WHP Sections I8N/I5E in the Central Indian Ocean

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One of the central purposes of the WHP Indian Ocean expedition is to determine the fate of the deep water which enters from the south. Toole and Warren (1993) and Fu (1986) both suggest that there is anomalously large upwelling in the Indian Ocean compared with the Pacific and Atlantic; Warren (1995) has hypothesized the net heat gain in the tropics to account for it. The apparent anomaly may well reflect the lack of a sizeable northern source of intermediate or deep water, leaving the Indian Ocean far more asymmetric than the other two, and thus not masking the actual amount of upwelling of southern-source deep water by production of another northern deep water on top of it. It is not known whether monsoonal forcing in the Indian Ocean also plays a role in the deep upwelling.

To study the distribution and circulation of deep waters in the Central Indian Basin, and other items of interest (see the cruise plan for I8N) RV Knorr departed Colombo, Sri Lanka on 10 March 1995, and arrived in Fremantle, Australia on 15 April 1995 to carry out its third WOCE hydrographic leg in the Indian Ocean. Eighteen principal investigators were involved. Basic technical support was provided by Scripps Institution of Oceanography's Oceanographic Data Facility. ADCP operations were carried out by U. Hawaii (Firing). Water samples were collected for analyses of salt, oxygen and nutrients on all stations and of CFC-11, CFC-12, carbon tetrachloride, helium-3, helium-4, tritium, AMS C14, pCO_2, total dissolved inorganic carbon, alkalinity, and barium on selected stations. The basic sampling program was accomplished very smoothly. The full cruise report listing all parameters sampled can be obtained from the author. A longer report of the physical oceanography results might be published in a later edition of the WOCE Newsletter.

The cruise track for these sections is shown in the overview figure for this newsletter (page 22). The goals of the sampling were to obtain a section through the centre of the Central Indian Basin to observe the distribution and possible sources of bottom water in the basin, and to repeat the crossing of the northward flow of deep water just to the west of Australia. The northern end of the section lay close to a current meter array set out by Schott *et al*., (1994). Particular attention was paid to a potential source of deep water for the Central Indian Basin, through a sill in the Ninety-East Ridge, located at about 28°S. The section along 33°S was a nominal repeat of the 1987 section (Toole and Warren, 1993). There was time to deviate from the

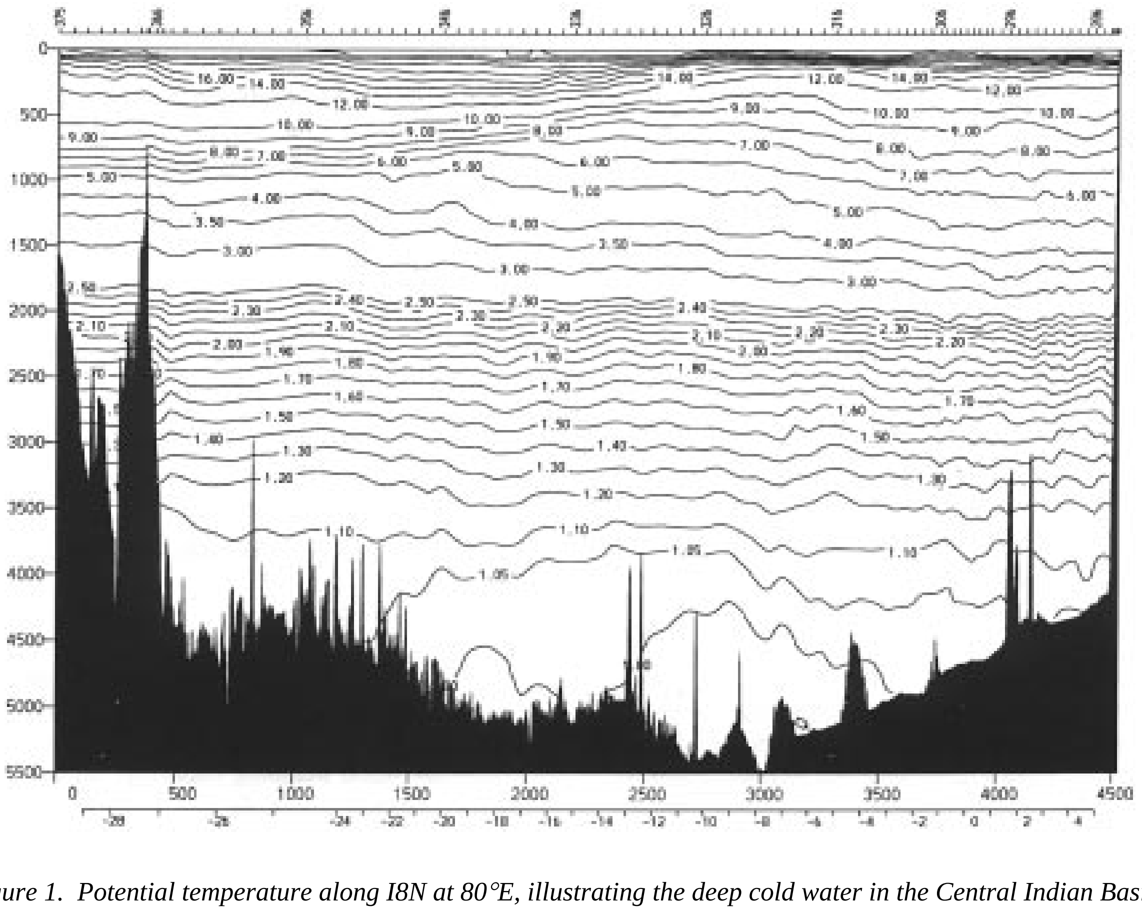

Figure 1. Potential temperature along I8N at 80°E, illustrating the deep cold water in the Central Indian Basin.

32°S section, and sample in the deep water south of Broken Ridge instead of along the top of the ridge. Between Broken Ridge and Australia we chose to move the section slightly north of the original position of I5E in order to resolve whether the deep flow splits around Dirck Hartog Ridge.

Preliminary observations indicate that the 11°S sill in the Ninety-East Ridge is indeed the principal source of bottom water. A preliminary estimate of flow through the 28°S sill indicates that about 2 Sv enter there, and turn southward. Northward flow into the Perth Basin, based on water properties, is almost all between the Broken and Dirck Hartog Ridges. There are differences in properties throughout the water column between the 1987 and 1995 sections between Broken Ridge and Australia; some of the differences are not attributable to the slight difference in location of the sections.

Shallower features of note on I8N south of the equator were the westward flow of water between 10°S and 14°S originating partially in the Indonesian throughflow (surface flow >70 cm/sec based on ADCP and geostrophic transport relative to the bottom of 21 Sv), and a swift equatorial countercurrent south of the equator (surface flow >70 cm/sec based on ADCP and eastward geostrophic transport of approximately 55 Sv). At the equator appeared a well-defined equatorial undercurrent centred at about 80 metres carrying saline Arabian Sea water eastward beneath the westward flow of fresher Bay of Bengal water. The halocline separating them was particularly intense off the equator, especially in the Sri Lankan coastal jet, which carried about 6 Sv of fresh surface water westward and 30 Sv of more saline water eastward beneath. Brunt-Vaisala frequency shows short vertical scales to the ocean bottom within 3 degrees of the equator like in the Pacific and Atlantic Oceans, indicating the presence of the stacked equatorial jets.

The surface layer north of 10°S was very warm (29°C) and essentially well mixed down to the strong halocline (except for a very shallow diurnal thermocline), suggesting that there is a continual forcing. Because the winds were light during the cruise and because the climatological winds for this period are light, and because the surface layer was very warm and fresh, we hypothesize that evaporation might be an important component in the mixing.

South of 14°S lies the oxygen-rich subtropical gyre with very saline surface or subsurface water (subtropical underwater). An oxygen maximum is apparent along the whole of the I8N and I5E section centred at about $26.8\sigma_\theta$; this is the northward extension of the Subantarctic Mode Water (SAMW) which is ventilated in the southeastern Indian Ocean and enters the subtropical circulation there. All along the I5E section the SAMW is apparent as a potential vorticity minimum, reflecting its origin as a deep convective layer north of the Subantarctic Front. In contrast, the Antarctic Intermediate Water along these sections has no signature in potential vorticity or oxygen, and it does not extend north of the subtropical gyre as a salinity minimum; while AAIW represents the densest thermocline ventilation in the South Pacific and South Atlantic, the SAMW originating in the southeast Indian Ocean dominates ventilation in the Indian Ocean's lower thermocline.

In summary, the cruise went very smoothly and we observed a number of interesting features which will form the basis of further work with this and the other Indian Ocean data sets.

References

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WHP Indian Ocean I9N

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The RV Knorr commenced cruise 145-6, WOCE WHP Indian Ocean section I9N (for location see page 22) on 24 January 1995 from Fremantle, Australia, terminating in Colombo, Sri Lanka on 5 March 1995. Arnold L. Gordon was Chief Scientist; Don Olson was co-Chief Scientist. The average station spacing along this section is 30 nm, with a minimum spacing of 20 nm from 3°S to 3°N and with a maximum spacing of 36 nm. There was ample time to obtain an additional section along the central axis of the Bay of Bengal at a station spacing of 46 nm. This section allows for some mapping capability within this poorly sampled embayment of the Indian Ocean. Stations 148, 149, 150, 152 repeated stations of the previous Knorr cruise, I8S and I9S. The last station is 277 at 80°E in the