

The second scheduled rotation for ISW was carried out on *Nathaniel B. Palmer* as cruise NBP 92-1. On the return leg, eight CTD stations were occupied, and analyses were performed using the ship's SBE CTD profiler and GO rosette system. Water samples were collected for the analysis of salinity and oxygen isotopes. The NBP 92-1 data extend the ISW CTD section north. The dramatic thickening of the bottom sheet of concentrated antarctic bottom water types seen at the ISW stations 65-70 (65-66° S) continues to the north of 65° S; the sheet is not renewed by an additional injection of bottom water.

Both AF and NBP participated in the recovery of ISW. CTD stations were occupied from both vessels; here we report on only the 17 occupied from NBP. These were performed with an NBIS MKIIB CTD mounted in a 12-liter, 24-position rosette sampler. Water samples were collected for the analysis of salinity, dissolved oxygen, chlorofluorocarbons, oxygen-18, and barium. Casts were lowered to within approximately 10 meters of the bottom, conditions permitting. NBP 92-2 CTD data along 45° W reveals an eastward flow of antarctic bottom water that has the characteristics seen in the archived data, with bottom potential

temperature slightly below -1 °C and salinity near 34.62. The complex layering, revealed for the first time by the ISW data, in the thin benthic layer along the western edge of the Weddell Sea, has been lost to vertical mixing. The ISW data indicate that the final bottom water product is due to more than one bottom water type. There are at least two types of antarctic bottom water feeding the western Weddell Sea—a low-salinity variety and a high-salinity variety that is much like the one observed in the Ross Sea, though not as salty. The NBP 92-2 CTD data reveals the blend that spreads into the circumpolar belt.

It is worth noting that air temperature on the stations during NBP 92-1 and NBP 92-2 were often below -25 °C and occasionally as cold as -35 °C. At such temperatures, there is a constant risk of damage to a lowered instrument package and a risk of the freezing of water samples. Neither occurred during these cruises to any significant degree, primarily because of the unique design of the NBP's baltic room for over-the-side work.

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## Ice Station Weddell #1: Thermohaline stratification

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The conductivity-temperature-depth (CTD)/Tracer component of Ice Station Weddell #1 (ISW) and associated ship activity was designed to resolve water mass stratification of the Weddell Gyre's western rim. The perennial ice cover of this region has blocked such observations before ISW, therefore, the western Weddell was depicted by a data void (Gordon and Lukin). Archived data reveal the nature of the water entering the Weddell Sea from the east and water flowing out of the western rim of the Weddell Gyre into the Gyre's northwest corner. It is clear that water mass modification occurs in the Weddell's western margin. However, neither the oceanic, sea ice, or atmospheric environmental conditions responsible for the water mass alteration or the perennial ice cover are known. Because the western Weddell is perennially covered by sea ice, there is reason to believe that processes there are markedly different from those in the seasonal ice regions to the east.

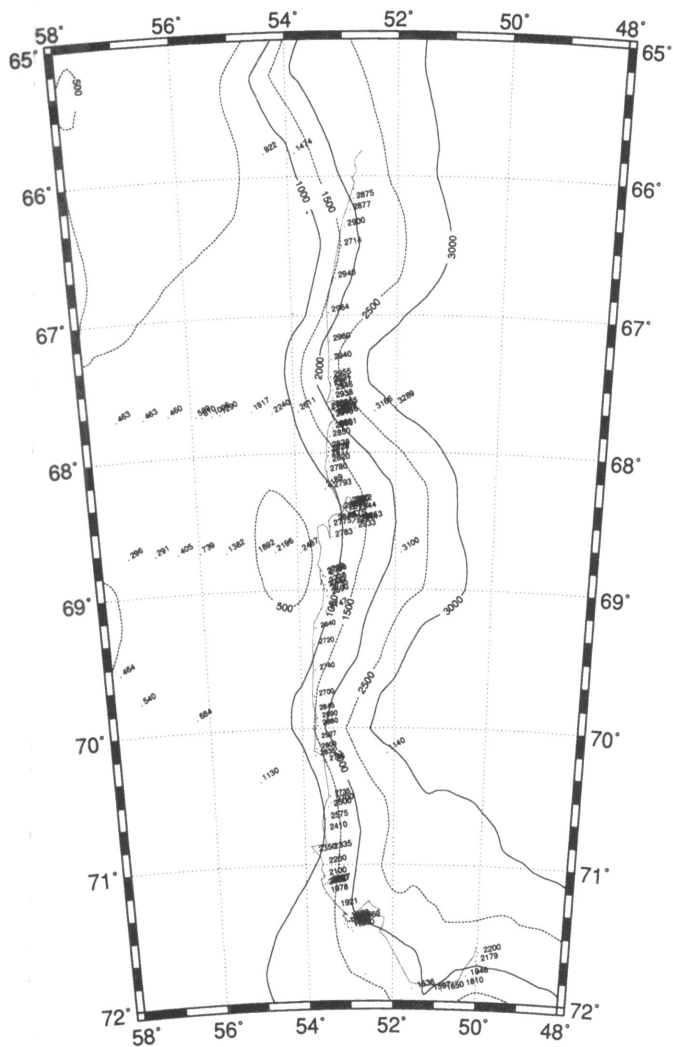
Ocean stratification features that are of particular interest to the CTD program research include: mixed layer and pycnocline characteristics and their relationships to the sea ice cover; the attenuation of the relatively warm, salty Weddell deep water (WDW) along the flow of the western boundary current and with distance from the continental margin; western rim contributions to the quality and quantity of antarctic bottom water; and the nature of the water mass structure over the continental margin of

the Antarctic Peninsula. In addition, the CTD baroclinic information with ISW current meter data (Muench et al.) allows estimation of the absolute velocity and transport of the Weddell Gyre's western-boundary current. The CTD data also provide the large scale setting for the oceanic boundary layer small scale processes research and pycnocline thermohaline steps observed at ISW and to the east.

CTD measurements at ISW (see figure 1 of Gordon and Lukin for station positions) consisted of CTD/hydrographic casts to the sea floor at ISW at a nominal spacing of 10 kilometers along the drift track (the Russian CTD program obtained daily stations to 1,000 meters) and CTD casts using lightweight equipment flown by helicopter to remote sites (helicopter CTD or hCTD) positioned along four lines perpendicular to the drift track reaching onto the continental shelf. Seventy CTD/hydrocasts were obtained at the ISW site using non-conducting wire with up to 15 5-liter bottles per station with an internally recording CTD profiler. Water samples were drawn and analyzed for salinity and dissolved oxygen. Additional samples were drawn for later analysis of tritium, helium, oxygen-18, and chlorofluorocarbons (Schlosser et al. this issue).

Of the 37 hCTD profiles, most of which reached the ocean floor. Many of the profiles were accompanied by two to four bottle samples, which were analyzed for salinity and dissolved oxygen. Emphasis was placed on occupying stations to the west of the drift track to extend data coverage into this otherwise inaccessible area of the continental margin.

An effort was made to obtain sea-floor depth measurements at each CTD and hCTD station by precision depth recorder and acoustic pinger mounted on the wire (figure 1). These data indicate that the continental margin is nearly 100 kilometers west of the position indicated on existing charts (and that the Weddell's western boundary current is much wider than previously suspected), confirming similar conclusions based on remote measurements of gravity and magnetic anomalies (LaBrecque and Ghidella). The topography on the shelf and slope appears to be



**Figure 1.** The ocean depth measurements from Ice Station Weddell and at remote sites from helicopter, superimposed on the bottom depths as given in the Gebco map. The actual bottom depths are greater than shown on the Gebco map and agree with the revised topography of LaBrecque and Ghidella, this issue (see their figure 1).

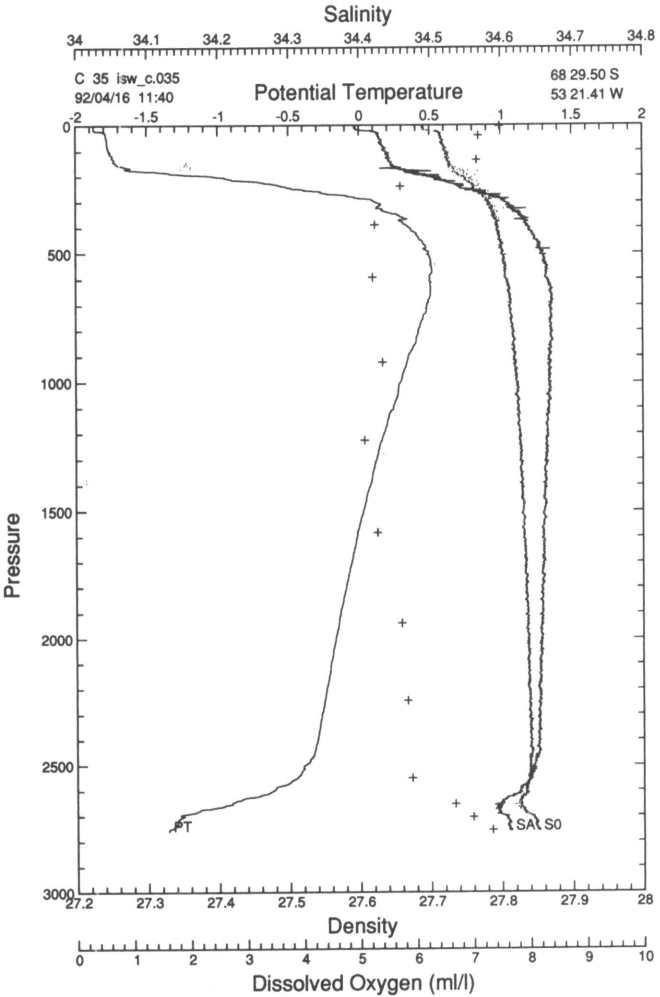
irregular, with many east-west oriented troughs that may funnel dense water to the deep ocean.

The water column at the ice station (figure 2) is characterized by a relatively thin (mostly 50 to 125 meters thick) surface mixed layer, which was not quite as homogeneous (perhaps because the full winter conditions were not yet attained) as observed below the seasonal ice to the east. The pycnocline is somewhat more stable than that found to the east in the seasonal sea ice zone, which suppressed vertical exchange and accounts for the reduced oceanic heat flux (McPhee et al.). There appears to be a fresh-water input to the pycnocline in the southwestern corner of the gyre that tends to cap the heat of the WDW. The WDW temperature maximum ranged from 0.6 °C on the southern end of the drift track to 0.4 °C at the northern end. Perhaps the most unexpected observation is the thin (200 to 300 meters thick) very cold, highly oxygenated bottom boundary layer draped over the sea floor seaward of the shelf break. The bottom layer often displays increased salinity at the sea floor (e.g., figure 2), which

can be traced by hCTD via slope plumes to saline, near freezing point shelf water and perhaps in the southern region of ISW coverage, to outflow from the Ronne Ice Shelf. The thin layer of concentrated antarctic bottom water clearly indicates active bottom water formation along the western margin of the gyre. Suddenly near 66° S this thin layer mixes up into the water column to at least 800 meters off the sea floor, looking more like the bottom water form observed in archived data emerging from the western Weddell.

In addition to the CTD/hydrographic and hCTD data obtained at ISW, CTD/rosette casts were obtained from the icebreaker/research vessels *Akademik Federov* and *Nathaniel B. Palmer* during deployment, rotation, and recovery of the ice station (Gordon et al.). The ISW CTD and hCTD with the ship stations represent a unique opportunity to reveal the important water-mass modification and ventilation mechanisms under the perennial sea ice of the western Weddell Gyre.

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**Figure 2.** Vertical profile of potential temperature, salinity, oxygen, and sigma-O at ISW CTD station #35 (68° 29.50' S and 53° 21.41' W). The minimum in sigma-O near 2,670 meters does not appear if density is reported with reference to higher pressure (e.g., sigma-2).

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## Upper-ocean variability during Ice Station Weddell

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The upper ocean physics component of Ice Station Weddell (ISW), a field experiment in the western Weddell Sea between February and June 1992, was designed to obtain a time series of upper-ocean properties, horizontal and vertical fluxes, velocities, and shear. Measurements of the upper ocean evolution and ocean/sea ice interaction are required to test and refine our existing understanding of the relationship between the large-scale (easily observed) property distributions, and vertical and horizontal fluxes.

Here we present some of our initial upper ocean observations. Other aspects of the upper ocean program are described in Padman and Levine (this issue) and McPhee et al. (this issue). The general program is reviewed by Gordon and Lukin (this issue).

One of the more important events to be monitored during the ice station involved the fall erosion of the seasonal pycnocline. To our knowledge these are the first observations of the actual

transition of the upper ocean from its summer configuration to its winter configuration in the ice-covered Weddell region. The summer configuration was characterized by a relatively thin surface mixed layer, approximately 35 to 50 meters deep, underlain by a relatively weak and thin seasonal pycnocline predominantly reflecting the seasonal halocline ( $\Delta S/\Delta z \sim 0.24 \text{psu}/25\text{m}$ ). The seasonal pycnocline was underlain by a well preserved remnant winter mixed layer (approximately 100 to 150 meters thick) to the permanent pycnocline.

For an average ice growth rate of 7 to 10 centimeters per day in the 5 percent lead areas, the erosion of the seasonal pycnocline would require over 100 days. Ackley et al. showed that no net growth occurred at the base of the existing ice cover during the period of the ice station, thus ice growth was limited to the lead areas. However, the erosion was seen to proceed irregularly through out the drift until late April when the density step across the seasonal pycnocline was reduced to ( $\Delta S/\Delta z \sim 0.03 \text{psu}/3\text{m}$ ) (equivalent to approximately 14 centimeters ice growth per day in 5 percent lead area on average since early March if the erosion was strictly due to local ice growth). At this time a passing storm provided enough surface mixing to overcome the density step and complete the erosion. The storm forced the mixed layer to a depth of approximately 100 meters within a period of a few hours. The mixed layer restabilized to a shallower depth when the storm abated. This latter effect may reflect a freshwater input associated with some melting due to the upward heat flux accompanying the mixed layer erosion into slightly warmer water. However, after several days and some oscillation of the mixed layer depth, the deep winter mixed layer was established to the depth of the permanent pycnocline (approximately 100 meters).

On 7 April the station drifted over a region stabilized by a shallow (approximately 18 meters) surface freshwater cap. This layer was monitored (19 microstructure casts and continuous turbulence measurements) as the mixed layer reestablished itself through intense surface mixing to its previous deeper (approximately 30 meters) level over the next 20 hours. This episode provides an ideal period for testing our existing surface layer models.

Throughout most of the drift region, a thick remnant winter mixed layer was very well preserved (typically less than 0.1 °C above freezing) beneath the seasonal pycnocline. This suggests low mixing activity below the surface layer and in general imposes strong constraints on the flux rates across the permanent pycnocline during the period over which the remnant winter mixed layer has been isolated (since the previous spring melt).

In early April the station drifted over an eddy that displayed no remnant winter mixed layer, instead having a relatively deep mixed layer (approximately 65 meters) directly overlaying a shallow permanent pycnocline. The ice station passed over this