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Relative Microalgal Concentration in Prydz Bay, East Antarctica during Late Austral Summer, 2006

Rahul Mohan[1], Sunil Kumar Shukla[1*], N. Anilkumar[1], M. Sudhakar[1+], Satya Prakash[2++] and R. Ramesh[2]

[1]*National Centre for Antarctic & Ocean Research (Ministry of Earth Sciences), Headland Sada, Vasco-Da-Gama, Goa - 403 804, India*
[2]*Physical Research Laboratory, Navrangpura, Ahmedabad - 380 009, India*

Microalgae using a submersible fluorescence probe in water column (up to 100 m) were measured during the austral summer of 2006 (February) in Prydz Bay, East Antarctica (triangular-shaped embayment in the Indian sector of Southern Ocean). Concurrently, environmental parameters such as temperature, salinity and nitrogen (nitrate, ammonium, urea) uptake rates were measured. The concentration of phytoplankton is relatively high due to availability of high nutrients and low sea surface temperature. Phytoplankton community is dominated by diatoms whereas cryptophytes are in low concentration. The maximum concentration of total chlorophyll is 14.87 μg L^{-1} and is attributed to upwelled subsurface winter water due to local wind forcing, availability of micro-nutrients and increased attenuation of photosynthetically available radiation (PAR). Concentration of blue-green algae is low compared to that of green algae because of low temperature. Comparatively high concentration of yellow substances is due to the influence of Antarctic melt-water whereas cryptophytes are low due to high salinity and mixed water column. Varied concentrations of phytoplankton at different times of Fluoroprobe measurements suggest that the coastal waters of Prydz Bay are influenced by changing sub-surface water temperature and salinity due to subsurface upwelling induced by local winds as also melting/freezing processes in late summer. The productivity is high in coastal water due to the input of macro as well as micro-nutrients.

Key Words: East Antarctica, nutrients, phytoplankton, Prydz Bay, salinity, temperature, total chlorophyll

INTRODUCTION

Antarctica and the surrounding waters which form a part of Southern Ocean has a significant influence on the global climate. Southern Ocean is characterized by latitudinal fronts marked by steep changes in sea surface temperature, salinity as also biological productivity (Orsi *et al*. 1995; Sparrow *et al*. 1996). The coastal waters of Antarctic continent adjoining the Southern Ocean are some of the most productive regions of the world oceans (Davis and Mcnider 1997). Icebergs also play their part in increasing the productivity of the region (Smith *et al*. 2007; Schwarz and Schodlok 2008). Marine productivity has a significant role in the transfer of atmospheric carbon to Antarctic waters. Antarctic phytoplankton biomass and primary production are known for its variability (Fogg 1977; Holm-Hansen *et al*. 1977) with diatoms dominating the phytoplankton (Guillard and Kilham 1977). Importance of other taxonomic groups in Antarctic water was reported by Hewes *et al*. (1985) for e.g. Green algae (Merchant et al. 1989) and cryptophytes (Taylor and Lee 1971). The Southern Ocean biome is widely predominated by Antarctic Phytoplankton. The Prydz Bay region lying in Indian Sector of Southern Ocean has few published studied on phytoplankton (Kang and Fryxell 1991; Zhu *et al* 2003; Kopczynska *et al*. 1995). However, *in situ* data on phytoplankton of Prydz Bay is lacking. It is essential to understand the photosynthetic capacity of water so as to differentiate various types of microalgal components. The standard methods for determination of microalgal components include sampling of water and application of standard methods to determine the total amount of chlorophyll (Strickland and Parsons 1965).

*Corresponding author (sunilshuklancaor@gmail.com)
+Present Address: Ministry of Earth Sciences, Govt. of India, New Delhi - 110 003, India.
++Present Address: Indian National Centre for Ocean Information Services (Ministry of Earth Sciences), Ocean Valley, Hyderabad - 500 055, India.

The currently available methods for determination of the microalgal population in waters typically lack the *in situ* and temporal resolution required to obtain a thorough understanding of the role of the phytoplankton in aquatic ecosystems (Beutler *et al*. 2002). The limitations of traditional methods have been illustrated by various workers (Edgar and Laird 1993; Carrick and Schelske 1997). Although, some *in vivo* studies have been carried out by different workers using light emitting diodes (Kolboeski and Schreiber 1995; Hilton and Jaworski 1989), they are limited by their inability to differentiate the different algal classes. A submersible fluorometer with several excitation and emission wavelength bands was introduced by Desiderio *et al*. (1997) and Cowles *et al*. (1992). They presented vertical profiles of phycoerythrin containing algae using light-emitting diodes and were able to distinguish fluorescence kinetics resulting from different groups of algae *in vivo*. *In vivo* fluorescence of photosynthetic pigments present in phytoplankton cells offers a potential way to determine total phytoplankton amount and even the condition of individual groups (Yentsch and Yentsch 1979). The spectrofluorometric determination and indirect discrimination of individual algal groups have been facilitated by the use of fluorescence properties of phytoplankton photosynthetic pigments (Oldham et al. 1985; Yentsch and Phinney, 1985; Porynkina et al. 1994; Babichenko *et al* 1999; Millie et al. 2002). The present data was collected to assess and understand the role of phytoplankton in Prydz Bay area, *in situ* profiling of total chlorophyll and their micro algal components.

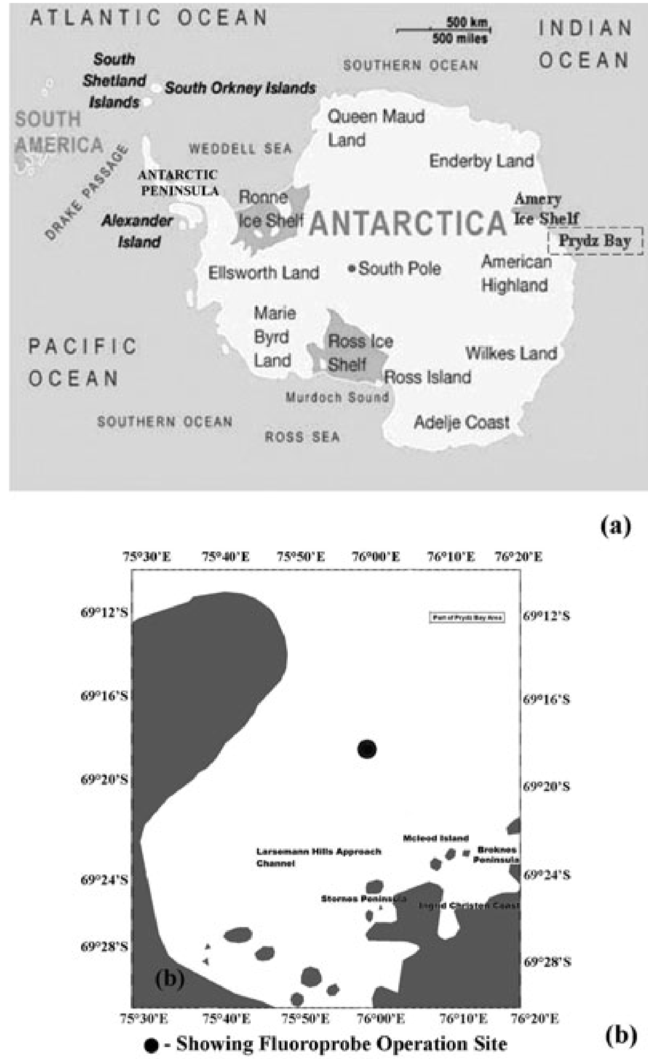

Fig. 1. (a) Map of Antarctica showing location of Prydz Bay. (b) Map of Prydz Bay, Antarctica showing station location (Modified after Stagg, 1966).

STUDY AREA

Prydz Bay, covering an area of about 80,000 km^2, is a triangular-shaped embayment in the Indian sector of Southern Ocean (Stagg 1985) (Fig. 1). This is situated between West Ice Shelf (around 80°E) and Cape Darnley (70°E) and the region off the Mawson coast which is often ice-covered similar to the two major Antarctic coastal seas - the Weddell and Ross Sea. In summer season, Antarctic Surface Water mass in Prydz Bay is subdivided into summer surface water and continental shelf water. Summer surface water is relatively warm water having temperature 0-2°C and salinity 33.5-34 psu which is attributed to summer heating and melting (Smith *et al*. 1984).

Kang and Fryxell (1991) opined that surface layer depends upon local sea-surface conditions and thermohaline structures which is regulated by horizontal advection through wind-forcing. The base of the summer surface layer has been assumed to correspond with the top of the seasonal thermocline in the 20-50 m depth range. The thickness of the surface layer generally increases to the north outside Prydz Bay, consistent with its relationship to the density of the ice coverage (Smith *et al*. 1984). Below the highly variable summer surface water lies relatively low-temperature (<0°C) and high-salinity (>34 psu) continental shelf water. Volume of high-salinity shelf water is less prevalent in Prydz Bay comparative to Weddell and Ross Sea. The production of high-salinity shelf water within Prydz Bay is due to the absence of broad shelf areas attributed to its geography and bathymetry (Smith *et al*. 1984). The principal surface water flow associated with the Antarctic Circumpolar

Current is driven eastward by the prevailing westerlies (Jacobs and Georgi 1977; Gordon *et al.* 1978). To the south the prevailing winds are to the west, giving rise to a divergence zone (around 65°S) in the surface layer commonly referred to as the Antarctic Divergence (Tolstikov 1966). South of the divergence zone the East Wind Drift dominates. An atmospheric low-pressure belt encircles the continent, this being the residue of the many depressions that track from west to east around this latitude (Deacon 1982). The water masses and circulation within Prydz Bay resemble those of similar sites within the Weddell and Ross Seas, but there are significant differences in the large-scale circulations and in the geostrophic and topographic constraints imposed on the flows (Smith *et al.* 1984).

Smith *et al.* (1984) observed icebergs off Princess Elizabeth Land moving southwest, while those calved from the Amery Ice Shelf normally follow the western periphery of Prydz Bay toward Cape Darnley. Observation of pack ice movement, iceberg tracks and buoy trajectories near the Antarctic coast provide additional evidence of a westward coastal current (Swithinbank *et al.* 1977; Tchernia and Jeannin 1980). Physical parameters measured in the Prydz Bay indicate a typical thermohaline structure as also mixing in that area by periodic upwelling processes associated with tides and continental shelf waves (Middleton and Humphries 1989). Nunes Vaz and Lennon (1996) reported based on the hydrographic data collected during the 1980's that this area is a production site for dense water. During the present study XBT operations (type: T-7; accuracy: ±0.15°C; depth resolution: 0.65 m) were carried out upto 100 m. The sea surface temperature was recorded using a bucket thermometer (accuracy: ±0.1°C) whereas Portable CTD (make: SBE 9/11 plus, Sea-Bird Electronics, USA; temperature accuracy: ±0.001°C, conductivity: ±0.0001 sm^{-1} and depth ±0.005%) was operated for deeper depth. Temperature varied from ~ -1.0 to 1°C in the water column/surface (Fig. 2) and salinity varied from 32.88 to 34.32 psu (Fig. 3).

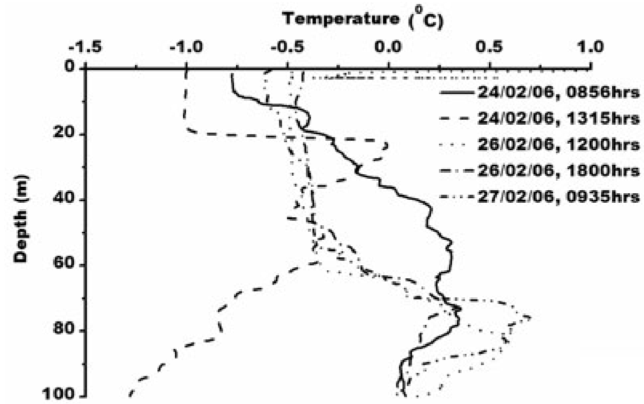

Fig. 2. Temperature profile upto 100 m depth in Prydz Bay at different times from 24th to 27th February, 2006.

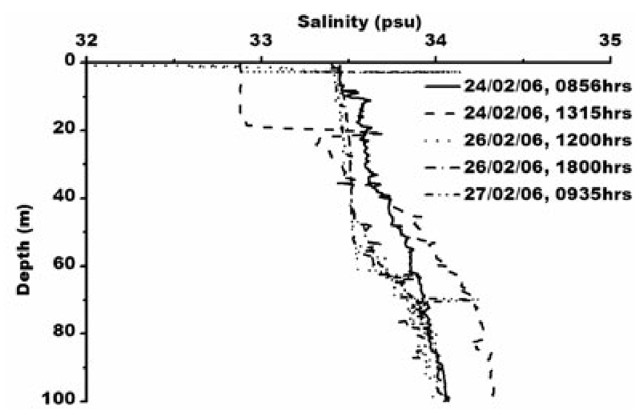

Fig. 3. Salinity profile upto 100 m depth in Prydz Bay at different times from 24th to 27th February, 2006.

MATERIALS AND METHODS

During the Special Expedition to Larsemann Hills and Southern Ocean (2006) in the summer to winter transition (last week of February 2006) R/V Akademik Boris Petrov was off the Prydz Bay area for undertaking multibeam swath bathymetry of the channel to the station site. A submersible fluorescence probe (FluoroProbe, bbe-Moldaenke, Kiel, Germany) was operated up to 100 m depth for *in situ* measurement of total chlorophyll and phytoplankton concentration. A total of seven stations at different time intervals between 24-27 February, 2006 were carried out at 69°18'S, 76°00'E. The FluoroProbe for algal differentiation uses 5 light emitted diodes (LED) for fluorescence excitation. The LEDs emit pulsed light at fixed wavelengths (450 nm, 525 nm, 570 nm, 590 nm and 610nm). Fluorometric emission is measured at 680 nm by photomultiplier at an angle of 90° to the exciting light source (Buetler *et al.* 2002). The probe is connected online mode to a laptop from which it is operated and to which the data on depth and phytoplankton composition are sent every second. The division of Chlorophyceae (Green algae) shows a broad maximum of fluorescence at the 450 nm LED that corresponds to chlorophyll-a and chlorophyll-b excitaion. The Cyanophyceae (Blue-green algae) pigments are characterized by maximum excitation at 610 nm caused by photosynthetic antenna pigment phycocyanin. 525 nm region for Bacillariophyceae

(Diatoms) originates from xanthophylls, fucoxanthin and peridin for the division of Dinophyceae. The maxima at 450 nm is caused by chlorophyll-a and chlorophyll-c. Group Cryptophyceae originates from phycoerythrin at 570 nm. For precision of the Fluoroprobe measurements and calibration see Buetler *et al*. (2002). We have reported ^{15}N based production measurements in the Southern Indian Ocean elsewhere (Personal communication). We measured the nitrate, ammonium and urea uptake rates and *f*-ratio for the surface waters of Prydz Bay. 250 ml of samples were separately collected for nutrient measurements (for details of experimental techniques reference is made to Kumar *et al*. (2004).

RESULTS AND DISCUSSION

Total chlorophyll concentration ranges from 0.03-14.87 μg L^{-1} (Fig. 4). Maximum chlorophyll concentration of 14.87 μg L^{-1} was observed at 1303 h, 24th February. The chlorophyll maxima is recorded at 15 meter water depth. One of the key characteristics of the chlorophyll 'a' is its fluorescence. Fluorescence of photosynthetic pigments is partly dependent on the physiological status of the cell and its photosystems, which is affected by factors, such as life history of the cell, nutrients availability and light conditions (Kiefer 1973; Vincent *et al*. 1984; Soohoo *et al*. 1986). Photosystem II (PSII) is mainly responsible for chlorophyll fluorescence which consists of a peripheral and core antenna. The former contains a species-dependent light absorbing pigment, the later an evolutionary conserved molecule of chlorophyll (Buetler *et al*. 2002). Fluorescence emission of PSII measured around 685 nm is generally accepted as a measure of chlorophyll content of algae in aquatic system (Yentsch and Menzel 1963; Holm-Hansen 1965). Higher chlorophyll concentration in oceanic water of Prydz Bay is attributed to higher primary productivity and eutrophic nature of Antarctic waters. Persistence of abundant chlorophyll-a in the coastal waters in the eastern part of Prydz Bay could be attributed to cooler coastal waters which are generally more productive (Nicol *et al*. 2000) which substantiate our study as maximum chlorophyll concentration of 14.87 μg L^{-1} occurs where water temperature is -1°C at surface to 20m depth indicating upward movement of water due to local wind forcing. This subsurface cold water is due to the winter water which occurs as residue from the previous winter mixed layer, limited by seasonal warming and freshening (Park *et al*. 1998). Chlorophyll less than 14.87 μg L^{-1} occurs where temperature is greater than -1°C

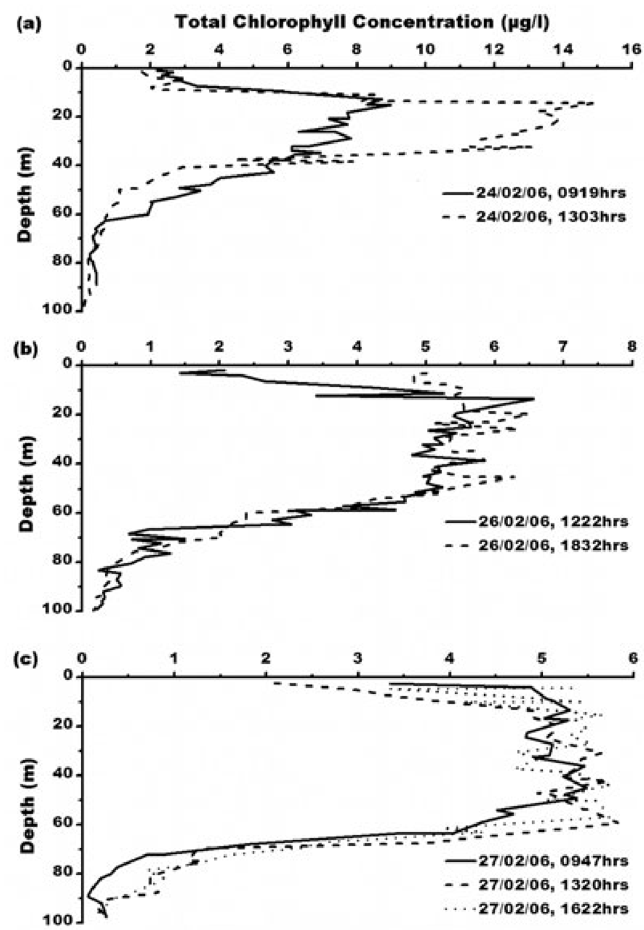

Fig. 4. (a-c) Concentration of total chlorophyll upto 100 m depth in Prydz Bay. (a) 24th February, 2006 at 0919 h and 1303 h. (b) 26th February, 2006 at 1222 h and 1832 h. (c) 27th February, 2006 at 0947 h, 1320 h and 1622 h.

and shows negative correlation with chlorophyll (R^2 = -.29, -.79, -.86, -.69 for temperature station 1, 3, 4 and 5 respectively, Fig. 2). Chlorophyll-a concentration in the euphotic zone increases and the critical depth decreases due to increased attenuation of PAR, as light levels may become limiting for phytoplankton growth (Strutton *et al*. 2000). Earlier study also suggests that the chlorophyll-a concentration in the Prydz Bay is high (Gibson and Trull 1999). They reported chlorophyll concentration >15 mg m^{-3} during the mid summer (January). Mongoni *et al*. (2004) have reported 2.5 fold higher chlorophyll-a concentration of 102 and 206 mg m^{-2} during January and February respectively in Ross Sea. They observed broken pack and melting ice which was coloured by an extensive algal biomass suggesting that the phytoplankton was a result of seeding from ice algal communities. Higher level of chlorophyll concentration may be attributed to coverage of summer ice in late summer season

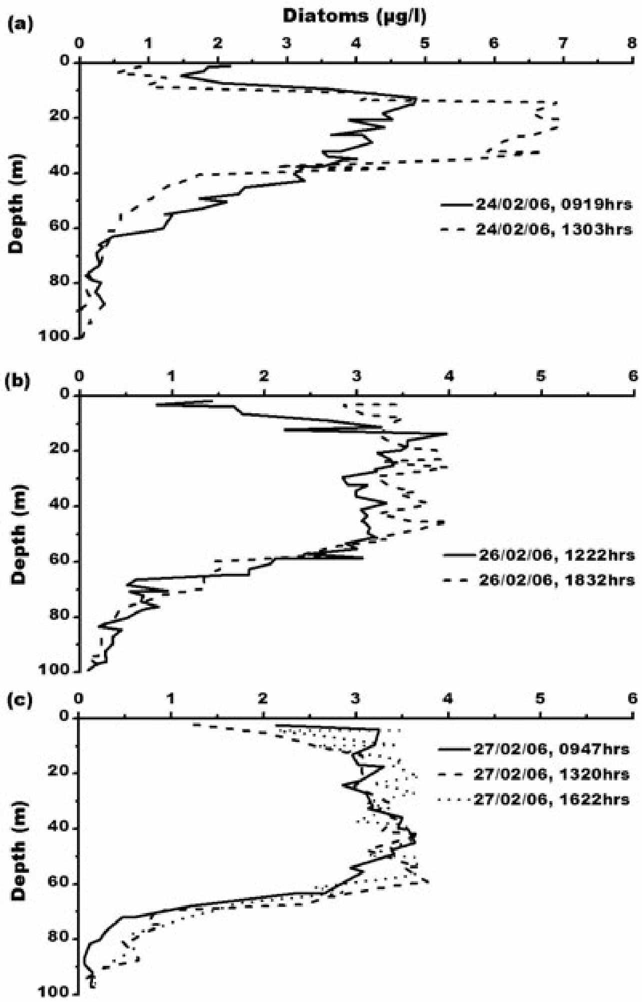

Fig. 5. Concentration of diatoms upto 100 m depth in Prydz Bay. (a) 24th February, 2006 at 0919h and 1303h. (b) 26th February, 2006 at 1222h and 1832h. (c) 27th February, 2006 at 0947h, 1320h and 1622h.

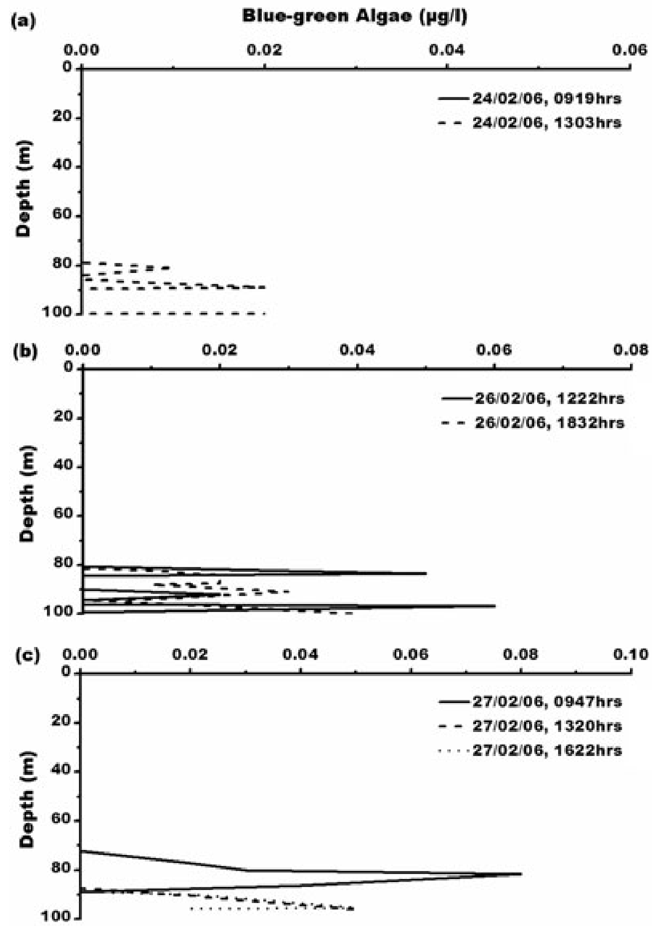

Fig. 6. Concentration of blue-green algae upto 100 m depth in Prydz Bay. (a) 24th February, 2006 at 0919h and 1303h. (b) 26th February, 2006 at 1222h and 1832h. (c) 27th February, 2006 at 0947h, 1320h and 1622h.

when freezing starts. In Indian Sector of Southern Ocean, 63°S onwards to Antarctica, melting/freezing processes are more prominent in late austral summer (Srivastava *et al*. 2007). During freezing, salinity increases as ice discards salt; conversely melting decreases the salinity due to input of fresh water (Archambeau *et al*. 1998). The variable concentration of chlorophyll at the same location in different timings could be attributed to melting/freezing processes. During melting, a stable surface layer forms with ample amount of nutrients and warmer water temperature favouring the growth of phytoplankton (Mitchell and Holm-Hansen 1991). This is further substantiated by higher Total N uptake rate (~12.3 mmol N m^{-2} d^{-1}). The photic zone concentrations of nitrate, ammonia and urea are 7.70, 3.30, and 1.27 mmol N m^{-2} d^{-1} respectively. In terms of carbon, the total carbon uptake during late austral summer in the Antarctic coastal zone is 981.5 mmol N m^{-2} d^{-1}. The *f*-ratio here is 0.63. High carbon uptake rate in coastal regions of Antarctica was also reported by other authors (Treguer and Jacques 1992). The production in the region is high as the coastal region receives ample nutrients from the Antarctic continent. These nutrients are derived through the coastal continental erosion and contain significant amount of iron along with other major nutrients.

Diatom concentration ranges from 0.01-6.94 μg L^{-1}. Maximum diatom concentration of 6.94 μg L^{-1} has been observed at 1303 h, 24th February, 2006 (Fig. 5). Elevated levels of diatom concentration is due to high nutrient concentration. Earlier studies also reported diatom dominance in Prydz Bay (Kang and Fryxell 1991; Kopczynska *et al*. 1995; Zhu *et al*. 2003) which substantiates our study. It is widely accepted that *Phaeocystis* sp. and diatoms are the dominant phytoplankton taxa throughout Antarctic

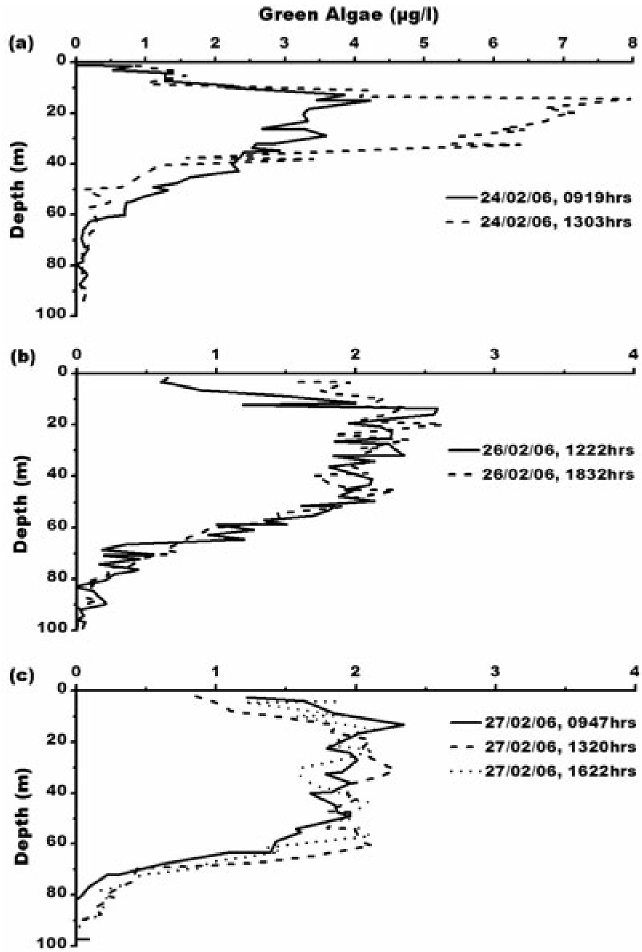

Fig. 7. Concentration of green algae upto 100 m depth in Prydz Bay. (a) 24th February, 2006 at 0919 h and 1303 h. (b) 26th February, 2006 at 1222 h and 1832 h. (c) 27th February, 2006 at 0947 h, 1320 h and 1622 h.

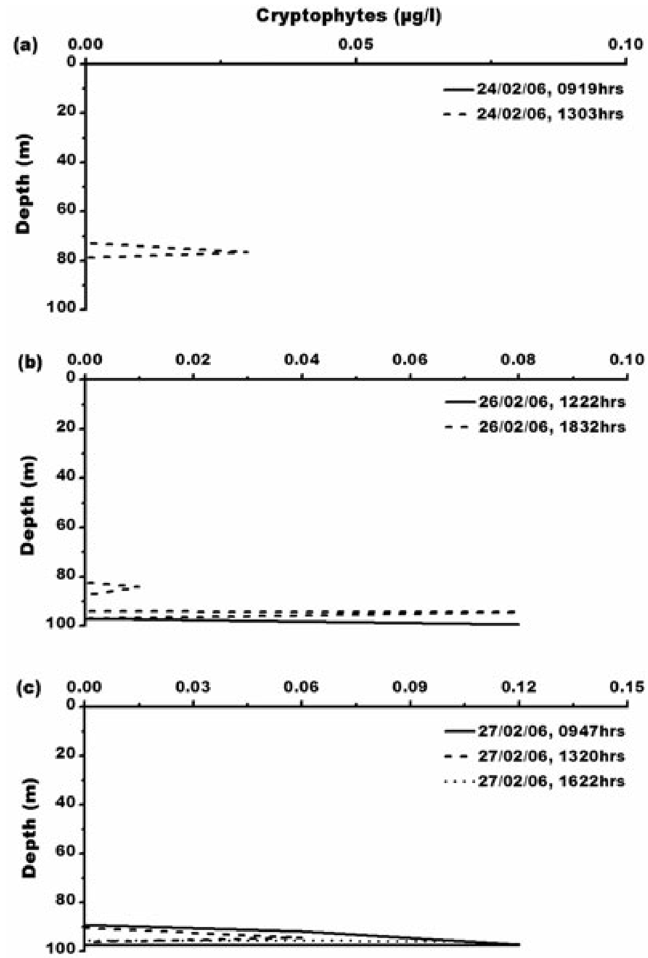

Fig. 8. Concentration of Cryptophytes upto 100 m depth in Prydz Bay. (a) 24th February, 2006 at 0919h and 1303h. (b) 26th February, 2006 at 1222h and 1832h. (c) 27th February, 2006 at 0947h, 1320h and 1622h.

and Arctic waters (El-Sayed and Fryxell 1993). Arrigo *et al*. (1999) have reported dominance of diatoms in Ross Sea in stratified water column whereas presence of *Phaeocystis antarctica* occurs in mixing condition.

Concentration of blue-green algae (BGA) varies from 0.01-0.08 μg L^{-1}. Its maximum concentration of 0.08 μg L^{-1} is at 0947 h, 27th February, 2006 (Fig. 6) which is between 65-85 m depth where water is comparatively warmer with temperature of 0.6°C with maximum salinity-33.3 psu. Green algae concentration ranges from 0.01-7.97 μg L^{-1}. The maximum concentration of green algae (7.97 μg L^{-1}) is at 1303 h, 24th February, 2006 (Fig. 7). Green algal concentration is following same trend like chlorophyll concentration suggesting that lower temperature of -1°C is favouring their growth (Fig. 7a). Concentration of green algae is high compared to that of blue-green algae which is due low sea surface temperature and also widespread distribution of chlorophyll-b (Bidigare *et al*. 1986; Buma *et al*. 1992) that play an important role in photosynthesis and serve as food for heterotrophic organisms. Concentration of cryptophytes ranges from 0.01-0.12 μg L^{-1} with higher concentration of 0.12 μg L^{-1} recorded at 0947 h, 27th February, 2006 (Fig. 8). Concentration of cryptophytes is low because presence of cryptophytes is usually related to a successional change occurring after a diatom bloom (Moline and Prezelin 1996) and could be due to higher salinity. Cryptophytes are frequently associated with low salinity, highly stable water layers where they are maintained by active swimming or to the confluence of different water masses with high phytoplankton biomass values (Schloss and Estrada 1994; Mura *et al*. 1995) which corroborate our study, as their presence is only at deeper stable layer of water depth 80-100 m. Concentration of yellow substances ranges from 0.02-0.32 μg L^{-1} with maximum concentration of 0.32 μg L^{-1} at 0947 h, 27th February 2006

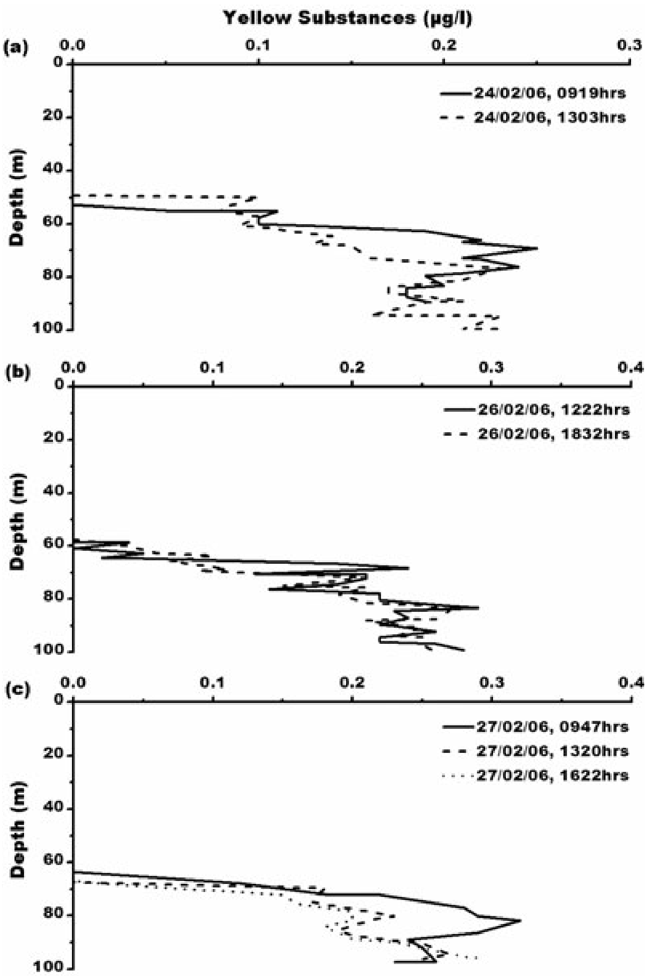

Fig. 9. Concentration of Yellow Substances upto 100 m depth in Prydz Bay. (a) 24th February, 2006 at 0919 h and 1303 h. (b) 26th February, 2006 at 1222 h and 1832 h. (c) 27th February, 2006 at 0947 h, 1320 h and 1622 h.

(Fig. 9). Yellow substances, in addition to pigments and non-living material, are one of the factors determining the shape of the total absorption spectrum in the visible range and this causes variations in ocean colour. Yellow substances higher than 1 m^{-1} are rare and are observed only in the Baltic Sea or in highly contaminated areas. In coastal area of Prydz Bay, yellow substances are comparatively higher which could be attributed to fluvial discharges (Bricaud *et al*. 1981).

CONCLUSION

The Prydz Bay studied area is characterized by abundant phytoplankton assemblage dominated by diatoms. Maximum chlorophyll concentration occurs where water temperature is lowest (-1°C) from surface to 20 m depth due to upward movement of winter water. An adequate light availability associated with vertical stability seems to favour phytoplankton blooms in Antarctic waters. In coastal upwelling regions, the dominant primary producers are diatoms which contribute to high siliceous ooze as they have high sinking velocities and sink either as individuals, aggregates, mats or in fecal pellets. The particular area has high productivity (981.5 mgC m^{-2} d^{-1}) and high *f*-ratio (0.63) [Personal communication]. The productivity is high due to the intrusion of macro as well as micro-nutrient (especially iron) from icebergs which favours the phytoplankton growth in Prydz Bay. This study is solely based on *in situ* measurements of microalgal concentration but highlights Prydz Bay area as one with high productivity (High *f*-ratio) inferred from elevated chlorophyll level.

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