

Studies on the nutrient distribution in the Southern Ocean waters along the 45° E transect

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Seawater samples from the surface as well as at different depths of the water column were collected from 30 stations during the Pilot Expedition to Southern Ocean (PESO). The sampling stations were along a transect between latitude 27°59'48" S and 56°00'14" S and longitude 50° E and 45° E in the Indian Ocean Sector of the Southern Ocean. An attempt has been made to study the nutrient distribution in the water column. The physico-chemical parameters like pH, surface temperature and surface dissolved oxygen have also been studied. The results are useful to infer the mixing of different water mass and distribution of nutrients in the surface and below surface water column. A first order comparison of surface water physico-chemical parameters in the study area with the planktic foraminiferal abundance shows a profound influence of seawater pH on the planktic foraminiferal abundance in the southwestern Indian Ocean.

[Keywords: nutrients, planktic foraminifera; Indian Ocean sector, Southern Ocean; pH]

Introduction

The Southern ocean receives the nutrient input from the Antarctic Circumpolar Current (ACC) which provides pathway between the major ocean basins and has a vital role in the global redistribution of salt, nutrient, heat etc^{1,2}. The ACC extends from the sea surface to depths of 2000-4000 m and can be spatially as spread as 1000-2000 km. The water column circulation or mixing is also due to the rise of relatively warmer deep ocean waters to the colder sea surface just south of the current which compensate for the sinking of surface water along the edge of icy Antarctica and further north³. These and other associated processes change the nutrient dynamics of this region and ultimately help in sinking of carbon into the deep ocean as particulate organic matter. As the particulate matter decays, the carbon in the organic matter gets oxidised into carbon dioxide. Because of this deep ocean "biological pump" of carbon, the atmospheric carbon dioxide is lower than it otherwise would be.

In view of the complex processes involved in the nutrient dynamics in the Southern Ocean, a detailed

understanding of the water column properties becomes important to unfold the effect of physico-chemical processes on the biological characteristics of this region.

The present study discusses spatial distribution of water column temperature, salinity, dissolved oxygen, surface nutrients (silicate and nitrate) and pH in the Indian Ocean sector of the Southern Ocean. Attempt has also been made to identify the signatures of the various mechanisms of nutrient transport and its relation to the water column characteristics of the southwestern Indian Ocean. The possible influence, if any, of water column characteristics on the planktic foraminiferal abundance is also explored.

The Study area

The studied area is an integral part of the South Indian Ocean where circulation is characterized by a subtropical anticyclonic gyre³. The poleward Agulhas Current lies to its west, the eastward flowing Antarctic Circumpolar Current (ACC) on its south and equator ward flowing West Australian Current on its east. The Subtropical Front (STF) is located at approximately 42-43° S latitude in central south Indian Ocean⁴.

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Previous studies have already reported the physical properties of the water column along the study area^{5,6}. Various frontal regions such as, STF in-between 42-43° S (water temperature ~13°C), SAF (seawater T in the range of 7-9°C) identified between 44-45° S and (PF) between 52-56° S (seawater T near 5°C)⁵ have been demarcated on the basis of these physical properties of the water column. Sea surface temperature change from 21.8°C to 19.0°C (Fig. 1) was reported between 35° to 40° S; whereas salinity varied from 34.2 to 35.5‰⁵. The mixed layer depth was reported at 50-75 m in this region. The vertical variation of temperature indicates the possibility of thermocline depth upto 100 m. The temperature minimum was noticed around 100-200 m after the 49° S.

Materials and Methods

Water samples from 30 locations along the cruise track were collected from the sea surface as well as different depths with the help of Niskin water samplers, attached with the CTD rosette. The sampling was carried out in the region south of Mauritius, along a transect between 27°59'48" S and 56° 00' 14" S latitude and 50° E and 45° E longitude in the Indian Ocean Sector of the Southern Ocean (Table 1). The water sample collection, preservation (storage at 4°C) and all the analysis were performed following the standard scientific procedures⁷. The pH of the water samples was determined immediately after the collection with the help of calibrated digital pH meter ELICO model LI 127 with automatic temperature compensation (ATC) probe. Dissolved oxygen was measured immediately after systematic collection of water sample by Winkler's method⁸. The nutrient concentrations have been measured by using the onboard 'Autoanalyser' (Skalar) facility.

The procedure adopted for the nutrients analysis was taken from the literature^{7,8}. For the analysis of silicate, small volumes of water samples were

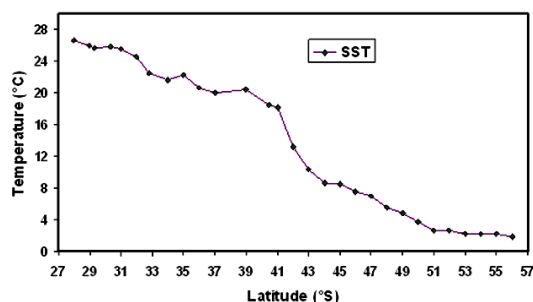


Fig. 1—Sea surface temperature variation in the studied region.

acidified and reacted with ammonium molybdate to form molybdo-silicic acid, followed by reduction with ascorbic acid to form blue colour dye and measured at 810 nm. The results were replicated with suitable calibrated standards and are plotted as per the need for the interpretations. The procedure followed to estimate planktic foraminiferal abundance is discussed elsewhere (Saraswat *et al.*, communicated).

Results and Discussions

Nutrient distribution in the study area

The distribution of dissolved oxygen, nutrients and carbon in the ocean is strongly affected by production of biomass in the euphotic zone, vertical particle fluxes and remineralization of particles during sinking and post depositional processes at the ocean floor. The major nutrients (nitrate, phosphate and silicate) required for phytoplankton growth are abundant in the surface waters of the sub-Arctic, Pacific, equatorial Pacific and Southern oceans.

In the study area the silicate concentration varies from 0.5 μM – 4.0 μM in the surface waters between 28° S to 40° S latitude (Fig. 2). A slight increase in silicate concentration was noticed upto 250 m in this region. At 41° S latitude, the surface silicate concentration was almost double than the previous location (8 μM). Tremendous increase in silicate concentration was noticed towards further southern latitude. The surface silicate concentration was 16 μM at 51° S and further increase was noticed till 56° S. The increased silicate concentration beyond 51° S could be used as a marker for the identification of PF region^{5,6,9}. After 52° S an ice-berg was sited towards the eastern side of the track. This shows the input of the nutrients from the continental ice as well as transport of molten cold water from southern latitudes. This probably explains the sudden increase of nutrient between 51-52° S latitudes. The oxygen value probably reflects the relatively high productivity in this region (during the study period). There exists a significant excess in surface nutrient concentration. The silicate concentration was found useful in identifying the cold water transport at 40 m depth beyond 51° S latitude. This could be the effect of transport of Antarctic intermediate water at subsurface (Fig. 3). Even though the high silicate values do not vary significantly below 200 m water depth, significant increase in silicate concentration is noticed in the near bottom waters.

There is no abrupt change in surface phosphate value in the entire study area¹⁰, as was noticed in case

Table 1—Details of the water sample collected with the help of CTD for chemical analysis.

Sr No.	Station No.	Latitude ° ' '' (S)	Longitude ° ' '' (E)	Date D M Y	Time G M T	Sonic Depth (m)	Max. Depth (m)	SST BKT (°C)
1.	Ctd 4	27 59 48	50 00 00	27 01 04	18 15	4976	4902	26.6
2.	Ctd 6	28 59 26	47 59 31	28 01 04	19 05	2779	2006	26.0
3.	Ctd 7	29 19 30	47 00 47	29 01 04	03 55	3069	1981	25.7
4.	Ctd 8	30 20 28	45 48 12	29 01 04	16 40	1778	1751	25.9
5.	Ctd 9	31 00 39	44 59 40	30 01 04	05 55	2251	2197	25.5
6.	Ctd 10	32 00 00	44 57 27	31 01 04	13 52	1988	1903	24.6
7.	Ctd 11	32 50 30	44 54 06	01 02 04	06 54	1166	1051	22.5
8.	Ctd 12	34 00 05	44 59 12	02 02 04	00 45	1100	1062	21.6
9.	Ctd 13	35 04 46	44 59 46	02 02 04	12 17	2275	2197	22.3
10.	Ctd 14	36 08 08	44 59 37	03 02 04	03 33	2850	2795	20.6
11.	Ctd 15	36 59 16	44 59 17	03 02 04	20 17	2979	754	20.0
12.	Ctd 16	38 00 44	45 00 07	04 02 04	11 02	3081	2604	20.7
13.	Ctd 17	39 00 00	45 00 00	05 02 04	05 20	4004	3724	20.4
14.	Ctd 18	40 26 04	45 00 03	06 02 04	08 03	3854	3302	18.5
15.	Ctd 19	41 00 22	44 59 52	06 02 04	20 50	3256	3000	18.1
16.	Ctd 20	41 59 44	45 00 48	07 02 04	17 27	3480	3384	13.2
17.	Ctd 21	43 01 11	45 00 27	08 02 04	09 15	30 97	2948	10.3
18.	Ctd 22	44 00 15	45 01 36	09 02 04	10 16	2205	2100	8.6
19.	Ctd 23	45 01 23	45 06 08	10 02 04	03 00	1613	1503	8.5
20.	Ctd 24	46 00 45	45 00 25	10 02 04	16 08	1897	1804	7.5
21.	Ctd 25	47 00 25	45 03 42	11 02 04	04 10	3227	2995	7.0
22.	Ctd 26	47 59 36	45 00 24	11 02 04	23 00	3927	3000	5.5
23.	Ctd 27	48 59 42	45 00 28	12 02 04	19 46	4245	3200	4.8
24.	Ctd 28	49 59 33	45 00 54	13 02 04	14 20	4383	3600	3.7
25.	Ctd 29	51 00 15	44 59 46	14 02 04	04 37	4051	3600	2.6
26.	Ctd 30	51 59 51	44 59 56	14 02 04	19 07	3129	3050	2.6
27.	Ctd 31	53 00 00	44 59 45	15 02 04	06 12	319	301	2.2
28.	Ctd 32	53 59 49	45 00 09	15 02 04	19 50	3876	3850	2.2
29.	Ctd 33	54 59 50	45 00 14	16 02 04	17 25	4137	4121	2.2
30.	Ctd 34	56 00 14	45 00 25	17 02 04	11 45	4814	4780	1.9

of surface silicate concentration in the region. The surface phosphate values in the tropical region (28-40° S of latitude) are in the range of 0.2-1.6 μM but the values are in the range of 1.0-2.5 μM , at the same depths of 42 - 46° S, sub tropical region¹⁰. Relatively low phosphate concentration was identified in the study area.

The surface nitrate values remain lower than 2 μM (0.4 to 1.98 μM) in the tropical region (28-42° S). A significant increase was recorded in the nitrate concentration after sub-tropical front region (Fig. 4). The small spikes of nitrate value in the tropical region of 28° S and at 40° S were probably due to the intense algal blooms observed in the surface waters in this

region. The increase in the nitrate concentration noticed at 43° S was almost 10 fold (21.9 μM) whereas at 50° S, almost 16 fold (33.6 μM) increase was noticed, especially in the surface waters. The abrupt increase recorded in the surface nitrate in the southern latitude could be due to the nutrient inputs from the melting of ice in surface and near surface in the southern region during the peak summer period in addition to the regional biological activities¹⁰.

Oxygen and pH trends

The surface oxygen concentration clearly indicates the presence of different frontal zones (Fig. 5). The evidence for Antarctic intermediate water (AIW) is also noticed near 48-49° S (oxygen concentration

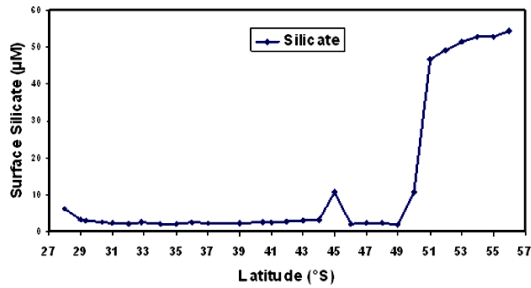


Fig. 2—The silicate concentration in the surface water along the transect.

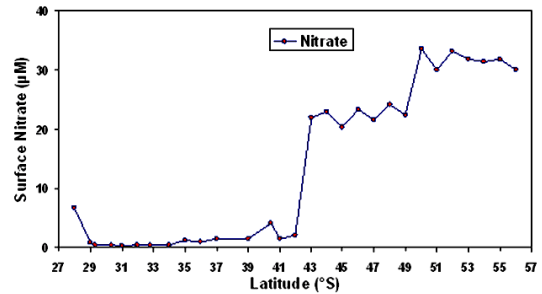


Fig. 4—Fluctuations in the surface nitrate concentration in the surface waters.

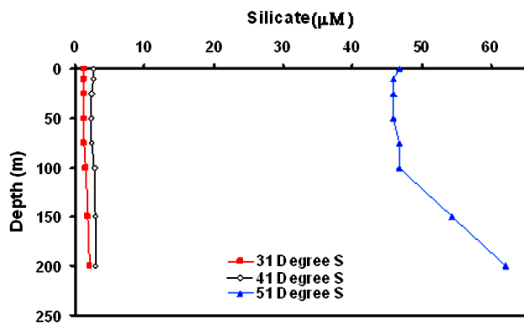


Fig. 3—The vertical silicate distribution in surface and subsurface waters at three locations.

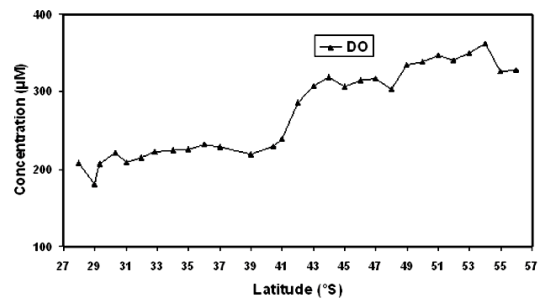


Fig. 5—Dissolved oxygen variation in the surface waters from tropical to polar region

303 μM). The oxygen minimum observed at 51° S (oxygen concentration 340 μM) latitude probably reflects the PF region. Further decrease in the surface oxygen beyond 55° S and further at 56° S provides a hint for the northern boundary of Subantarctic frontal signature^{5,10}. The oxygen minimum has been observed in upper deep water columns in conjunction with the temperature values. The oxygen values follow trend identical with the *pH* values at each station (Fig. 6). The *pH* curve follows the DO variation between at 49° S, 51-52° S and 55-56° S latitudes. The water column with comparatively lesser *pH* value (surface *pH* 7.95) in the upper deep waters provides evidence for the Antarctic intermediate water 49° S (*pH* 7.9), which is also supported by salinity profiles recorded and reported during CTD observations⁵.

Nutrient and biogeochemistry

Major nutrients are required for biological activities. The amount of nutrients and their relative proportion regulates the biological productivity. Phytoplanktons are the major organisms utilizing surface nutrients. The phytoplankton availability or population in any oceanic region can be recognized by the nutrient values of the region. From the

southern hemisphere, three key phytoplankton communities have been identified according to their planktonic food-web with different ecological and biogeochemical providence. These include diatoms, *Phaeocystis* colonies and nano-phytoplankton. Nano-phytoplankton reflects the regeneration-based-production¹¹.

Indirect evidence of the link between phytoplankton community structure and carbon exportation is given by nitrate and silicate signatures¹¹⁻¹³. Evidence exists that the Polar Front area, a diatom-dominated system, has the potential for silicate limitation. Nitrate to silicate regressions indicate nitrate excess at concentration silicate exhaustion¹⁴. The silicate found in the study is little less as compared with the previous reports¹⁵⁻¹⁷.

The high values of nutrients (silicate, nitrate and phosphate) observed may be due to the high degree of diatomaceous ooze, especially at post STF stations. The silicate concentration increases in the deeper water columns after STF towards further southern latitude upto 56° S which is evidenced by *E. huxleyi* cell density in earlier reports¹⁸. The same trend is also noticed in nitrate concentration. The abrupt increase in nitrate concentration in the surface water is believed to support the growth of *E. huxleyi* by

overcoming the silicate influence. This is an interesting relationship has also been reported earlier between the nitrate concentration and the growth of *E. huxleyi* population in cold waters¹⁸.

Silica concentration is comparatively low upto 51° S (highest value of 98.4 μM in PF and around sub-Antarctic zones). The silicate depletion along with the nitrate excess in the surface and near surface water could be an indication of diatom domination^{19,20}. The gradient of silicic acid depletion and nitrate excess in the polar front towards the higher latitude is in agreement with the earlier reports^{15,19}.

Physico-chemical characteristics and planktic foraminiferal abundance

The planktic foraminiferal abundance, in general, appears to be affected by the average pH conditions in the study area and the regions of increased planktic foraminiferal abundance coincide with comparatively alkaline pH (Figs 6 & 7). The prominent low planktic foraminiferal abundance at ~30° S latitude probably arises due to the dissolution of majority of the foraminiferal tests at this station as the sample lies below the reported lysocline around the study area²¹⁻²².

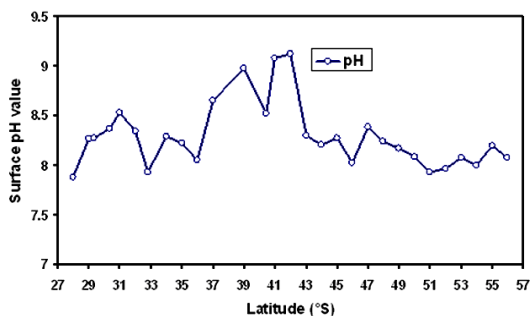


Fig. 6—The variation of surface seawater pH along the transect.

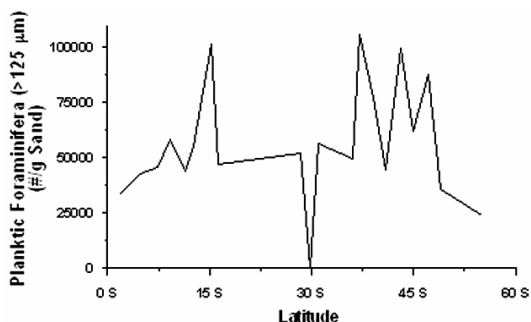


Fig. 7—Planktic foraminiferal (>125 μm) abundance/g sand fraction along the transect.

Conclusions

The trend of nutrients confirms the various frontal areas from subantarctic region along the east meridian upto 56° S latitude, which is in corroboration with the published physical oceanographic results. The nutrient data along with dissolved oxygen values at each location provides clues to understand the productivity change in the study region. The pH and dissolved oxygen data shows good correlation for different water masses and their mixing zones along the cruise track. The first order observation shows significant effect of seawater nutrient concentration and pH on the planktic foraminiferal abundance in the southwestern Indian Ocean. Though the data provides only a seasonal picture of the physico-chemical characteristics of the seawater in the study region, it significantly corroborates the recent report of physical oceanographic parameters for the identification of the water masses of this region.

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