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ALESSANDRA ASIOLI (*) & LEONARDO LANGONE (*)

RELATIONSHIP BETWEEN RECENT PLANKTIC FORAMINIFERA AND WATER MASS PROPERTIES IN THE WESTERN ROSS SEA (ANTARCTICA)

ABSTRACT: ASIOLI A. & LANGONE L., *Relationship between recent Planktic Foraminifera and water mass properties in the Western Ross Sea (Antarctica).* (IT ISSN 0391-9838, 1997).

Planktic foraminifera collected in floating traps were studied in two stations of the Western Ross Sea. The assemblage is composed of one species (*Neogloboquadrina pachyderma*) of which two morphs were distinguished: the first with thin and lobate test constitutes the juvenile stage and is present in the uppermost levels of the water column. The other morph has heavily encrusted test and is represented by a small number of specimens occurring at depth greater than that of the chlorophyll maximum. The depth of the chlorophyll maximum seems to be responsible for the foraminiferal abundance peak, thus confirming the hypothesis that this species is linked to the chlorophyll maximum. We found no relationship between foraminifera distribution and the physical parameters of the water column emerged, or with the biogenic fluxes. Intrusions of modified Circumpolar Deep Water are shown by the presence of dextral coiling specimens.

KEY WORDS: Planktic foraminifera, Floating traps, Chlorophyll, Biogenic fluxes, Ross Sea.

RIASSUNTO: ASIOLI A. & LANGONE L., *Relazione tra i Foraminiferi planctonici recenti e caratteristiche delle masse d'acqua nel Mare di Ross occidentale (Antartide).* (IT ISSN 0391-9838, 1997).

Sono stati studiati i Foraminiferi planctonici presenti in trappole flottanti in due stazioni del Mare di Ross occidentale. Essi sono rappresentati unicamente da due morfotipi della specie *Neogloboquadrina pachyderma*: quello con guscio sottile e lobato costituisce lo stadio giovanile e si trova nei livelli più superficiali della colonna d'acqua; quello pesantemente incrostato costituisce lo stadio adulto ed è rappresentato da pochi individui a profondità superiori al massimo di clorofilla. La profondità del massimo di clorofilla sembra essere responsabile dei picchi di abbondanza degli individui, confermando l'ipotesi che tale specie è legata al massimo di clorofilla. Non è stata notata una correlazione tra la distribuzione dei foraminiferi con i parametri fisici della massa d'acqua, né con i flussi biogenici. Le intrusioni di Circumpolar Deep Water modificata sono testimoniate dal ritrovamento di individui destrogiri.

TERMINI CHIAVE: Foraminiferi planctonici, Trappole flottanti, Clorofilla, Flussi biogenici, Mare di Ross.

INTRODUCTION

In polar marine environments, seasonal advance and retreat of sea ice is thought to control the phytoplankton blooms and to play a key role in maintaining high productivity (e.g., Smith & Nelson, 1985). Although the Ross Sea (Antarctica) display unusually high levels of new production (Nelson & *alii*, 1996), recent results show that the annual production is low, and intense blooms are episodic and limited in time. The occurrence of such episodes is more likely early in the austral summer, in connection with the seasonal sea ice melting. In this period, marginal ice zones are subject to continuous modifications in position, length and shape. The ice melting produces a stratification of the water column that triggers the phyplankton bloom with the enhanced availability of light and nutrients (Smith & Nelson, 1985).

The purpose of the Italian project Rossmize is to characterise the temporal and spatial changes of primary production, biogenic export fluxes and seabed accumulation along a N-S transect in the Ross Sea during the seasonal sea ice retreat. Nutrient concentration, light attenuation and zooplankton distribution were also studied to provide a better understanding of their role in controlling the spring algal bloom. In this context, we deployed at stations 11c and 15c (fig. 1) a sediment trap array, floating for 12-13 hours, to measure fluxes of the major biogenic components in the upper water column. Here we discuss data relative to abundance and composition of the foraminifera assemblage collected by floating traps, relating the results to the characteristics of the water masses and biogenic fluxes.

(*) *Istituto di Geologia Marina del Cnr, via P. Gobetti 101 - 40129 Bologna, Italy.*

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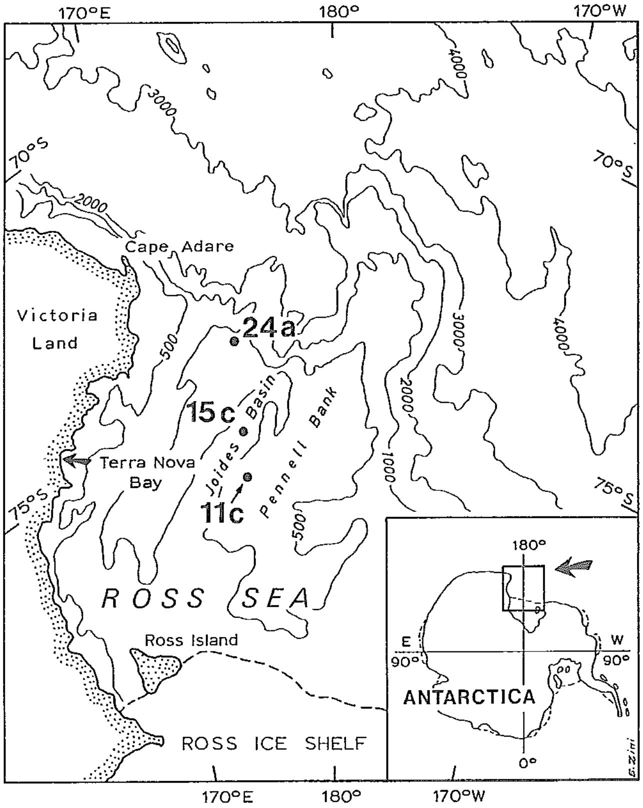

FIG. 1 - Study area and sample location.

STUDY AREA

The Ross Sea is characterised by a wide and deep continental shelf with a mean depth of 500 m (200-1100 m). Its eastern region is characterised by slightly elevated reliefs, while the western side shows a extremely irregular topography, largely due to glacial erosion.

Both oceanic and shelf water masses impinge on the study area (see Jacobs & *alii*, 1985 for details). The former are mainly represented by the Circumpolar Deep Water (Cdw) and display relatively high temperature (ca. 1.17°C), high salinity (34.7‰), high silica and low oxygen content (Jacobs & *alii*, 1985). Cdw intrudes frequently in the shelf. Its interaction with the shelf water gives rise to the Warm Core (Wmco), a water mass with relatively high temperature (ca. –1°C) and low salinity (ca. 34.5‰), that favours ice melting and phytoplankton blooms.

Several shelf water masses can be distinguished (Jacobs & *alii*, 1985):

Ice Shelf Water (Isw), characterised by temperatures (<–2°C) below the sea surface freezing;

High Salinity Shelf Water (Hssw) is the densest water in the Antarctic oceans. Its stability is maintained by the increase in salinity (34.84‰) with depth. Its origin is mainly related to the brine formation from sea surface freezing during the winter.

Low Salinity Bottom Water (Lsbw) and High Salinity Bottom Water (Hsbw) seem to give rise to the Antarctic Bottom Water (Aabw).

A thin water tongue (50 to 100 m thick), displaying a considerable spatial and temporal variability of temperature and salinity values, overlays the water masses described above. This water, called Antarctic Surface Water (Aasw), evolves from the Cdw modified by the interaction with atmosphere, ice and Temperature Minimum.

During the Rossmize cruise several parameters such as temperature, salinity, chlorophyll and turbidity, provided by a Ctd were measured (Artegiani & *alii*, 1996; Russo, 1997; fig. 2). Although it was not possible to obtain samples from St. 24a because of the interference of the pack ice, the physical parameters measured by Ctd, are here taken into account to understand the local oceanographic conditions of the area of the three stations at sampling time (fig. 3). At station 24a, close to the retreating pack ice and to the shelf edge of the Ross Sea, three water masses are present. Cold and low salinity water testifies to the ice melting at the surface. Below 80 m, the Cdw intrudes onto the shelf. At the bottom, the Lsbw probably flushes out from the shelf. At station 15c, in the Joides Basin, below the surface water, the Low Salinity Shelf Water (Lssw) overlies Hssw. At station 11c, on the western flank of the Pennell Bank, the structure of the water column is determined by surface water, modified Cdw, Lssw and Hssw. The chlorophyll *a* distribution displays the following trend: at station 24a, the peak is narrow and it enlarges as we approach to station 15c and 11c: the depth penetration of the biomass is a function of the time elapsed from the release of material from the ice melting and/or the development of phytoplankton blooms following the retreat of the ice margin (Langone & *alii*, 1997). Carrada & *alii* (1996) reported data on phytoplankton biomass indicating that the total production were sustained by nano- and pico-phytoplankton at the two stations during our sampling. The corresponding high concentration of pheopigments (Saggiomo & *alii*, 1996) suggested that the selective removal by grazing might be the key factor in determining the size structure of phytoplankton communities (Carrada & *alii*, 1996).

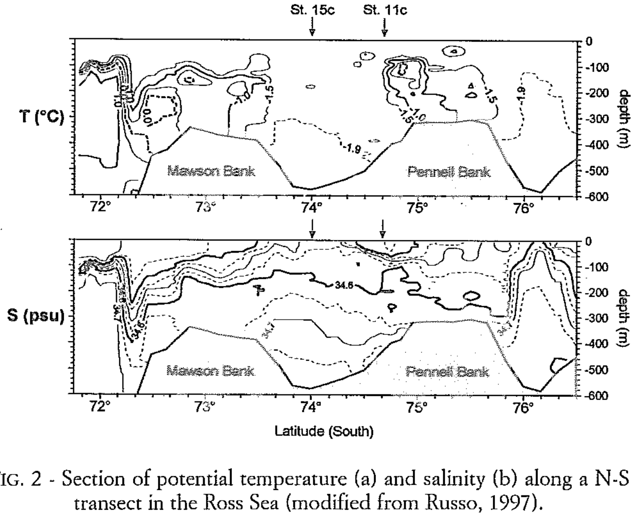

FIG. 2 - Section of potential temperature (a) and salinity (b) along a N-S transect in the Ross Sea (modified from Russo, 1997).

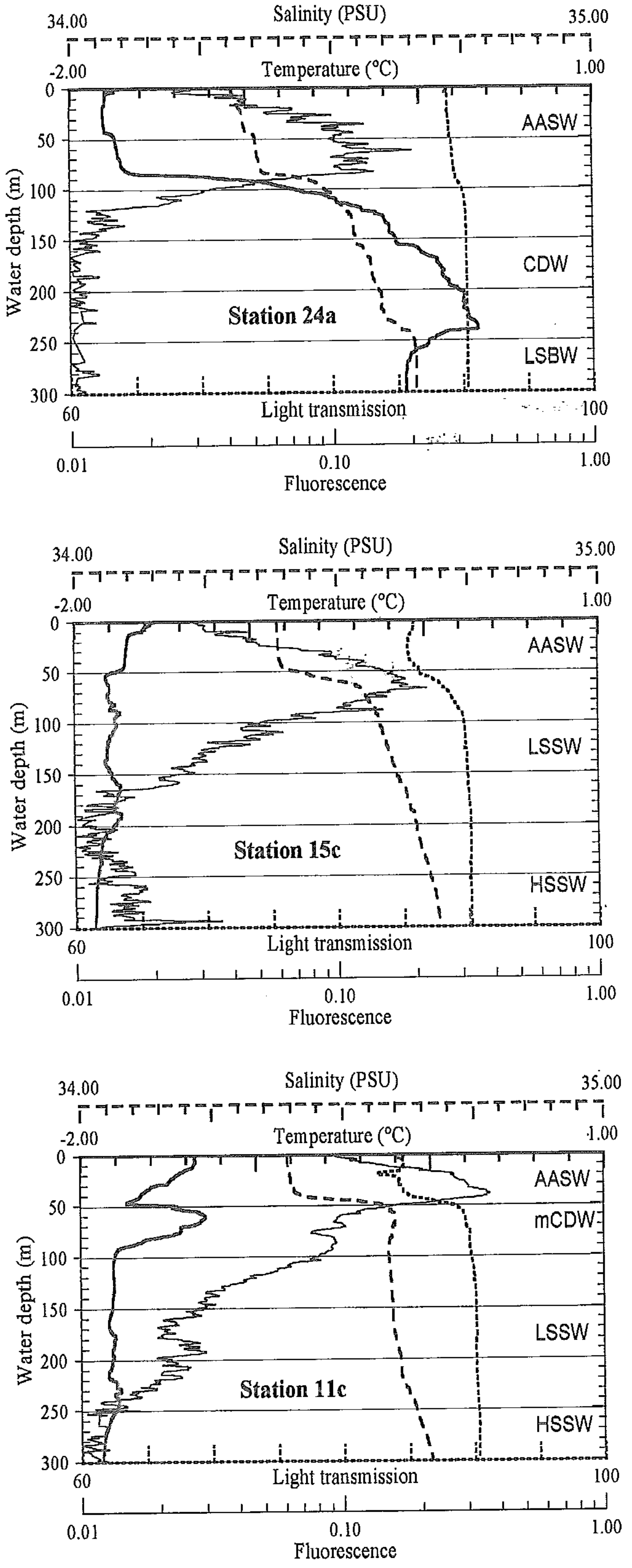

FIG. 3 - Hydrographic structure of the sampling stations and deep distributions of fluorescence and turbidity. At station 24a it was not possible to deploy the sediment trap array because of the interference of the pack ice.

MATERIALS AND METHODS

Sampling was carried out in December 1994, during the cruise of the Pnra, Rossmize, on board the R/V Italica. The stations were occupied in the following order: 15c (December 12, 1994) and 11c (December 13, 1994) (tab. 1). Floating traps with a collecting area of 0.5 m^2 were deployed, at depths of 50 m, 100 m, 150 m, and 200 m. These samplings lasted 12-13 hours. The material collected by traps was split into several fractions for analysis. Pre-weighted 0.45 µm MF-Millipore filters were used to obtain the bulk mass flux. The content of each trap was also examined for foraminiferal content although it was not possible to distinguish living and dead specimens. A fraction was filtered on a glass fiber filter to obtain the material for organic carbon and nitrogen determination, which was carried out using a Chn Analyzer.

RESULTS

Almost all the foraminifera specimens are left coiling, only nine dextral coiling specimens were found in St. 11c (200 m) (fig. 4-3a, b). The following two morphs were recognised:

- morph A has a subspheric and very thickened test, 4-4$^{1}/_{2}$ chambers in the last whorl, umbilical aperture with a lip; the average size is 200-300 mm along maximum dimension (fig. 4-4 and 4-5);
- morph B has a lobate and thin walled test, 4-4$^{1}/_{2}$ chambers in the ventral side. The aperture is provided with a lip and extends from umbilicus to periphery. The sutures are depressed. The average size is ca. 250 µm along maximum dimension (fig. 1, 2, 3a and 4-3a, b).

According to Bè (1960), Kennett (1966), Lipps & Krebs (1974) and Kohfeld & *alii* (1996), both these morphs belong to the species *Neogloboquadrina pachyderma* (Ehrenberg). In the literature, morph B is known to represent the early stage of the life cycle in the surface water and morph A is the terminal stage. During the latter stage N. pachyderma moves to deeper waters (>200 m) producing the typical heavy encrustation that obscures the pores and the reticulate surface visible in the morph B specimens.

Foraminifera fluxes were also calculated (tab. 2). Both stations show a minimum flux value, but at different depths: 100 m depth at St.11c (66 specimens m^{-2} d^{-1}) and 150 m at St. 15c (72 spec. m^{-2} d^{-1}).

Mass fluxes are similar at the two sites: 88-123 mg m^{-2} d^{-1} at station 11c and 66-138 mg m^{-2} d^{-1} at site 15c. The lowest value at each station was recorded just below the fluorescence peak.

Concentrations and fluxes of organic carbon and nitrogen are maximum at the top of the water column. The highest organic carbon fluxes (10-12 mg m^{-2} d^{-1}) are low if compared with those (25-93 mg m^{-2} d^{-1}) measured during January 1990 at two stations in the southern part of the Ross Sea (Smith & Dunbar, 1995). The composition of sinking material varies almost regularly with depth, showing a decrease of carbon and nitrogen contents. The

TABLE 1 - Location of the floating trap experiments and sampling details

Station	Water depth (m)	Date	Time	Latitude	Longitude	Trap drifting
15c-traps deployment	577	12/12/1994	22:30	74°01'70 S	175°01'70 E	
15c-traps recovery	583	12/13/1994	10:30	74°02'87 S	175°06'19 E	North-East
11c-traps deployment	416	12/13/1994	21:48	74°42'41 S	175°07'28 E	
11c-traps recovery	415	12/14/1994	11:00	74°42'48 S	175°06'30 E	North-East

maximum rate of change occurs in both cases between 50 and 100 m. C/N ratios increase with depth from ca. 7 to 20, showing the progressive and selective decomposition of the organic matter. The initial C/N ratio in Antarctic diatoms is ca. 7 (Brzezinski, 1985).

DISCUSSION

As mentioned above, the two stations show contrasting structures of the water column. The intrusion of Wmco on the Pennell Bank does not seem to affect the foraminiferal abundance. In fact, although in St. 11c the minimum quantity of specimens occurs at the same depth as the Wmco intrusion (easily detectable by the temperature profile in figs. 2, 3), we note a minimum also at St. 15c where only LSSW is present below the surface water. On the other hand, the presence of Wmco influences the distribution of foraminifera morphology (coiling direction of *N. pachyderma*). In fact, sinistral coiling specimens are known to live in polar and subpolar regions, whereas the dextral variety inhabits subpolar to tropical areas when the subthermocline temperatures are colder than 12°C (Be' & Tolderlound, 1971). Donner & Wefer (1994) reported the presence of dextral coiling specimens, although not dominant, in sediment traps, but they did not find a relationship with the temperature and they believe that other factors controlled the coiling direction. In this study all dextral coiling specimens belong to morph B and were found at St. 11c (200 m). Although only two stations are available, the Wmco may be responsible for the presence of the dextral coiling specimens, regardless of whether they were live or dead. If this hypothesis is correct, the presence of dextral coiling specimens can be used as an indicator of Circumpolar Deep Water intrusions.

An explanation of the different depths at which the minimum value of the number of specimens occurs, could be the different depth of the chlorophyll maximum in the two stations (fig. 3). At St.11c, the uppermost 50 m are characterised by maximum values of foraminifera specimens and chlorophyll. At St. 15c, the total number of foraminifera is high down to 100 m and the chlorophyll profile peaks at 60 m. This suggests that at St. 15c the food availability for *N. pachyderma* extended to a depth greater than 50 m and that *N. pachyderma* left coiling is somewhat related to the chlorophyll maximum. *N. pachyderma* is a deep-dwelling species, herbivorous (diatoms) and symbiont lacking. Maximum abundance of this species (in particular the dextral coiling variety) is generally found at the depth of maximum chlorophyll biomass when the upper part of the water column is isothermal and cold (Pujol & Vergnaud-Grazzini, 1995). Furthermore, *N. pachyderma* has been associated to the nutricline in Panama basin (Fairbanks & Wiebe, 1980), in Northeastern Pacific (Reynolds & Thunell, 1986) and suggested by Rohling & Gieskes (1989) for the Mediterranean Sea. Kohfeld & *alii*, (1995), in a study carried out in Arctic areas on *N. pachyderma* (left coiling) collected with tows and sediment traps, related peak abundance of this species to chlorophyll maximum.

The distribution of the two morphs confirms that late calcification takes place at deep levels. In fact, only morph B was found in the uppermost traps, while morph A occurred in the deepest ones. The depth of the occurrence of morph A is different at the two stations and it is located below the minimum value of the foraminifera flux. Kohfeld & *alii* (1996) report the presence of two abundance peaks of *N. pachyderma* in the water column: the former is composed of non encrusted forms (morph B of the present study) and it is located above the main pycnocline in the cold mixed layer, where a shallower pycnocline caused by

TABLE 2 - Concentrations and vertical fluxes of studied parameters. OC, organic carbon; N, nitrogen

Station	Trap depth (m)	Number of specimens (total)	Number of specimens (morph A)	OC (wt%)	N (wt%)	C/N	Mass flux (mg m^{-2} d^{-1})	Foram flux (n. spec. m^{-2} d^{-1})	OC flux (mg m^{-2} d^{-1})	N flux (mg m^{-2} d^{-1})
15c	50	54	0	11.0	1.51	7.3	106	216	11.7	1.60
	100	81	0	7.1	0.47	15.1	66	324	4.7	0.31
	150	18	0	6.3	0.32	20.0	109	72	6.9	0.34
	200	126	27	3.6			138	504	5.0	
11c	50	108	0	11.9	1.34	8.9	88	399	10.4	1.17
	100	18	0	5.0	0.55	9.1	123	66	6.1	0.67
	150	99	9	4.8	0.45	10.5	104	365	5.0	0.47
	200	72	9	6.1	0.35	17.4	119	266	7.2	0.41

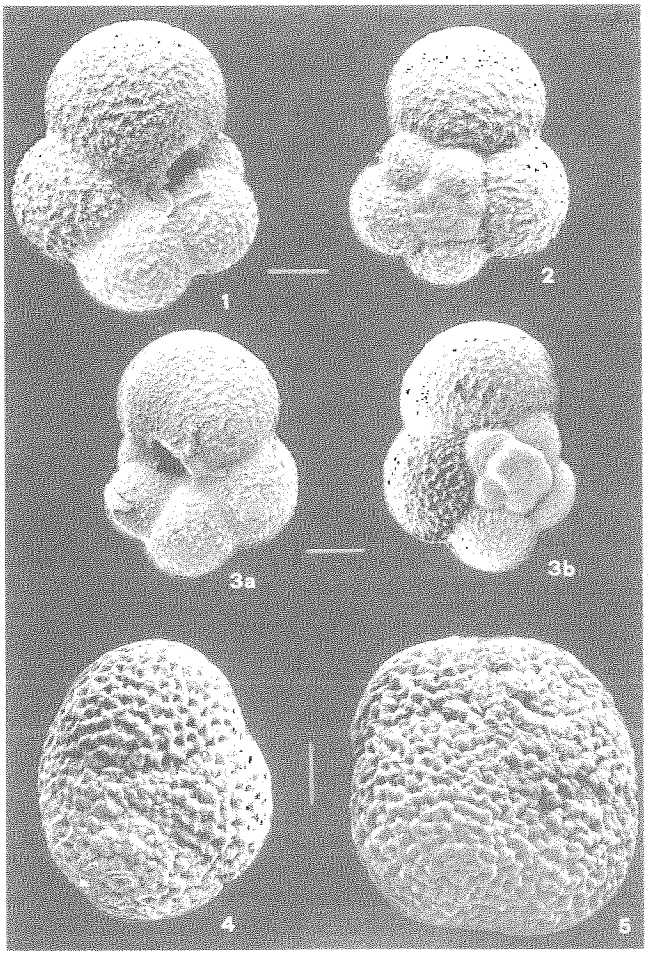

FIG. 4 - 1, 2: *Neogloboquadrina pachyderma* (Ehrenberg) morph B sinistral coiling. 3a, b: *Neogloboquadrina pachyderma* (Ehrenberg) morph B dextral coiling (St. 11c, 200m water depth). 4, 5: *Neogloboquadrina pachyderma* (Ehrenberg) morph A. bar = 50 µm.

the seasonal ice melting is present, while the second peak, dominated by encrusted forms (morph A of the present study) is located within the main pycnocline. The structure of the water column in the area of the present study does not show the presence of a second deep pycnocline at the sampling time; however, morph A is present in the deepest floating traps.

Below the two observed minima, the foraminifera flux increases again paralleling the mass flux. We do not yet have an exhaustive explanation this trend. Nevertheless, we think that the contribution of another living population of *N. pachyderma* has to be taken into account. In fact, the foraminifera population found over the minimum flux values is totally composed of specimens of morph B. These specimens can be considered alive at the sampling time because the tests were internally green, owing probably to phytoplankton ingestion, although the protoplasm was not completely preserved. Therefore, we can consider that morph B is the only component at the levels with chlorophyll maxima and the downward increasing foraminifera flux is mainly constituted by dead specimens. The presence of several specimens of morph A living at deeper levels suggest that this deep living population may contribute to the observed increase of the total number of specimens.

No previous data about planktic foraminifera collected by floating traps are available in the literature in this area. Information on planktic foraminifera of the Ross Sea was provided by Kennett (1966) in a study on total (benthic and planktic) assemblage collected by grab. Donner & Wefer (1994) calculated *N. pachyderma* fluxes in sediment traps deployed in Weddell Sea. They report maxima flux values of 40-60 spec m^{-2} day^{-1} for the early spring (26 Nov.-14 Dec. 1985). They also report fluxes calculated for the period January-March, but we do not have results for the austral summer. The foraminifera flux in our study is higher than the values reported by Donner & Wefer (1994). The fact that the fluxes of Donner & Wefer (1994) were obtained from moored sediment traps implies that the values are an average. This suggests that our foraminifera fluxes reflect a temporary situation of planktic foraminifera bloom, triggered, for instance, by sudden phytoplankton availability. Then, a strong temporal variability in foraminifera fluxes can be expected in this area for the early austral spring. Further data on planktic foraminifera of polar areas were also provided by Carsola (1953), Lipps & Krebs (1974), and Dieckmann & *alii* (1991) in a study carried out on foraminifera trapped in freezing sea ice. Spindler & Dieckmann (1986) and Dieckmann & *alii* (1991) confirmed that *N. pachyderma* is capable of living in the ice interstices and also showed that in the new sea ice the number of foraminifera is much higher than in the underlying water column. Therefore, in our study, we have to consider the possibility that foraminifera can be released into the sea water during the ice melting.

Finally, we cannot exclude, on the basis of these data, the contribution of additional factors (e.g. predation, foraminifera settling velocity) in determining the observed differences in the fluxes.

CONCLUSION

This study provided data on recent planktic foraminifera sampled with floating sediment traps during the spring season. Only one species (*N. pachyderma*) was found in this area. Two morphs (A and B) were recognised: the former is typical of the deeper levels and the latter of levels with chlorophyll maximum. In the uppermost 200 m of the water column, morph B, the juvenile stage, is the most abundant component of the population. The chlorophyll maximum seems to be responsible for the maximum foraminifera abundance observed at the shallower levels. No unequivocal relationship between foraminifera abundance and biogenic content and fluxes was found; neither do physical parameters of the water such as temperature and salinity seem to influence the population. The presence of a small number of dextral coiling specimens at St. 11c, influenced by the modified Circumpolar Deep Water (Wmco), confirms the potential use of this variety as water mass indicator.

REFERENCES

Aa.Vv. (1995) - *Programma Nazionale di Ricerche in Antartide. Rapporto sulla Campagna Antartica Estate Australe 1994-95.*

Artegiani A., Budillon G., Moretti M., Paschini E., Russo A. & Spezie G. (1996) - *Water mass characteristics of the Ross sea- Italian Expedition 1994-95. Part II.* International Workshop «Ross Sea Ecology» (Taormina, 14-16 May 1996) Abstract, 149-151.

Bè A.W.H. (1960) - *Some observations on arctic planktonic Foraminifera.* Contr. Cush. Found. Foram. Res., 11 (2), 64-68.

Bè A.W.H. & Tolderlound D.S. (1971) - *Distribution and ecology of living planktonic Foraminifera in surface waters of the Atlantic and Indian Oceans.* In: Funnel B.M. & Riedel W.R. (eds.): *The micropaleontology of Oceans.* Cambridge University Press, London, 105-149.

Brzezinski M.A. (1985) - *The Si:C:N ratio of marine diatoms. Interspecific variability and the effect of some environmental variables.* Journ. Phycol., 21, 347-357.

Carrada G.C., Mangoni O., Russo G.F. & Saggiomo V. (1996) - *Phytoplankton size fractionated biomasses in the Ross Sea during the austral spring and summer.* International Workshop «Ross Sea Ecology» (Taormina, 14-16 May 1996) Abstract, 24-26.

Carsola A. (1953) - *Possible planktonic occurrence of Globigerina pachyderma (Ehrenberg).* Journ. Paleont., 27 (5), 742-743.

Dieckmann G.S., Spindler M., Lange A., Ackley S.F. & Eicken H. (1991) - *Antarctic sea ice: a habitat for the foraminifer Neogloboquadrina pachyderma.* Journ. Foram. Res., 21 (2), 182-189.

Donner B. & Wefer G. (1994) - *Flux and stable isotope composition of Neogloboquadrina pachyderma and other planktonic foraminifers in the Southern Ocean.* Deep Sea Research, Part I. 41 (11/12), 1733-1744.

Fairbanks R.G. & Wiebe P.H. (1980) - *Foraminifera and Chlorophyll maximum: vertical distribution, seasonal succession and paleoceanographic significance.* Science, 209, 1524-1526.

Jacobs S.S., Fairbanks R.G. & Horibe (1985) - *Origin end evolution of water masses near the Antarctic continental margin: evidence from H218O/H216O ratio in seawater.* In: Jacobs S.S. (ed.), *Oceanology of the Antarctic Continental Shelf.* Antarctic Research Series, 43, American Geophysical Union, 59-85.

Kennett J.P. (1966) - *The fauna of Ross Sea: Part 6, Ecology and distribution of Foraminifera.* New Zealand Department of Scientific and Industrial Research, Bull. 186. New Zealand Ocean. Inst., Mem. 46, 47 pp.

Kohfeld K. E., Fairbanks R.G., Smith S.L. & Walsh I.D. (1996) - *Neogloboquadrina pachyderma (sinistral coiling) as paleoceanographic tracers in polar oceans: Evidence from Northeast Water Polynya plankton tows, sediment traps, and surface sediments.* Paleoceanography, 11 (6), 679-699.

Langone L., Frignani M., Cochran J.K., Ravaioli M. (1997) - *Scavenging processes and export fluxes close to a retreating seasonal ice margin (Ross Sea, Antarctica).* 99, 705-715 Water, Air and Soil Pollution.

Lipps J.H. & Krebs W.N. (1974) - *Planktonic foraminifera associated with Antarctic Sea ice.* Journ. Foram. Res., 4 (2), 80-85.

Nelson D.M., DeMaster D.J., Dunbar R.D. & Smith W.O. Jr. (1996) - *Cycling of organic carbon and biogenic silica in the Southern Ocean: Estimates of water-column and sedimentary fluxes on the Ross Sea continental shelf.* Journ. Geophys. Res., 101, 18519-18532.

Pujol C. & Vergnaud Grazzini C. (1995) - *Distribution of live planktic Foraminifers as related to regional hydrography and productive systems of the Mediterranean sea.* Mar. Micropal., 25 (2/3), 187-217.

Reynolds L.A. & Thunell R.C. (1986) - *Seasonal production and morphologic variation of Neogloboquadrina pachyderma (Ehrenberg) in the northeast Pacific.* Micropal., 32 (1), 1-18.

Rohling E. J. & Gieskes W.W.C. (1989) - *Late Quaternary changes in mediterranean intermediate water density and formation rate.* Paleoceanography, 4, 531-545.

Russo A. (in press) - *Water mass characteristics during the Rossmize cruise (Western sector of the Ross Sea, November-December 1994).* In: Faranda F., Guglielmo G. & Ianora I. (eds.), *Ross Sea Ecology.* Springer Verlag.

Saggiomo V., Carrada G.C., Mangoni O. & Ribera D'Alcalà M. (1996) - *Physiological and ecological aspects of primary production in the Ross sea.* International Workshop «Ross Sea Ecology» (Taormina, 14-16 May 1996) Abstract, 152-154.

Smith W.O. Jr. & Dunbar R.B. (1995) - *The relatinship between New Production and Vertical Flux on the Ross Sea Continental Shelf.* Journ. Marine Systems, in press.

Smith W.O. Jr. & Nelson D.M. (1985) - *Phytoplankton bloom produced by a receding ice edge in the Ross Sea: Spatial coherence with the density field.* Science, 227, 163-166.

Spindler M. & Dieckmann G.S. (1986)- *Distribution and Abundance of the planktic Foraminifer Neogloboquadrina pachyderma in Sea Ice of the Weddell Sea (Antarctica).* Polar Biology, 5, 185-191.