

THE OFFICIAL MAGAZINE OF THE OCEANOGRAPHY SOCIETY

# Oceanography

#### CITATION

Key, R.M., and A. McNichol. 2012. Radiocarbon measurements in the Indian Ocean aboard RVIB *Nathaniel B. Palmer*. *Oceanography* 25(3):152–153, <http://dx.doi.org/10.5670/oceanog.2012.89>.

#### DOI

<http://dx.doi.org/10.5670/oceanog.2012.89>

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# Radiocarbon Measurements in the Indian Ocean Aboard RVIB *Nathaniel B. Palmer*

BY ROBERT M. KEY AND ANN MCNICHOL

Research Vessel Icebreaker *Nathaniel B. Palmer* departed Cape Town, South Africa, on May 3, 1996, to complete the Indian Ocean portion of the “S04” line, a circumnavigation of Antarctica that was part of the US contribution to the World Ocean Circulation Experiment (WOCE). The WOCE Line S04I voyage ended at Hobart, Tasmania, on July 4, 1996, following completion of 108 stations, despite suspension of science operations for seven days on June 8, when the *Palmer* was diverted to deliver emergency food supplies to Russia’s Mirny Station in the Davis Sea. During this extreme south cruise, with Thomas Whitworth III (Texas A&M University) and James H. Swift (Scripps Institution of Oceanography) as co-chief scientists, a total of 816 radiocarbon samples were collected by author Key at 31 stations, and these samples were later analyzed by author McNichol at the National Ocean Sciences Accelerator Mass Spectrometry Facility at the Woods Hole Oceanographic Institution.

Radiocarbon enters the ocean, along with common carbon dioxide, via gas exchange at the sea surface. Once dissolved, radiocarbon becomes part of the inorganic carbon system, except that it radioactively decays with a half-life of 5,730 years. The global meridional overturning circulation influences radiocarbon distribution in the ocean’s interior. Consequently, near-surface waters and sinking newly formed bottom waters over the Antarctic continental margins have relatively high radiocarbon concentrations. They are often said to be “young,” in reference to the short time since those water

parcels last contacted the atmosphere. In contrast, “old” deep waters have relatively low radiocarbon concentrations.

The vertical distribution of radiocarbon on the S04I line shows a weak minimum (Figure 1a) at mid-depths (1,000 m–2,500 m). The lowest concentrations of about  $-160\text{‰}$  are measured near 1,500 m depth at the western stations, located near the eastern limb of the Weddell Gyre cyclonic circulation. The core lies within the “oldest” Circumpolar Deep Water (CDW) derived from Drake Passage along the strong eastward-flowing Antarctic Circumpolar Current (ACC). Farther to the east, rather than “aging” downstream, the radiocarbon minimum *increases* to  $-155\text{‰}$  in the Enderby Basin due to the southward input of relatively younger (higher radiocarbon concentrations) North Atlantic Deep Water (NADW) from the southeastern Atlantic Ocean. If we were to follow CDW farther along the ACC path (i.e., from the Australian-Antarctic Basin all the way across the Pacific), radiocarbon concentration would steadily decrease, achieving an absolute minimum of approximately  $-165\text{‰}$  near Drake Passage. Measurement uncertainty for any given radiocarbon sample is about 4‰, but we can be quite confident of this general trend because of the large number of samples measured along that path.

Oceanographers generally think of the Weddell Sea as the primary location for Antarctic Bottom Water (AABW) production. But Figure 1a shows another interesting feature—the near-bottom water east of Kerguelen

Plateau (80°E) is younger ( $> -145\text{‰}$ ) than that to the western side ( $> -150\text{‰}$ ). Radiocarbon data clearly demonstrate that significant production and export of newly formed AABW must occur somewhere east of Kerguelen Plateau because that topography effectively blocks abyssal flow from the west, via the Princess Elizabeth Trough.

During this expedition, we were able to occupy stations along two short north-south sections, extending from about 62°S to near the Antarctic shelf break. The section nearly along 90°E shown in Figure 1b extended to 65.5°S. The high radiocarbon signal measured at the foot of the continental slope, combined with knowledge of the regional bottom topography and general flow pattern of the ACC, implies AABW formation and export at reasonably close source sites over the Indian Ocean continental shelf, including off Adélie Coast. A similar cross-slope section was occupied near 55°E, where the radiocarbon vertical section also shows relatively high concentrations at the bottom of the continental slope, albeit not as high as those found east of Kerguelen Plateau. Therefore, the most likely source for this newly formed AABW type must be located in Prydz Bay.

Chlorofluorocarbon (CFC) measurements on the two slope sections at 55°E and 90°E show basically the same patterns as radiocarbon data—elevated near-bottom values indicative of recent contact with the atmosphere. Information from the radiocarbon vertical sections is perhaps more significant to climate

change studies, due to the much longer (decades vs. weeks) time it takes to equilibrate atmospheric and oceanic concentrations. Radiocarbon data tend to integrate oceanic signals over much longer time intervals than CFC data. An important implication inferred from radiocarbon measurements during the S04I cruise is that deep ocean ventilation by AABW types produced at sources in Prydz Bay and off Adélie Coast is a persistent feature of the Southern Ocean.

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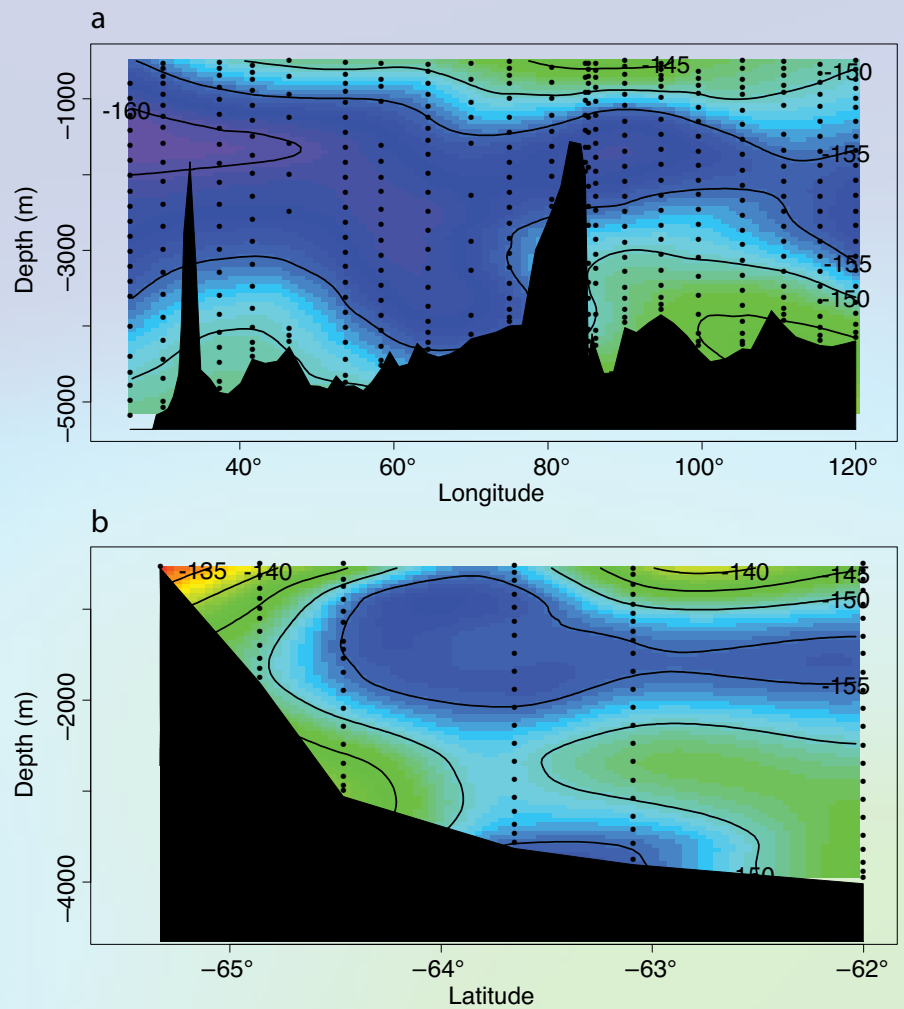


Figure 1. Vertical distribution of radiocarbon concentrations, shown only below 500 m to allow more color contrast in the deep and bottom waters (a) along 62°S on the long World Ocean Circulation Experiment Line S04I between 20°E and 120°E, and (b) along 90°E on a short section over the Antarctic continental slope. Radiocarbon-poor (old) Circumpolar Deep Water is shown above recently ventilated (young) Antarctic Bottom Water to the west (Weddell Sea Bottom Water) and east (Adélie Bottom Water) of the Kerguelen Plateau.