

## The Basin Waters of the Bransfield Strait<sup>1</sup>

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### ABSTRACT

Hydrographic data were obtained within the Bransfield Strait and adjacent waters during February and March 1975 by R/V *Conrad* and R/V *Melville* as part of FDRAKE 75. Within the Strait the Circumpolar Deep Water is either missing or its influence is weak. The salinity maximum, oxygen minimum and silicate maximum present in the upper layers of the Strait attenuate toward the east, demonstrating the eastward decrease of Bellingshausen Sea influence. The Strait contains three basins separated from one another by sills less than 1500 m deep and from adjacent ocean areas by depths near or less than 500 m, except for a channel to the northeast of slightly over 1100 m depth. The deep and bottom waters of these basins, with depths to nearly 2600 m, are significantly colder, less saline, higher in oxygen and lower in nutrient concentrations than the deep exterior water adjacent to the Strait. These characteristics confirm Clowes' (1934) contention that the waters of these basins are renewed by local convection. Supportive evidence for post-bomb renewal is provided by tritium measurements from the easternmost basin of the Strait. Bottom (2566 m) tritium values are essentially the same as surface values, which are greater than expected for subsurface water which has not recently been in contact with the surface waters. Comparison of *T-S* relations suggests that one mixing component of near-surface water in the convective renewal of Bransfield bottom water is the same as that involved in Weddell Sea bottom water formation. The FDRAKE data set shows that the character of the deep and bottom waters is different within each of the three major basins, suggesting significant spatial (or temporal) variability of the convective events occurring in the Strait. Water mass distributions of the southern Drake Passage and the Weddell Sea are apparently not influenced by outflow of Bransfield basin water. Likewise, there seems to be no direct outflow of deep or bottom waters from the Bransfield basins into the Weddell-Scotia Confluence Zone.

### 1. Introduction

The Antarctic Peninsula is the northernmost extremity of Antarctica, reaching well north of the Antarctic Circle. North of the Peninsula lie the South Shetland Islands, and between these Islands and the Peninsula is the Bransfield Strait. The Bransfield Strait extends from near Clarence Island toward the southwest for approximately 460 km to Low Island.

The Strait is occupied by the Bransfield trough (Fig. 1), whose axial depth varies from 1100 m in the southwest to 2800 m just south of Elephant Island (Barker and Griffith, 1972). There are three major basins comprising the trough, which for the purpose of this study are called the eastern, central and western basins. The basins are separated from one another by sills of less than 1500 m. The deepest channels between the Strait and contiguous ocean areas are at the eastern end near Clarence Island (slightly over 1000 m) and at the western end between Snow and Smith Islands (slightly over 500 m).

Thus the waters of the basins are not in direct communication with the open ocean at depths much below 1 km.

Based on data collected during 1927, 1929, and 1930 aboard the *William Scoresby* and *Discovery*, Clowes (1934) described the hydrography of the Bransfield Strait. Most data collected since then have been limited to the upper kilometer, though some deep measurements were made during cruise 6 of the USNS *Eltanin*.

Clowes concluded that the relatively warm, low-salinity surface waters found during summer in the western and northern Bransfield Strait as well as the subsurface maxima in temperature and salinity are derived from the Bellingshausen Sea water advected into the Strait. The southeastern Bransfield is influenced by colder, more saline waters of the Weddell Sea, which enters the Strait over the broad continental shelf near d'Urville and Joinville Islands. The Weddell waters show much variability in the extent of their influence in the Bransfield Strait; often the Weddell water spreads along the coast of the Antarctic Peninsula to Trinity Island,

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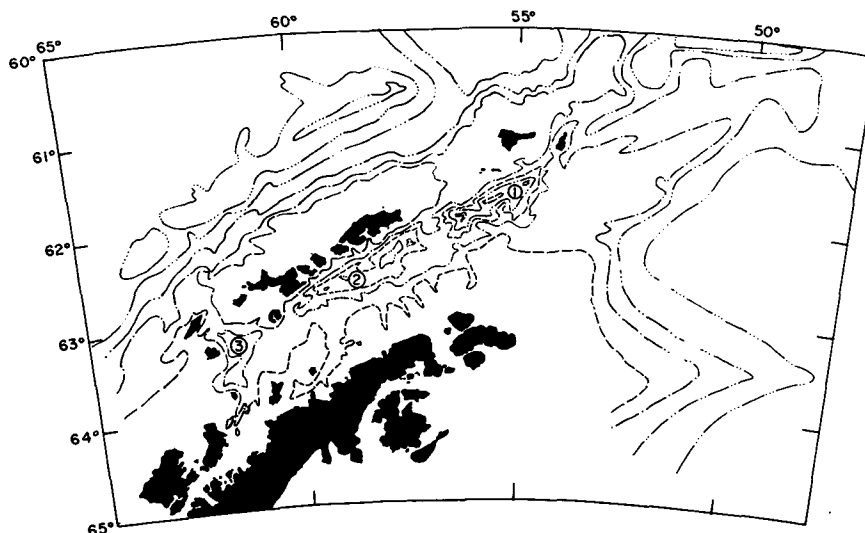


FIG. 1. The bottom relief of the Bransfield Strait and environs [drawn from information given in the Antarctic map prepared by the American Geographic Society (1970) and by Barker and Griffiths (1972)]: (1) eastern basin, (2) central basin, (3) western basin. Number of dots in contours indicates depth of contour in kilometers. The 500 and 1500 m contours are shown as dashed lines.

where it apparently converges with water entering the Bransfield Strait via the Gerlache Strait.

The deep and bottom waters of the Bransfield Strait are unlike those of the adjacent deep ocean, which led Clowes (1934, p. 10) to conclude "The bottom water inside the Strait is essentially formed within the Strait". He further concluded (p. 50) that it is winter thermohaline alteration of the waters situated over the continental shelf of the Antarctic Peninsula bounding the Bransfield Strait which contributes to the renewal of bottom water in that Strait.

The first objective of this paper is to describe the hydrographic conditions within the three distinct basins of the Bransfield Strait. Second, the possible influence of Bransfield Strait deep/bottom water on the exterior ocean is examined. Finally, we consider the possible sources of the bottom waters within these basins and the frequency of renewal.

## 2. FDRAKE data from Bransfield Strait

As part of the ISOS project FDRAKE (Neal, 1974) the R/V *Conrad* and R/V *Melville* occupied a number of hydrographic stations within the Bransfield Strait and adjacent waters (Fig. 2).

The distributions of potential temperature, salinity, oxygen and silicate along the axis of the Bransfield Strait (Fig. 3) clearly show the uniqueness of Bransfield Strait deep and bottom water. Below sill depth the basins are significantly colder, lower in salinity and silicate, and higher in oxygen than the water in the Weddell Sea to the immediate east. The central and eastern basins do not display

the relatively warm, saline, low-oxygen signature of the circumpolar deep water so characteristic of the Southern Ocean, including the Weddell Sea. The western basin does show a broad salinity maximum and oxygen minimum within the upper kilometer, but this signal is much less intense and shallower than within the waters of the adjacent open ocean, and thus the waters of the western basin may also be considered unique.

Above sill depth at station 60 there was slightly warmer, more saline and lower oxygen water than observed at other stations in the central basin. The structure observed at the upper levels of station 60 shows some remnants of the structure observed at station 57 in the western basin. This is attributed to the eastward advection, either of an isolated bolus or of a current which, according to Clowes, enters the central basin from the west, passing to the south of Deception Island.

The vertical distributions of potential temperature, salinity, oxygen and nutrients (Fig. 4) indicate significant differences of the characteristics within each basin below sill depth. The sub-sill water of the central basin is the coldest (0.5° colder than the eastern basin), highest in oxygen (83% of full saturation versus 78% within the eastern basin) and lowest in nutrients of the three basins. The salinity profiles of the central and eastern basins are similar, except that the waters of the central basin are more saline at 300 m (the Bellingshausen Sea influence) and below 1000 m. In the western basin were found larger vertical gradients, with reversals in depth, in contrast to the more nearly homogeneous conditions of the other basins.

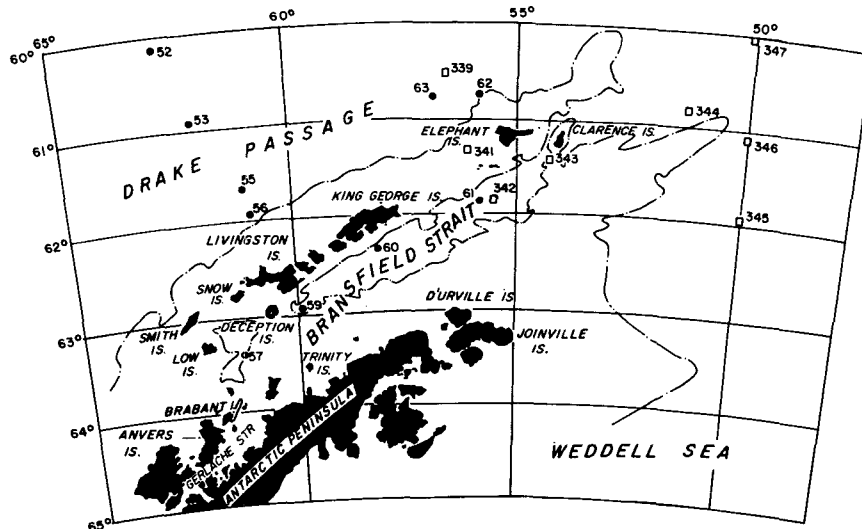


FIG. 2. Positions of FDRAKE hydrographic stations occupied during February and March 1975 in the Bransfield Strait and adjacent area using R/V *Melville* (dots) and R/V *Conrad* (open squares). The 1000 m isobath is shown.

The nutrient profiles in the eastern basin show few large-scale features below 500 m. The central basin shows the most deep and bottom structure: a broad nutrient minimum (most pronounced in silicate, least in nitrate) is seen below 1000 m within the interval of steady increase in salinity toward the basin floor.

Deep convection in the eastern basin is confirmed by tritium measurements at station 342 (Fig. 5). Although temperature and salinity were nearly uniform with depth in the basin waters, the tritium concentration increased toward the bottom after attaining a minimum near 300 m. The bottom tritium value was 0.71 tritium units (T.U.); this is nearly 0.1 T.U. above the sea surface concentration and 0.4 T.U. above the minimum at 300 m. Such tritium values in the bottom waters must be the result of deep convection which has occurred since the late 1950's and early 1960's when man introduced tritium into the atmosphere.

### 3. Discussion

Within the Bransfield Strait the Circumpolar Deep Water is either absent or its influence is weak. The salinity maximum, oxygen minimum and silicate maximum in the upper layers of the Strait attenuate toward the east, demonstrating the eastward decrease of Bellingshausen Sea influence. Likely this is due, at least in part, to the melting of ice in the Strait during summer.

The observed characteristics of the waters below sill depth strongly suggest that the waters of these basins are derived in part from surface or near-surface sources. Although there may be significant changes in water properties across the Strait (e.g.,

see Clowes, 1934), the available data indicate that the summer surface water is too warm and fresh to qualify as a source for the basin waters. It is therefore reasonable to conclude, as does Clowes, that it is the (unsampled) winter surface water which contributes by convective means to the deep and bottom waters of the basins. The Weddell inflow, being the most saline surface water component observed, is the most likely candidate for a surface source water.

Comparison of the data from different Bransfield Strait stations with one another and with data from stations to the north and east using characteristic plots (Fig. 6) again illustrates the distinctive properties within these basins. This comparison also provides a means of assessing the possible influence of Bransfield basin waters on the exterior adjacent deep waters and shows possible relationships between formation of the Bransfield Strait bottom waters and the formation of Antarctic Bottom Water.

Stations 344 and 347, to the east of the Bransfield Strait (Figs. 2 and 3), are within the Weddell-Scotia Confluence (WSC) which is a zone of reduced vertical stratification separating the Scotia Sea water from the northern Weddell Sea (Gordon, 1967; Gordon *et al.*, 1977). These stations show nearly homogeneous conditions below 1000 m (potential temperature of  $-0.1$  to  $-0.4^{\circ}\text{C}$ ; salinity near 34.65‰; oxygen near  $5.4 \text{ ml l}^{-1}$  and silicate near  $120 \mu\text{mol l}^{-1}$ ). This deep WSC water (below 1000 m) evidences less surface water influence than the Bransfield trough waters. Overflow into the WSC from the Bransfield Strait is not indicated by the longitudinal sections of observed properties (Fig. 3). If the deep waters within the WSC are formed in part

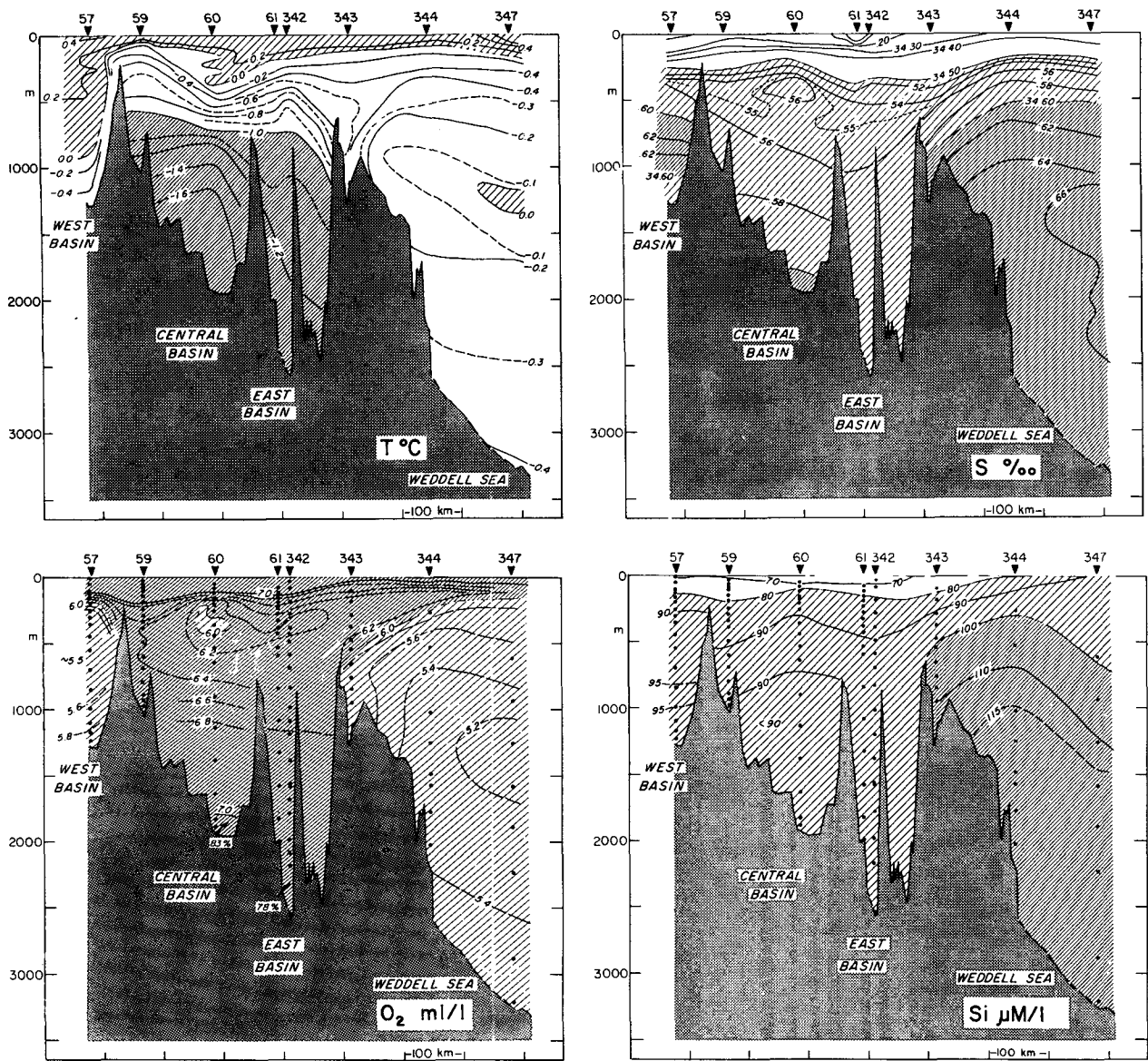


FIG. 3. Potential temperature (a), salinity (b), oxygen (c) and silicate (d) along the axis of the Bransfield Strait and adjacent Weddell and Scotia Seas. Bottom topography is taken from the sonic records of the *Conrad* and *Melville*. The dashed bottom bathymetry line is for sections not transversed by either ship. The topographic high to the immediate east of station 342 is believed to be an isolated feature and not a ridge dividing the eastern basin. The *Conrad* data points for temperature and salinity are taken at the standard level from the corrected STD data. The *Melville* temperature and salinity data are taken from water bottle reversing thermometer data at the same levels as shown in the chemistry plots. The *Conrad* chemistry observations are taken from water samples obtained by a 12-bottle rosette and bottles added to the cable.

from the overflow from the Bransfield trough, such overflow water must be mixed with a significantly warmer and more saline water (such as Circumpolar Deep Water of the Scotia of Weddell Sea) in order to derive the observed properties of the WSC. Alternatively, the deep water within the WSC may be a product of nearly *in situ* convection (Deacon and Moorey, 1975) or derived from a location outside of the Bransfield Strait, such as the east coast of the Antarctic Peninsula.

The change in slope of the  $T$ - $S$  curve near 2550 m (accompanied by a silicate maximum) at station 339 in the southern Drake Passage indicates the height above the sea floor of a bottom water mass. The similarity of this bottom water with that of the WSC deep and bottom water suggests westward spreading of WSC water into the southern Drake Passage, as has been discussed by Wüst (1933), Gordon (1966) and Reid and Nowlin (1971).

Station 345 is within a deep basin of the north-

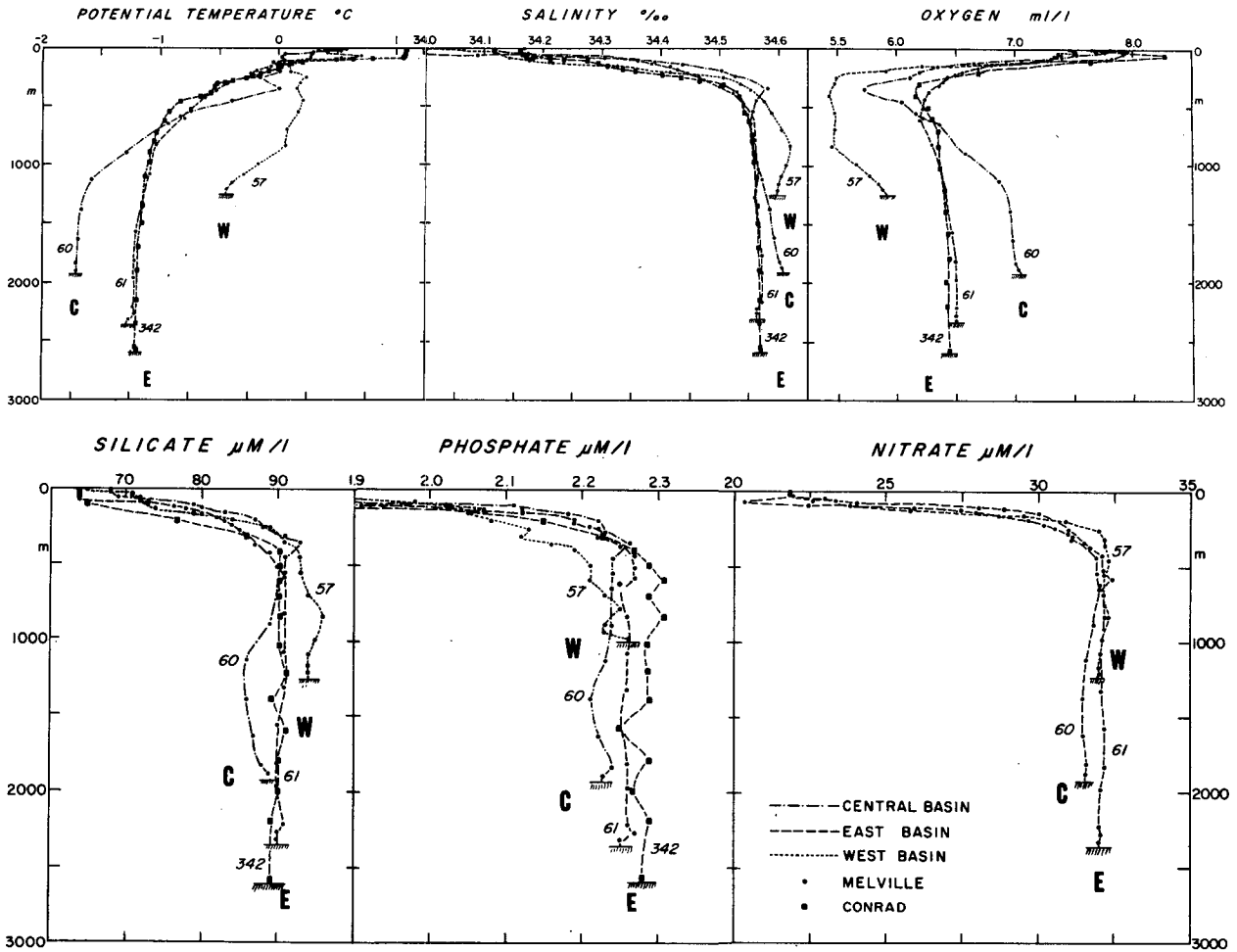


FIG. 4. Vertical traces for potential temperature, salinity and oxygen (a) and nutrients (b) for FDRAKE stations in the eastern (E), central (C) and western (W) basins of Bransfield Strait. There were no Conrad nitrate data. The Conrad nutrient values were increased by 3% to compensate for an observed offset between values determined by autoanalyzer (Melville) and DU spectrophotometer (Conrad) methods.

western Weddell Sea. Below 850 m the *T-S* relationship is nearly straight (a line can be fit by linear regression with a coefficient of determination of 0.993). The *T-S* curve for station 342 in the eastern basin of the Bransfield Strait also is nearly straight

below 625 m (a coefficient of 0.996). Extrapolation of these lines to the sea water freezing point yields nearly the same salinity for the two *T-S* relations: 34.613 and 34.620‰. Both of these *T-S* relations could therefore result from mixing with surface water initially at the freezing point and having a salinity of 34.62‰, which is near the salinity often associated with the shelf water contribution to Antarctic Bottom Water.

It is probable that on the broad continental shelf of the northern tip of the Antarctic Peninsula winter shelf water is formed at the freezing point with salinity near 34.62‰, and sinks both into the adjacent northwestern Weddell Sea and into the eastern Bransfield Strait basin. The different characteristics of the resulting deep and bottom waters on either side of the shelf are a consequence of the lack of Circumpolar Deep Water in the Bransfield Strait.

The WSC deep and bottom water falls along the *T-S* curve of station 345 from the Weddell Sea. Thus,

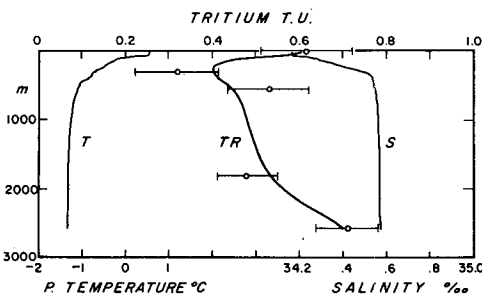


FIG. 5. Vertical profiles of *in situ* temperature and salinity from STD and tritium profile as fit to measurements at five levels at Conrad station 342. The bars extend one standard error to either side of the tritium values.

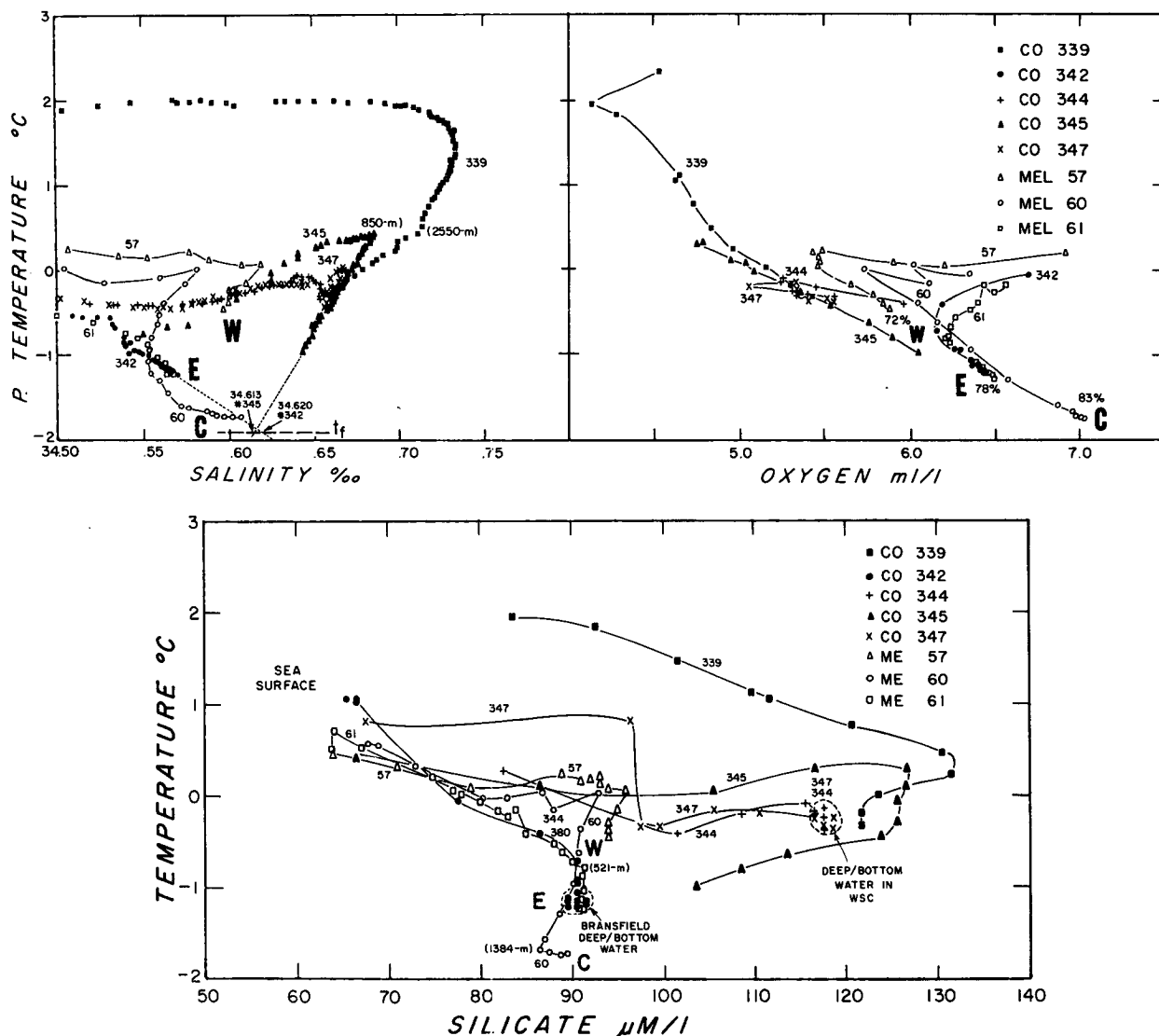


FIG. 6. Salinity and oxygen (a) and silicate (b) plotted against potential temperature for the FDRAKE stations within the Bransfield Strait (E, C, W denote basin) and to the east (station 344, 345, 347) and to the north (station 339) of the Bransfield Strait. The *Conrad* nutrient values were increased by 3% to compensate for an observed offset between values determined by autoanalyzer (*Melville*) and DU spectrophotometer (*Conrad*) methods.

this WSC water observed below approximately 2000 m at stations 344 and 347 probably represents that component of the northern Weddell Sea water column that can enter the southern Scotia Sea over the controlling sill depth near 40°W in the South Scotia Ridge (Gordon, 1966). The water in the northern Weddell Sea at deeper levels would continue to flow eastward to the south of the Ridge.

The more complex stratification below sill depth in the central basin suggests that the processes responsible for the formation of those waters are more involved than those occurring in the eastern basin. Compared with the eastern basin, the waters below 1000 m in the central basin are relatively cold, and show depth increases in the salinity, oxygen and

nutrient concentrations. This distinction is illustrated clearly by the temperature/silicate plot. The present data base is not sufficient to uniquely determine the spatial or time-dependent events leading to the more complex stratification of the central basin.

The stratification revealed by station 57 in the western basin may be explained by overflow from the central basin with entrainment of the relatively warm saline Bellingshausen Sea input. No evidence of *in situ* convection of freezing-point shelf water is apparent in the western basin.

In 1963 the USNS *Eltanin* occupied a number of deep stations in the Bransfield Strait. We have compared the FDRAKE 75 data with data from

*Eltanin* stations 70 and 74 in the eastern and central basins, respectively. [These are station numbers 6-17 and 6-21, respectively, as given in an early *Eltanin* data report (Friedman, 1964).] The position of station 70 is 37 km from that of FDRAKE station 342 and 17 km from station 61; the position of station 74 is 6 km from that of FDRAKE station 60. Based on the vertical profiles (not shown) the 1963 conditions were warmer by many tenths of a degree than the 1975 conditions. Except within the lower 300 m at station 60 the waters were saltier in 1963 than in 1975.

*Discovery* station 1013 (December 1932) is situated in the eastern basin 9 km to the southeast of FDRAKE station 342. Conditions during that *Discovery* station were similar to the 1975 situation. *William Scoresby* stations 383 and 385 were located in the central basin within 19 km of FDRAKE station 60; they were separated from one another by a distance of 28 km and by only one day in time (15 and 16 February 1929). Data from the two *William Scoresby* stations differ by 0.5°C and 0.1‰ (station 385 being warmer and less saline), which is roughly the same or greater than the difference observed between 1963 and 1975 data. To the extent that these differences are real, they indicated spatial variations as large as the variations observed between 1963 and 1975 data. The differences between the *William Scoresby* stations 383 and 385 are not entirely real, however, for Clowes (1934) pointed out that at station 385 the wire angle was large and no unprotected thermometers were used below 400 m. The paucity of accurate data in the Bransfield Strait does not allow meaningful study of variability of the deep and bottom waters of the Bransfield stations.

## 5. Conclusions

Deep convection of surface or near-surface water with characteristics similar to the shelf water traditionally associated with formation of Antarctic Bottom Water occurs within the basins of the Bransfield Strait. This is interesting from two standpoints: Antarctic Bottom Water is produced at the northernmost extremity of Antarctica north of the Antarctic Circle, and (because of the lack of Circumpolar Deep Water in that source region) it represents a form of Antarctic Bottom Water quite different from the low- and high-salinity varieties previously discussed by Gordon (1974). This deep and bottom water formed locally in the Bransfield Strait does not seem to measurably influence the waters of comparable density in adjacent oceanic regions.

It is possible that saline shelf water is advected with the general northward drift of water along the east coast of the Antarctic Peninsula. Although this

shelf water may also be involved in sinking along the east coast of the Peninsula, some remnants may reach the Bransfield Strait at the tip of the Peninsula. It is interesting to further note that the bottom temperature maps of the Weddell Sea (Gordon, 1967; Carmack and Foster, 1975) show that the coldest bottom water occurs in the northwestern Weddell Basin. Therefore, the cold shelf water which contributes as a source to bottom water formed in this region may be derived from the east coast of the Peninsula rather than from the southwestern corner of the Weddell Sea.

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