MAUSAM, **62**, 4 (October 2011), 659-664

551.583.7 : 551.326.7 (292.32)

Comparison of modern and fossil diatom assemblages and their implication on sea-ice conditions in coastal Antarctic region

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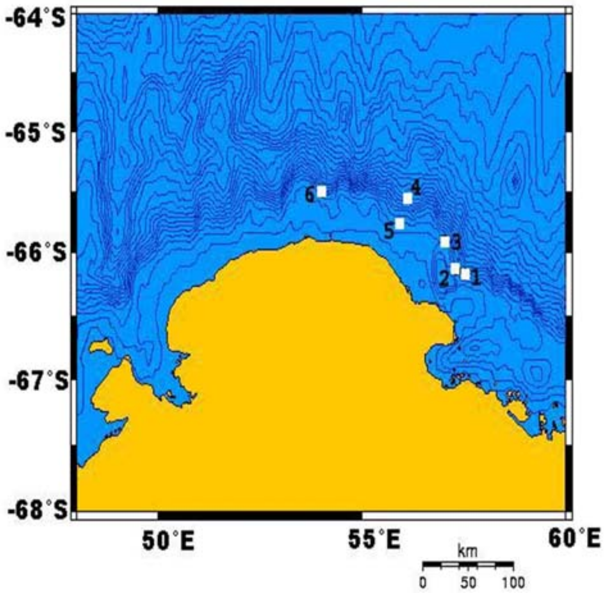
सार – प्रायः एंटार्कटिक तटीय क्षेत्र द्विआणविकों की बहुलता के कारण उच्च उत्पादकता के लिये विशेष रूप से जाने जाते हैं। भूमंडलीय कार्बन जैव पम्प में उनकी प्रमुख महत्ता को देखते हुए डायेटम वितरण एवं बहुलता अध्ययनों को एंटार्कटिका के तटीय क्षेत्रों में विशेष रूप से सम्पादित किया गया। जैव उत्पादित सिलिका भीतरी संतृप्त महासागरीय जल में विघटन द्वारा गम्भीर रूप से प्रभावित पाई गई है, इसलिए जल स्तम्भ तथा तलछटों में पाये जाने वाले डायेटम सचयनों का संयुक्त अध्ययन करना महत्वपूर्ण है। फलतः, तटीय एंटार्कटिका से एकत्रित सतही जल डोयटमों के साथ–साथ तलछट डोयटमों का संयुक्त अध्ययन किया गया। जीवाश्म अभिलेखों के साथ आधुनिक संचयनों से की गई तुलना से स्पष्ट होता है कि ग्रीष्मकालीन संचयनों के अधिकांश महत्वपूर्ण डायेटम निचले तलछटों में परिरक्षित नहीं हुए हैं। अध्ययन दर्शाते हैं कि मात्र *एफ. करग्यूलमनसिस* जल तथा तलछट दोनों ही में मिलने वाली आम बहुल प्रजाति है, इससे पता चलता है कि तटीय एंटार्कटिक क्षेत्र में अपेक्षाकृत अधिक खुला महासागरीय प्रभाव है। इसके विपरीत, सतही तलछटों में मिलने वाली समुद्री हिम संबंधी डायेटम प्रजातियों की उपस्थिति समुद्र हिम विस्तार या जल स्तम्भ से संलग्न हिम किनारों में प्रदर्शित हुई है, जबकि संभवतः निम्न समुद्र हिम विस्तार के कारण ऊपर की ओर मिलने वाल जल प्रादर्शों में ये प्रजातियाँ नही पाई गई हैं।

ABSTRACT. Antarctic Coastal regions are thought to be characterized by high productivity usually dominated by diatoms. Considering their prime importance in global carbon biological pump, diatom distribution and abundance studies are sparse especially in coastal regions of Antarctica. Biogenic silica is considered to be severely affected by dissolution in the undersaturated ocean water, therefore, combined study of diatom assemblages from water column and those found in the sediments is important. Therefore, we conducted a combined study of sediment diatoms along with surface water diatoms collected from Coastal Antarctica. When the modern assemblages are compared to the fossil record, it is clear the most of the important diatoms from the summer assemblages are not preserved in the underlying sediments. The studies reveal that only *F. kerguelensis* is common abundant species in both water and sediment which suggests that coastal Antarctic region could be having more open ocean influence. In contrast, the presence of sea ice related diatom species from surface sediment indicate for expansion of sea ice or ice edge adjacent to the water column, however such species were not found in the overlying water samples which could be due to less sea-ice extent.

Keywords – Costal Antarctica, Indian Ocean Sector, Modern diatoms, Fossil diatoms.

1. Introduction

The understanding of diatom abundance and assemblage composition found in the water column and sediments are helpful to figure out how diatoms are preserved in the sediments and how modern environmental conditions have modulated their abundance and distributions (Pokras and Molfino, 1986; van Iperen *et al*., 1987; Abrantes and Moita, 1999). Biogenic silica is thought to be severely affected by dissolution in the undersaturated ocean water (Nelson *et al*., 1995; Ragueneau *et al*., 2000), therefore, combined study of diatom assemblages from water column and those found in the sediments is essential (Sancetta and Calvert, 1988; Romero *et al*., 2000; Koning *et al*., 2001). The Antarctic Coastal and continental shelf zones are characterized by high degree of phytoplankton growth dominated by diatoms, therefore, account for 76% and 3.5% of the total primary productivity of the marginal ice zone and Southern Ocean (SO) respectively, as a result considered among the most productive regions of SO (Smith and Gordon, 1997; Arrigo *et al*., 2008). Instead of their prime importance in the global carbon biological pump (*i.e*., the amount of carbon removed from the atmosphere and permanently buried in the sediment) and related atmospheric pCO_2 modulations (Longhurst and Harrison, 1989; Nelson *et al*., 1995), combined studies on fossil and modern diatom assemblages are rare and carried out from



STATION No.	Latitude	Longitude
1.	66°10'S	57°31'E
2.	66°08'S	57°18'E
3.	65°54'S	57°02'E
4.	65°29'S	55°56'E
5.	65°44'S	55°45'E
6.	65°30'S	54°E

Fig. 1. Sampling locations of surface water and surface sediment samples. (Figure adopted from Mohan et al., 2011)

Ross Sea (Truesdale and Kellogg, 1979; Cunningham and Leventer, 1998), Atlantic Sector of SO (Zielinski and Gersonde, 1997), Southwest Atlantic Ocean (Olguin *et al*., 2006) and western Antarctic Peninsula shelf (Pike *et al*., 2008). To date very few attempts have been made to understand the distribution of phytoplankton (diatoms) in Indian Sector of the SO (Fiala *et al*., 1998a,b, 2002; Gomi *et al*., 2005, 2007, 2010) but these studies were mainly from open ocean not from coastal regions. Recently Mohan *et al*., 2011 have described surface sediment diatoms from enderby basin of Indian Sector of SO, hence, our attempt is to compare those sediment diatoms with surface water diatoms to asses how diatoms are incorporated on the seabed and how environmental conditions regulated their abundance, distribution and preservation in coastal Antarctica.

2. Regional Settings

The Indian Sector of SO comprises different oceanographic fronts (Orsi *et al*. 1995; Anilkumar *et al*. 2005). The coastal Antarctic region in Indian Sector of SO named as Enderby Basin which starts from 60°S onwards to Antarctica just after the Winter Sea Ice Limit. The detailed oceanography has been described by Park *et al*. (1991, 1998), Park and Gambéroni (1995, 1997), Charrassin *et al*. (2004) and Park *et al*. (2008a,b). Antarctic surface water is characterized by an irregular spatial distribution of mixed layer with a number of low and high salinity patches (Park *et al*., 1998). During late austral summer, melting/freezing processes are more predominent in Indian Sector of the Southern Ocean, from 63°S onwards towards Antarctica (Archambeau *et al*. 1998).

3. Materials and methods

Sampling was performed during third Indian Scientific Expedition to Southern Ocean during March 2009 onboard *R/V Akademik Boris Petrov*. Surface sediment samples were collected using (Petterson grab sampler whereas surface water samples particularly for diatoms were collected (Fig. 1 for location) using 10 µm multiple plankton net (Hydrobios, Kiel, Germany) and the samples were preserved in 10% buffered formaldehyde solution. Assemblage composition of diatoms were determined using a Nikon microscope following the technique described by Uthermöhl (1958). Sediment treatment, slide preparations and diatom analysis were carried out following the method proposed by Schrader and Gersonde (1978).

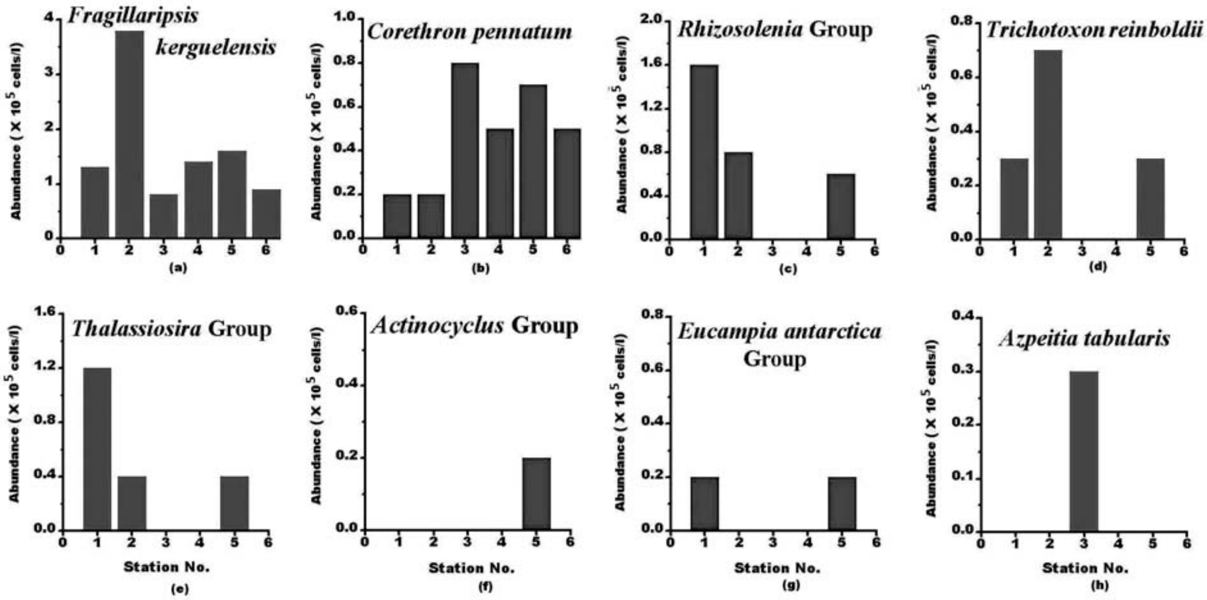
4. Results

4.1. *Diatom assemblages in the surface water*

On an average diatom abundance varies between 1.4×10^5 to 5.9×10^5 cells L^{-1}. The maximum concentration of 5.9×10^5 cells L^{-1} was recorded at station 2 while minimum concentration of 1.4×10^5 L^{-1} was at station 6. Diatoms were represented by *Fragilariopsis kerguelensis, Corethron pennatum, Rhizosolenia* group, *Trichotoxon reinboldii, Thalassiosira* group, *Actinocyclus* group, *Eucampia Antarctica* group and *Azpeitia tabularis* been the most abundant species or species groups.

F. kerguelensis was most dominant taxa accounting in range of 0.8×10^5 to 3.8×10^5 cells L^{-1}. Its maximum abundance of 3.8×10^5 cells L^{-1} (64.41%) was reported at station 2 whereas minimum abundance of 0.8×10^5 cells L^{-1} (42.11%) was at station 3. [Fig. 2(a)].

Corethron pennatum was second most abundant diatom which was present at all stations after *F. kerguelensis*. Its concentration ranged between 0.2×10^5 to 0.8×10^5 cells L^{-1}. The maximum



Figs. 2(a-h). Concentration of diatom assemblages in cells L^{-1} from surface waters: (a) *Fragilariopsis kerguelensis* (b) *Corethron pennatum* (c) *Rhizosolenia* group (d) *Trichotoxon reinboldii* (e) *Thalassiosira* group (f) *Actinocyclus* group (g) *Eucampia antarctica* group and (h) *Azpeitia tabularis*

TABLE 1

Relative abundance of fossil diatom species marked with their presence at stations (1-6)

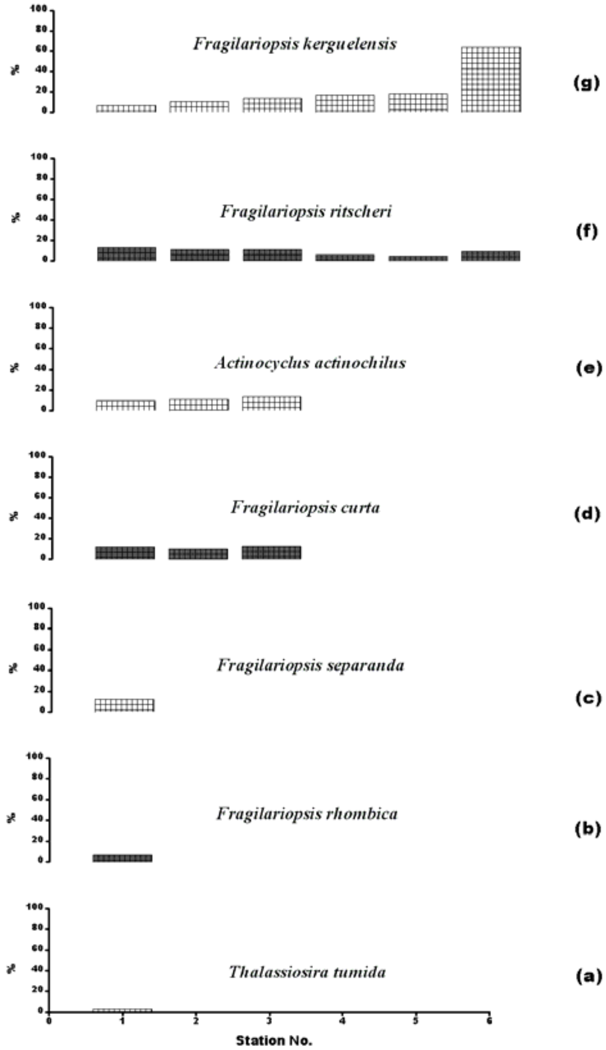
S. No.	Diatom species	Relative abundance	Minimum	Maximum
1.	*Fragilariopsis rhombica*	6.25%	-	Station 1
2.	*Fragilariopsis separanda*	12.5%	-	Station 1
3.	*Fragilariopsis curta*	10.53 – 13.33%	Station 2	Station 3
4.	*Fragilariopsis ritscheri*	9.09 – 12.5%	Station 6	Station 1
5.	*Actinochilus actinochilus*	9.38 – 13.33%	Station 1	Station 3
6.	*Thalassiosira tumida*	3.13%	-	Station 1
7.	*F. kerguelensis*	6.25 – 63.64%	Station 1	Station 6

concentration of 0.8×10^5 cells L^{-1} (42.11%) was at station 3 while minimum concentration of 0.2×10^5 cells L^{-1} was at stations 1 and 2 (4.17% and 3.39% respectively). [Fig. 2(b)].

Rhizosolenia group and *Thalassiosira* group were present only at 3 stations and their concentrations were 0.5×10^5 to 1.6×10^5 cells L^{-1} and 0.4×10^5 to 1.2×10^5 cells L^{-1} respectively [Figs. 2(c&e)]. The maximum concentration (1.6×10^5 cells L^{-1}, 33.33%) of *Rhizosolenia* group was at station 1 while its minimum concentration (0.5×10^5 cells L^{-1}, 13.51%) was at station 5. *Thalassiosira* group was maximum (1.2×10^5 cells L^{-1}, 25%) at station 1 whereas minimum 0.4×10^5 cells L^{-1} at station 2 and 5 (6.78% and 10.81% respectively).

Trichotoxon reinboldii was encountered only at three stations and its concentration ranged between 0.3×10^5 to 0.7×10^5 cells L^{-1} with a maximum concentration at station 2 (11.86%) while minimum at station 1 and 5 (6.25% and 7.69% respectively). [Fig. 2(d)].

Actinocyclus group was present only at station 5 and its concentration was 0.2×10^5 cells L^{-1} (5.12%). [Fig. 2(f)].



Figs. 2(a-g). Relative abundances of diatom assemblages from surface sediment: (a) *Thalassiosira tumida* (b) *Fragilariopsis rhombica* (c) *Fragilariopsis separanda* (d) *Fragilariopsis curta* (e) *Actinocyclus actinochilus* (f) *Fragilariopsis ritscheri* (g) *Fragilariopsis kerguelensis*. (adopted from Mohan *et al*., 2011)

Eucampia antarctica group was present only at station 1 and 5 with concentration of 0.2×10^5 cells L^{-1} [Fig. 2(g)] (4.17% and 5.13% respectively) whereas *Azpeitia tabularis* was only present at station 3 with concentration of 0.3×10^5 cells L^{-1} [Fig. 2(h)] (15.79%).

4.2. *Diatom assemblages in the surface sediment*

The distribution pattern of diatom abundance in surface sediments ranged between 1.1×10^4 (station 6) and 3.2×10^4 (station 1) valves/g. Diatom community comprised *Fragilariopsis rhombica*, *Fragilariopsis separanda*, *Fragilariopsis curta*, *Fragilariopsis ritscheri*, *Actinochilus actinochilus*, *Thalassiosira tumida* and *F. kerguelensis* as described by Mohan *et al*., 2011. The relative abundance of these diatom species were calculated and shown in Fig. 3 and Table 1.

5. Discussion

This study compares one set of summer surface water diatoms with the diatom fossil records. Mohan *et al*., (2011) investigated the diatom assemblages retrieved from surface sediment samples. From the same sample location we investigated surface water diatom distribution and abundance which allowed comparison of surface water *versus* sedimentary diatom data. They identified seven diatom species of which six species were sea-ice related species (*F. rhombica*, *F. separanda*, *F. curta*, *F. ritscheri*, *A. actinochilus* and *T. tumida*) and only *F. kerguelensis* was open ocean species, however, our plankton diatoms are much different from those species except for the presence of *F. kerguelensis*, genera *Thalassiosira* and *Actinocyclus* (for these genera we have considered species groups due to their lower abundances).

F. kerguelensis was dominant taxa in both water and sediments which indicates that studied area is under the influence of more open ocean conditions as *F. kerguelensis* is an indicator of open water production and negatively correlated with sea ice concentration (Burckle and Cirilli, 1987). Other species of *Fragilariopsis* (*F. curta, F. rhombica*, *F. separanda*, and *F. ritscheri*), *A. actinochilus* and *T. tumida* are sea ice related species and associated with melting sea ice and surface water stratification, therefore, their high abundances reported in the water column next to the ice edge. The presence of these species in the surface sediments indicates that studied area was under the influence of long sea ice season and significant expansion of stratified water at the ice edge (Armand *et al*., 2005). However, these species were absent from surface water diatoms and characterized by typical coastal Antarctic diatom species. The presence of *Eucampia antarctica* in surface water diatom community which is a neritic diatom (Froneman *et al*., 1995), occurring in association with sea ice and ice berg melt areas (Burckle, 1984) further argue for presence of ice edge which was close to water column. Although, there are marked differences in surface water diatoms and surface sediment diatom assemblages, but sedimentary diatom are mainly characterized by summer diatom assemblages rather than the spring assemblages. Our results are consistent with the findings of other workers (*e.g.*, Zielinski and Gersonde, 1997; Olguín, *et al*., 2006; Pike *et al*., 2008).

The comparison of surface water diatoms and surface sedimentary diatom assemblages allowed us to infer that there is complete disagreement between the species of diatoms except for *F. kerguelensis* which is the most abundant species in both planktonic and sedimentary material as this species is heavily silicified and having high preservation potential (Crosta *et al*., 2005). The other diatom which are present in the surface water but not in the sediments might have undergone selective dissolution as also reported earlier (Romero and Hensen, 2002). The other reasons could lateral advection of water masses, sediment redistribution and spatial variations in the preservation of silica frustules which affected the siliceous signal produced in overlying water and its burial in underlying sediments (Nelson *et al*., 1995). On the other hand, diatoms those were present in the sediments but not in the water column can be explained in such a way that sediment deposition is an average of many years including several time seasons rather than seasonal and seasonal variability plays important role in mismatching patterns (Boltovskoy, 1970).

6. Conclusions

The investigations show that diatom assemblages from surface water and surface sediment collected from coastal Antarctic region are much different. Only *F. kerguelensis* is common abundant species among both type of samples (water and sediment) which suggests the coastal region could be having more open ocean influence rather than sea-ice extent. Contrary to it, presence of sea ice related species from surface sediment argue for expansion of sea ice or ice edge adjacent to the water column, however those were absent from water samples. In order to establish the open ocean influence it is essential to deploy moorings with sediment traps for time series data and sample collection, which would be the first such attempt in the coastal Antarctic region within the Indian Sector of the Southern Ocean. Such a long term data collection would be useful to investigate into the boundary conditions of sea-ice extent during austral summer and winter seasons which may also provide clues to understand the influence of climate change in coastal Antarctica and Southern Ocean.

Acknowledgements

We are thankful to Secretary, Ministry of Earth Sciences and Director, NCAOR for funding support. Dr. S. M. Pednekar, the Scientific team, Master and crew onboard R.V. Boris Petrov is acknowledged for their support in data collection during the Expedition.

References

Abrantes, F. and Moita, T.,1999, "Water column and recent sediment data on diatoms and coccolithophorids, off Portugal, confirm sediment record as a memory of upwelling events", *Oceanol. Acta*, **22**, 319-336.

Anilkumar, N., Dash, M. K., Luis, A. J., Ramesh Babu, V., Somayajulu, Y. K., Sudhakar, M. and Pandey, P. C., 2005, "Oceanic fronts along 45°E across Antarctic Circumpolar Current during austral summer 2004", *Curr. Sci.*, **88**, 1669-1673.

Archambeau, A. S., Pierre, C., Poisson, A. and Schauer, B., 1998, "Distribution of oxygen and carbon stable isotopes and CFC- 12 in the water masses of the Southern Ocean at 30°E from South Africa to Antarctica: results of CIVA1 cruise", *J. Mar. Syst*., **17**, 25-38.

Armand, L. K., Crosta, X., Romero, O. and Pichon, J. J., 2005, "The biogeography of major diatom taxa in Southern Ocean sediments: 1. Sea ice related species", *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **223**, 93-126.

Arrigo, K. R., Van Dijken, G. L. and Bushinsky, S., 2008, "Primary production in the Southern Ocean, 1997–2006", *J. Geophys. Res*., **113**, C08004, doi: 10.1029/2007JC004551.

Boltovskoy, E., 1970, "Masas de agua (características, distribución, movimientos) en la superficie del Atlántico sudoeste, según indicadores biológicos - Foraminíferos", Serv. Hidrogr. Naval, Argentina, H **643**, 1-99.

Burckle, L. H. and Cirilli, J., 1987, "Origin of the diatom ooze belt in the Southern Ocean: implications for the late Quaternary paleoceanography", *Micropaleontol.*, **33**, 1, 82-86.

Burckle, L. H., 1984, "Diatom distribution and paleoceanographic reconstruction in the Southern Ocean - present and Last Glacial Maximum", *Mar. Micropaleontol*., **9**, 241-261.

Charrassin, J. B., Park, Y. H., Le Majo, Y. L. and Bost, C. A., 2004, "Fine resolution 3D temperature fields off Kerguelen from instrumented penguins", *Deep-Sea Res.-I*, **51**, 12, 2091-2103.

Crosta, X., Romero, O., Armand, L. and Pichon, J. J., 2005, "The biogeography of major diatom taxa in Southern Ocean sediments: 2. Open ocean related species", *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **223**, 66-92.

Cunningham, W. and Leventer, A., 1998, "Diatom assemblages in surface sediments of the Ross Sea: relationship to present oceanographic conditions", *Ant. Sci*., **10**, 2, 134-146.

Fiala, M., Semeneh, M., and Oriol, L., 1998a, "Size-fractionated phytoplankton biomass and species composition in the Indian sector of the Southern Ocean during austral summer", *J. Mar. Syst.,* **17**, 179-194.

Fiala, M., Kopczynska, E E.., Jeandel, C., Oriol, L. and Vetion, G., 1998b, "Seasonal and interannual variability of size-fractionated phytoplankton biomass and community structure at station Kerfix, off the Kerguelen Islands, Antarctica", *J. Plank. Res.,* **20**, 1341-1356.

Fiala, M., Machado, M. C. and Oriol, L., 2002, "Phytoplankton distribution in the Indian sector of the Southern Ocean during spring" *Deep-Sea Res. II,* **49**, 1867-1880.

Froneman, P. W., Perissinotto, R., McQuaid, C. D. and Laubscher, R. K., 1995, "Summer distribution of netphytoplankton of the Southern Ocean", *Pol. Biol*., **15**, 77-84.

Gomi, Y., Umeda, H., Fukuchi, M. and Taniguchi, A., 2005, "Diatom assemblages in the surface water of the Indian sector of the Antarctic Surface Water in summer of 1999/2000", *Pol. Biosci.,* **18**, 1-15.

Gomi, Y., Taniguchi, A. and Fukuchi, M., 2007, "Temporal and spatial variation of the phytoplankton assemblage in the eastern Indian sector of the Southern Ocean in summer 2001/2002", *Pol. Biol.,* **30**, 817-827.

Gomi, Y., Fukuchi, M. and Taniguchi, A., 2010, "Diatom assemblages at subsurface chlorophyll maximum layer in the eastern Indian sector of the Southern Ocean in summer", *J. Plank. Res.,* **32**, 7, 1039-1050.

Koning, E., van Iperen, J. M., Van Raaphorst, W. W., *et al.,* 2001, "Selective preservation of upwelling-indicating diatoms in sediments off Somalia, NW Indian Ocean", *Deep-Sea Res.*, **48**, 2473-2495.

Longhurst, A. R. and Harrison, W. G., 1989, "The biological pump: Profiles of plankton production and consumption in the upper ocean", *Prog. Oceanogr.*, **22**(1), 47-123, doi:10.1016/0079-6611(89)90010-4.

Mohan, R., Shukla, S. K., Patil, S. M., Shetye, S. S. and Kerkar, K. K., 2011, "Diatoms from surface sediments of Enderby Basin of Indian Sector of Southern Ocean. *J. Geol. Soc. Ind.*, **78**, 36-44.

Nelson, D. M., Tréguer, P., Brzezinski, M. A., Leynaert, A. and Quéguiner, B., 1995, "Production and dissolution of biogenic silica in the ocean: revised global estimates, comparison with regional data and relationship to biogenic sedimentation", *Glob. Biogeochem. Cyc.*, **9**(3), 359-372.

Olguín, H. F., Boltovskoy, D., Lange, C. B. and Brandini, F., 2006, "Distribution of spring phytoplankton (mainly diatoms) in the upper 50 m of the Southwestern Atlantic Ocean (30–61°S)", *J. Plank. Res.*, **28**, 12, 1107-1128.

Orsi, A. H., Whitworth III, T. and Nowlin, W. D., 1995, "On the meridonal extent and fronts of the Antarctic circumpolar current", *Deep-Sea Res.*, **42**, 5, 641-673.

Park, Y. H. and Gambéroni, L., 1995, "Large-scale circulation and its variability in the south Indian Ocean from TOPEX/POSEIDON altimetry", *J. Geophys. Res.*, **100**(C12), 24911-24924, 24929.

Park, Y. H. and Gambéroni, L., 1997, "Cross-frontal exchange of Antarctic Bottom Water in Crozet Basin", *Deep-Sea Res.-II*, **44**, 5, 963-986.

Park, Y. H., Gambéroni, L., and Charriaud, E., 1991, "Frontal structure and transport of the Antarctic Circumpolar Current in the South Indian Ocean sector, 40-80°E", *Mar. Chem.*, **35**, 45-62.

Park, Y. H., Charriaud, E. and Fieux, M., 1998, "Thermohaline structure of the Antarctic surface water/winter water in the Indian sector of the Southern Ocean", *J. Mar. Syst.*, **17**, 5-23.

Park, Y. H., Fuda, J. L., Durand, I. and Naveira Garabato, A. C., 2008a, "Internal tides and vertical mixing over the Kerguelen Plateau", *Deep-Sea Res.-II*, **55**, 582-593.

Park, Y. H., Roquet, F., Durand, I. and Fuda, J. L., 2008b, "Large scale circulation over and around the Northern Kerguelen Plateau", *Deep Sea Res.-II*, **55**, 566-581.

Pike, J., Allen, C. S., Leventer, A., Stickley, C. E. and Pudsey, C. J., 2008, "Comparison of contemporary and fossil diatom assemblages from the western Antarctic Peninsula shelf", *Mar. Micropaleontol.*, **67**, 274-287

Pokras, E. M. and Molfino, B., 1986, "Oceanographic control of diatom abundances and species distributions in surface sediments of the tropical and southeast Atlantic", *Mar. Micropaleontol.*, **10**, 165-188.

Ragueneau, O., Tréguer, P., Leynaert, A., Anderson, R. F., Brzezinski, M. A., DeMaster, D. J., Dugdale, R. C., Dymond, J., Fischer, G., Francois, R., Heinze, C., Maier-Reimer, E., Martin-Jézéquel, V., Nelson, D. M. and Quéquiner, B., 2000, "A review of the Si cycle in the modern ocean: recent progress and missing gaps in the application of biogenic opal as a paleoproductivity proxy", *Glob. Planet. Chan.*, **26**, 317-365.

Romero, O. and Hensen, C., 2002, "Oceanographic control of biogenic opal and diatoms in surface sediments of the southwestern Atlantic", *Mar. Geol.*, **186**, 263-280.

Romero, O. E., Fischer, G., Lange, C. B. and Wefer, G., 2000, "Siliceous phytoplankton of the western equatorial Atlantic: sediment traps and surface sediments", *Deep-Sea Res. II* **47**, 1939-1959.

Sancetta, C. and Calvert, S. E., 1988, "The annual cycle of sedimentation in Saanich Inlet, British Columbia : implications for the interpretation of diatom fossil assemblages", *Deep-Sea Res.*, **35**, 71-90.

Schrader, H. J. and Gersonde, R., 1978, "Diatoms and Silicoflagellates. Micropaleontological counting methods and techniques - an exercise on an eight metres section of the Lower Pliocene of Capo Rossello, Sicily. *In*: W. Zachariasse, J. Riedel, R. Sanfilippo *et al.* (Ed.), Utrecht Micropaleontological Bulletin,**17**, 129-176.

Smith, W.O., Jr. and Gordon, L. I., 1997, "Hyperproductivity of the Ross Sea (Antarctica) polynya during austral spring", *Geophys. Res. Lett.*, **24**(3), 233-236, doi:10.1029/96GL03926.

Truesdale, R. S. and Kellogg, T., 1979, "Ross Sea diatoms : modern assemblage distributions and their relationship to ecologic, oceanographic, and sedimentary conditions", *Mar. Micropaleontol.*, **4**, 13-31.

Uthermöhl, H., 1958, "Zur Vervollkommnung der quantitativen Phytoplankton-Methodik. Mitt.", *Int. Ver. Theor. Angew. Limnol.*, **9**, 1-38.

van Iperen, J. M., Van Weering, T. C. E., Jansen, J. H. F. and Van Bennekom, A.J., 1987, "Diatoms in surface sediments of the Zaire deep-sea fan (SE Atlantic Ocean) and their relation to overlying water masses", *Neth. J. Sea Res.*, **21**, 203-217.

Zielinski, U. and Gersonde, R., 1997, "Diatom distribution in Southern Ocean surface sediments (Atlantic sector): implications for paleoenvironmental reconstructions", *Palaeogeogr. Palaeoclimatol. Palaeoecol.*, **129**, 213-250.