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Suspended Particulate Matter In Southern Ocean – An Approach To Understand Source And Processes

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The Southern Ocean, also known as Antarctic Ocean or the South Polar Ocean is the fourth largest of the world's five oceans. It encompasses roughly 20.3 million sq. km (7.8 million sq mi) in area. Geologically the Southern Ocean is the youngest of the world's oceans. It formed around 30 million years ago when Antarctica and South America moved apart. It has several seas, the most oceanographically distinctive of which are the Ross and Weddell seas. It is considered as a crucial area in the contemporary cycle of matter.

Two major sources responsible for supply of particles to the ocean are biogenic particles formed as a result of planktonic metabolism and Lithogenic particles, mostly clay and rock detritus, transported from continents by rivers, coastal erosion and wind. Also, as a result of resuspension of sediments, a large volume of lithogenic particles is transferred within the interior of the ocean. The mass concentrations of suspended particulate matter (SPM) in the ocean vary in different regions and at different depths due to various biotic and abiotic factors and depend on the geographical location, its productivity and the dynamics of its water masses. The knowledge on the distribution of SPM is an important prerequisite for the description and prediction of the ecological conditions. The SPM in the water column regulates the penetration depth of light and therefore it is an important parameter influencing primary productivity. Suspended barite is being used as a tracer of biological activity in Southern Ocean. Elemental chemistry of SPM will help us in understanding source of matter. The fundamental physical and chemical properties of water will vary depending on the type and origin of SPM.

So far India through NCAOR of MoES, launched four expeditions in the

Indian sector of the Southern Ocean during January - March 2004, January - April 2006, January - April 2009 and January - March 2010 and fifth one is presently on for January - April 2011. We from the Department of Marine Sciences of Goa Universality are part of all the expeditions except for the first one. Our studies on SPM and its chemistry have given interesting results. The observed variations in SPM were attributed to changes in productivity and/or to the difference in source of matter. In order to understand climatic changes through the study of Southern Ocean continuous and long term monitoring is essential. It is therefore proposed to be part of future Southern Ocean expeditions. We also propose to collect sediment cores to support our studies on past climate changes.

The Southern Ocean is the fourth largest of the world's five oceans as it encompasses roughly 20.3 million sq. km (7.8 million sq mi) in area and is also known as Antarctic Ocean or the South Polar Ocean. Southern Ocean surrounding the Antarctic continent due to its dynamic nature played a key role in the long term global paleo-environmental evolution (Kennett and Barron, 1992). Further, coastal waters of Antarctic continent along the periphery of Southern Ocean play a crucial role in climatic change especially that related to ocean-ice system response to global warming, carbon sequestration due to bottom water formation and biological productivity (Davis and McNider, 1997). Southern Ocean receives nutrient input from the Antarctic Circumpolar Current (ACC) which provides pathway between the major ocean basins and has a vital role in global distribution of salt, heat nutrient etc (Peterson and White, 1998). Suspended Particulate Matter (SPM) in the water column regulates the penetration of light and therefore it is an important parameter influencing the primary productivity. Various processes such as biological activity, lithogenic inputs through melting of ice, submarine volcanic activity, hydrothermal and extraterrestrial inputs determine the composition of SPM.

Research in the Southern Ocean underlines the sensitivity of the region to climate variability and its importance in understanding climate change. Southern ocean is also important in the context of global biogeochemical cycling because it contains sites of deep water convection and also because its surface waters contain a large pool of unutilized nutrients, presumably due to the limitation of biological productivity by low dissolved iron levels (Pandey *et al.*, 2006). In our attempt therefore, an effort is being made to investigate the distribution of SPM and its components to understand the source and processes operating in the region.

Methodology

a. Study area - The Southern Ocean is characterized by three different zones representing Sub Tropical (28^0 – 43^0 S), Sub- Antarctic (43^0 – 59^0 S) and Antarctic (59^0 S onwards). The Antarctic Zone of the Southern Ocean is largely covered for most of the year by sea ice and is isolated from human induced activities. It is dominated by several frontal zones i.e. Sub-Tropical Front (STF), the Sub Antarctic Front (SAF); the Polar Front (PF); and a deep-reaching front observed persistently to the south, the Southern Antarctic Circumpolar Current Front (SACCF). The larger variation in environmental forcing parameters of Southern Ocean is the result of these Frontal Zones and in turn influence global climate.

b. Field Methods - During the expeditions, five litres of surface water samples were collected at one degree interval from 28°S to 66°S of Indian sector of Southern Ocean representing three zones i.e. Sub Tropical, Sub- Antarctic and Antarctic in 2006, 2009 and 2010 (Fig.1). In addition, water samples were also collected from four different depths i.e. 100 m, 200 m, 500 m and 1000 m using rosette sampler at selected locations. The water samples were stored in acid washed pre cleaned plastic containers to avoid metal contamination.

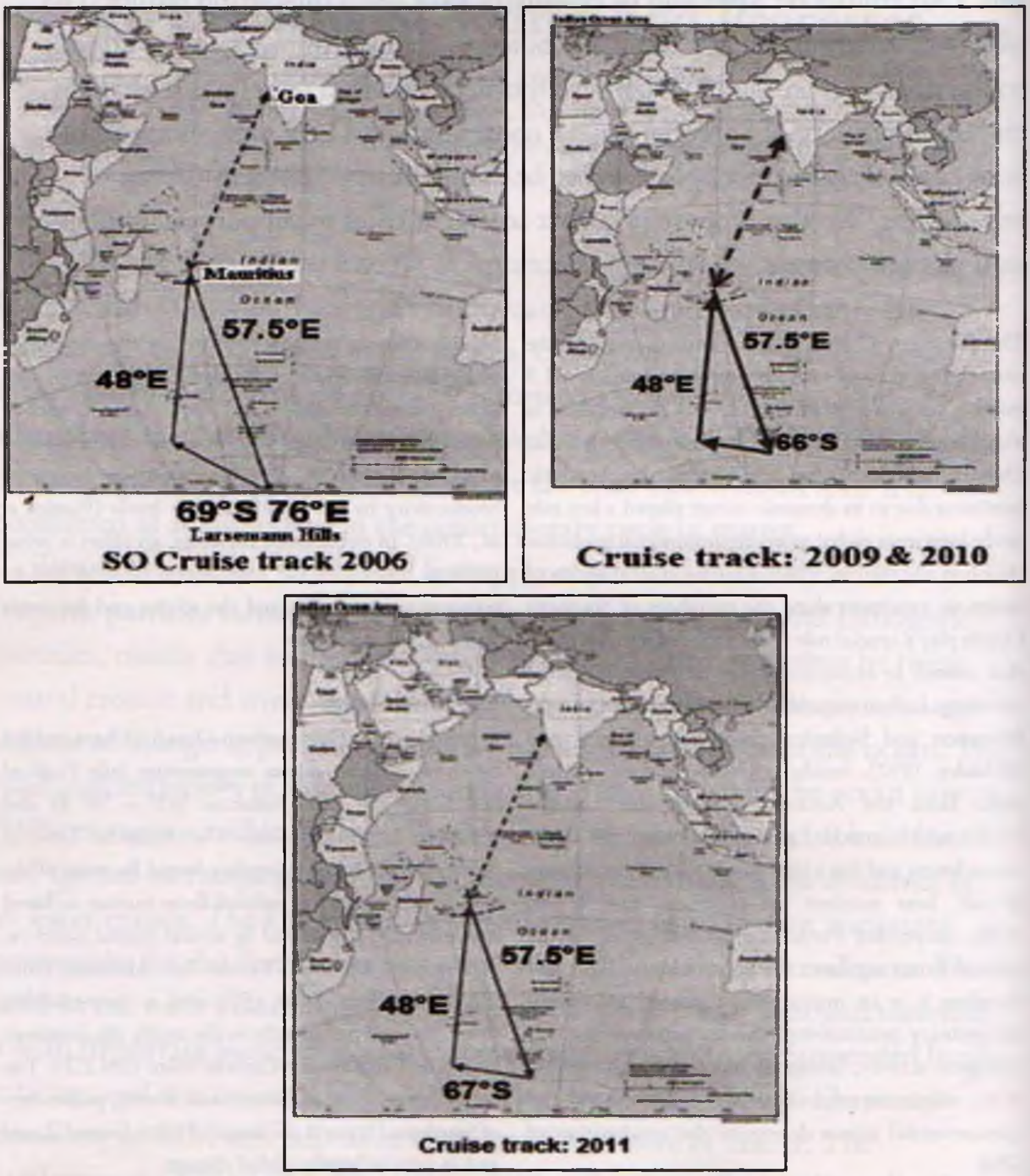

Figure 1: Cruise tracks of 2nd (2006), 3rd(2009), 4th(2010) and 5th(2011) expeditions

c. Laboratory analyses - Samples were analyzed, in the laboratory, for the following parameters: Salinity and Suspended Particulate Matter (SPM) onboard and SPM constituents and Particulate metals in the laboratory on land.

i) Salinity: Salinity was measured by using Autosal in which the readings of the collected water samples both at surface and depth were directly noted.

ii) SPM: A known volume of water sample (5 litres) was vacuum filtered through pre-weighed millipore membrane filter having a pore size of 0.45 µm. The filter paper was then oven dried at 600 C and reweighed on the four-decimal balance. Suspended Particulate Matter (SPM) concentration was then calculated using the sample volume and sample weight. SPM was expressed as mg/l.

iii) SEM photographs: Sample preparation for SEM photography was done by taking a portion of the dried filter paper containing suspended particulate matter which was mounted onto a stub coated with platinum in a sputter coater. SEM photographs were obtained by using model JEOL 6360. SEM uses a beam of electrons to scan the surface of a sample to build a three-dimensional image of the specimen. In order to take better resolution image, the SEM was operated at an accelerating voltage range, 6 kv. Low magnification (1000-2000X) was used for a quick overview of the sample. For selected particle, magnification was increased (3000-11000X) and a photograph was taken. Five images for each selected samples were digitally captured and among these best ones were chosen for analysis.

iv) Digestion of SPM and metal analysis: Digestion of filter papers containing suspended particulate matter of the water samples collected at both surface and depth was carried out using following procedure given by (Satyanarayana *et al.*, 1985). The digested samples were analyzed for selected elements using Atomic Absorption Spectrophotometer (VARIAN – AA 240 FS model) equipped with deuterium background corrections. Blank corrections were applied for all the metals.

Results And Discussion

The range and average values of SPM in surface water samples from 28^0 S up to 66^0 S representing Sub-Tropical, Sub – Antarctic and Antarctic zones are been displayed in the Table 1.

SUSPENDED MATTER IN SOUTHERN OCEAN

2006

SAMPLING ZONES	SUBTROPICAL ZONE 28 - 43°S	SUBANTARTIC ZONE 43 - 59°S	ANTARTIC ZONE 59 - 66°S
TSM RANGE (mg/l)	5.20 – 6.70	2.30 – 5.95	0.70 – 7.05
AVERAGE (mg/l)	5.71	4.60	4.10

2009

TSM RANGE (mg/l)	0.52 – 7.56	0.52 – 2.68	0.96 – 3.36
AVERAGE (mg/l)	3.20	1.60	2.43

2010

TSM RANGE (mg/l)	6.62 – 9.22	5.78 – 8.02	6.10 – 7.06
AVERAGE (mg/l)	7.95	6.72	6.60

Table 1: Ranges and Average values of suspended matter concentration in surface water samples along the study stretch in year 2006, 2009 and 2010.

In the Sub tropical zone SPM values fluctuated between 5.2 and 6.7 mg/l during the year 2006, 0.52 and 7.56 mg/l in the year 2009 and 6.62 and 9.22 mg/l during the year 2010. SPM showed less variation during 2006 (Fig.2a), overall decrease trend during 2009 (Fig.2b) with few peak values. However during 2010 (Fig.2c), the values showed initial increase up to 330 and then decrease from 280 to 330. This indicates overall decreasing trend towards 43° S with fluctuating higher values.

In the Sub – Antarctic zone, SPM varied from 2.3 to 5.95 mg/l during the year 2006, 0.52 to 2.68 mg/l during 2009 and 5.78 to 8.02 mg/l during 2010. The values showed almost a constant trend from 43° S up to 54° S followed by alternate high decreasing and increasing concentration up to 59° S during the year

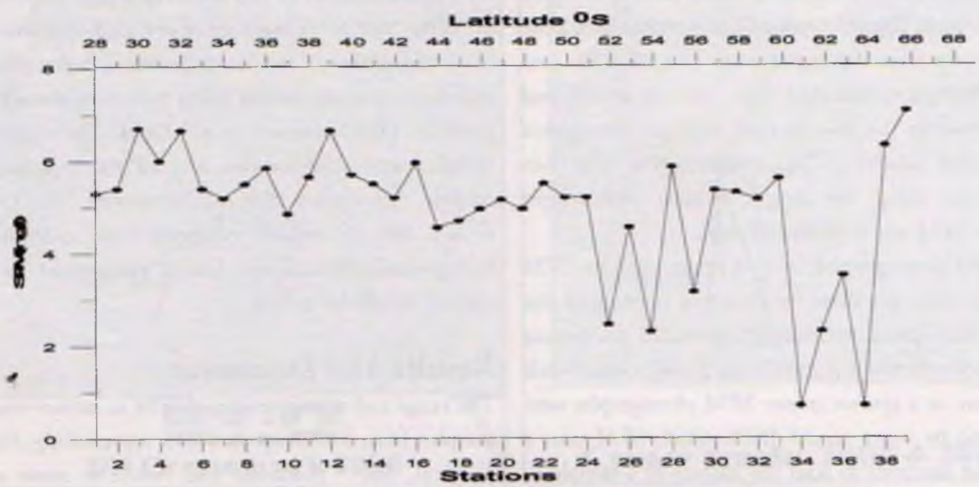

Figure 2a: Concentration and distribution of surface SPM along the studied stretch in 2006.

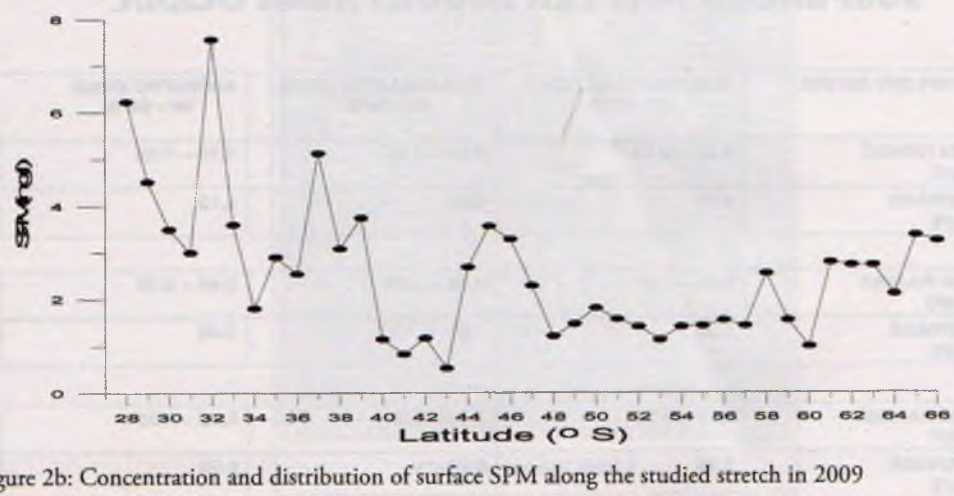

Figure 2b: Concentration and distribution of surface SPM along the studied stretch in 2009

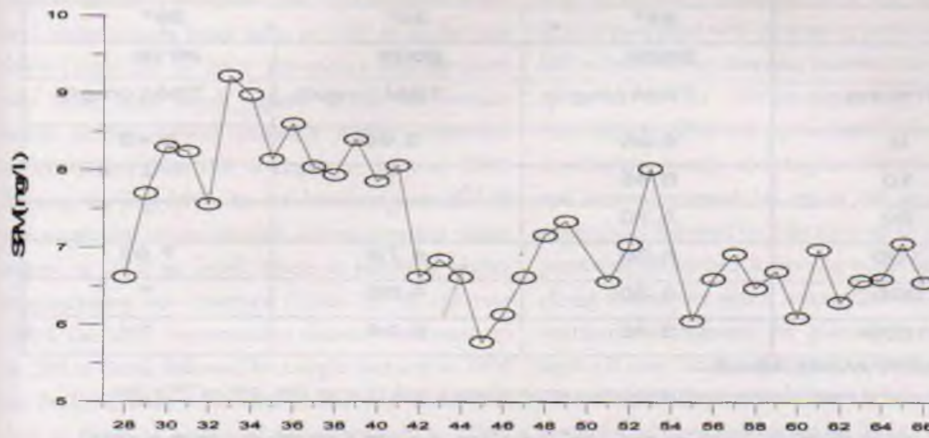

Figure 2c: Concentration and distribution of surface SPM along the studied stretch in 2010.

2006 (Fig. 2a). In the year 2009 (Fig. 2b), significant increase between 43⁰ S up to 45⁰ S is noted followed by a decrease up to 48⁰ S. Further an almost constant trend is observed up to 59⁰ S except a minor peak observed at 58⁰ S. In the year 2010 (Fig. 2c), alternate decreasing and increasing trend is noted between 43⁰ S to 59⁰ S except significant peak value is noted at 53et al. The values remained low during 2009 as compared to 2006 and 2010.

In the Antarctic zone, during the year 2006 the value varied from 0.7 to 7.05 mg/l, during 2009 it was between 0.98 and 3.36 mg/l and in 2010 it was from 6.1 to 7.06 mg/l, maintaining very high values during 2010 and lower during 2009 and during 2006 with a large range. In 2006 (Fig.2a) very high fluctuating values are seen with comparatively lower SPM concentration observed at 63⁰ S and 66⁰ S. In the year 2009 (Fig.2b), overall gradual increasing trend is noted in this zone. In the year 2010 (Fig.2c), fluctuating trend with minor variations but high values of SPM is observed.

When data of the three years are compared, in case of Sub – Tropical zone, Sub – Antarctic zone and Antarctic zone it is been observed that higher average values of SPM is noted in the year 2010 followed by 2006 and lower values during 2009 indicating yearly fluctuation in SPM in all the three zones. Higher variation in values reveals dynamics of the zones (Queguiner *et al.*, 1997; Baldwin and Smith, 2003) and variation in supply of source material (Thamban *et al.*, 2005) and processes including productivity (Pasquer, *et al.*, 2010).

Variation with Depth - In Sub – Tropical zone, when the data of the three years i.e. 2006, 2009 (35⁰ S) and 2010 (39⁰ S) with respect to depth are compared (Table 2a). In 2006, the SPM showed not much variation with depth except at 10 m where in slightly higher value is noted. In 2009, the SPM showed increasing values with depth while in 2010 surface concentration was higher than 100 m.

DEPTH PROFILE (SUBTROPICAL ZONE)

	36°	35°	39°
	2006	2009	2010
DEPTH (m)	TSM (mg/l)	TSM (mg/l)	TSM (mg/l)
0	5.65	2.90	8.40
10	6.45	*	*
50	5.70	*	*
100	5.30	4.70	7.97
200	5.20	4.56	*
1000	5.65	5.34	*

* DATA NOT AVAILABLE

Table 2a: Ranges values of suspended matter concentration in water samples collected at depth 35° in year 2006, 2009 and 39° in 2010.

DEPTH PROFILE (SUBANTARTIC ZONE)

	43°	43°	43°
	2006	2009	2010
DEPTH (m)	TSM (mg/l)	TSM (mg/l)	TSM (mg/l)
0	4.29	0.52	5.84
10	4.55	*	*
50	4.25	*	*
100	4.00	1.16	4.74
200	4.16	1.72	*
1000	2.25	1.52	*

* DATA NOT AVAILABLE

Table 2b: Ranges values of suspended matter concentration in water samples collected at depth 43° in year 2006, 2009 and 2010

DEPTH PROFILE (ANTARCTIC ZONE)

	65°	59°	66°
	2006	2009	2010
DEPTH (m)	TSM (mg/l)	TSM (mg/l)	TSM (mg/l)
0	4.00	3.36	7.06
10	4.53	*	*
50	4.20	*	*
100	4.00	3.22	6.92
200	4.60	1.96	*
1000	5.30	2.86	*

* DATA NOT AVAILABLE

Table 2c: Ranges values of suspended matter concentration in water samples collected at depth 65° in year 2006, 2009 and 59° in 2010.

In Sub - Antarctic zone (43^0 S), SPM concentration showed almost a constant trend up to 200 m depth and comparatively lesser value at 1000 m in the year 2006 (Table 2b). In 2009, the surface concentration was lesser than depth values. While the surface water sample showed relatively higher suspended concentration than 100 m depth in the year 2010. During the year 2006, in the Antarctic zone (65^0 S) the suspended matter showed almost constant values except at 1000 m depth where in relatively higher concentration was observed (Table 2c). In the year 2009, the SPM concentration showed a decrease up to 200 m depth followed by a slight increase at 1000 m. In 2010, lesser suspended matter was observed at 100 m depth as compared to surface values. When yearly data of the three zones were compared it has been observed that higher SPM concentration is seen in the year 2010 at surface and 100 m depth followed by 2006 and with relatively lower value during 2009.

Distribution of SPM and associated particulate Fe - In the Sub – Tropical Zone i.e. 35^0 S, SPM showed increase up to 100 m and Fe decreasing trend up to 200 m depth followed by constant trend in deeper zones (Fig. 3). In Sub – Antarctic Zone (43^0 S), increasing SPM is associated with decreasing particulate Fe up to 100 m followed by alternate increase and decrease i.e. up to 200 m and 1000 m respectively. In Antarctic Zone (65^0 S), SPM and particulate Fe showed similar distribution pattern showing an alternate decreasing and increasing trend i.e. up to 100 m and 200 m respectively followed by a decrease up to 1000 m. The particulate Fe showed decreasing values up to 100 m in all the three zones which reveals that it being a micro nutrient it is essential for primary productivity in euphotic zone. Sources of iron in near shore Antarctic waters include inputs from iron-rich sediments and iron released from melting sea ice (Martin *et al.*, 1990) might have resulted higher Fe beyond 100 m depth at 43^0 S and 65^0 S.

Components of SPM - SEM photographs of suspended matter largely show lithogenic (Plate 1) and biogenic (Plate 2) components. The biogenic components are largely dominated by Fragilariopsis sp.

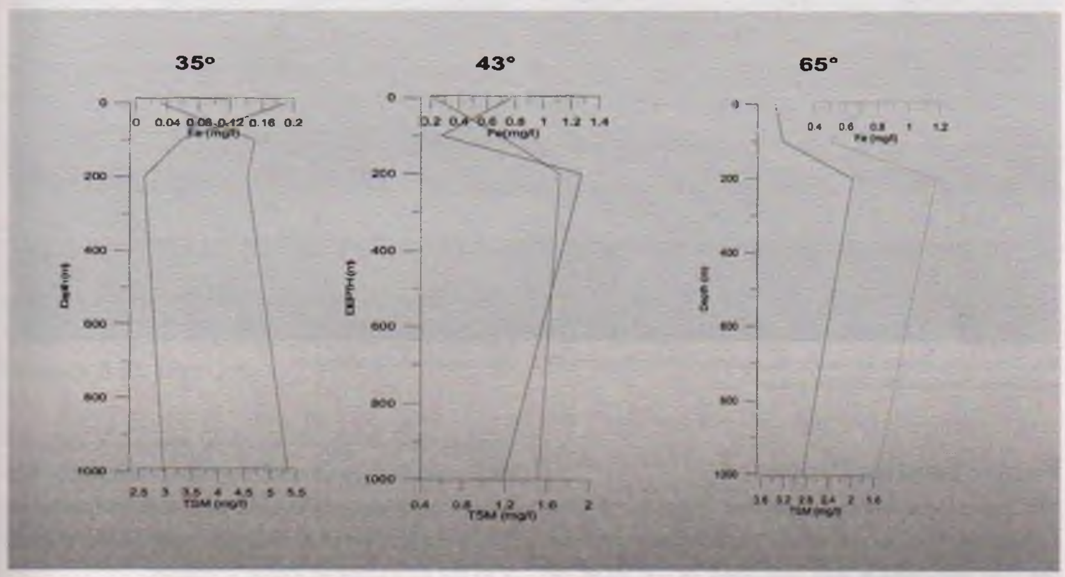

Figure 3: SPM and Iron distribution with depth

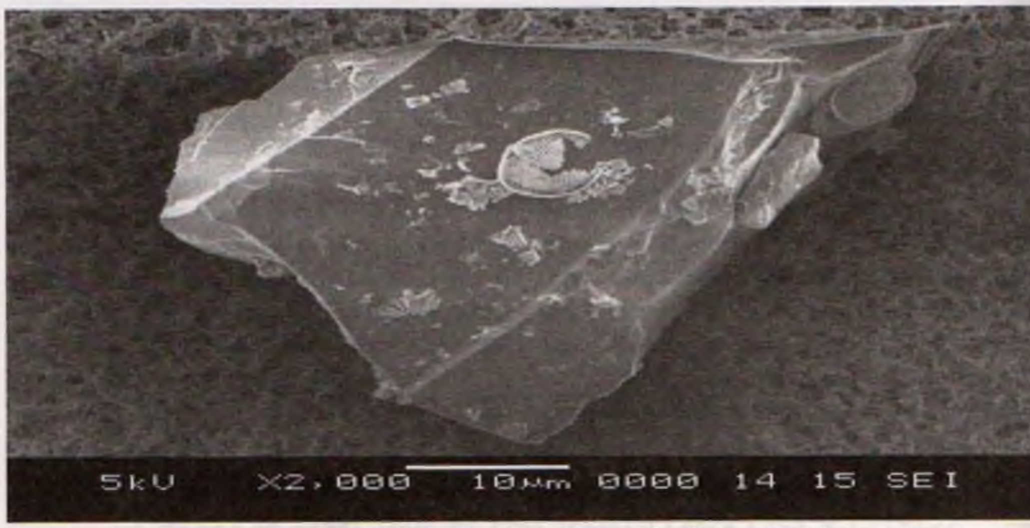

Plate 1. Scanning electron microscope photograph of SPM collected at 40° S. SPM consists of angular inorganic particle.

Plate 1. Scanning electron microscope photograph of SPM collected at 4C consists of angular inorganic particle.

Plate 2. Scanning electron microscope photograph of SPM collected at 69° S. SPM consists mainly of biogenic components dominated by Fragilariopsis sp.

Future Studies Proposed

We from Department of Marine Sciences of Goa Universality are part of all the expeditions except for the first one, which was organized by NCAOR of MoES, in the Indian sector of the Southern Ocean during January - March 2004, January - April 2006, January - April 2009 and January - March 2010 and fifth one is presently on for January - April 2011. Our studies carried out on SPM and its chemistry has given interesting results. The observed variations in SPM were attributed to changes in productivity and/ or to the difference in source of matter.

In order to understand climatic changes through the study of Southern Ocean continuous and long term monitoring is very much essential. It is therefore proposed to be part of future Southern

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