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Possible Source of the Antarctic Bottom Water in the Prydz Bay Region

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It has been inferred that the Prydz Bay region is one of the source regions of Antarctic Bottom Water (AABW) based on rather indirect evidence. In order to examine this inference, we investigate the hydrographic condition of the bay based mainly on XCTD data obtained during the Japanese Whale Research Program in the Antarctic (JARPA). The JARPA hydrographic data reveal Circumpolar Deep Water (CDW), which is a salty, warm water mass approaching the shelf break, and capture Modified CDW (MCDW) intruding into the shelf water. AABW production requires mixing of CDW and cold shelf water saltier than 34.6 psu, which is a saltier type of Low Salinity Shelf Water (LSSW). Saltier LSSW is observed near the bottom over the shelf, being mixed with MCDW. We further identify saltier LSSW near the shelf break. This saltier LSSW appears close enough to unmodified CDW to be mixed with it over the continental slope, indicating a possible source of AABW in Prydz Bay.

Keywords:
· Antarctic Bottom Water,
· Prydz Bay,
· Amery Basin,
· JARPA,
· Circumpolar Deep Water,
· Ice Shelf Water,
· XCTD,
· continental shelf,
· ice shelf.

1. Introduction

Antarctic Bottom Water (AABW) is the cold, dense water that spreads over the abyssal layer of the world ocean, and is thought to originate mainly in the Weddell Sea and the Ross Sea (see Orsi *et al*., 1999 for a review). Some earlier studies suggested other contributors to AABW. Jacobs and Georgi (1977) proposed that one of the sources of AABW comes from the Enderby Land/Prydz Bay coast. They detected cold, high oxygen water near the bottom of the continental slope near 60°E. Since this type of AABW was not observed at 37°E, they ruled out the existence of an eastward flow from the Weddell Sea through the 37°E meridian, which would directly transport AABW originating in the Weddell Sea. That is, the type of AABW observed at 60°E was unlikely to come from the west. Accordingly it was inferred that AABW formation should occur east of 60°E. One of the regions most likely to contribute to bottom water formation in that region is the Prydz Bay region (70°–80°E), which is the third largest shelf region around Antarctica. Orsi *et al*. (1999) also inferred AABW formation not only in the Weddell Sea and the Ross Sea but also in other coastal area, including the Prydz Bay region, from the large-scale flow pattern of AABW and chlorofluorocarbon (CFC) distribution.

Recent CFC measurement also supported this idea. Meredith *et al*. (2000) analyzed CFC and hydrographic data at Section A23 of the World Ocean Circulation Experiment (WOCE) Hydrographic Programme across the Weddell Gyre from the Antarctic continental shelf (72.5°S, 16.5°W) to South Georgia (55°S, 34.5°W). The A23 CFC data showed a high CFC concentration signal in Weddell Sea Deep Water (WSDW). WSDW is the relatively warm part of AABW in the southern Weddell Sea and had been suggested to be transformed from colder AABW ventilated in the western Weddell Sea. However, the high CFC concentration of WSDW was inconsistent with this hypothesis and consequently suggested a direct ventilation of WSDW, probably in the Prydz Bay region.

The Prydz Bay region is located in the Indian sector of the Southern Ocean. Its topography is characterized by a large continental shelf area and a basin deeper than 600 m, the Amery Basin (Fig. 1), the deepest point of which reaches 900 m. The large continental shelf plays an important role in the formation of bottom water according to Fahrbach *et al*. (1994), who indicated that the narrow continental shelf in the southeastern Weddell Sea

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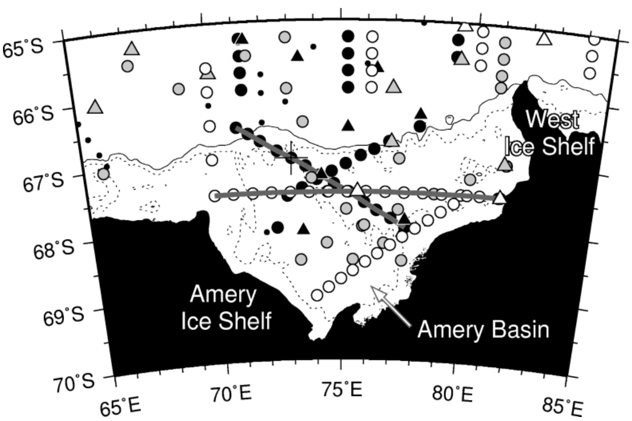

Fig. 1. Topography of the Prydz Bay region with the station positions of JARPA-97/98 data (small closed circles), 99/00 (closed symbols), 01/02 (gray symbols) and 03/04 data (open symbols) indicated by circles (XCTD) and triangles (CTD). The 1000 m contour (solid line) and 500 m contour (broken line) are added. The position of the section shown in Figs. 2 and 3 is indicated by the solid gray line. Station JARPA-99/00-113 mentioned in the text is indicated by a cross.

allows the heat of warm, deep water to enter beneath the ice shelf, resulting in melting at the base of the ice shelf and thus a supply of fresh water. While such narrowness of the continental shelf prevents shelf water from remaining saline, a wide continental shelf, such as that in the Prydz Bay region, makes it possible to provide shelf water with enough salt to produce bottom water.

The hydrographic feature in the Prydz Bay region is characterized by relatively warm ($\theta > 0.5$°C) and salty ($S > 34.65$ psu) deep water, Circumpolar Deep Water (CDW) (Callahan, 1972), which is distributed outside of the bay, and Modified CDW (MCDW) and cold shelf water in the shelf region (Nunes Vaz and Lennon, 1996). MCDW is a mixture of low salinity shelf water and intruding CDW, and it is colder and less saline than unmodified CDW. One of the crucial processes of AABW formation is the mixing of MCDW with salty shelf water (Foster and Carmack, 1976). The terms Low Salinity Shelf Water (LSSW) and High Salinity Shelf Water are used to describe water masses characterized in the shelf domain, which were previously based on an ambiguous definition. Here the shelf water in Prydz Bay is classified as LSSW as redefined by Whitworth *et al.* (1998). When the salinity of the shelf water is over 34.6 psu, the mixing process can make bottom water dense enough to descend the continental shelf slope. The newly formed bottom water in the Prydz Bay region is termed Prydz Bay Bottom Water (Middleton and Humphries, 1989). Although Nunes Vaz and Lennon (1996) investigated the hydrographic features of the Prydz Bay region and revealed the existence of LSSW more saline than 34.6 psu, which they called High Salinity Shelf Water, the mixing process bringing about AABW formation has not been demonstrated on the shelf of the region.

Since 1987, the Institute of Cetacean Research (ICR) has carried out the Japanese Whale Research Program in the Antarctic (JARPA) with the purpose of improving the scientific information necessary for the management of cetacean resources. While the primary survey item of JARPA is a sighting survey, hydrographic observation is also conducted in order to elucidate the effects of environmental changes on cetaceans (Matsuoka *et al.*, 2003), which allows JARPA to provide long-term, extensive hydrographic data in the Antarctic Ocean including the Prydz Bay region. In this paper we examine whether any AABW sources could lie in the Prydz Bay region, based on the JARPA dataset.

2. Data

JARPA has been carried out during the austral summer, from December to March. The survey region extends from 60°S to the Antarctic coastal area, over half the circumpolar area including the western Ross Sea, the Adélie Coast and the Prydz Bay region. In this study we mainly analyze the data collected during JARPA-97/98 (the cruise from December 1997 to March 1998), 99/00, 01/02 and 03/04, because the cruises covered the area including the Prydz Bay region, and because salinity measurement was done during the cruises.

The temperature and salinity data were obtained using expendable conductivity-temperature-depth profilers (XCTD) or conductivity-temperature-depth profilers (CTD). All of the XCTD and CTD data are sampled using TSK XCTDs and SBE CTDs (SBE 19 SEASCAT profilers), respectively. The maximum depth of the CTD profiles is limited to 500–600 m due to the limitation of the ship time. The depth range of XCTD is about 1050 m. Observation stations occupied during four cruises are indicated in Fig. 1, in which 117 XCTD stations and 19 CTD stations are distributed. CTD was not employed in JARPA-97/98.

The manufacturer's specified accuracy of XCTD temperature and conductivity is 0.02°C and 0.03 mS/cm, respectively. The accuracy of XCTD salinity is accordingly expected to be about 0.04 psu within the temperature range in this study area (typically 1° to –2°C). Actually, Mizuno and Watanabe (1998) concluded that the overall salinity accuracy of TSK XCTDs is better than 0.04 psu based on their XCTD/CTD comparison in the Indian Ocean.

Positive biases in the XCTD salinity have been reported by Mizuno and Watanabe (1998). In their XCTD/CTD comparison they detected 0.036 psu as the maximum of the XCTD salinity bias. In the present study, each

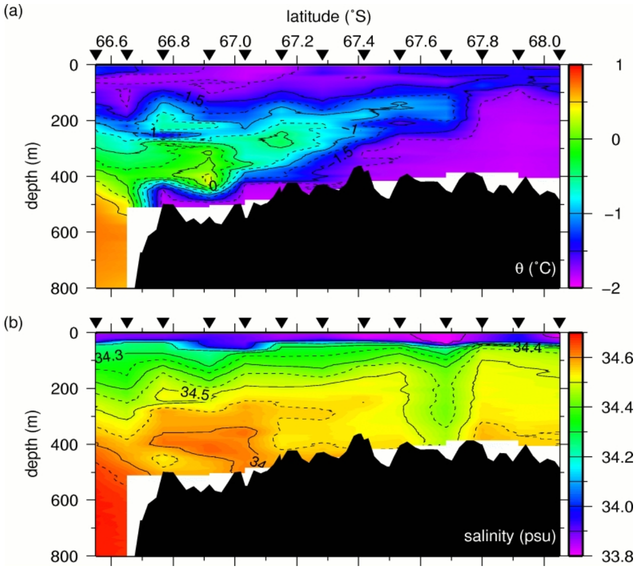

Fig. 2. Potential temperature (a) and salinity (b) along the vertical section during JARPA-99/00, indicated by the circles connected by the solid gray line in Fig. 1. Station positions are indicated by triangles at the top.

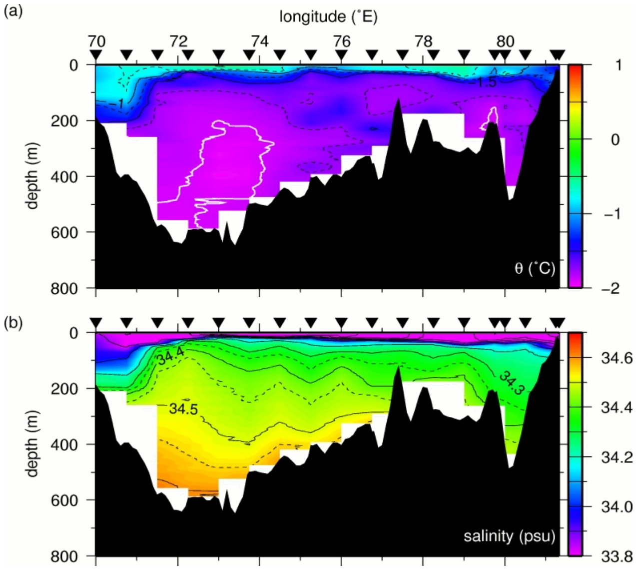

Fig. 3. As Fig. 2 except for JARPA-03/04, indicated by circles connected by the solid gray line in Fig. 1. White lines indicate surface freezing temperature, T_f.

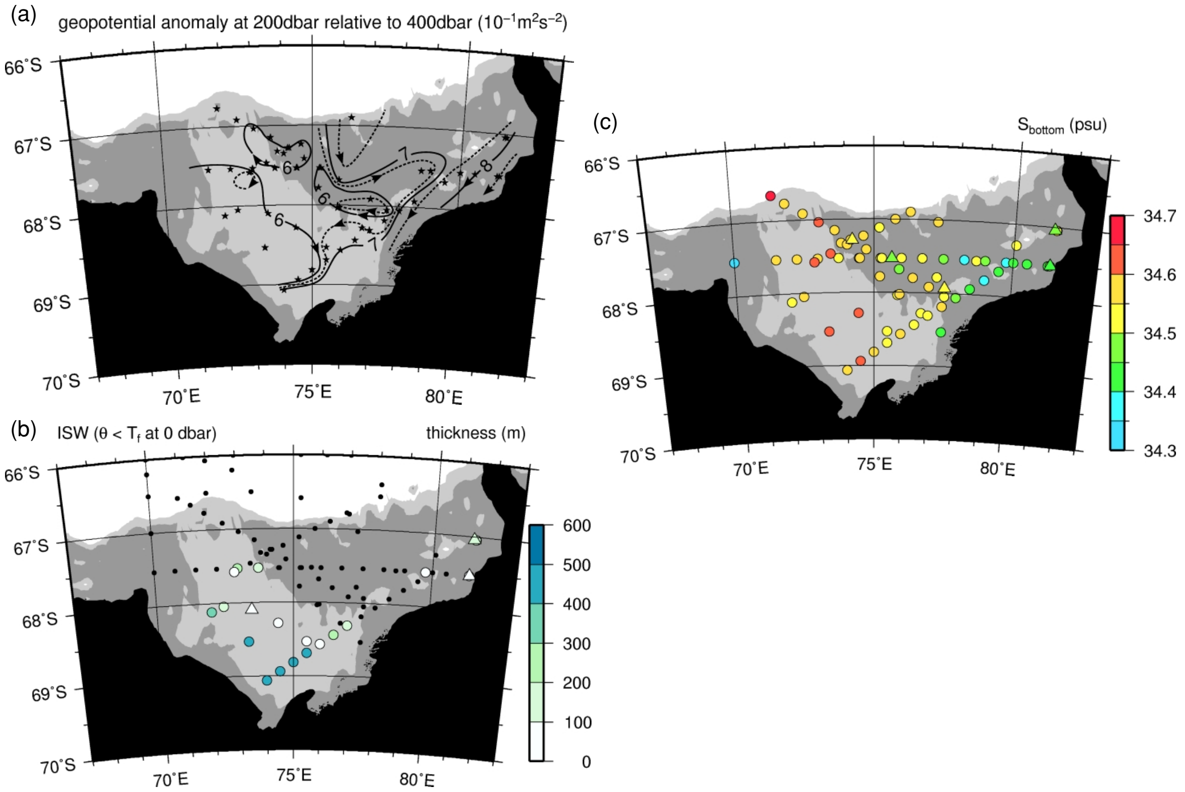

Fig. 4. (a) Geopotential anomaly at 200 dbar relative to 400 dbar, based on the data obtained at positions indicated by stars. (b) ISW thickness distribution. (c) Salinity distribution at the bottom. Only stations that provide properties within 100 m from the bottom are depicted. Data observed by XCTD are indicated by circles and CTD by triangles. The area shallower than 1000 m is shaded and shallower than 500 m darkly shaded.

of the salinity data points at 1000 m observed by XCTD was compared with the annual mean salinity at 1000 m of the World Ocean Atlas (WOA 2001) (Conkright *et al.*, 2002a) at its nearest 1° × 1° grid point. Here we regarded the overall salinity at 1000 dbar as fairly stable, because the standard deviation presented by WOA 2001 has a mean of 0.012 psu in this region. The mean differences for each cruise are 0.079, 0.003, 0.011 and 0.032 psu in JARPA-97/98, 99/00, 01/02 and 03/04, respectively. As Mizuno and Watanabe (1998) point out, the salinity collected by early XCTDs have larger bias, which probably causes an exceptionally large difference in JARPA-97/98. We regarded the mean difference for JARPA-97/98 as the bias for the corresponding XCTD lots and subtracted it from all XCTD salinity values for that cruise. Since the mean differences for the other cruises are within the manufacturer's specified accuracy, no corrections were made.

The manufacturer's specifications for accuracy of CTD are 0.01°C in temperature and 0.01 mS/cm in conductivity, leading to a salinity error less than 0.015 psu. The temperature and conductivity sensors of CTD are calibrated by the manufacturer every year. The drifting values since the preceding calibration do not exceed 0.02 mS/cm by the end of each cruise, which would lead to a salinity drift less than 0.03 psu.

To exclude suspicious data from the analysis, all XCTD data were subjected to a statistical check as follows. For each profile, a set of profiles located in the one-degree-wide zonal band whose center latitude was the position of the profile being checked were extracted from all XCTD profiles during four cruises. The mean and standard deviation (σ) of the set were calculated every 100 m. The profile was checked based on the mean and standard deviation and the data that deviated from the means by more than 3σ were regarded as suspicious data. All profiles were checked by the above method and suspicious data were eliminated. Consequently, of the 118 XCTD profiles deployed in the study region, one entire XCTD cast was discarded.

3. Results

Each of the three cruises, JARPA-99/00, 01/02 and 03/04, provided two XCTD vertical cross sections across the shelf region of Prydz Bay (Fig. 1). These vertical cross sections show the intrusion of CDW, that is MCDW over the shelf region, and the underlying cold shelf water as exemplified in Fig. 2. The vertical cross section shown in Fig. 2 crosses Prydz Bay northwest to southeast, indicated as one of the gray lines in Fig. 1. Figure 2 shows that the salinity of near bottom shelf water is higher than 34.5 psu. In the southern part of the section, 67.8°–68.05°S, the shelf water colder than –1.5°C is captured in almost the entire column. These features are consistent with the observations of Nunes Vaz and Lennon (1996).

MCDW is clearly depicted in Fig. 2 as the tongue of water warmer than –1.0°C. While it is not as apparent in this section, the other section indicated in Fig. 1, which crosses Prydz Bay zonally near 67.5°S, shows that relatively warm water (–1.5° to –1.7°C) appears at 100–200 dbar between 75°–76°E, which is regarded as MCDW (Fig. 3). It is suggested that MCDW is supplied to Prydz Bay mainly by way of 75°–76°E.

The intrusion of CDW into the bay is supported by the distribution of geopotential anomaly at 200 dbar, near the MCDW core, relative to 400 dbar (Fig. 4(a)). To depict the flow pattern on the shelf, Fig. 4(a) is constructed from the data located in the area shallower than 1000 m. Figure 4(a) shows a strong southward current near 75°E, which is consistent with the relatively warm water captured in Fig. 3. The distribution of geopotential anomaly is characterized by this southward current, along-shore current and the cyclonic circulation. These features suggest that MCDW comes into the bay and joins in the cyclonic circulation. The situation where CDW intrudes on the continental shelf in Prydz Bay is similar to that in the Weddell Sea and the Ross Sea (Jacobs *et al.*, 1970; Foster and Carmack, 1976; Foldvik *et al.*, 1985; Jacobs, 1991; Gordon, 1998). It should be mentioned that the barotoropic component of the geostrophic flow is much larger than the baroclinic one in the shelf region and that a tidal flow is also strong there. The flow pattern depicted above should be examined further in future study.

The cross section presented in Fig. 3 captures cold water whose potential temperature is lower than surface freezing temperature, T_f, at 270–430 m, 73°–74°E. Because cooling at the sea surface will not result in such cold water, internal cooling by ice shelves must be at work and the water formed in this way is called the Ice Shelf Water (ISW). The thickness of ISW is calculated from individual XCTD and CTD profiles and its distribution is presented in Fig. 4(b). ISW is found in the western part of the bay and is especially thick near the Amery Ice Shelf. It is thus suggested that ISW originates from the Amery Ice Shelf. Moreover, the ISW distribution is restricted within the western Amery Basin, which is characterized by the cyclonic circulation delineated with the geopotential anomaly contour of 6×10^{-1} m^{2}s^{-2} (Fig. 4(a)). ISW found at the eastern part of the bay is probably related to the West Ice Shelf (Fig. 1).

The saline shelf water shown in Figs. 2 and 3 is more saline than 34.5 psu. Its most saline part (saltier than 34.6 psu) is regarded as saltier LSSW. In order to show the distribution and the spread of LSSW saltier than 34.6 psu, a map of near-bottom salinity is shown in Fig. 4(c). The bottom salinity in the bay ranges from 34.5 to 34.7 psu. Water saltier than 34.6 psu is mainly observed in the deepest part of the Amery Basin, indicating that saltier LSSW

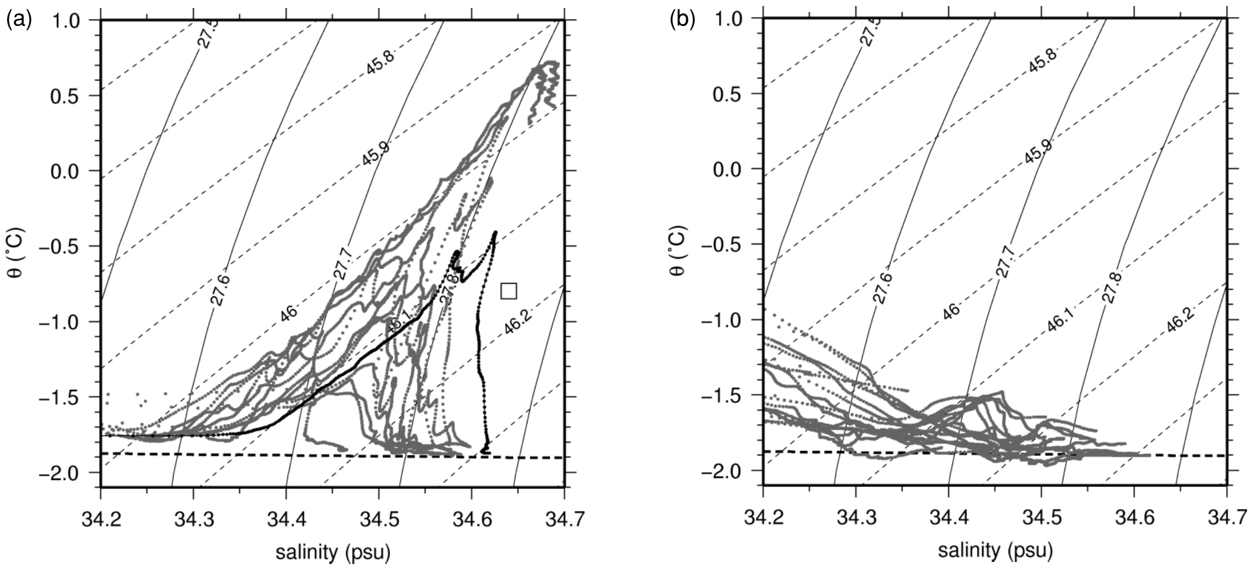

Fig. 5. (a) Potential temperature-salinity diagram for the data along the section shown in Fig. 2 and (b) Fig. 3. Data from station JARPA-99/00-113 are plotted with black dots. The AABW property shown by the square is adapted from Jacobs and Georgi (1977). Lines of constant potential density (solid line) and density referenced to 4000 dbar (broken line) are drawn. Bold broken line indicates T_f.

fills the Amery Basin. The saline water is also observed in the vicinity of the shelf break. The water observed at the bottom of the station at 73°E, 67°S, JARPA-99/00-113, has a temperature colder than –1.5°C and thus indicates the existence of saltier LSSW near the shelf break. This saltier LSSW captured near the shelf break is also obvious in Fig. 2. Note that most of the saline water, which is observed at 71.4°E, 66.7°S, is relatively warm and is regarded not as saltier LSSW but as CDW.

The θ-S diagrams from the section in Figs. 2 and 3 are indicated in Fig. 5. The characteristics of saltier LSSW captured at the shelf break are shown in the θ-S diagram (Fig. 5(a)) from the section in Fig. 2. Vertical mixing of saltier LSSW with MCDW has occurred on the shelf, as indicated by the θ-S profile at the station JARPA-99/00-113. The mixing results in the formation of water that has properties fairly close to those of AABW found by Jacobs and Georgi (1977). Since this is the only profile indicating vertical mixing of saltier LSSW and MCDW in the JARPA data, we searched all profiles, passed through a series of quality controls, near this station in World Ocean Database 2001 (Conkright *et al.*, 2002b) for additional evidence. As a result, we found another profile similar to this station by serial observation (not shown), supporting the present finding.

4. Discussion and Conclusions

Nunes Vaz and Lennon (1996) identified the cyclonic circulation in the bay. Comparing the distribution of geopotential thickness between 50 dbar and 200 dbar with that between 50 dbar and 500 dbar, they suggested that the inflow to the bay and the clockwise circulation are dominant at depth 200–500 m. Their notion is consistent with the distribution of geopotential anomaly based on JARPA (Fig. 4(a)). Note that the reference depth (400 m) is adopted in the present study in order to retain more data in the bay area, which is largely shallower than 500 m. Since the depth of the MCDW core corresponds with the depth near 200 m (Fig. 2), it is suggested that MCDW comes into the bay and is involved in the cyclonic circulation. The relatively warm water depicted in Fig. 3 supports this MCDW flow pattern, which implies that MCDW enters the shelf area near 75°E.

The inflow of MCDW provides salt for the shelf water and will be a main source of saltier LSSW. One of the important processes for modifying the intruding MCDW into saltier LSSW is thought to be a brine rejection associated with ice formation. Ice formation in Prydz Bay occurs not only at the sea surface but also under the Amery Ice Shelf, which is one of the major embayed ice shelves of Antarctica, located in western Prydz Bay. Large ice shelves cool underlying water, resulting in basal freezing. Jacobs *et al.* (1970) discussed such a process occurring beneath the Ross Ice Shelf in the Ross Sea. The thick ISW layer near the Amery Ice Shelf in Fig. 4(b) confirms internal cooling by the ice shelf. Fricker *et al.* (2001) describes the circulation beneath the Amery Ice Shelf and indicates that the clockwise circulation results in marine ice concentrated in the northwest of the ice shelf. This observation suggests that the basal freezing presumably provides salt in Prydz Bay.

Given that salt inputs resulting from processes such as the basal freezing beneath the Amery Ice Shelf occur, high salinity water accumulates in the deeper portion because of its higher density, resulting in the formation of saltier LSSW. Actually, the distribution of bottom salinity (Fig. 4(c)) illustrates that saline water is found in the Amery Basin. The high salinity water has near-freezing temperature and is thus identified as saltier LSSW. Based on the circulation pattern shown in Fig. 4(a), salinity distribution at the bottom in the bay implies that intruding MCDW is modified into saltier LSSW due to air-sea and sea-ice interaction passing through the cyclonic gyre.

It is inferred that the path through which saltier LSSW overflows from the Amery Basin is located near 73°E because the trough there connects the Amery Basin and open sea. The bottom salinity at the trough is higher than 34.6 psu, as depicted by the bottom salinity at the station 113 during JARPA-99/00 (Fig. 4(c)). It is also found that several profiles in the vicinity of the station 113 show a salinity higher than 34.6 psu at a depth just greater than 500 m (the depth at station 113), indicating that saltier LSSW accumulated in the Amery Basin. The highly saline water at the bottom of the basin and at the trough together suggests that saltier LSSW fills basin and outflows from the Amery Basin to the open ocean.

When the LSSW saltier than 34.6 psu observed near the shelf break outflows and descends the continental slope, saltier LSSW can mix with unmodified CDW distributed in the vicinity of the slope. The properties resulting from such mixing would be those of AABW. Actually, the properties of AABW observed by Jacobs and Georgi (1977), indicated by square symbols in Fig. 5(a), would be achieved if saltier LSSW (–1.7°C, 34.6 psu) captured at the station JARPA-99/00-113 were mixed with unmodified CDW (0.5°C, 34.7 psu). This observation of saltier LSSW approaching the shelf break is stronger evidence of the AABW source than has ever been presented previously.

The role of topography in determining the path of the shelf water outflow is discussed by Foldvik *et al.* (1985) and Gordon (1998). Gordon (1998) indicated that northward flowing high salinity shelf water in the western Weddell Sea is blocked by the shallower part of the continental shelf, and that the topography can guide high salinity shelf water to the deep ocean. The topography of the western Weddell Sea probably causes high salinity shelf water to flow effectively out from the basin. Similarly, the deeper part of the shelf break presumably works as a path between the Amery Basin and the open ocean. In the map of salinity distribution in JARPA-99/00 and 01/02, saltier LSSW is observed exactly at the stations along such a path (Fig. 4). It is likely that saltier LSSW filling in the Amery Basin overflows along the path and the mixing of saltier LSSW with unmodified CDW results in the formation of AABW. According to Tanaka and Akitomo (2000), the East Wind Drift, the narrow westward coastal current, has the effect of intensifying the dense water outflow as the bottom Ekman current. Nunes Vaz and Lennon (1996) indeed described a westward coastal current in Prydz Bay, which supports the mechanism of descending saltier LSSW on a continental slope.

The present observational results confirm the formation of saltier LSSW in the Prydz Bay region, and provide evidence for the idea that saltier LSSW originating in the Amery Basin mixed with unmodified CDW in continental slope results in the formation of the AABW source. In order to acquire more certain, direct evidence of it, a more intensive survey, especially near the shelf break, is needed.

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References

Callahan, J. E. (1972): The structure and circulation of deep water in the Antarctic. *Deep-Sea Res.*, **19**, 563–575.

Conkright, M. E., R. A. Locarnini, H. E. Garcia, T. D. O'Brien, T. P. Boyer, C. Stephens and J. I. Antonov (2002a): *World Ocean Atlas 2001: Objective Analysis, Data Statistics, and Figures, CD-ROM, Documentation*. National Oceanographic Data Center, Silver Spring, MD, 17 pp.

Conkright, M. E., J. I. Antonov, O. Baranova, T. P. Boyer, H. E. Garcia, R. Gelfeld, D. Johnson, R. A. Locarnini, P. P. Murphy, T. D. O'Brien, I. Smolyar and C. Stephens (2002b): *World Ocean Database 2001, Volume 1: Introduction*, ed. by S. Levitus, NOAA Atlas NESDIS 42, U.S. Government Printing Office, Washington, D.C., 167 pp.

Fahrbach, E., R. G. Peterson, G. Rohardt, P. Schlosser and R. Bayer (1994): Suppression of bottom water formation in the southeastern Weddell Sea. *Deep-Sea Res. I*, **41**, 389–411.

Foldvik, A., T. Gammelsrød and T. Tørresen (1985): Circulation and water masses on the Southern Weddell Sea Shelf. p. 5–20. In *Oceanology of the Antarctic Continental Shelf, Antarctic Research Series*, **43**, ed. by S. S. Jacobs, AGU, Washington, D.C.

Foster, T. D. and E. C. Carmack (1976): Frontal zone mixing and Antarctic Bottom Water formation in the southern Weddell Sea. *Deep-Sea Res.*, **23**, 301–317.

Fricker H. A., S. Popov, I. Allison and N. Young (2001): Distribution of marine ice beneath the Amery Ice Shelf. *Geophys. Res. Lett.*, **28**, 2241–2244.

Gordon, A. L. (1998): Western Weddell Sea thermohaline stratification. p. 215–240. In *Ocean, Ice and Atmosphere: Interactions at the Antarctic Continental Margin*, **75**, ed. by S. S. Jacobs and R. Weiss, Antarctic Research Series, AGU, Washington, D.C.

Jacobs, S. S. (1991): On the nature and significance of the Antarctic Slope Front. *Mar. Chem.*, **35**, 9–24.

Jacobs, S. S. and D. T. Georgi (1977): Observations on the southwest Indian/Antarctic Ocean. In *A Voyage of Discovery*, ed. by M. Angel, *Deep-Sea Res.*, **24**(suppl.), 43–84.

Jacobs, S. S., A. F. Amos and P. M. Bruchhausen (1970): Ross Sea oceanography and Antarctic Bottom Water formation. *Deep-Sea Res.*, **17**, 935–962.

Matsuoka, K., T. Watanabe, T. Ichi, H. Shimada and S. Nishiwaki (2003): Large whale distributions (south of 60S, 35E–130E) in relation to the southern boundary of the ACC. p. 26–30. In *Antarctic Biology in a Global Context*, ed. by A. H. L. Huiske, W. W. C. Gieskes, J. Rozema, R. M. L. Schrno, S. M. van der Vies and W. J. Wolff, Backhuys Publishers, Leiden, The Netherlands.

Meredith, M. P., R. A. Locarnini, K. A. Van Scoy, A. J. Watson, K. J. Heywood and B. A. King (2000): On the sources of Weddell Gyre Antarctic Bottom Water. *J. Geophys. Res.*, **105**, 1093–1104.

Middleton, J. H. and S. E. Humphries (1989): Thermohaline structure and mixing in the region of Prydz Bay, Antarctica. *Deep-Sea Res.*, **36**, 1255–1266.

Mizuno, K. and T. Watanabe (1998): Preliminary results of insitu XCTD/CTD comparison test. *J. Oceanogr.*, **54**, 373–380.

Nunes Vaz, R. A. and G. W. Lennon (1996): Physical oceanography of the Prydz Bay region of Antarctic waters. *Deep-Sea Res. I*, **43**, 603–641.

Orsi, A. H., G. C. Johnson and J. L. Bullister (1999): Circulation, mixing, and production of Antarctic Bottom Water. *Prog. Oceanogr.*, **43**, 55–109.

Tanaka, K. and K. Akitomo (2000): Density current descending along continental slope and the associated deep water formation: two dimensional numerical experiments with a nonhydrostatic model. *J. Oceanogr.*, **56**, 114–130.

Whitworth, T., III, A. H. Orsi, S.-J. Kim, W. D. Nowlin, Jr. and R. A. Locarnini (1998): Water masses and mixing near the Antarctic Slope Front. p. 1–27. In *Ocean, Ice, and Atmosphere: Interactions at the Antarctic Continental Margin, Antarctic Research Series*, **75**, ed. by S. S. Jacobs and R. F. Weiss, AGU, Washington, D.C.