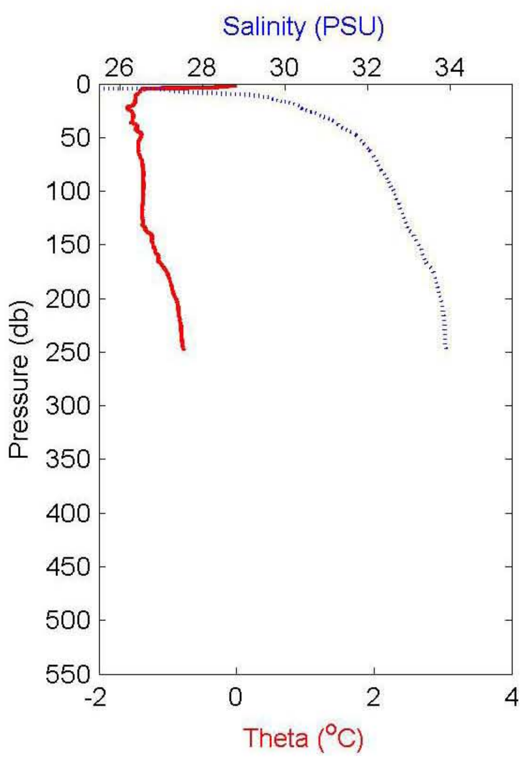
Cast 1128 Station 34-a



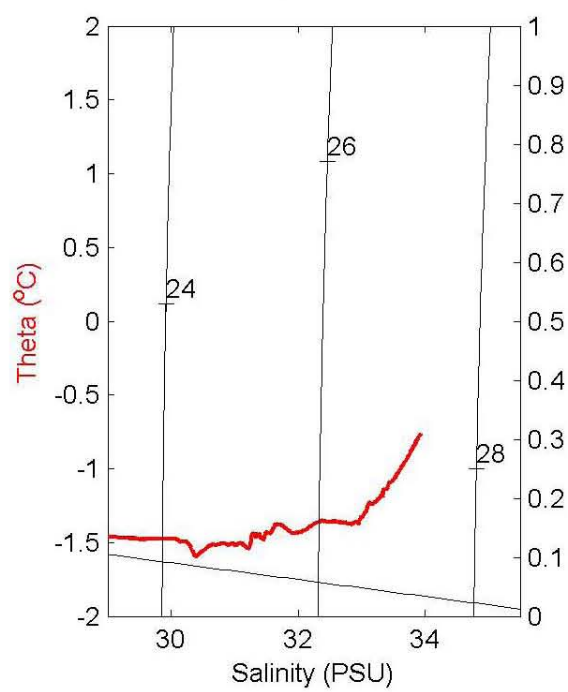
Cast 1128 Station 34-a



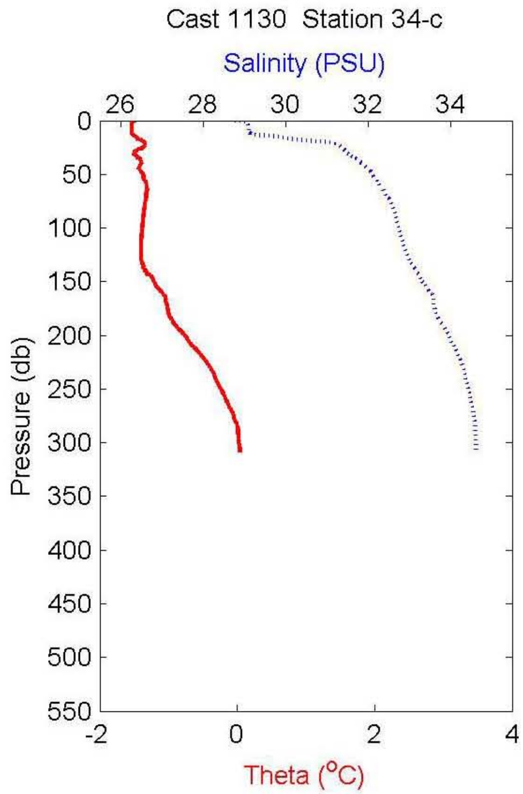
Cast 1129 Station 34-b

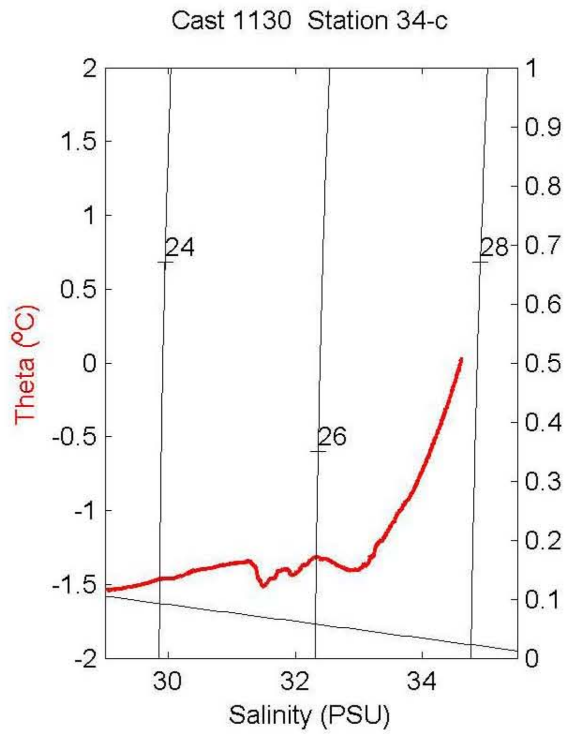


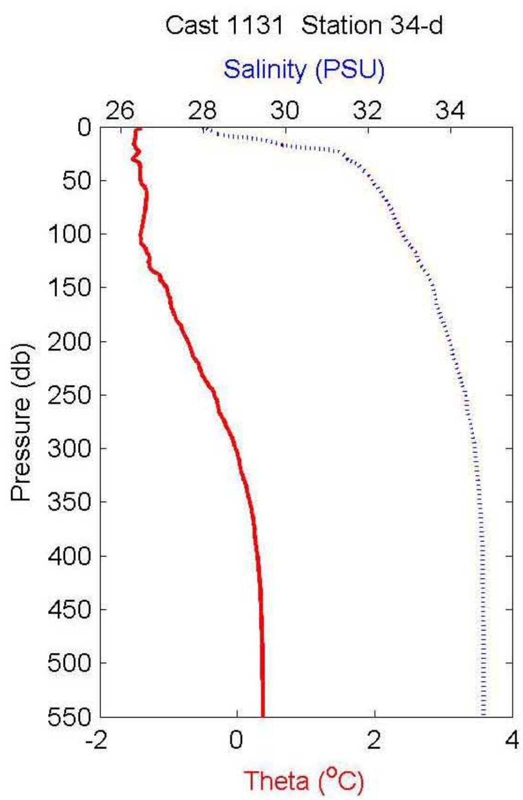
Cast 1129 Station 34-b

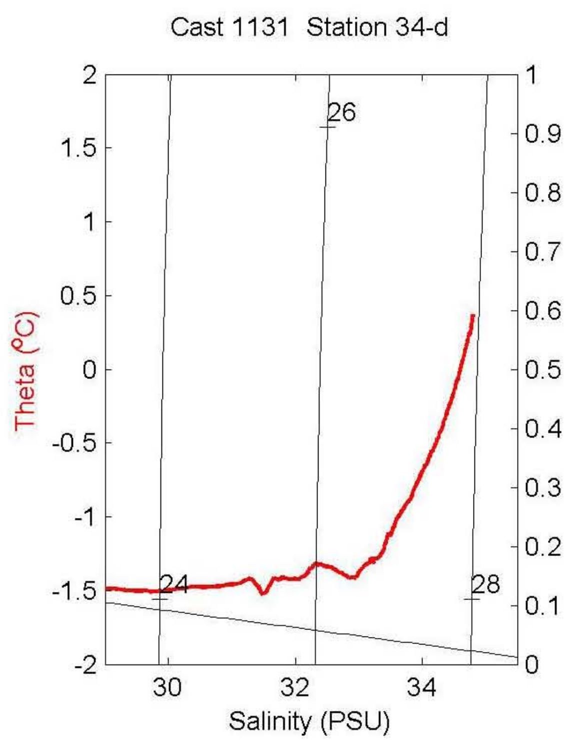


1997-22: CTD-only Casts

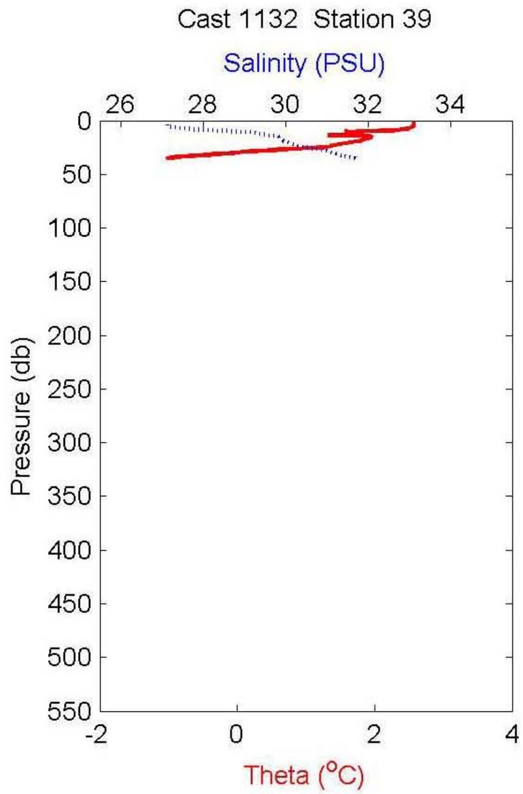


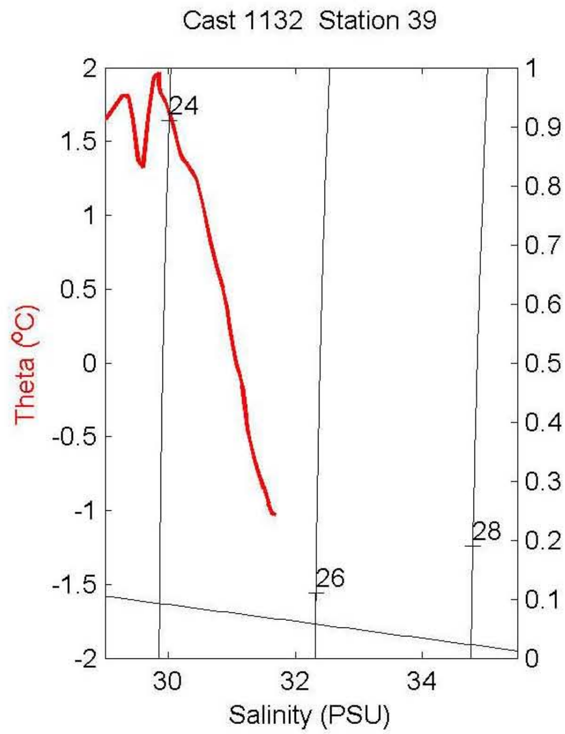


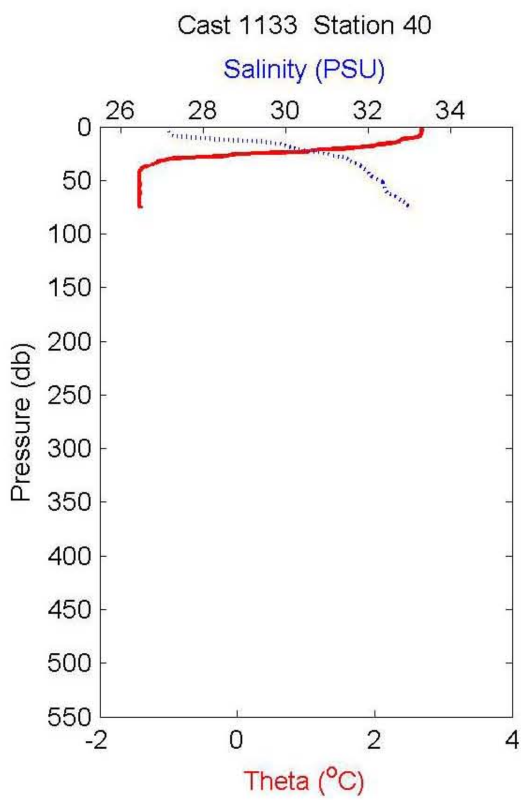


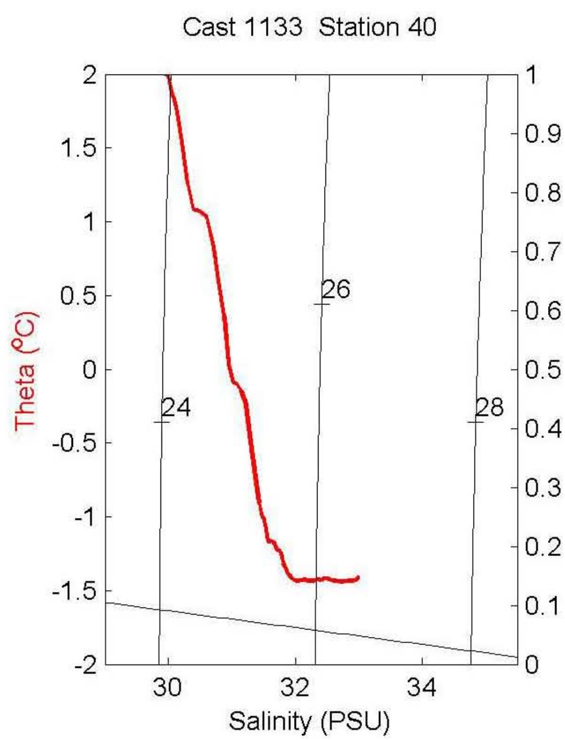


1997-22: CTD-only Casts



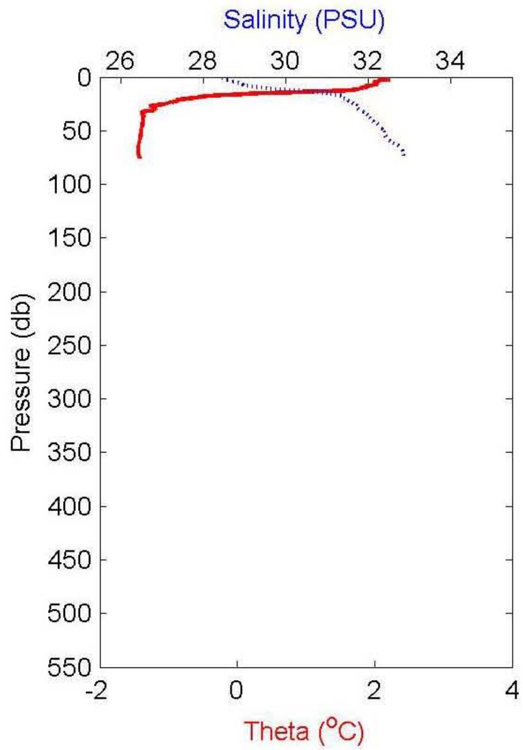




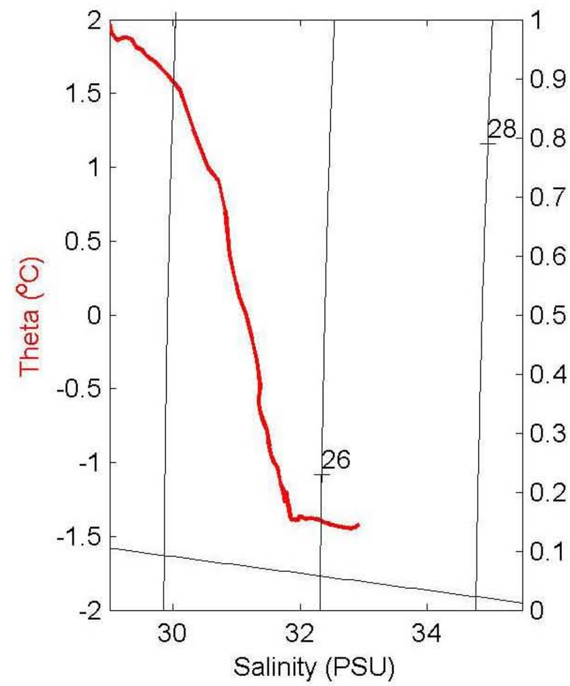


1997-22: CTD-only Casts

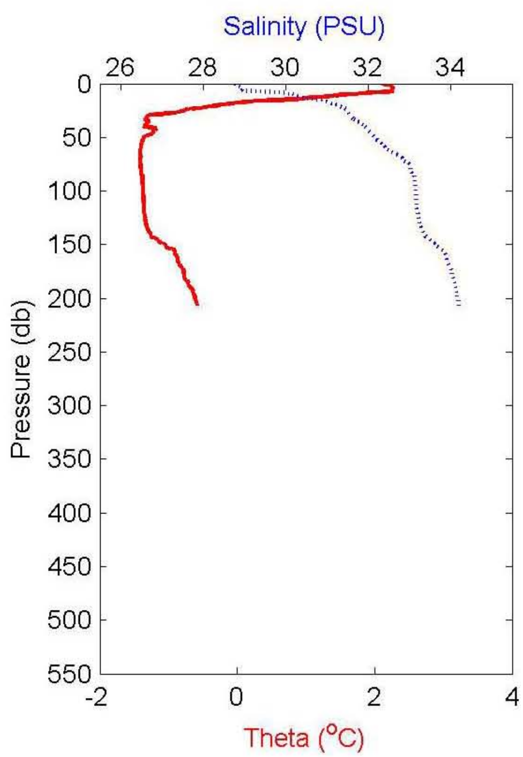
Cast 1134 Station 41



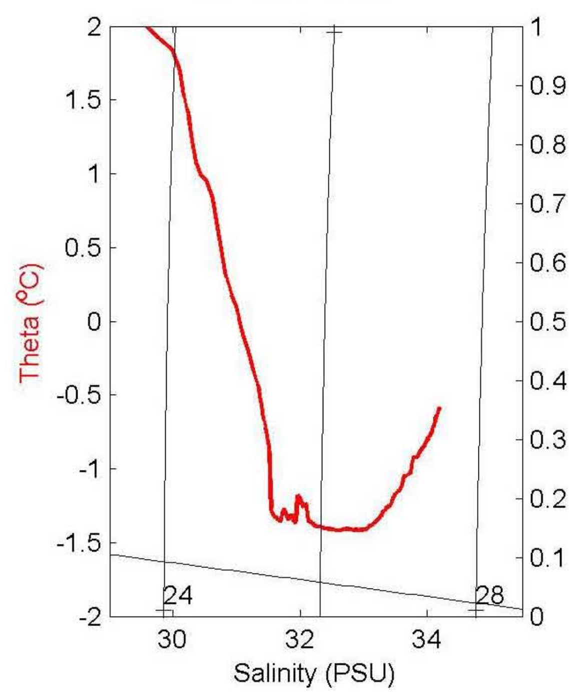
Cast 1134 Station 41



Cast 1135 Station 44

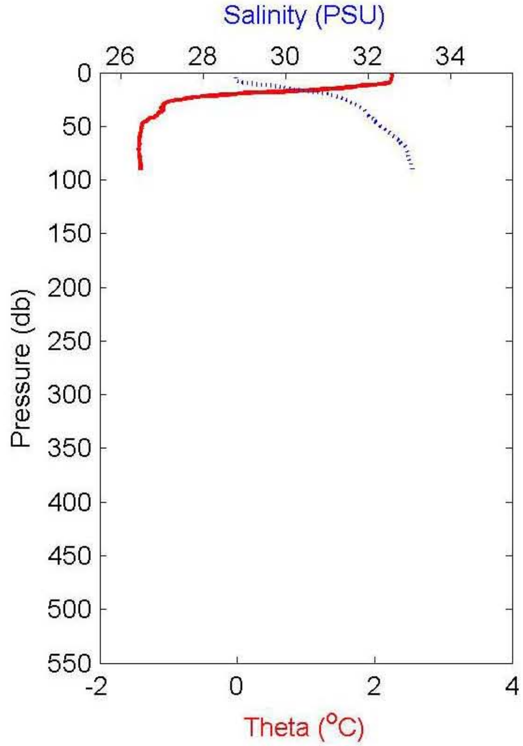


Cast 1135 Station 44

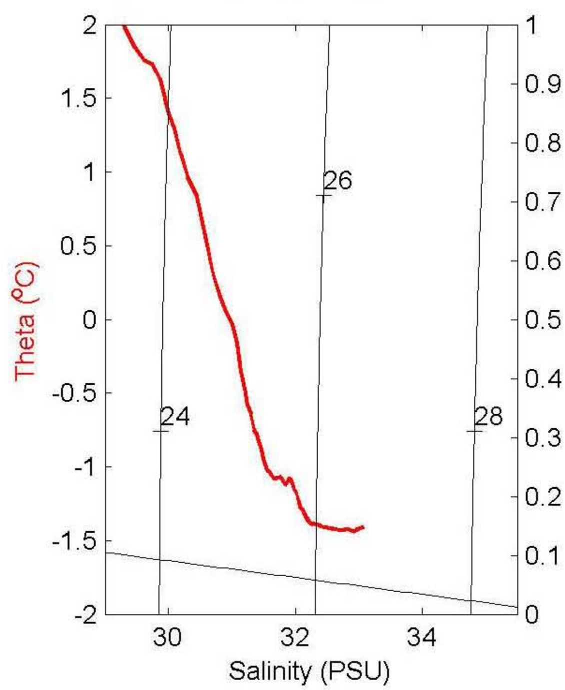


1997-22: CTD-only Casts

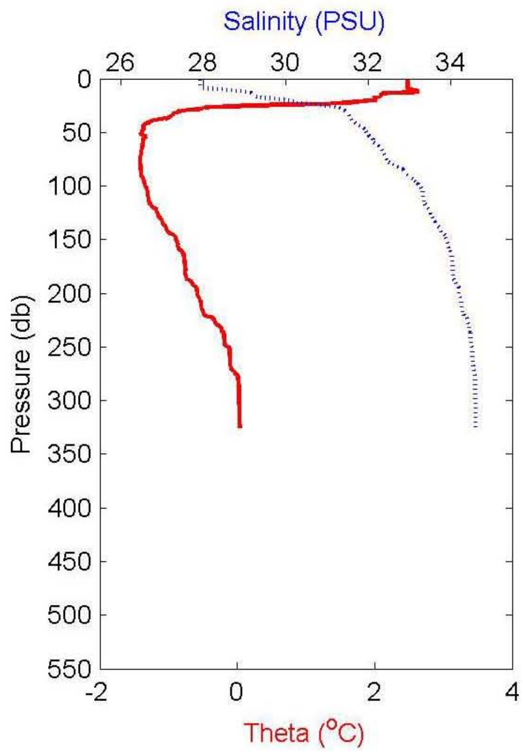
Cast 1136 Station 43



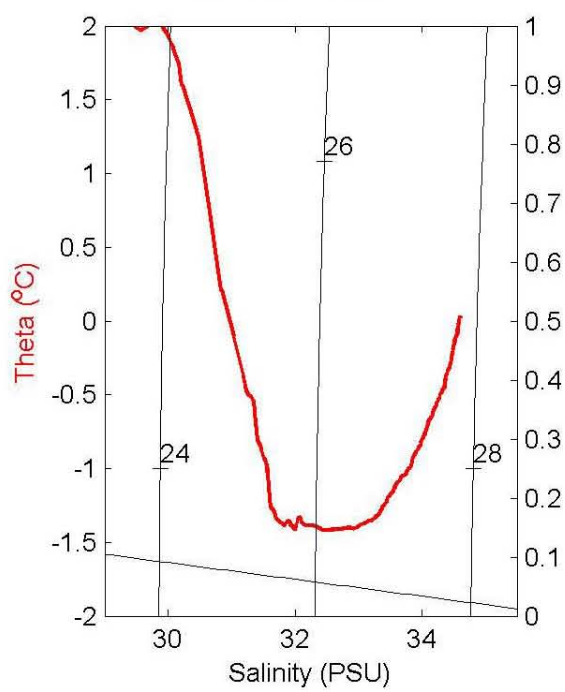
Cast 1136 Station 43



Cast 1137 Station 45

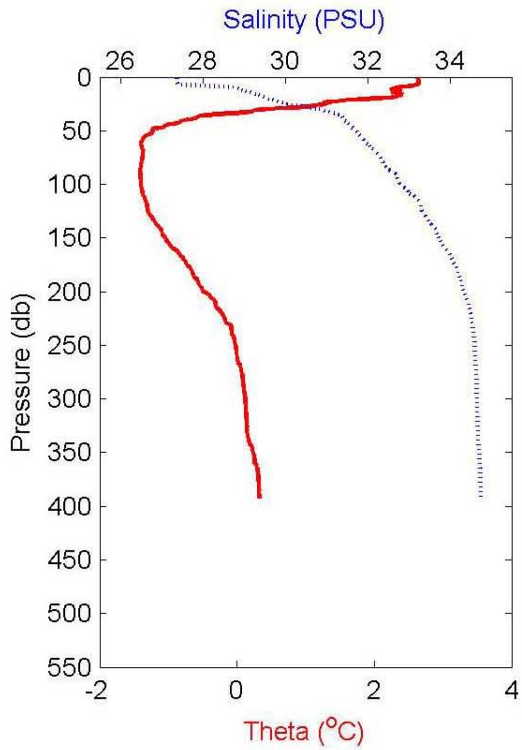


Cast 1137 Station 45

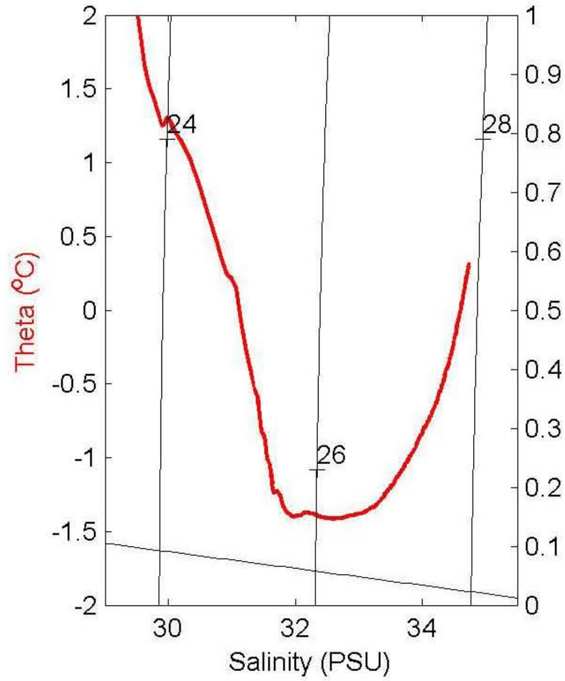


1997-22: CTD-only Casts

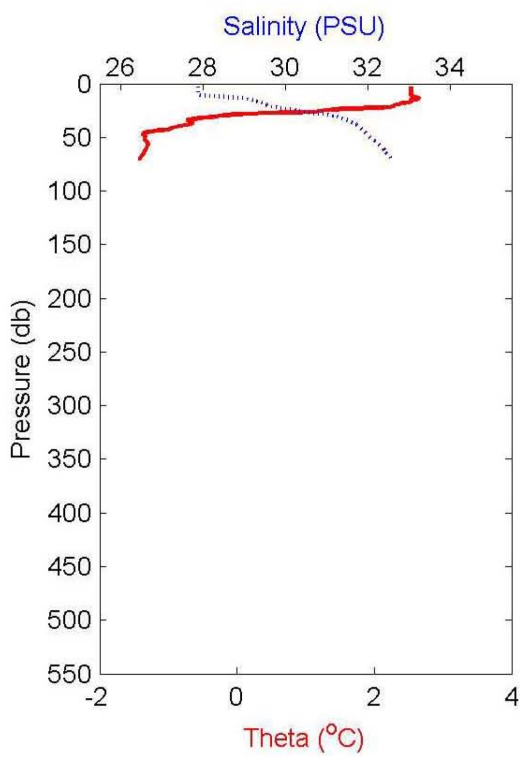
Cast 1138 Station 46



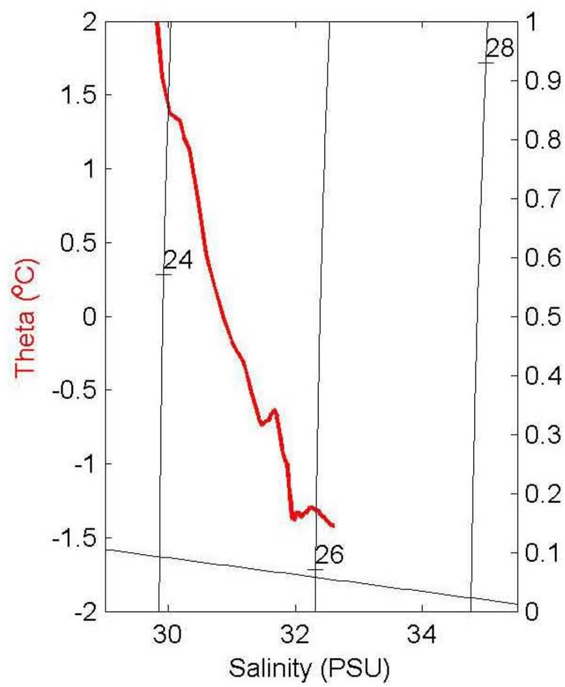
Cast 1138 Station 46



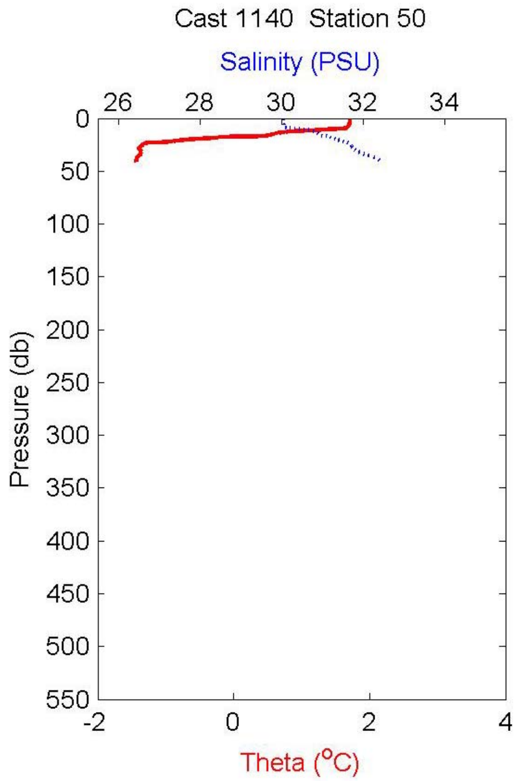
Cast 1139 Station 49

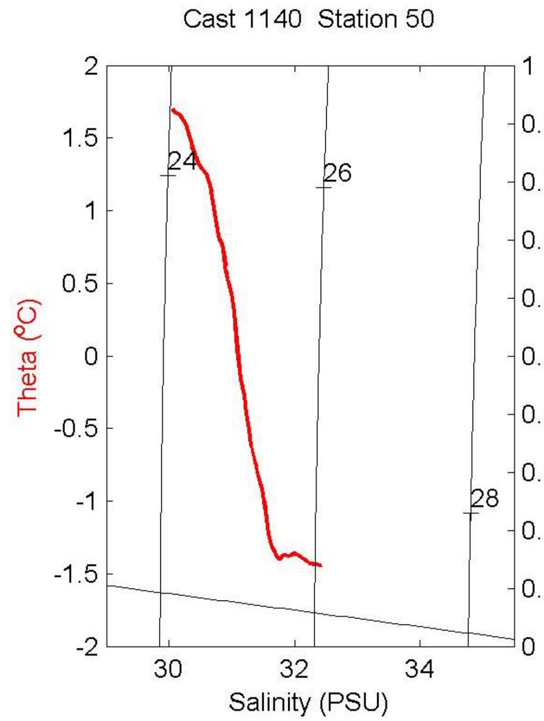


Cast 1139 Station 49

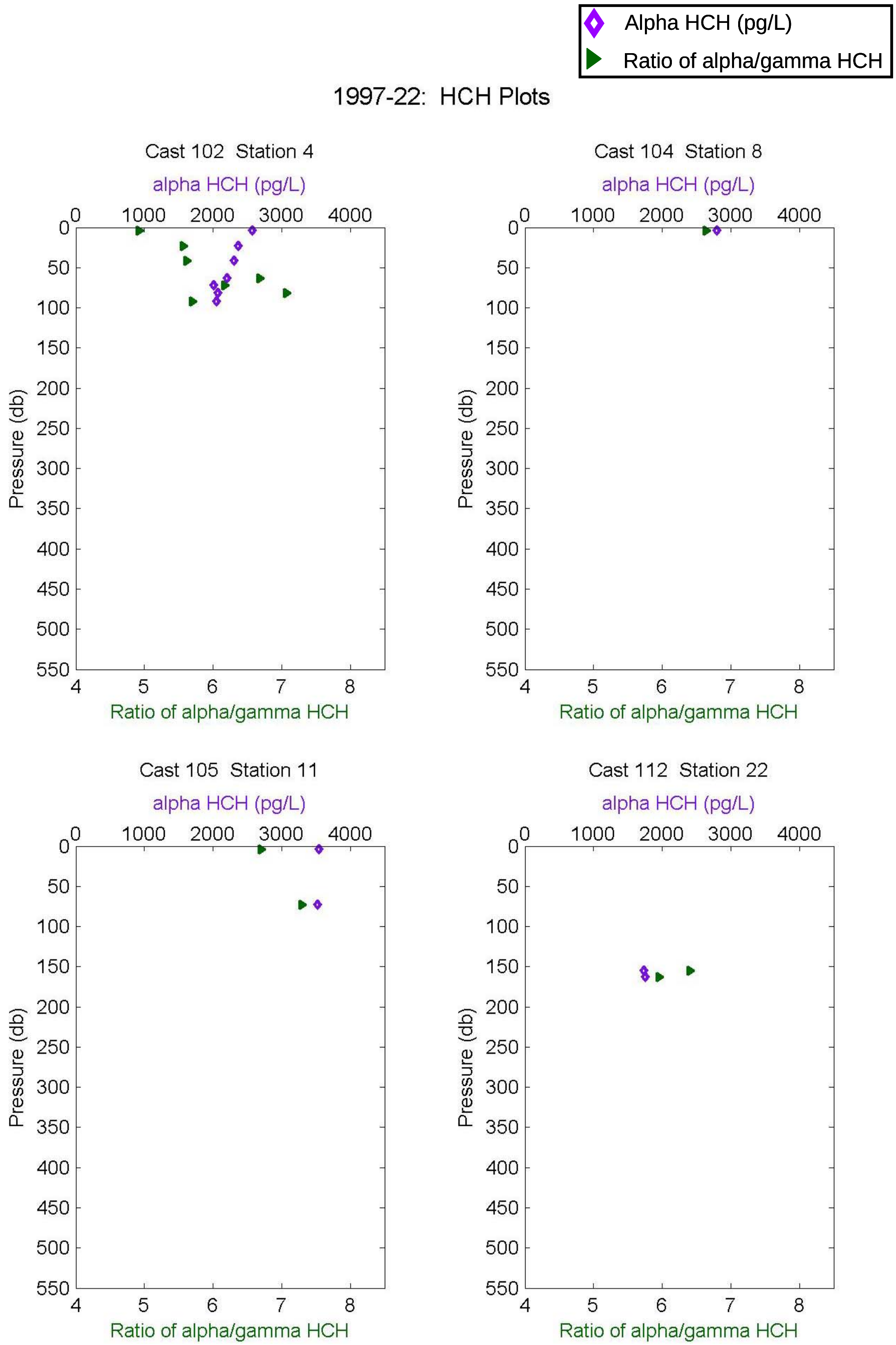


1997-22: CTD-only Casts



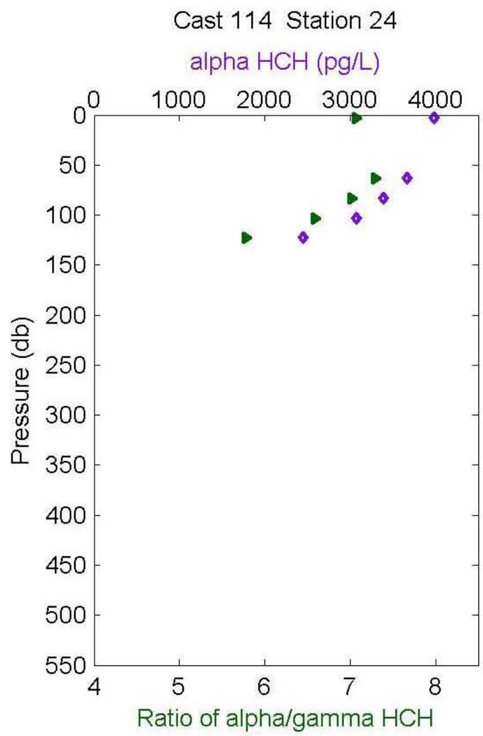


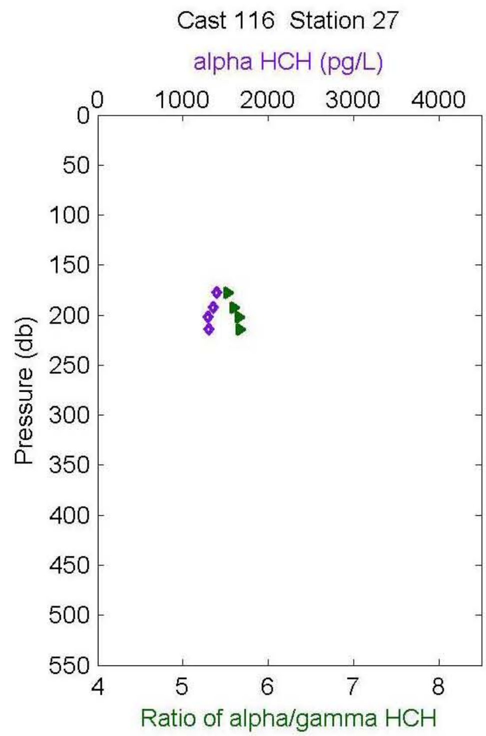
4.5.3 HCH

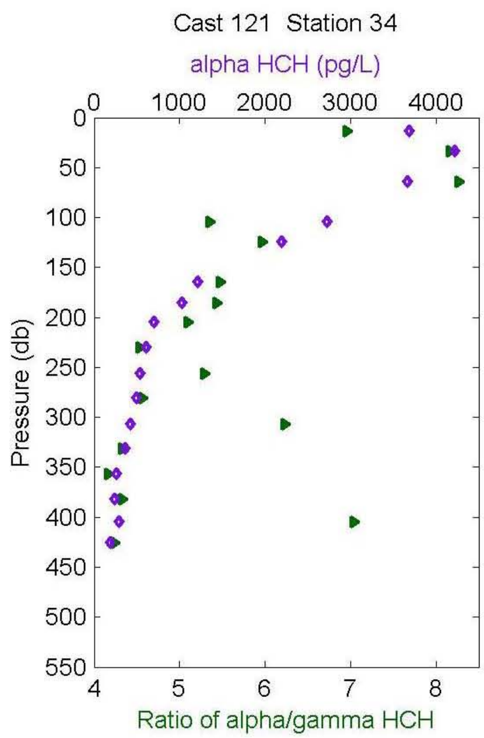


Alpha HCH (pg/L)
Ratio of alpha/gamma HCH
1997-22: HCH Plots
Cast 102 Station 4
Cast 104 Station 8
Cast 105 Station 11
Cast 112 Station 22
alpha HCH (pg/L)
Pressure (db)
Ratio of alpha/gamma HCH

1997-22: HCH Plots



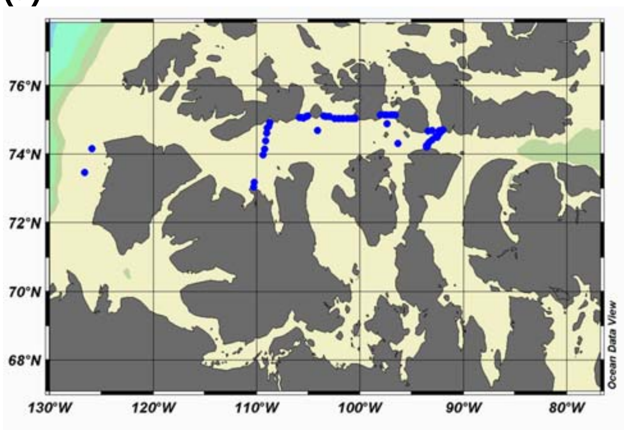




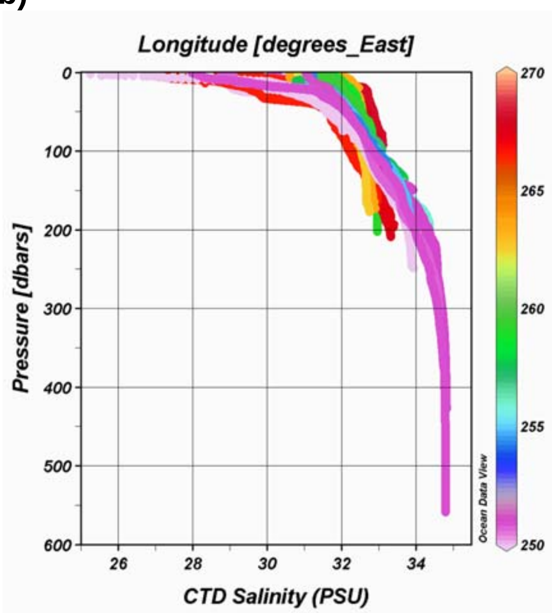
4.6 DYNAMIC HEIGHT AND SECTION PLOTS

(a) Map showing location of all 1997-22 cruise stations in the Canadian Arctic Archipelago; (b) CTD salinity profiles and (c) dynamic height profiles, both coloured by longitude. Note: Longitude in (b) and (c) are reported in degrees East; in order to relate to longitude in (a), this value must be subtracted from 360 degrees.

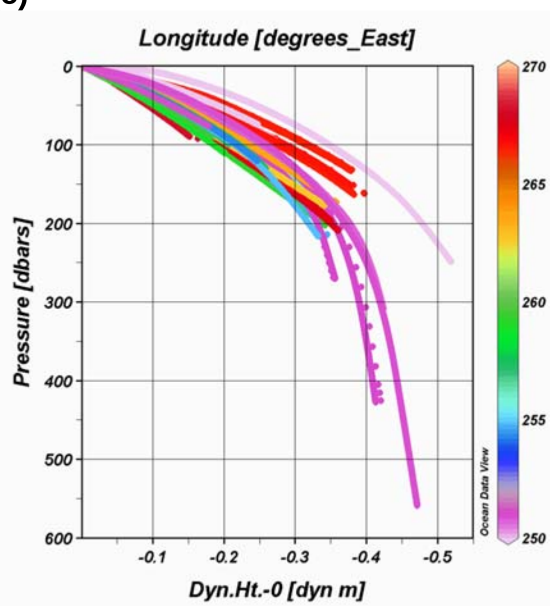
(a)



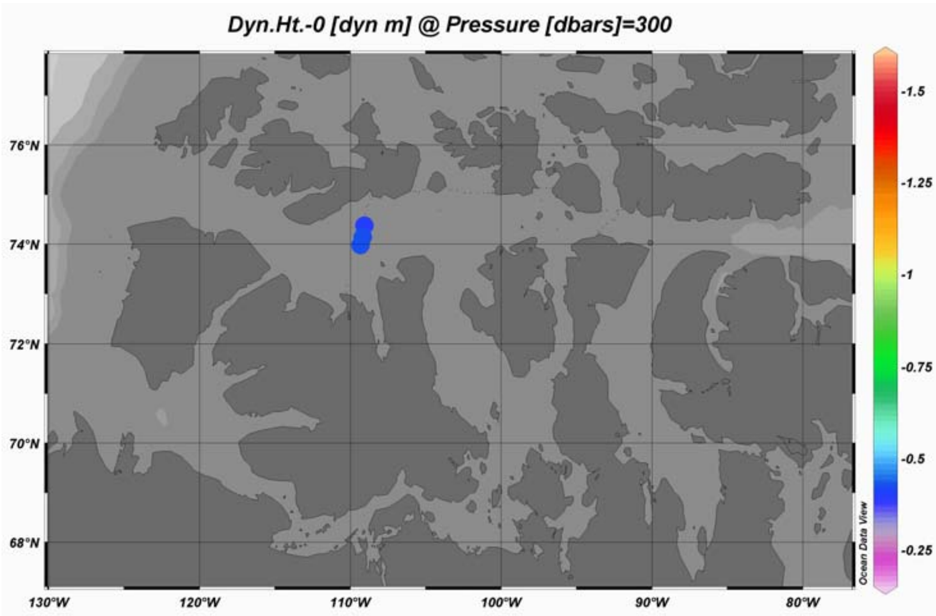
(b)



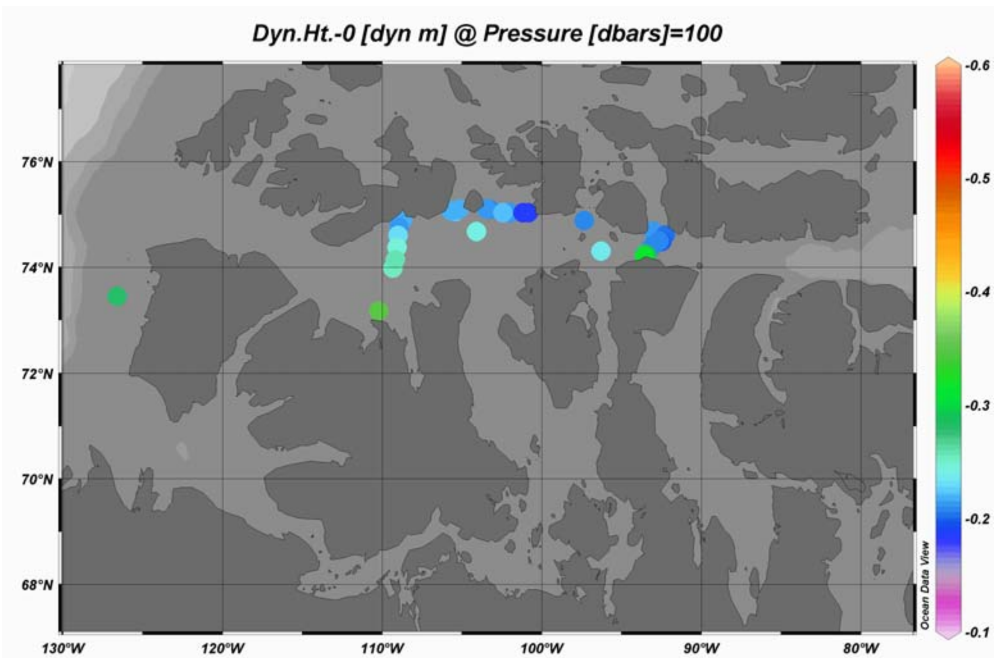
(c)



Dynamic height in Viscount Melville Sound, calculated with 300 m as the depth of no motion.

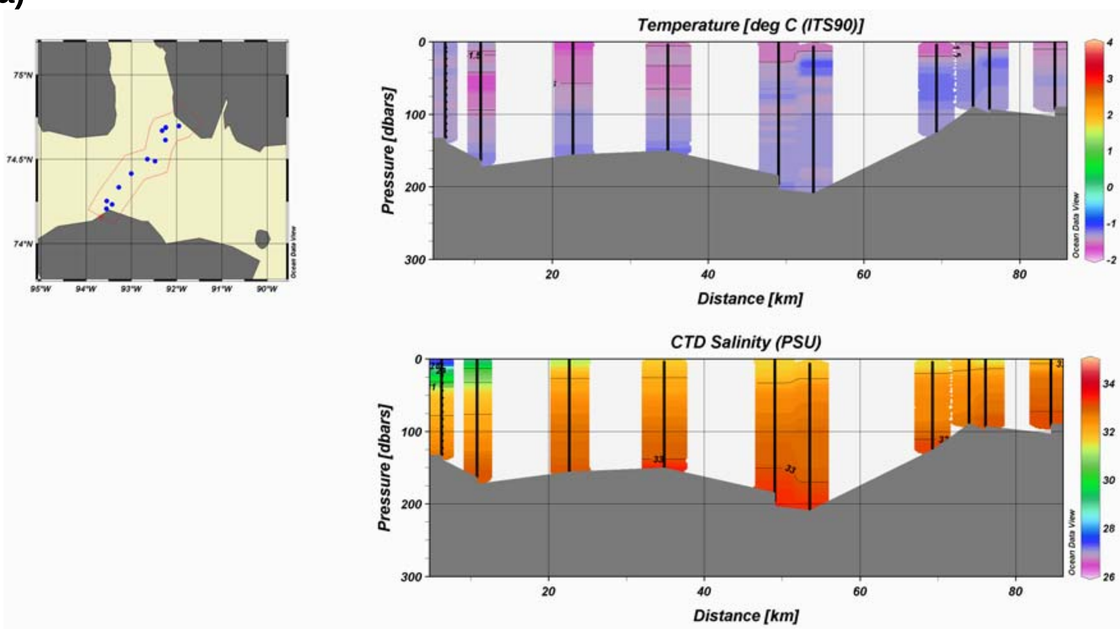


Dynamic height at all stations across the Canadian Arctic Archipelago, calculated with respect to 100 m.

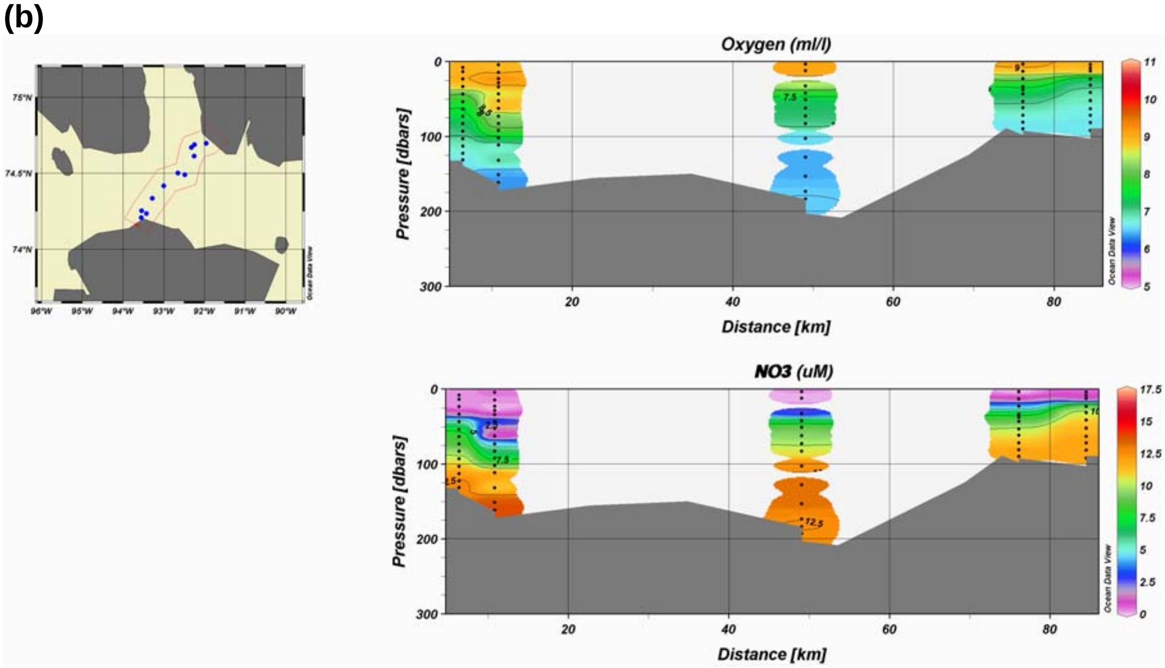


Barrow Strait Section:
(a) Temperature and Salinity; (b) Oxygen and Nitrate

(a)

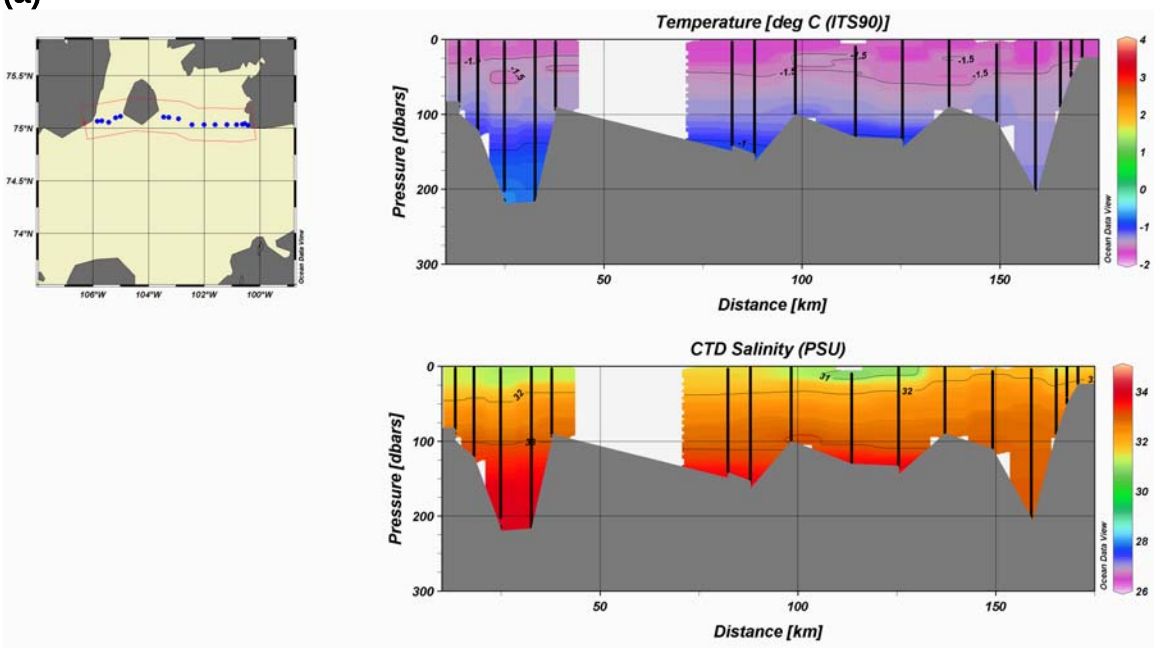


(b)

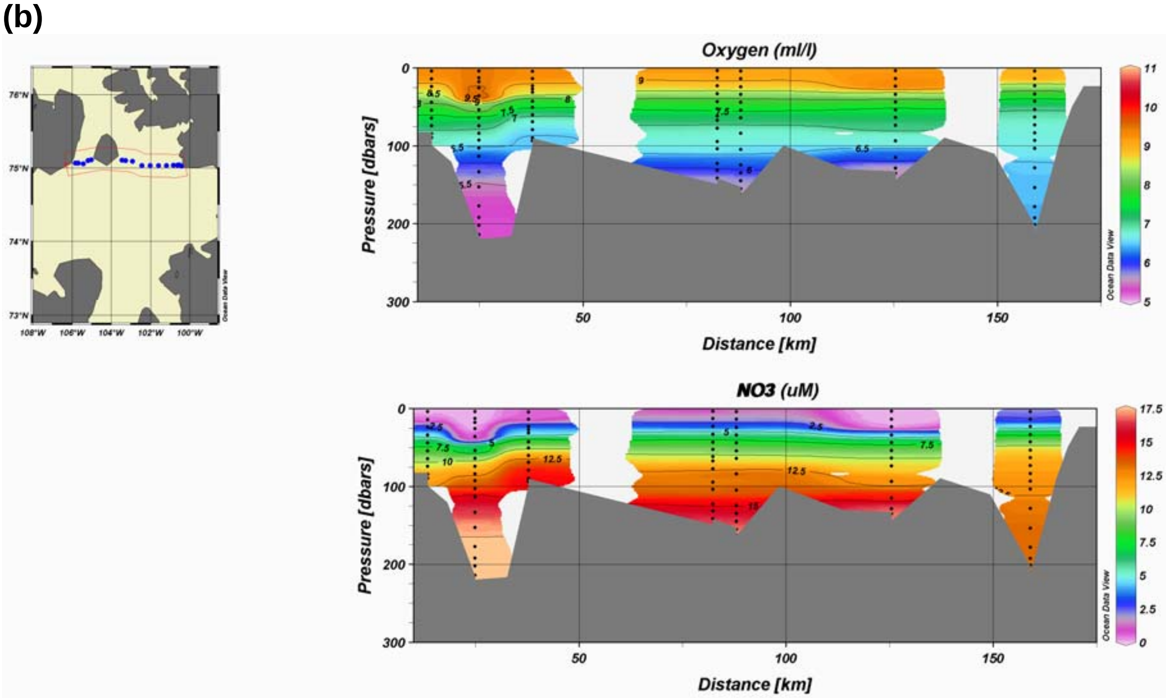


Byam Channel / Austin Channel Section:
(a) Temperature and Salinity; (b) Oxygen and Nitrate

(a)

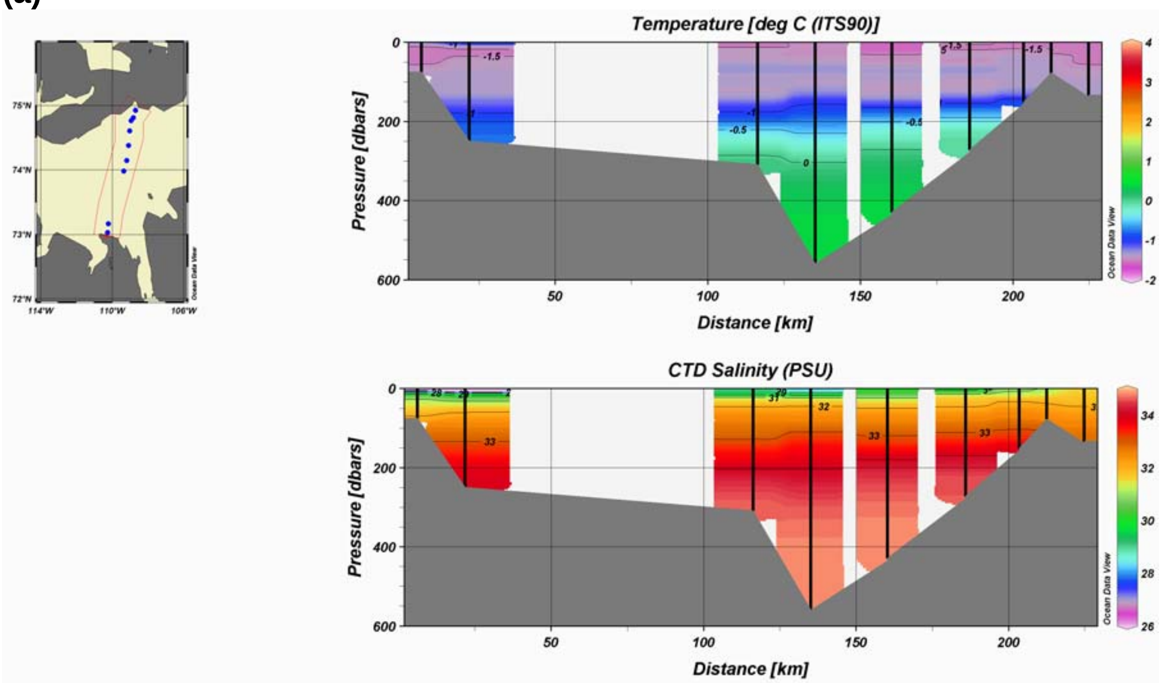


(b)

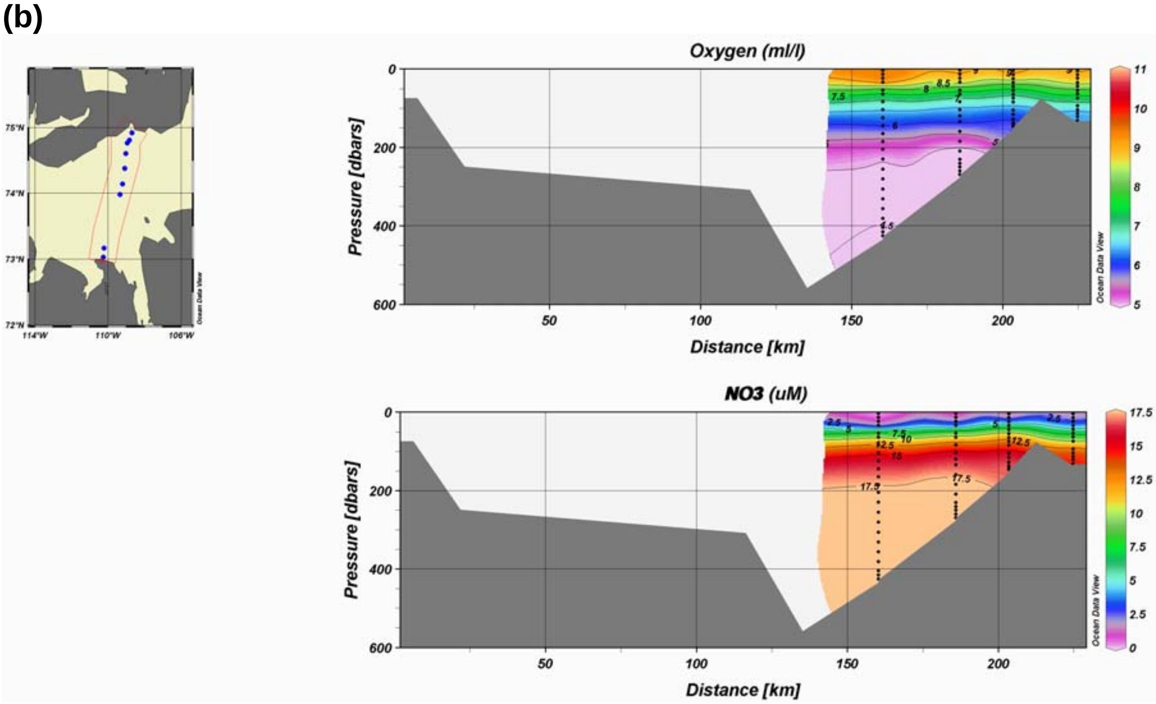


Viscount Melville Sound Section:
(a) Temperature and Salinity; (b) Oxygen and Nitrate

(a)



(b)



4.7 CHLOROPHYLL-A, SUSPENDED NITROGEN, CARBON AND PHOSPHATE DATA

Table 11. Chlorophyll-a, suspended nitrogen, suspended carbon and suspended phosphate data.

Station	Depth (dbars)	Sample number	Last revised	Susp N (µg/L)	Susp C (µg/L)	Chlor-a (µg/L)	Susp P (µg/L)
2	50.8	189221	19/02/98	68	500	2.18	
2	41.6	189222	19/02/98	58	400	3.87	
2	11.1	189226	19/02/98	81	820	4.85	
2	5.9	189227	19/02/98	80	570	3.89	
2	30.8	189223	19/02/98	55	560	4.21	
2	20.2	189224	19/02/98	76	670	5.32	
2	15.5	189225	19/02/98	114	930	4.95	
2	3.3	189228	19/02/98	78	530	4.10	
4	72.1	189231	19/02/98	49	230	0.53	
4	63.1	189232	19/02/98	14	120	0.25	
4	52.4	189233	19/02/98	34	220	0.19	
4	51.8	189234	19/02/98	11	340	0.20	
4	41.6	189235	19/02/98	25	140	0.29	
4	31.6	189236	19/02/98	33	260	0.50	
4	23.4	189237	19/02/98	18	150	0.73	
4	12.9	189238	19/02/98	103	510	2.87	
5	61.7	189247	19/02/98	24	370	0.50	
5	53.2	189248	19/02/98	13	190	0.67	
5	43.3	189249	19/02/98	11	170	0.39	
5	37.8	189250	19/02/98	17	180	0.39	
5	33.7	189251	19/02/98	19	220	0.75	
5	23.0	189252	19/02/98	30	240	2.85	
5	13.3	189253	19/02/98	45	360	4.26	
5	3.5	189254	19/02/98	51	610	3.15	
8	72.8	189261	19/02/98	8	120	0.56	
8	62.0	189262	19/02/98	16	120	0.39	
8	51.2	189263	19/02/98	11	110	0.68	
8	42.3	189264	19/02/98	29	190	1.62	
8	32.7	189265	19/02/98	66	480	4.20	
8	12.4	189266	19/02/98	91	730	3.60	
8	3.6	189267	19/02/98	50	400	3.96	
11	101.9	189274	25/02/98	41	310	1.08	
11	62.7	189278	19/02/98	62	570	6.31	
11	52.5	189279	19/02/98	59	480	4.10	
11	43.1	189280	19/02/98	43	460	1.82	
11	33.8	189281	19/02/98	37	300	2.24	
11	28.3	189282	19/02/98	69	550	2.82	
11	23.0	189283	19/02/98	50	480	2.25	

Station	Depth (dbars)	Sample number	Last revised	Susp N (µg/L)	Susp C (µg/L)	Chlor-a (µg/L)	Susp P (µg/L)
11	14.4	189284	19/02/98	44	360	1.00	
11	4.2	189285	19/02/98	40	280	0.63	
12	73.3	189292	19/02/98	10	110	0.24	
12	63.5	189293	25/02/98	10	160	0.24	
12	53.8	189294	25/02/98	9	110	0.31	
12	43.6	189295	25/02/98	14	140	0.38	
12	33.5	189296	25/02/98	26	210	0.85	
12	23.4	189297	25/02/98	15	190	0.95	
12	13.5	189298	25/02/98	22	260	0.57	
13	63.5	189309	25/02/98	21	200	0.51	
13	54.1	189310	25/02/98	12	120	0.45	
13	43.7	189311	25/02/98	19	140	0.34	
13	33.6	189312	25/02/98	10	100	0.39	
13	23.4	189313	25/02/98	32	230	2.17	
13	13.8	189314	25/02/98	26	170	2.21	
13	8.4	189315	25/02/98	25	170	2.07	
13	3.6	189316	25/02/98	29	190	1.83	
14	71.9	189325	25/02/98	25	180	1.25	
14	52.1	189327	25/02/98	34	200	3.87	
14	42.2	189328	25/02/98	68	380	4.35	
14	12.9	189331	25/02/98	60	390	6.08	
16	73.2	189344	25/02/98	16	390	0.50	
16	63.3	189345	25/02/98	15	360	0.24	
16	53.2	189346	25/02/98	9	120	0.50	
16	42.9	189347	25/02/98	14	130	0.63	
16	33.5	189348	25/02/98	25	160	2.38	
16	23.1	189349	25/02/98	72	400	4.17	
16	13.8	189350	25/02/98	50	290	3.85	
16	4.1	189351	25/02/98	38	230	4.02	
19	73.8	189356	25/02/98	13	160	0.35	
19	63.6	189357	25/02/98	19	180	0.29	
19	53.7	189358	25/02/98	10	110	0.81	
19	43.9	189359	25/02/98	21	170	2.54	
19	33.9	189360	25/02/98	42	510	3.24	
19	23.3	189361	25/02/98	84	520	5.67	
19	13.7	189362	25/02/98	33	220	1.10	
19	3.6	189363	25/02/98	27	180	0.59	
22	104.5	189369	25/02/98	13	150	0.12	
22	54.2	189372	25/02/98	12	90	0.33	
22	44.0	189373	25/02/98	12	80	0.75	
22	33.9	189374	25/02/98	18	120	0.95	
22	24.1	189375	25/02/98	62	290	0.92	
22	3.9	189377	25/02/98	26	170	1.16	
23	131.3	189379	25/02/98	18	180	0.21	
23	61.9	189385	25/02/98	16	90	0.11	
23	52.4	189386	25/02/98	27	170	0.11	

Station	Depth (dbars)	Sample number	Last revised	Susp N (µg/L)	Susp C (µg/L)	Chlor-a (µg/L)	Susp P (µg/L)
23	43.1		25/02/98	15	90	0.16	
			25/02/98	41	300	1.28	
23	32.9	189388	25/02/98	18	90	0.30	
23	22.8	189389	25/02/98	19	90	0.55	
23	12.8	189390	25/02/98	30	200	1.22	
23	3.6	189391	25/02/98	27	140	1.09	
27	64.0	189431	26/02/98	NA	530	0.12	
27	53.9	189432	26/02/98	18	240	0.15	
27	36.0	189433	26/02/98	71	310	1.03	
27	25.6	189434	26/02/98	30	220	3.74	
27	17.7	189435	26/02/98	102	660	2.67	
27	12.7	189436	26/02/98	77	470	2.11	
27	3.7	189437	26/02/98	86	570	2.01	
23	67.1	189384	26/02/98	45	270	0.18	
23	61.9	189385	26/02/98	32	240	0.12	
23	52.4	189386	26/02/98	48	170	0.14	
23	43.1	189387	26/02/98	14	180	0.13	
23	32.9	189388	26/02/98	46	240	0.54	
23	22.8	189389	26/02/98	30	220	1.34	
23	12.8	189390	26/02/98	68	370	2.65	
23	3.6	189391	26/02/98	59	390	2.25	
24	83.6	189400	26/02/98	18	200	0.12	61
24	63.5	189401	26/02/98	39	300	0.14	74
24	53.2	189402	26/02/98	32	250	0.40	71
24	43.4	189403	26/02/98	18	200	0.51	68
24	33.1	189404	26/02/98	39	290	0.67	72
24	24.3	189405	26/02/98	69	320	0.32	N/A
24	13.2	189406	26/02/98	46	290	0.23	57
24	3.1	189407	26/02/98	60	270	0.16	73

4.8 RELATED DATA REPORTS IN THE CANADIAN DATA REPORT OF HYDROGRAPHY AND OCEAN SCIENCES SERIES

Birch, J.R., Lemon, D.D., Fissel, D.B., and Melling, H. 1987. Arctic data compilation and appraisal. Beaufort Sea and Amundsen Gulf: physical oceanography: temperature, salinity, currents, water levels and waves: revised and updated to include 1914 through 1986. *Can. Data Rep. Hydrogr. Ocean. Sci.* 5(12): 469 p.

Carmack, E.C., Macdonald, R.W., O'Brien, M., Pearson, R., Timmermans, L., Sieberg, D., Von Hardenberg, B., Sutherland, N., Tuele, D., Jackson, F., and L. White, L. 1996. Physical and chemical data collected in the Beaufort Sea and the Canadian archipelago, August-September 1995. *Can. Data Rep. Hydrogr. Ocean. Sci.* 147: 281 p.

Carmack, E.C., Papadakis, J.E., Macdonald, D.M., and Macdonald, R.W. 1989. NOGAP B.6. Physical data collected in the Beaufort Sea, summer, 1987. *Can. Data Rep. Hydrogr. Ocean. Sci.* 60(6): 219 p.

Cornford, A.B., Lemon, D.D., Fissel, D.B., Melling, H., Smiley, B.D., Herlinveaux, R.H., and Macdonald, R.W. 1982. Arctic data compilation and appraisal. Beaufort Sea: physical oceanography: temperature, salinity, currents and water levels. *Can. Data Rep. Hydrogr. Ocean. Sci*. 5(1): 279 p.

Cuypers, L.E., Blaskovich, A.W., Carmack, E.C., and Macdonald, R.W. 1988. NOGAP B.6. Physical data collected in the Beaufort Sea, September 1986. *Can. Data Rep. Hydrogr. Ocean. Sci.* 59: 149 p.

Macdonald, D.M., Cuypers, L.E., McCullough, D., Carmack, E., and Macdonald, R.W. 1988. NOGAP B.6. Physical data collected in the Beaufort Sea, March-June 1987. *Can. Data Rep. Hydrogr. Ocean. Sci.* 60(2): 157 p.

Macdonald, R.W., Carmack, E.C., McLaughlin, F.A., Sieberg, D., O'Brian, M.C., Paton, D., Pearson, R., Liangfeng, Y., and Gobeil, C. 1991. Oceanographic data collected from the HENRY LARSEN in the Beaufort Sea, August-September 1990. *Can. Data Rep. Hydrogr. Ocean. Sci.* 97: 142 p.

Macdonald, R.W., Carmack, E.C., O'Brien, M.C., McLaughlin, F.A., Minkley, B.G., and Berger-North, K. 1990. Oceanographic data collected from the Sir John Franklin in the Beaufort Sea, September 1989. *Can. Data Rep. Hydrogr. Ocean Sci.* 80: 100 p.

Macdonald, R.W., Iseki, K., Carmack, E.C., Macdonald, D.M., O'Brien, M.C., and McLaughlin, F.A. 1988. Data report: NOGAP B.6: Beaufort Sea oceanography, September, 1986. *Can. Data Rep. Hydrogr. Ocean Sci.* 58: 68 p.

Macdonald, R.W., Iseki, K., O'Brien, M.C., McLaughlin, F.A., McCullough, D., Macdonald, D.M., Carmack, E.C., Adams, H., Yunker, M., Miskulin, G., and Buckingham, S. 1988. NOGAP B.6. Chemical data collected in the Beaufort Sea, Summer, 1987. *Can. Data Rep. Hydrogr. Ocean Sci.* 60(4): 103 p.

Macdonald, R.W., Iseki, K., O'Brien, M.C., McLaughlin, F.A., McCullough, D., Macdonald, D.M., Carmack, E.C., Yunker, M., Buckingham, S., and Miskulin, G. 1988. NOGAP B.6. Chemical data collected in the Beaufort Sea and Mackenzie River delta, March-July 1987. *Can. Data Rep. Hydrogr. Ocean Sci.* 60(5): 55 p.

Macdonald, R.W., O'Brien, M., Carmack, E.C., Pearson, R., McLaughlin, F.A., Sieberg, D., Barwell-Clarke, J., Paton, D.W., and Tuele, D. 1995. Physical and chemical data collected in the Beaufort, Chukchi and east Siberian seas, August-September 1993. *Can. Data Rep. Hydrogr. Ocean. Sci.* 139: 287 p.

Macdonald, R.W., Pearson, R., Sieberg, D., McLaughlin, F.A., O'Brien, M.C. Paton, D.W., Carmack, E.C., Forbes, J.R., and Barwell-Clarke, J. 1992. NOGAP B.6. Physical and chemical data collected in the Beaufort Sea and Mackenzie River delta, April-May 1991. *Can. Data Rep. Hydrogr. Ocean. Sci*. 104: 154 p.

Macdonald, R.W., Sieberg, D., Pearson, R., Paton, M., O'Brien, M.C., McLaughlin, F.A., and Carmack, E.C. 1992. Oceanographic data collected from the Henry Larsen in the Beaufort Sea, September 1991. *Can. Data Rep. Hydrogr. Ocean. Sci.* 112: 108 p.

McLaughlin, F., Carmack, E.C., Zimmermann. S., Sieberg, D., White, L., Barwell-Clarke, J., Steel, M., and Li, W.K.W. 2008. Physical and chemical data from the Canada Basin, August 2004. *Can. Data Rep. Hydrogr. Ocean. Sci.* 140: vi + 185 p.

Paton, D.W., Abehennah, A., Grieve, W., and Macdonald, R.W. 1994. NOGAP B.6. Oxygen isotope data from water and ice cores from the Beaufort Sea, September 1990 and May 1991. *Can. Data Rep. Hydrogr. Ocean. Sci* 134: 118 p.

Paton, D.W., Knight, V., and Macdonald, R.W. 1997. NOGAP B.6. Oxygen isotope data from water and ice cores from the Beaufort Sea, May 1992. *Can. Data Rep. Hydrogr. Ocean. Sci.* 149: 23 p.

Pearson, R., O'Brien, M., Sieberg, D., McLaughlin, F.A., Paton, D.W., Tuele, D., Barwell-Clarke, J., Carmack, E.C., Macdonald, R.W., and Galbraith, M. 1994. NOGAP B.6. Physical and chemical data collected in the Beaufort Sea and Mackenzie River delta, April-May and September, 1992, and ice core data collected in 1991-1992. *Can. Data Rep. Hydrogr. Ocean. Sci*. 129: 199 p.

Thomas, D.J., Macdonald, R.W., and Cornford, A.B. 1982. Arctic data compilation and appraisal. Beaufort Sea: chemical oceanography. *Can. Data Rep. Hydrogr. Ocean. Sci*: 5(2): 243 p.

Thomas, D.J., Noone, F., Blyth, A., and Smiley, B.D. 1990. Arctic data compilation and appraisal. Beaufort Sea: chemical oceanography: hydrocarbons, metals, pigments, nutrients, oxygen and others: revised and updated to include 1950 through 1987. *Can. Data Rep. Hydrogr. Ocean Sci* 5(20): Pt 1&2; 2 v.

Woods, S.M., and Smiley, B.D. 1987. Arctic data compilation and appraisal. Beaufort Sea: biological oceanography: bacteria, plankton, epontic community, 1914 to 1985. *Can. Data Rep. Hydrogr. Ocean Sci.* 5(9): 394 p.