CO_2 Transport in Deep Waters Off Wilkes Land

BY TARO TAKAHASHI AND DAVID W. CHIPMAN

The densest waters in the world ocean are formed on the continental shelf areas around Antarctica by ice formation and by the loss of heat and water to the air. The Weddell Sea (e.g., Gordon, 1971; Carmack and Foster, 1975; Foldvik et al., 1985), the Ross Sea (e.g., Jacobs et al., 1970, 1985) and other continental margin areas such as the coasts of the Adélie and Wilkes Lands (e.g., Gordon and Tchernia, 1972; Carmack and Killworth, 1978; Foster, 1995) are known to be the major producers of these dense waters. These waters spill over the shelf edge and, during their descent, mix with components of Circumpolar Deep Water (CPDW) to form the Antarctic Bottom Water (AABW) that fills the major abyssal basins of the world ocean. This process constitutes an important pathway between the atmosphere and the abyssal ocean for long-term storage of CO_2. However, the CO_2 transport processes associated with bottom-water formation have not been well documented. Here, we present observations made during the 1992 World Ocean Circulation Experiment (WOCE) S4P cruise showing that atmospheric CO_2 taken up by Wilkes Land shelf waters is transported into the upper AABW.

Figure 1a–d shows four properties along a section (68°S, 173°E –70.7°S,168°E) that is nearly at right angles to the continental shelf off the coast of Wilkes Land west of the Ross Sea. Waters with the partial pressure of CO_2 (pCO_2) less than the 1992 atmospheric value of 375 µatm are found from the surface to about 200 m depth near the shelf edge (Figure 1b). These waters are likely a mixture of the offshore surface layer and shelf waters that are modified by processes involving sea ice and glacial ice (Jacobs et al., 1985); their low pCO_2 values are due to summertime phytoplankton blooms on the shelf and offshore. These waters absorb CO_2 from the atmosphere because of their low pCO_2 values (below the atmospheric value).

Circumpolar Deep Water (CPDW), which is characterized by high values of temperature (> 1.0°C), pCO_2, and total CO_2 concentration (TCO_2), and by lower silica concentrations, is located immediately under the 100 m thick offshore mixed layer (Figure 1a–d). It appears to mix with the low pCO_2 surface water, forming a transition in the shelf break zone down to about 500 m, as described by Gordon (1971). The AABW, with higher concentrations of silica and TCO_2, is found below the CPDW (Figure 1c,d). A layer of sub-0°C water with lower silica (< 100 µmol kg^{-1}) is observed from the surface to 3,000 m along the shelf slope. Near the base of the slope (3,000–3,500 m) lies a pool of dense cold water, the Ross Sea Bottom Water, with lower values of silica, TCO_2, and pCO_2 (Gordon and Tchernia, 1972; Carmack and Killworth, 1978), flowing westward along the base of the continental slope.

The potential temperature-salinity plot in Figure 1e shows the mixing relationships among these water masses. Between the less-cold CPDW and the colder high-salinity Ross Sea Bottom Water, a lower-salinity kink in the linear trend is seen at about 0.2°C and a salinity of 34.67 (sigma-2 density of 37.14 kg m^{-3}, about 1,060 m depth). This water has a local minimum for Apparent Oxygen Utilization (AOU) (not shown) and pCO_2 values (Figure 1f), indicating a more recent origin. These values, however, are considerably greater than the surface water values due to mixing with the high-AOU, high-pCO_2 CPDW. Because of the similarity in the temperature-salinity relationships and in the density, we consider that this water is the same type as that reported by Carmack and Killworth (1978) between 147°E and 162°E: potential temperature of 0° to –0.5°C, salinity of 34.68–34.70 PSS, and sigma-2 density of 37.20–37.25 kg m^{-3} at depths of 1,000–2,200 m. Using a turbulent plume model, they demonstrated that this water was formed by sinking of Wilkes Land shelf water that had entrained CPDW during its descent along the continental slope. The water was not dense enough to reach the bottom, but it interleaved into the thick body of the AABW. Because the shelf water had absorbed atmospheric CO_2 during the summer, the process described above suggests a transport pathway for atmospheric CO_2 into the AABW regime. The Ross Sea Bottom Water located at the base of the continental slope, which had absorbed atmospheric CO_2 when exposed at the surface during summer low pCO_2 periods (e.g., Bates et al., 1998; Hales and Takahashi, 2004), transported atmospheric CO_2 into the deepest regime of the AABW.

AUTHORS

Taro Takahashi (*taka@ldeo.columbia.edu*) *is Ewing Lamont Research Professor, Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY, USA.* **David W. Chipman** *is retired from the Lamont-Doherty Earth Observatory of Columbia University, Palisades, NY, USA.*

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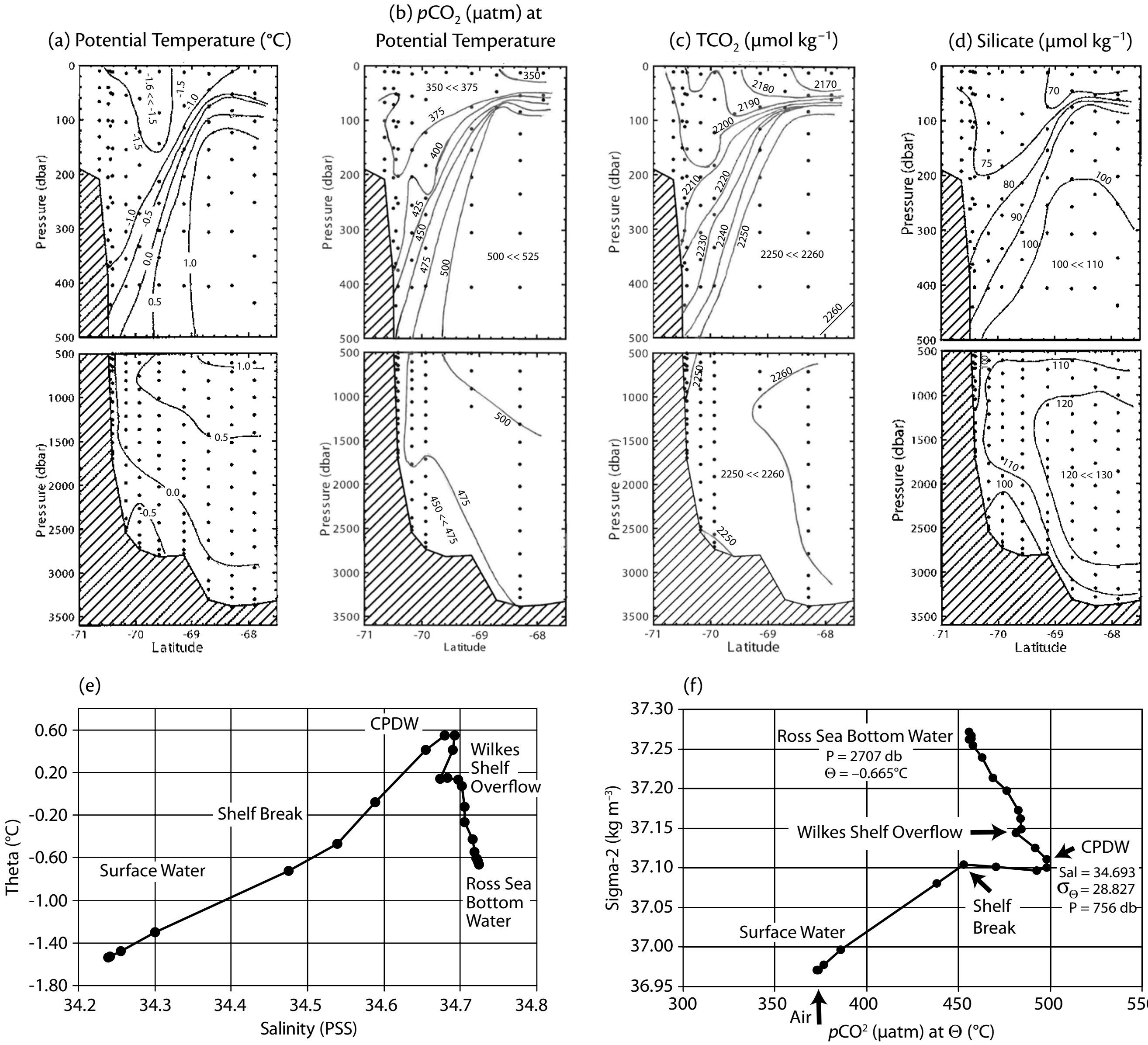

Figure 1. Depth profiles of (a) potential temperature (°C), (b) pCO_2 (μatm at potential temperature), (c) TCO_2 (μmol kg^{-1}), and (d) silicate concentration (μmol kg^{-1}) over the continental slope off the coast of Wilkes Land (67°03'S, 174°19'E to 70°39'S, 168°00'E) were measured from March 21 to 23, 1992, during the austral summer World Ocean Circulation Experiment (WOCE) S4P cruise (Chipman et al., 1997). Property-property plots are for the data at WOCE S4P Station 775 (69º56´S and 169º20´E): (e) potential temperature vs. salinity, and (f) sigma-2 density vs. pCO_2 at potential temperature. The presence of Wilkes Land shelf water is indicated as Wilkes Land Overflow (OF).

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