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RADIOCARBON IN THE WEDDELL SEA AS OBSERVED IN A DEEP-SEA CORAL AND IN KRILL

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Abstract. Radiocarbon measurements were performed on krill and coral samples collected from the Weddell Sea during IWSOE '80. These are the first radiocarbon measurements available from this area since 1973. These data reveal carbon-14 levels for Weddell surface water and southern Weddell Shelf water. These data indicate that the radiocarbon levels in surface waters in 1980 were the same or slightly lower than those present in 1973. In addition, an unusually low $\Delta^{14}C$ value for shelf water (from coral) at 500 m is evidence that Warm Deep Water (WDW) may penetrate much further and more frequently onto the shelf region than had previously been expected.

Introduction

The Weddell Sea is important to the circulation of the world's oceans, as it is the region where most oceanic bottom water is formed (Deacons, 1936). A complex mixing process involving Winter Water, Western Shelf Water and Warm Deep Water is coupled to the formation of bottom water. This process is most likely initiated by the penetration of WDW onto the continental shelf (Foster and Carmack, 1976). Transient tracers such as bomb-produced carbon-14 and tritium can provide useful information on the rates of bottom water formation and its subsequent movement into the Antarctic Circumpolar Current (the eastward flow surrounding Antarctica). At the present time, very little information is available on the carbon-14 levels in the Weddell Sea and in other water masses in the Antarctic Ocean.

The most extensive set of data was collected (Weiss et al., 1979) during the 1973 International Weddell Sea Oceanographic Expedition (IWSOE '73)(Figure 1). Weiss et al. (1979) found that surface waters had an average $\Delta^{14}C$ = -84 ± 5(SD) ‰ (Stations 1, 3, 5, 11, 13, 16, 18, 29 and 47) and that in WDW (at 300-600 m depth) was -157 ± 2(SD) ‰ (Stations 31 and 87) ($\Delta^{14}C$ is the per mille deviation from the activity [$^{14}C/^{12}C$] of nineteenth century wood). The level of carbon-14 in WDW was similar to that found in Circumpolar Current deep waters. The surface waters in the Weddell Sea had a much lower level (by 10-30%) than other surface waters in the world's oceans (Linick, 1975; Östlund et al., 1976); this was attributed to both the rapid upward mixing of intermediate and deep waters and to the inhibition of carbon dioxide exchange with the atmosphere due to ice cover. No measurements of carbon-14 have been made in the Weddell Sea since 1973. Measurements in the Ross Sea area (70-80°S, 160°E-160°W) in the late 1950's revealed surface $\Delta^{14}C$ values (-200 to -260 ‰) which were not substantially different from deep water values (Rafter, 1968), but were far lower than surface values in other major oceans (Bien et al., 1960; Broecker et al., 1960). After the major weapons testing of 1958 and 1961-62, surface levels of carbon-14 began to rise and were still rising in the Ross Sea in the late 1970's (Michel et al., 1979).

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Radiocarbon Measurements

During IWSOE '80, three biological samples were collected (Figure 1) and analyzed at the La Jolla Radiocarbon Laboratory (Table 1). The krill and salp samples were washed in dilute acid to remove inorganic carbon and were dried at 60°C. Each sample was combusted to produce carbon dioxide and then converted to acetylene gas, via lithium carbide (Linick, 1975). The coral sample was acidified to yield carbon dioxide and was then purified using standard procedures (Druffel and Mok, in press). Radiocarbon was measured in the resulting gases using standard gas proportional counting techniques.

All activities were corrected for isotope fractionation (to a standard $\delta^{13}C$ value (PDB) of -25.0‰) and for decay since the time of collection (to A. D. 1950). The standard used was 95 percent of the net NBS oxalic acid count rate, which was corrected to a $\delta^{13}C$ = -19.0 /oo. All results are reported in terms of $\Delta^{14}C$:

$$\Delta^{14}C = \delta^{14}C - 2(\delta^{13}C + 25.0)(1 + \delta^{14}C/1000) \quad (1)$$

Results

Two of the samples were collected from oblique net tows of a one meter net, towed at a depth of 20-100 meters at 2-3 knots. One sample on the southern Weddell continental shelf (Figure 1, Station A) contained almost exclusively juvenile krill and yielded a $\Delta^{14}C = -92 \pm 6$‰ (Table 1). The second tow (Station B) provided a mixture of krill and salps from the northern Weddell Sea with a $\Delta^{14}C = -96 \pm 13$‰. These carbon-14 levels represent those in the dissolved inorganic carbon (DIC) in the surface waters in which they lived. Krill have vertical mobility and traverse to depths where $\Delta^{14}C$ values are less than those at the surface; however, the carbon-14 level ($^{14}C/^{12}C$) in krill is not determined by where they live, but instead is dictated by what they eat. Most of the carbon in their food is derived directly from the mixed layer, where productivity is high, and thus reflect the ^{14}C levels in the mixed layer. In the Ross Sea, Michel et al. (1979) observed that the $\Delta^{14}C$ values found in krill were the same as

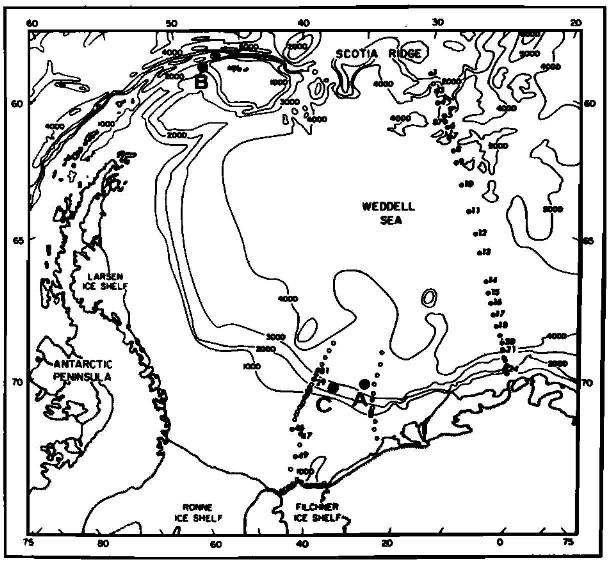

Figure 1. Station locations of samples taken for this study and those for Weiss et al. (1979) in the Weddell Sea. Krill were collected at Stations A and B and a branching coral was dredged from the bottom (500 m) at Station C. (Revised figure from Weiss et al., 1979).

that found in surface DIC. Salps, which are free floating organisms, generally reside in the mixed layer and should also have a $\Delta^{14}C$ representative of the DIC in that layer.

A branching ahermatypic coral (octocorallia) was collected live on the Southern Continental Shelf from the bottom (500 m, Station C) while dredging to recover a current meter (Figure 1). Ahermatypic corals accrete aragonite, a crystalline form of calcium carbonate, in near isotopic equilibrium with the DIC in the surrounding sea water. Stable isotopic analyses of the ahermatypic species Bathypsammia tintinnabulum collected from a depth of 850 m on the Blake Plateau escarpment (32°33'N, 76°59'W), showed less fractionation of the $^{13}C/^{12}C$ and $^{18}O/^{16}O$ ratios than in hermatypic (surface dwelling) corals (Emiliani et al., 1978). This indicates that the source of carbon in ahermatypic coralline aragonite is mainly DIC. Radiocarbon analyses of the one-gram coral sample revealed a $\Delta^{14}C = -147 \pm 18$ °/oo. Judging from the size of the coral, the measurement represents a $\Delta^{14}C$ value averaged over a two year period (1978-1980) on the southern Weddell Shelf (W. Newman, personal communication). This $\Delta^{14}C$ value is statistically the same as that found in 1973 for DIC in WDW (-156 ± 4°/oo, 600 m) at Station No. 31 by Weiss et al. (1979).

Discussion

The two surface values at Stations A and B are representative of $^{14}C/^{12}C$ ratios at the southern and northern edge of the Weddell gyre, respectively. The Weddell gyre has a clockwise circulation (Carmack and Foster, 1975), and heavy ice cover exists on the western shelf. Thus, it is not surprising that these two values would be similar.

The two surface values (-92 ± 6°/oo, -96 ± 13°/oo) are lower, but not significantly so (within two sigma counting error), from the average (-84 ± 5 SD) of nine surface values found by Weiss et al. (1979) in IWSOE '73. (This average does not include two samples in low-salinity water on the southeastern shelf. These low-salinity waters may ultimately be transformed into shelf waters typical of the areas sampled. However, this would require substantial physical changes which would also modify ^{14}C concentrations.) Weiss et al. (1979) postulated a short residence time for surface waters in the Weddell Sea and concluded that carbon-14 concentrations were strongly dependent on atmospheric values. It has been shown for surface water in the Peru Current, which also has a short residence time, that carbon-14 levels are dependent on the difference between the atmospheric $\Delta^{14}C$ value and that in upwelling subsurface waters (Druffel and Suess, 1983). Since atmospheric $\Delta^{14}C$ values have dropped since 1973 (from about +430 to +270°/oo), and since Weddell Surface Water has a short residence

Table 1. Isotopic measurements of krill and a coral collected from the Weddell Sea during IWSOE '80.

Description	Location	$\Delta^{14}C$	$\delta^{13}C$
Krill (juvenile)	Station A - surface (74°21.4'S, 31°17.3'W)	-92 ± 6°/oo	-28.8°/oo[1]
Krill and salps	Station B - surface (59°25.6'S, 47°57.8'W)	-96 ± 13°/oo	-31.2°/oo[1]
Coral (ahermatypic)	Station C - 500 m (74°36'S, 35°56'W)	-147 ± 18°/oo	0.0°/oo[2]

[1]Measured on CO_2 from reburned acetylene gas.

[2]Measured directly on CO_2 resulting from acidificaiton of coralline aragonite.

time, it is expected that surface values in this area would have been slightly lower in 1980.

The suspected decrease in radiocarbon concentration from 1973 to 1980 may also have been due to deep convection during polynya events in the late 1970's in the Weddell Sea (Gordon, 1978, 1982; Martinson et al., 1981). There was a dramatic change in WDW between the 1973 and 1980 IWSOE data, which these authors attribute to deep convective cooling in the open water polynya that existed in the Weddell Sea during 1980. Increased replacement of surface water by WDW during a polynya event would result in a lowering of surface $\Delta^{14}C$ values.

The radiocarbon result (-147 ± 18‰) for the coral sample from the shelf at 500 m depth is surprisingly low. From tritium data (Michel, unpublished data), it would appear that more bomb carbon-14 should be present in the bottom waters on the southern shelf. Instead, the coral result is indistinguishable from those found for WDW (-157 ± 2 [SD]) by Weiss et al. (1979). The area where the sample was obtained is near the shelf break, and it appears from this coral result that modified WDW may frequently penetrate into this region. Highly variable flow measured by current meters from nearby locations (T. Foster, pers. comm.) support this conclusion.

Conclusions

Radiocarbon levels in surface waters of the Weddell Sea in 1980 were the same or slightly lower (by 10‰) than those present in 1973. This decrease may have been the result of lower atmospheric carbon-14 concentrations during 1980, or due to polynya events that occurred in the late 1970's. The abnormally low $\Delta^{14}C$ value present at 500 m depth on the southern Weddell Sea shelf is evidence that WDW may penetrate much further onto the shelf than previously expected. These observations support suspicions of temporal variability taking place in the Weddell Sea. Continued observations must be made in order to define the frequency and amplitude of this variability.

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