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Deep and bottom water of the Bransfield Strait eastern and central basins

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Abstract. Temperature, salinity, oxygen, and chlorofluorocarbon (CFC) data obtained in September 1997 define the water types ventilating the deep eastern and central basins of the Bransfield Strait. These water types are observed adjacent to Joinville Island and are clearly derived from the Weddell Sea. The eastern basin bottom water characteristics closely match that of the bottom water at 310 dbar depth ~50 km east of Joinville Island. The eastern basin bottom water is a simple mixture of low-salinity freezing point shelf water (65%) and relatively warm saline Weddell Deep Water (35%), with a CFC-113: CFC-11 ratio age of 8.5 years. The eastern basin bottom water shares a common origin with a weak salinity minimum observed at 1000 dbar within the central basin, though overflow from the central basin to the eastern basin floor may also occur. The bottom water within the central basin is colder and saltier with higher concentrations of oxygen and CFC-11 than that of the eastern basin. The central basin bottom water with a CFC ratio age of 7.5 years is composed of same Weddell water types that form the eastern basin bottom water plus a large contribution of high-salinity freezing point shelf water of the characteristics of water observed 10 km northeast of Joinville Island and a small amount of Pacific pycnocline water. The components (and their percentage) are Weddell Deep Water (11%), low-salinity shelf (24%), high-salinity shelf (60%), to Pacific pycnocline (5%).

1. Introduction

Between the South Shetland Islands and Antarctic Peninsula are the three small deep basins of the Bransfield Strait (Figure 1), each with unique bottom water properties relative to those of the open Southern Ocean. Oceanographers have long been curious as to the origin and fate of these waters. To the north and west of the basins are topographic barriers that isolate Bransfield Strait water from the southern Drake Passage at depths >600 dbar [*Smith and Sandwell*, 1997]. To the east, Bransfield Strait is separated from the Weddell Sea by a shallow plateau (labeled "plateau" on Figure 1), with a deepest passage of 750 dbar (at station 79), stretching from Joinville Island to ~61°S and 52°W. A 1000 dbar passage between the plateau and Elephant Island is referred to as the Northeast Channel (Figure 1). The Bransfield eastern basin depth reaches a depth of 2700 dbar; the central basin reaches 1700 dbar; and the western basin reaches 1200 dbar [*Wilson et al.*, 1999].

Clowes [1934], using data from the *Discovery*, *Discovery II*, and *William Scoresby* expeditions, noted that the deep and bottom waters in the strait are different from those at corresponding depth in adjacent areas. He speculated that the thermohaline characteristics of the deep water filling the Bransfield Strait basins are derived at least in part from winter water mass conversion of Weddell shelf water along the southern boundary of the Bransfield Strait.

The Bransfield Strait stratification is similar to that of the Antarctic continental margin, with a much subdued expression of the warm saline deep water characteristic of the neighboring open ocean [*Hofmann et al.*, 1996; *Hofmann and Klinck*, 1998]. No evidence of dense shelf water formation is observed within the Bransfield Strait; rather the water over the western Antarctic Peninsula shelf is modified (cooled and freshened) Pacific Ocean derived Circumpolar Deep Water (CDW) [*Hofmann and Klinck*, 1998; *Smith et al.*, 1999] or drawn from the Weddell Sea along the southern boundary of the Bransfield Strait [*Clowes*, 1934; *Gordon and Nowlin*, 1978]. An eastward flowing current at the southern Drake Passage introduces Pacific water into the northern fringe of the Bransfield Strait within the 500–600 dbar deep channel separating Smith and Snow Islands of the South Shetland Island chain [*Capella et al.*, 1992; *Hofmann et al.*, 1996; *Hofmann and Klinck*, 1998]. Additional CDW is introduced, perhaps in episodic events, over the shallower shelf (400–500 dbar sill) between Smith Island and Brabant Island (Brabant Island is situated south of 64°S near 63°W, not included within the area covered by Figure 1 [*Hofmann and Klinck*, 1998; *Yang and Zhao*, 1989; *Smith et al.*,

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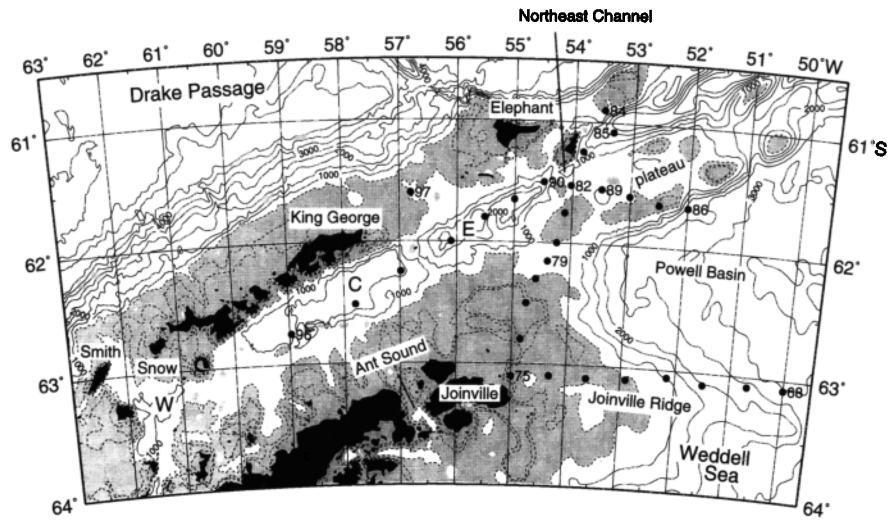

Figure 1. Region of the Bransfield Strait. DOVETAIL stations 68–97 used in this study are shown. The three deep basins are denoted by E, eastern; C, central; and W, western. "Ant Sound" is Antarctic Sound. The isobaths [*Smith and Sandwell*, 1997] included are 100, 200, and 500 dbar and at intervals of 500 dbar to the deepest values. The shaded area denotes ocean depths <500 dbar.

1999]. CDW may also enter the Bransfield Strait between the King George and Elephant Islands, with a sill depth of 400–600 dbar [*Yang and Zhao*, 1989] though *Hofmann et al.* [1996] find mainly export of Bransfield waters through that passage. *Smith et al.* [1999] find that the relatively strong geostrophic flow toward the northeast at 200 dbar relative to 400 dbar at the western end of Bransfield Strait coincides with a front marking the poleward limit of >0°C CDW. This may be considered the Bransfield Current and Bransfield Front, respectively [*López et al.*, 1999]. There is little exchange between the Bransfield Strait and west Antarctic Peninsula [*Smith et al.*, 1999].

Gordon and Nowlin [1978] studied the origin of the Bransfield basin water using a few deep-reaching stations obtained in 1975. From the potential temperature-salinity (θ/S) relationship they find that the Bransfield eastern basin and adjacent northwest Weddell Sea share a common cold end-member: freezing point water with a salinity of 34.62. They suggest that this water is derived from the continental shelf at the tip of Antarctic Peninsula. They surmise that it is advected from the Weddell Sea by the northward drift along Antarctic Peninsula's eastern margin. The lack of a significant presence of warm, saline deep water, in the form of CDW or of Weddell Deep Water (WDW) within the Bransfield Strait, explains the colder form of the Bransfield basin deep and bottom waters relative to the neighboring open ocean. The central basin deep water is substantially colder, more saline, and higher in oxygen than observed in the eastern basin. They find that the western basin bottom water is warmer than that of the other two basins, denoting much reduced access of the cold shelf water end-member or, more likely, increased modified CDW input from the west.

Whitworth et al. [1994] view both the Weddell-Scotia Confluence and Bransfield basin renewal not as a convective process but rather as an isopycnal process. Mixtures of CDW with somewhat cooler Weddell Deep Water (WDW) and near-freezing point Antarctic shelf water spread into the deep water along density surfaces.

In the present study the Weddell Sea shelf origin for the source of the Bransfield basin water is confirmed, and water mass mixing recipes consistent in temperature, salinity, oxygen, and CFC are presented.

2. DOVETAIL Data

As part of the Deep Ocean Ventilation Through Antarctic Intermediate Layers (DOVETAIL) program the northwestern Weddell, southern Scotia Sea, and Bransfield Strait were sampled from the polar research vessel *Nathaniel B. Palmer* for temperature, salinity, oxygen, and CFCs during the austral winter season of August–September 1997 [*Gordon et al.*, 1998; *Mensch et al.*, 1998a].

Drift between the precruise and postcruise temperature calibrations was <0.0004°C, implying a temperature accuracy of better than the manufacturer's stated value of 0.001°C. The average difference in readings between the two conductivity-temperature-depth (CTD) temperature sensors was 0.0005°C. The CTD conductivity was adjusted to conductivities derived from water samples analyzed for salinity during the cruise on a Guildline 8400B laboratory salinometer. The same batch of International Association for Physical Sciences of the Oceans (IAPSO) standard water was used throughout (P131). A CTD conductivity sensor drift correction of ~0.001 mmho/cm per month was applied prior to adjustment to the bottle data. Replicate salinometer salinity measurements agreed to within ±0.002 (two standard deviations). Dissolved oxygen concentration was measured with an automated titrator utilizing an optical endpoint detector. Replicate values agreed to within 0.01 mL/L (two standard deviations) or 0.2%. Measurement accuracy of CFC is estimated to be 0.005 pmol/kg or 1% with a detection limit of 0.005 pmol/kg.

Potential temperature, salinity, oxygen, and CFC-11 sections composed of stations 82 and 86–96 characterize the waters along the Bransfield Strait eastern and central basins, across the plateau, and into the northwest edge of Powell Basin (Figure 2). Stations 68–84 sample the waters over the crest of the Joinville Ridge (stations 68–75) which define the Weddell Sea input, across the plateau and Northeast Channel (stations 75–

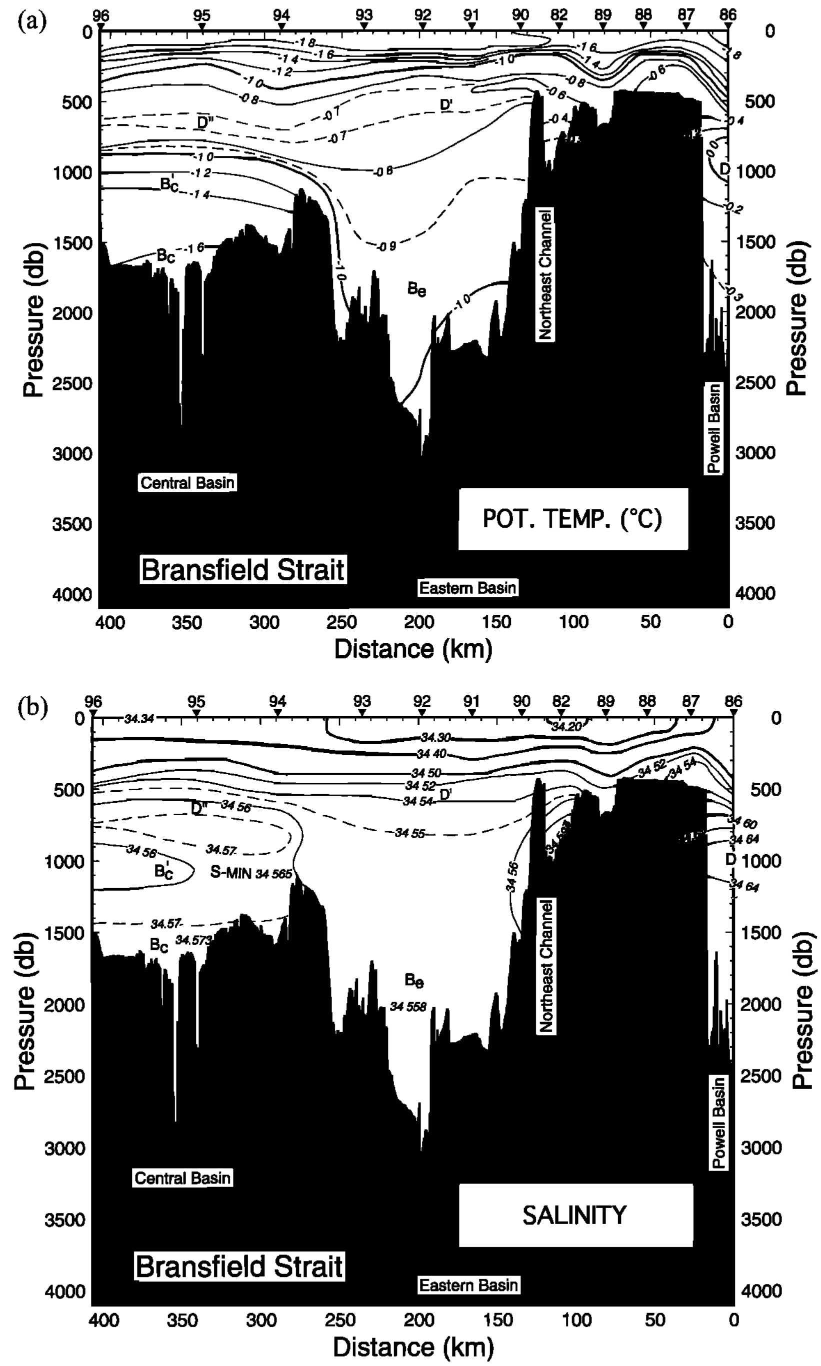

Figure 2. (a) Potential temperature (°C), (b) salinity, (c) oxygen (mL/L), and (d) CFC-11 (pmol/kg) along the central axis of the Bransfield Strait, composed of DOVETAIL stations 86–89, 82, and 90–96. The reference letters correspond to those given on the scatterplots (Figure 4): D denotes the Weddell Deep Water; D′ and D″ indicate the position of weak warm deep core layer (500–750 dbar) in the eastern and central basin, respectively. Be and Bc represent bottom water of the eastern and central Bransfield basins, respectively. Bc′ is the weak salinity minimum near 1000 dbar within the central basin.

84) of the Bransfield Strait eastern boundary (Figure 3). The potential temperature versus salinity, oxygen, and CFC-11 scatterplots (Figure 4) are referenced to the sections by S, shelf water; D, deep water; and B, bottom water.

The warmest water in the Weddell Sea is that of the WDW (D). The WDW potential temperature maximum θ_{max} core attenuates as the continental margin is approached, as typical of Antarctic margins. At the northwestern fringe of Powell basin, the WDW θ_{max} at 1000 dbar is only slightly above 0°C (station 86). At stations 87–89 (Figure 2) and 78–81 (Figure 3) the warmest, most saline water is in contact with or close proximity to the shallow sea floor. This water spans a temperature range of −0.4° to −0.7°C and salinity of 34.54–34.56, with oxygen levels of 6.0–6.3 mL/L and CFC-11 of 2.5–3.3 pmol/kg, and may be considered as modified WDW.

A weak θ_{max} (colder than −0.6°C) near 500 dbar within the

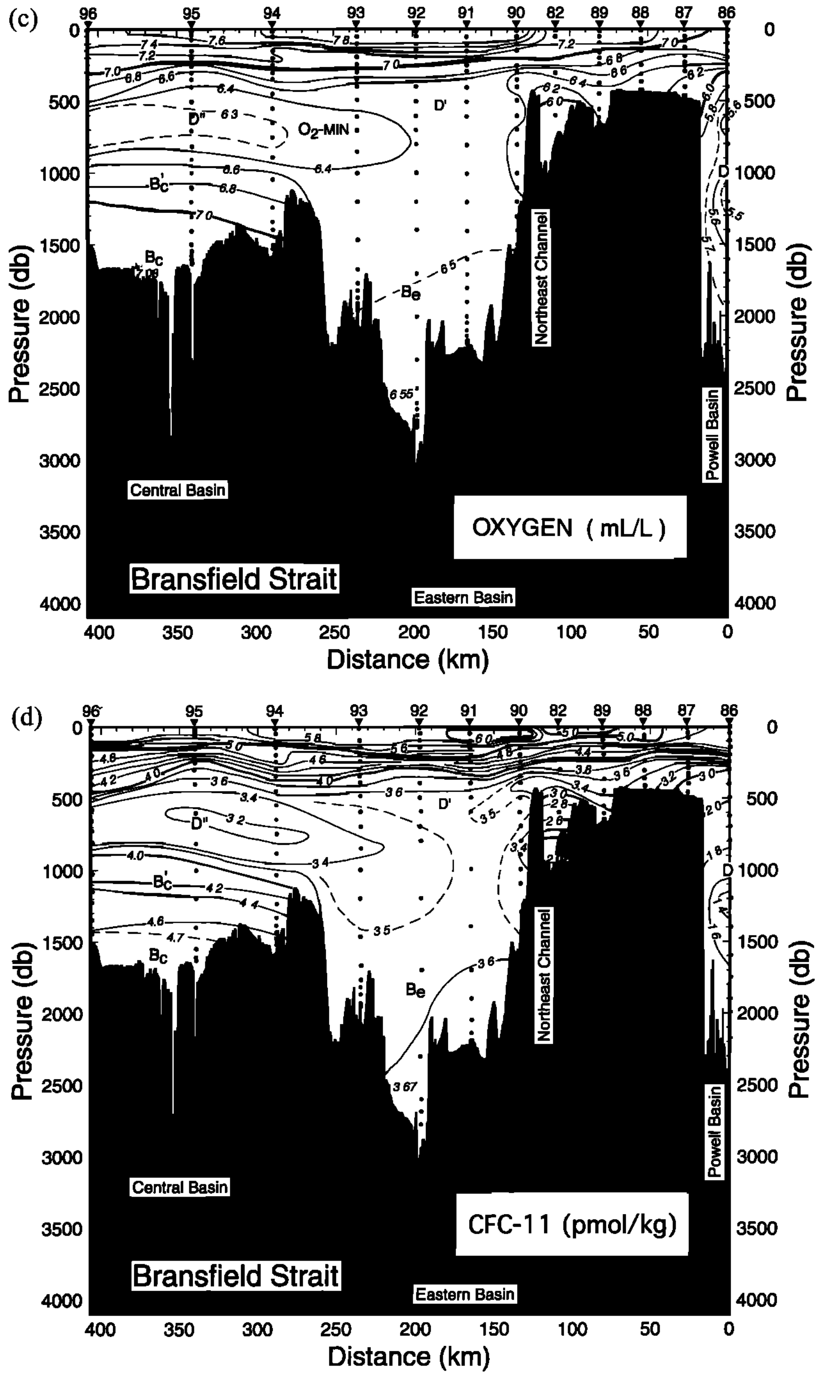

Figure 2. (continued)

eastern basin (D′), closer to 700 dbar in the central basin (D″), are both cooler and fresher than WDW (D). The eastern basin θ_{max} (D′) may be explained by westward spreading of the water observed slightly off the plateau sea floor to the east. The θ_{max} at station 90 is too warm for a perfect fit to D′. Therefore it is likely that southern Drake Passage pycnocline water, which is warmer than that of the Weddell Sea at any given salinity (e.g., station 84, Figure 4a), infiltrates the eastern basin.

Over the central Bransfield basin the θ_{max} (D″) is deeper than that in the eastern basin with higher salinity (34.570) and lower oxygen and CFC-11 concentrations (6.3 mL/L and 3.2 pmol/kg, respectively). The main difference of D″ from the near bottom water of the plateau is that D″ is saltier. While it is tempting to believe this is a reflection of CDW entering the Bransfield Strait between Snow and Smith Islands, this may not be the situation. The Snow/Smith CDW intrusion is expected to advect along the northern boundary of the Bransfield Strait, following the regional cyclonic circulation, probably exiting the Bransfield Strait without entering the central basin [*Clowes*, 1934; *Smith et al.*, 1999]. It is suggested that the central basin θ_{max} (D″) is a simple two-point mixture of low-salinity shelf water, S1, which is observed east of Joinville Island, with WDW (D; along the dashed line connecting S1 and D on Figure 4a). A slightly warmer form of such a mixture is ob-

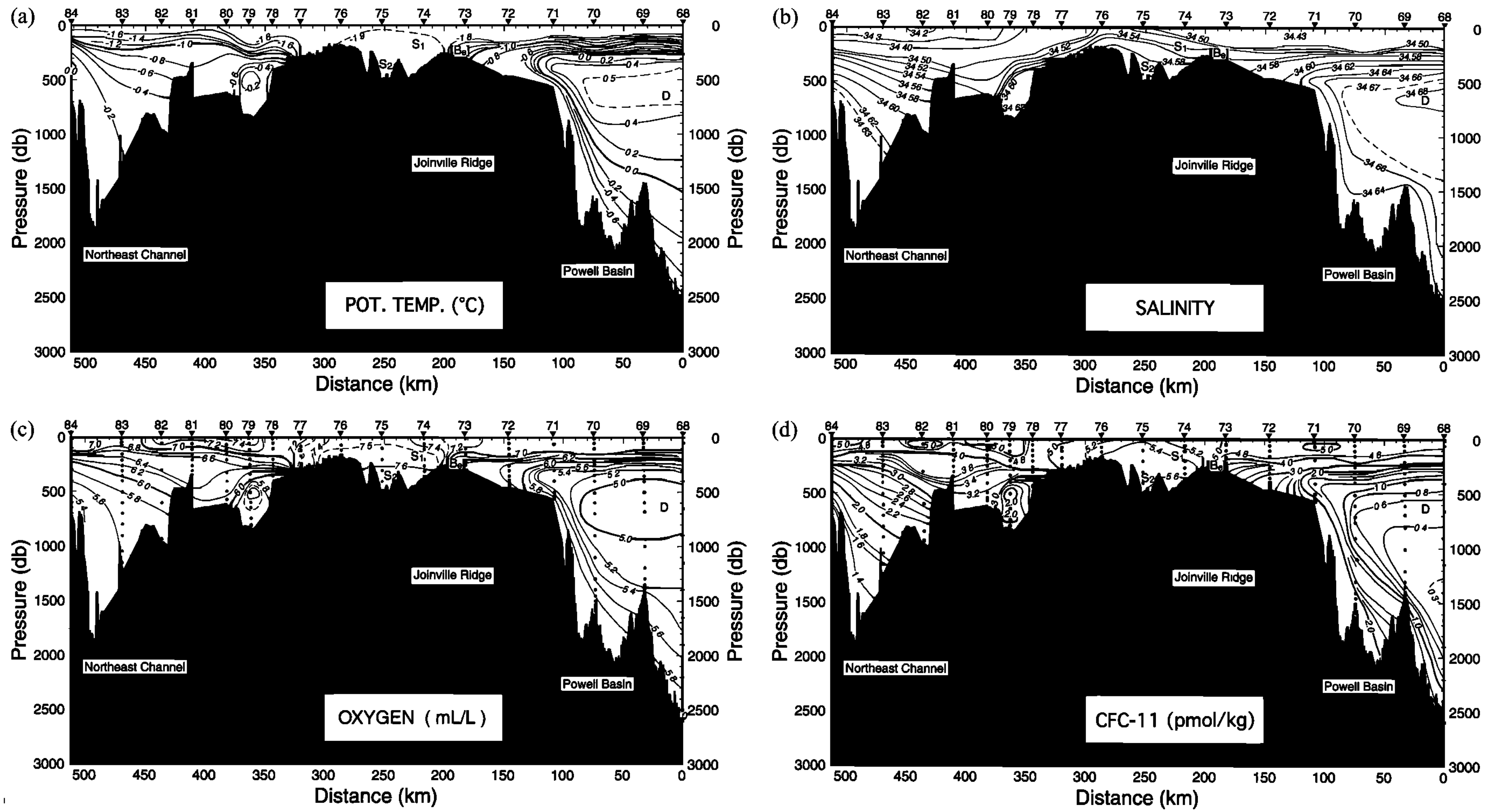

Figure 3. (a) Potential temperature (°C), (b) salinity, (c) oxygen (mL/L), and (d) CFC-11 (pmol/kg) across the eastern mouth of the Bransfield Strait and along the crest of the ridge stretching eastward from Joinville Island, crossing the plateau and northeastern channel (Figure 1; stations 68–84). The reference letters correspond to those given on the scatterplots (Figure 4): D denotes the Weddell Deep Water. S1 and S2 are the freezing point shelf waters found adjacent to Joinville Island. Be is the bottom water at shelf station 73 that matches the properties of the Bransfield eastern basin bottom water.

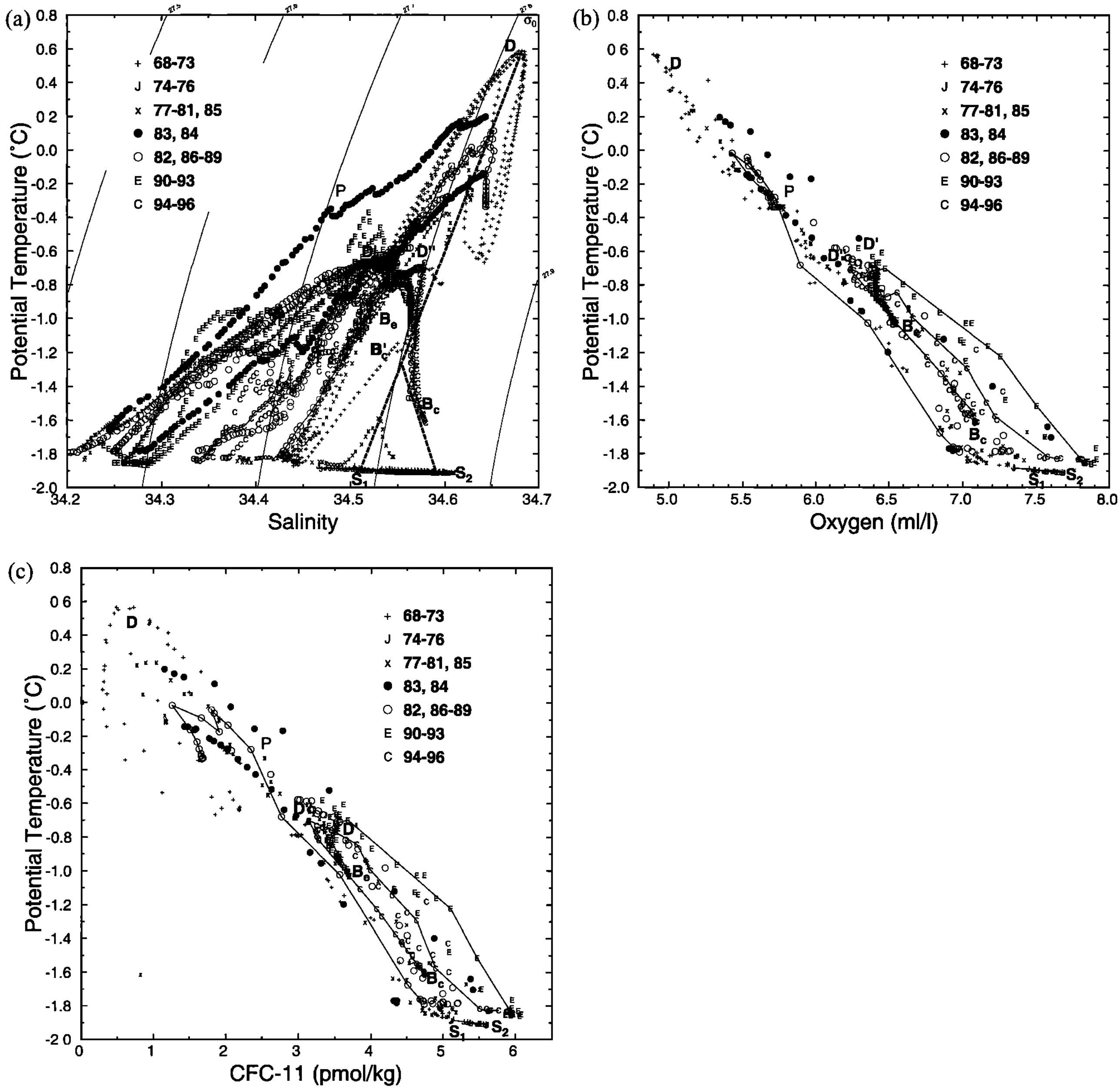

Figure 4. (a) Potential temperature (°C) versus salinity, (b) potential temperature (°C) versus oxygen (mL/L), (c) potential temperature (°C) versus chlorofluorocarbon CFC-11 (pmol/kg) relationships for the DOVETAIL stations shown in Figure 1. The reference letters correspond to those given on the sections (Figures 2 and 3): D for deep water; and Be and Bc for bottom water of the eastern and central Bransfield basins, respectively. Bc′ is the weak salinity minimum within the deep water of the central basin. S1 and S2 are the freezing point shelf waters found adjacent to Joinville Island. P is pacific pycnocline water observed at station 84 that may be form minor constituent of Bc.

served at the θ_{max} of station 79 near 600 dbar, the deepest connection of the Weddell Sea to the Bransfield Strait within the plateau region.

Bottom water in the eastern basin (Be) is about −1.01°C, with salinity slightly less than 34.558, oxygen of 6.55 mL/L (81% of full saturation), and CFC-11 of nearly 3.67 pmol/kg. Bottom water within the central basin (Bc) is substantially colder (−1.62°C) and saltier (34.580) with elevated oxygen concentrations (nearly 7.08 mL/L; 86% of full saturation), and CFC-11 of 4.79 pmol/kg. The central basin has a broad salinity minimum near 1000 dbar (Bc′), which may share a common origin with the eastern basin bottom water, discussed in section 3.

3. Discussion

3.1. Bransfield Basin Deep Basin Source Waters

With the eastern and central basin water characteristics in mind, we can inspect the Weddell water off the tip of Antarctic Peninsula (Figure 3) to locate the potential source waters and

Table 1a. Characteristics of Bottom Waters of the Eastern and Central Bransfield Strait Basins and of Contributing Source Water Types

DOVETAIL Station	Water Type	Identifier	Potential Temperature	Salinity	Oxygen	CFC-11
74 100 m	lower-salinity shelf	S1	−1.894	34.500	7.47	5.28
75 bottom	saline shelf	S2	−1.914	34.599	7.69	5.60
92	eastern basin	Be	−1.007	34.558	6.55	3.67
95	central basin	Bc	−1.615	34.580	7.08	4.79
70 θ_{max}	Weddell Deep Water	D	0.564	34.680	4.92	0.67
96 1000 m	S_{min} in central basin	Bc′	−1.200	34.550	6.76	4.13

derive quantitative mixing recipes consistent with the DOVETAIL temperature, salinity, oxygen, and CFC data.

Stations 68–75 (Figure 1) depict the typical continental margin stratification of the western Weddell Sea [*Fahrbach et al.*, 1995; *Gordon*, 1998]. The WDW θ_{max} core (D) is near 600 dbar at stations 68–70. The shelf-slope frontal transition occurs between stations 70 and 73. Within this zone, traces of WDW form a weak temperature maximum at middepth over the continental shelf and at the 300 dbar sea floor at station 73. Remarkably, the θ/S characteristics of the bottom water observed at station 73 matches the temperature and salinity of the eastern basin bottom water (Be; station 73 bottom water is 0.008°C colder and 0.003 saltier than Be). Station 73 bottom water is slightly lower in oxygen concentration (6.44 at station 73 versus 6.54 mL/L of Be) and CFC-11 values (3.4 versus 3.7 pmol/kg) than that of the eastern basin, but the oxygen and CFC-11 gradients between stations 73 and 74 are quite large (Figure 3), and one can envision water slightly west of station 73 more closely matching Be dissolved gas concentration without producing a significant mismatch with θ/S characteristics. Comparing θ/S properties east of Joinville Island with those north of the island (Figure 3) reveals continuity of properties along isobaths, implying an isobath following geostrophic flow path around Joinville Island into the eastern basin.

The source of the eastern basin bottom water is clearly drawn from the inshore edge of the shelf-slope front of the western Weddell Sea off Joinville Island. The water mass mixture that eventually fills the eastern Basin is already achieved east of Joinville Island near 300 dbar. This water sinks into the eastern basin without further dilution, in what *Whitworth et al.* [1994] refer to as isopycnal spreading. A mixture of WDW and low-salinity Weddell shelf water renders the simplest explanation for the eastern basin bottom water. No need is seen for further water mass modification within the Bransfield Strait.

The central basin salinity minimum (S_{min} near 1000 dbar; Bc′) is basically the same as the eastern basin bottom water (Be). The bottom water of the eastern basin may either share a common origin with the central basin S_{min} of may be derived from overflow of the S_{min} water into the eastern basin. As the match between Bc′ and Be is best at station 96, at the western end of the central basin, while at station 94, located closer to the controlling sill is slightly too saline to match the Be water, the shared common source is a favored explanation (though the two scenarios are not mutually exclusive). *López et al.* [1999] present 50 days of direct current meter data collected during the austral summer of 1992–1993 at 700 dbar depth near the sill dividing the eastern and central basin. The current is weak and directed toward the south, with no evidence of flow toward the east, as would be expected if overflow were present.

The nonlinear θ/S relationship of the central basin deep and bottom water portrays a more complex recipe than that of the eastern basin. The central basin saline bottom water (Bc) requires shelf water component more saline than that of S1. The water within the central basin deep water follows along a θ/S line connecting Bc′ and Bc. Extrapolating this θ/S structure to the freezing line suggests a shelf water component of salinity 34.59 (S2), about what is needed as the cold end-member for the bottom water of the western Weddell Sea [*Gordon*, 1998]. The saline shelf water, S2, required by the central basin bottom water is observed adjacent to Joinville Island. Stations 74–76 show near–freezing point shelf water, reaching a salinity of 34.60 at the sea floor. This water, proposed to be the cold end-member source for Bc, spreads into the Bransfield Strait along with the over the Antarctic Peninsula side of the Bransfield Strait, passing to the south of the eastern basin.

Freezing point shelf water is expected to be high in oxygen and CFC owing to recent interaction with the atmosphere across the sea-air-ice interface. The Joinville Island regional shelf water is indeed rich in these properties. The oxygen and CFC-11 of S1 are ~7.5 mL/L and 5.3 pmol/kg, respectively, and those of S2 are slightly higher at 7.7 mL/L and 5.6 pmol/kg, respectively. The S2 properties are close to that of the Weddell Sea high-salinity Western Shelf Water, believed to be a product of the coastal polynyas [*Gammelsrød et al.*, 1994]. That S2 is slightly more ventilated than S1 may be explained by its greater contact with the atmosphere afforded by the polynya environment.

3.2. Bransfield Basin Deep Basin Mixing Recipes

The water type blends inferred from property characteristics are used to find a mixing recipe consistent with the DOVETAIL temperature, salinity, oxygen, and CFC data. The percentages of the Be building blocks, S1, and D (Table 1a) are determined for each parameter (θ/S, O_2, and CFC-11), assuming a simple linear mixture. The suggested recipe is the average of the components (Table 1b). The bottom water of the eastern basin, Be, is approximately a 35:65 mixture of WDW (D) to low-salinity shelf water (S1). Temperature, salinity, oxygen, and CFC-11 all give essentially the same mixing ratios. That the time-dependent parameters of oxygen and CFC-11 yield the same ratio as temperature, and salinity implies a rapid ventilation timescale, 10 years or less.

As mentioned above, the recipe of the central basin bottom water, Bc, is more complex than that of the eastern basin, clearly involving more than two end-members. We first investigate the possibility that the formation of Bc involves only three water types: WDW (D), the low-salinity shelf water (S1), and the higher-salinity shelf water (S2). The percentage of the building blocks are calculated as follows: first a linear mixture of D and S1 is used to produce the warm end-member of the

Table 1b. Mixing Recipes for Production of Observed Bottom Waters of Eastern (Be) and Central Basin (Bc)

	Identifier	Potential Temperature	Salinity	Oxygen	CFC-11
		Eastern Basin			
Recipe for Be	D	36	32	36	35
	S1	64	68	64	65
		Central Basin			
Recipe for Bc	D	12	11	18	14
(Weddell	S1	30	28	47	41
Only)	S2	58	61	35	45

Values are given in percentage.

mixture with S2 forming Bc (see the dashed line between S2 and its intersection with the dashed line denoting the S1 and D linear mixture producing Be, Figure 4a). This warm end-member is approximately the same as Bc′, the S_{min} at 1000 dbars within the central basin. The percentages of S1 and D to produce the warm end-member for Bc are determined for each parameter. Calculation of the mixture of the warm end-member and S2 to form Bc are determined in similar manner. The average of the mixtures indicated by the four parameters are used for the final suggested recipe.

The percentage components of D:S1:S2 derived from temperature and salinity are 11:29:60 (Tables 1a and 1b). However, the ratios found from oxygen and CFC-11 are different from those based on thermohaline parameters, which are 18:47:35 for oxygen and 14:41:45 for CFC-11. This implies a slightly slower rate of ventilation for the central basin than for the eastern basin, but the CFC ratios do not support this. The bottom water in the central and eastern basin are estimated to have CFC-113:CFC-11 ratios ages of 7.5 years (based on five samples from the lower 500 dbar at station 95, CFC-113:CFC-11 ratio range of 0.084–0.086) and 8.5 years (based on the four samples from the lower 500 dbar at station 92, CFC-113:CFC-11 ratio range of 0.077–0.078) years, respectively. This is similar to the age of Weddell Sea Bottom Water, 7 ± 2 years, observed in the northwest Weddell Sea [*Mensch et al.*, 1998b].

We next explore a recipe for Bc, which requires a small contribution of Pacific pycnocline water (P). The Pacific pycnocline is of lower oxygen and CFC-11 concentration than the Weddell pycnocline. This water may enter the Bransfield Strait from the west between Smith Island and Antarctic Peninsula along with Pacific CDW [*Hofmann and Klinck*, 1998]. Tracing a straight line from S2 along the θ/S scatter of the bottom water in the central basin would meet the pycnocline of station 84 near −0.3°C (point P on Figure 4). Specific properties of point P are given in Table 1c, based on the average of water samples at 200 and 250 dbar. Station 84 displays the warmest pycnocline water of the DOVETAIL data set within the Bransfield Strait environs, reflecting influence of Pacific water. Using station 84 pycnocline properties as the warm end-member mixing partner with S2 yields a P:S2 of 19:81 for temperature and salinity but 40:60 for oxygen and 33:67 for CFC-11, no improvement over mixtures that involve only Weddell water types.

We find that mixtures involving all four water types (D, S1, S2, and P) provide a more convincing recipe. The four-point mixture involving Pacific pycnocline water to derive a recipe for Bc involves a trial and error process of adjusting percentages for D, S1, and S2 as P is increased from 1% by increments of 1% (the aim was to minimize the need for pycnocline water). The most probable recipe is determined when the resulting value for Bc is closest to the observed value for Bc. The result recipe leads to more consistent input of each parameter than afforded by only a three component mixture. A ratio D:S1:S2:P of 11:24:60:5 yields a Bc of nearly the observed properties of Bc (Table 1c). It appears that a small amount of Pacific pycnocline input to Bc is likely, effectively replacing some S1 water of a "Weddell-only" blend.

Wilson et al. [1999] present temperature and salinity data obtained in November 1995 from *Nathaniel B. Palmer* within the Bransfield Strait. They investigate the water mass blends of the bottom water of the eastern basin, but lacking oxygen and CFC data, they had less control of the recipe percentages than afforded by the 1997 DOVETAIL data set. Direct comparison of their recipe to ours is complicated as they did not use the primary water types that have access to the Bransfield Strait. They use Weddell Sea Bottom Water (WSBW) as one of the ingredients rather than its building blocks of WDW and freezing point shelf water. WSBW is clearly blocked by topography from entering the Bransfield Strait, whereas the building block water types have access. They do note this and say that the convection of surface waters that form WSBW have access to the Bransfield Strait, but they do not explore this quantitatively. Furthermore, their 1995 data do not include synoptic observations at the eastern boundary of Bransfield Strait as obtained during the DOVETAIL 1997 expedition; instead, they use 1976 data to represent one of their three ingredients, the Weddell Sea sill water (Weddell waters passing over the eastern boundary sills). They say that this represents the largest uncertainty in their calculations.

Wilson et al. [1999, p. 471] find that eastern basin bottom water is a mixture of "central basin sill water, Weddell Sea sill water, and Weddell Sea Bottom Water." The Weddell Sea sill water composes 40–60% of the eastern basin bottom water. We agree that the sill waters of the central basin may overflow into the eastern basin, but we alternatively state that they may share common origin involving low-salinity shelf water from the Weddell Sea. In the eastern basin this water type can descend to the sea floor, but in the central basin, denser bottom water, enriched in a high-salinity shelf water from the Weddell Sea, prohibits descent to the sea floor.

Perhaps the most significant contrast in the 1995 and 1997

Table 1c. Mixing Recipe for Central Basin Bottom Water Involving Pacific Pycnocline Contribution

Identifier	Potential Temperature	Salinity	Oxygen	CFC-11
P	−0.35	34.48	6.14	3.09
Bc observed	−1.615	34.580	7.08	4.79
Bc calculated	−1.556	34.579	7.26	4.86

Recipe Components	Percentage
D (Table 1a)	11
P (Table 1c)	5
S1 (Table 1a)	24
S2 (Table 1a)	60

The DOVETAIL station for Pacific pycnocline water (P) is station 84 between 200 and 250 dbar.

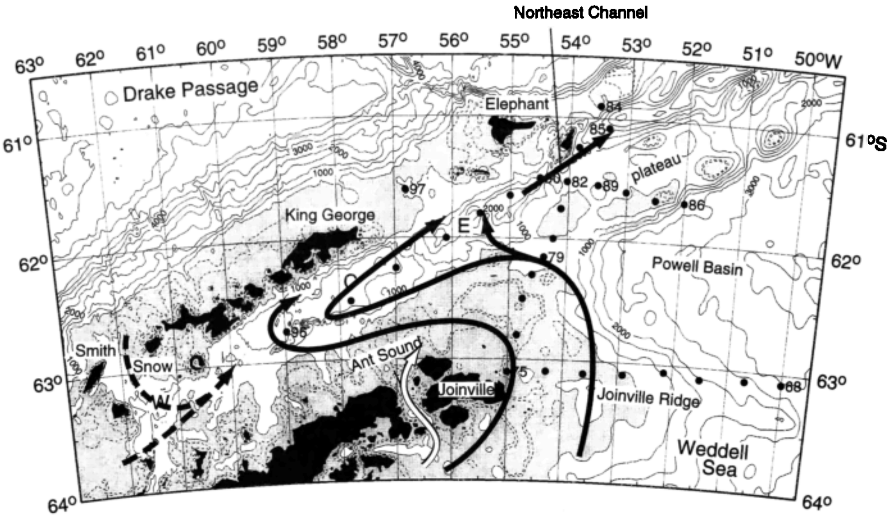

Figure 5. Schematic of the flow paths into the Bransfield Strait's eastern and central basins. Solid arrows denote movement of Weddell waters. These waters are a combination of freezing point low-salinity (S1) and high-salinity (S2) shelf water with smaller amounts of Weddell Deep Water. The central basin receives a more saline form of shelf water. Dashed arrows trace the pathways of Circumpolar Deep Water and pycnocline water from the Pacific sector into the Bransfield Strait. The pycnocline water may be a minor constituent of the central basin bottom water. The solid arrow drawn along the Northeast Channel is the expected export path for Bransfield basin waters. The open arrow through Antarctic Sound is pure conjecture, as no data are available in that area, but it is deep enough to provide a pathway for shelf water and hence is included as only a possibility.

data sets is the warming seen in the bottom waters of the eastern and central basins during the intervening 2 years. The *Wilson et al.* [1999] station 7, which coincides with DOVETAIL station 92, shows that the bottom water in 1995 is nearly 0.2 colder than that of 1997. Approximately the same difference is seen for the other stations in the eastern and central basins. Using a colder value for Be based on the 1995 data requires a WDW:S1 ratio of 28:72 rather than 36:64 (both based on temperature) as found with the 1997 data. Salinity differences between the 1995 and 1997 data are slight, as expected from the small salinity range of the component water types. It is suggested that a slight reduction in shelf water component has occurred in the intervening 2 years.

Wilson et al. [1999] investigate the temporal changes in the Bransfield Strait deep and bottom waters for the last 30 years. They find the changes in the eastern basin bottom water has been sporadic with the warmest, saltiest waters found in 1963 (−0.84°C; 34.60), while the 1995 values are the coldest and freshest. The 1997 bottom water properties reverse the 1963–1995 trend (though we do not have a complete time series between 1963 and 1995 to fully resolve higher-frequency variability); the 1997 bottom water was still much cooler than the 1963 conditions.

4. Conclusions

The bottom waters of the Bransfield Strait's eastern and central basins are primarily derived from the Weddell Sea waters entering the Bransfield Strait from the region off Joinville Island. The bottom waters of the central basin contain a small amount of pycnocline water from the Pacific water column. All of the deep water ingredients are imported; there does not appear to be a need for water mass modification within the Bransfield Strait. Freezing point shelf water along the western rim of the Weddell Sea composes ~65% of the bottom waters within the eastern basin and between 80 and 90% of the central basin bottom waters.

On the basis of the distribution of water types over Joinville Ridge and on the mixing recipes for Be and Bc a flow path schematic (Figure 5) is proposed. A mixture of Weddell shelf water and deep water advects northward past Joinville Island to enter the Bransfield Strait. The saltier freezing point shelf water (S2) turns into the Bransfield Strait very close to Joinville Island contributing to the central basin, bypassing the eastern basin. While a flow path of S2 water into the central basin passes around the eastern edge of Joinville Island, the possibility must be reserved for an additional flow path passing west of Joinville Island, within Antarctic Sound (Figure 1).

The lower-salinity shelf waters may enter the eastern basin directly or first enter the central basin forming a 1000 dbar deep salinity minimum with subsequent overflow into the eastern basin. Pacific water enters the Bransfield Strait from the west and through passages in the South Shetland Islands. Entering from the west contributes to the bottom water of the central basin.

Where does the basin residence water displaced by newly formed deep water go? Station 83 (the cooler of the two stations shown as solid circles in Figure 4, the other being station 84) within the Northeast Channel is the most likely candidate marking an export pathway. There is no obvious export of concentrated deep basin water. Rather it is suspected that the basin water is lifted into the pycnocline layer of the Weddell-Scotia Confluence, where it is rapidly exported eastward. The fate of this pycnocline water, as it spreads into the Scotia Sea, requires careful study. Its density may allow it to eventually ventilate the deep ocean.

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