

## EFFECTS OF LATE PLEISTOCENE-HOLOCENE CLIMATIC CHANGES ON THE PLANKTONIC FORAMINIFERA IN THE GULF OF GAETA (TYRRHENIAN SEA, ITALY)

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### ABSTRACT

Planktonic foraminiferal assemblages of core G93-C9, recovered in the Gulf of Gaeta (Tyrrhenian Sea) at 212 m of depth, were analysed by Principal Components Analysis. The analysis was computed first on raw percentage data and then on logratio transformed data. The most important difference between raw data and logratio data rests in the behaviour of *N. pachyderma* which in the first case, unlike the second, does not have significant loading on the first component. Sea surface temperatures exerted a strong control on foraminiferal assemblages. Hydrography and productive system also played an important role in determining composition of assemblages, as shown by the loadings of grazing species on the second component. During the last deglaciation and the Early Holocene eutrophic conditions allowed *Globorotalia inflata* to expand its distribution toward surface waters of the Gulf of Gaeta. During the Late Holocene, planktonic foraminiferal assemblages evidence a tendency towards oligotrophic conditions.

### RIASSUNTO

Effetti dei cambiamenti climatici tardo pleistocenici-olocenici sui foraminiferi planctonici del Golfo di Gaeta (Mar Tirreno, Italia). Vengono presentati i risultati di una Analisi dei Componenti Principali applicata alle associazioni a foraminiferi planctonici della carota G93-C9, prelevata nel Golfo di Gaeta a 212 m di profondità. L'analisi è stata effettuata prima sui dati originali e successivamente applicando ad essi una trasformazione logratio per correggere l'effetto della chiusura dei dati percentuali. I risultati ottenuti differiscono principalmente nel carico di *Neogloboquadrina pachyderma* sul primo componente, che risulta quasi nullo con i dati originali e significativo con i dati trasformati. Le temperature delle acque superficiali hanno svolto un controllo primario sulle variazioni delle associazioni, in cui si riconoscono chiaramente due gruppi di specie con carichi opposti sul primo componente. I punteggi del primo componente lungo la carota definiscono chiaramente i principali eventi climatici avvenuti durante l'ultima deglaciazione. I carichi sul secondo componente di specie prevalentemente erbivore evidenziano l'effetto di fattori trofici ed idrografici. In particolare tra Tardiglaciale e Olocene inferiore si instaurano condizioni eutrofiche che consentono a *Globorotalia inflata*, una specie prevalentemente mesopelagica, di proliferare anche in prossimità della costa. Viceversa nel corso dell'Olocene superiore i risultati evidenziano l'instaurarsi di condizioni oligotrofiche.

Keywords: planktonic foraminifera, climatic changes, Late Pleistocene-Holocene, Tyrrhenian Sea, Principal Components Analysis.

Parole chiave: foraminiferi planctonici, cambiamenti climatici, Pleistocene superiore-Olocene, Mar Tirreno, Analisi dei Componenti Principali.

## 1. INTRODUCTION

In the last few decades many studies involving the analysis of foraminiferal assemblages have been carried out on Late-Pleistocene-Holocene sediments in the Mediterranean Sea, allowing detailed reconstruction of the environmental changes occurred during the last climatic cycles (Blanc-Vernet et Sgarrella, 1989; Kallel et al. 1997, Ariztegui et al. 2000, among others). Relatively few studies, however, focus on neritic or coastal environments. An opportunity to study the effect of climatic changes in a neritic milieu was offered by an oceanographic cruise of the O/V Urania, in October 1993, during which several cores were collected from the Gulf of Gaeta continental shelf. The general results of an

integrated palaeontological study on three cores (G93-C5, G93-C8, G93-C9) involving descriptive analysis of planktonic foraminifera, calcareous nannofossils, pollen and ostracoda, were reported by Amore et al. (2000). A detailed analysis of calcareous nannofossil assemblages, involving comparisons with other sectors of the southern Tyrrhenian continental shelf, was carried out by Esposito (1999). Due to its continuous stratigraphical record and good quality of fossil assemblages, core G93-C9 offers the opportunity to examine planktonic foraminiferal assemblages in detail. With a view to examining the responses of foraminiferal assemblages to environmental changes, planktonic foraminifera of core G93-C9 are investigated by Principal Component Analysis (PCA).

## 2. MATERIALS AND METHODS

The study area is located within the Gulf of Gaeta continental shelf, in the southern Tyrrhenian Sea (Fig. 1). The area represents an extension of the Volturno river and Garigliano river coastal plains. Gravity core G93-C9 (Lat. 41°02' 4" N, Long. 13°32'18"E), 470 cm long, was collected at a depth of 212 m, along an ESE-WSW seismic line. The stratigraphy of core G93-C9, whose sediments consist mainly of clays, is summarised in Figure 2. For palaeontological analyses of core G93-C9, 47 samples spaced 10 cm apart were collected. Samples were washed through a 106 µm sieve. From each sample at least 300 specimens of planktonic foraminifera were collected by using complete splits. The choice of the sieve mesh, which may appear somewhat unusual, requires some explanation. In classical works on oceanic planktonic foraminiferal assemblages large sieve meshes were adopted (i.e. 149 µm) (Imbrie & Kipp, 1971; among others), obtaining very low percentages of undeterminable specimens. This method, however, also artificially reduces the percentages of small species. At the opposite end, in recent works on Mediterranean planktonic foraminiferal assemblages (Capotondi, 1999; among others) very small sieve meshes (65 µm) were adopted, obtaining higher (and less biased) abundances of small species. Assemblages resulting from treatment with a small sieve mesh, however, contain high percentages of undeterminable specimens and, consequently, a lower number of actual specimens. At the same time the number of censored values (i.e. values below the detection limit) for less abundant larger species distinctly increases, with a negative effect on the accuracy of data (Sanford *et al.*, 1993). To avoid such shortcomings it would be necessary to increase the number of specimens counted per sample. By adopting an intermediate sieve mesh (i.e. 106 µm) fewer censored values result, together with only slightly reduced percentages of small species.

In order to investigate the relationship among planktonic foraminiferal species, in the present paper assemblages are investigated by means of a PCA. The PCA was first computed on the raw data and then by applying a logratio transformation (Aitchison, 1986; Kucera and Malmgren, 1998) to the original variables for closure correction. With regards to the foraminiferal species included in the analysis, *Globoturbotalita tenella* and *Globoturbotalita rubescens* were lumped together, while no distinctions were made about *Neogloboquadrina pachyderma*, since it was almost entirely represented by right coiled specimens. No rotations were applied to the components. Since in the original data the three most abundant species (*Turbotalita quinqueloba*, *Globigerina bulloides* and *Globigerinoides ruber*) constitute more than the 64% of total assemblages, it was preferred to operate on the correlation matrix rather than the variance-covariance matrix, in order to investigate relationships between less abundant species. The results obtained with logratio transformed data are less affected by the choice of the matrix to be factored. The interpretation of assemblages is based on the present distribution of species (Bé & Torfalden, 1971; Hembleben *et al.* 1983; Pujol and Vergnaud Grazzini, 1995; among others). The analyses were performed with Systat.

## 3. CHRONOSTRA-TIGRAPHICAL FRAMEWORK

Only one AMS <sup>14</sup>C dating obtained from radiocarbon measurement of *Globigerinoides spp.*, *Globigerina bulloides* and *Orbulina* shells, was available for core G93-C9. In order to improve the age model, some events recorded in planktonic foraminifera assemblages were tentatively correlated with the ecozone boundaries of Capotondi *et al.* (1999). The age model is shown in Table 1. The climatostratigraphy reconstructed for core G93-C9 by palaeontological proxies (Amore *et al.*, 2000) is reported in Figure 2. The Last Glacial period (LG) is represented from the base of the core up to 205 cm. The deglaciation, in which events corresponding with the Bølling-Allerød and the Younger Dryas were identified, was recorded in the 205-125 cm interval. The upper part of the core represents the Holocene.

## 4. RESULTS

Percentages of planktonic foraminifera recorded in core G93-C9 are shown in Table 2. Tables 3a and 3b

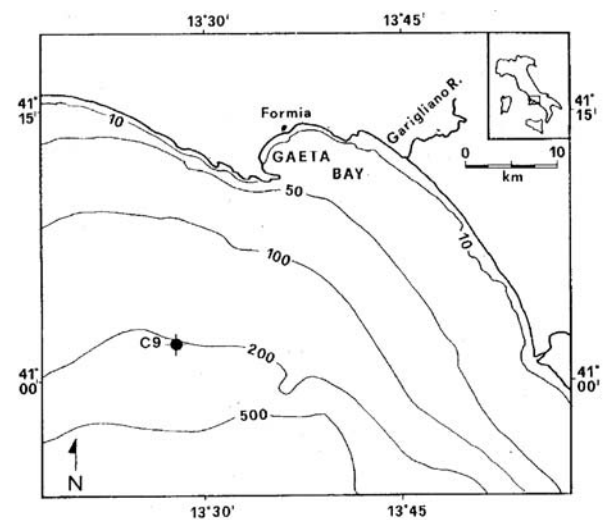


Figure 1 - Location map.

Ubicazione della carota G93-C9.

Tab. 1. Age sources for Core G93-C9. AMS C<sup>14</sup> dating were calibrated with CALIB 4.3 (Stuiver and Reimer, 1994).

Riferimenti per l'inquadramento cronologico della carota G93-C9. La calibrazione delle età radiocarbonio è stata effettuata con CALIB 4.3 (Stuiver and Reimer, 1994).

Depths in Core C9 (cm)	Age source	Radiocarbon ages (kyr)	Calendar ages (kyr BP)	References
55	Ecozones 2-1 boundary	2.8	2.5	Capotondi <i>et al.</i> (1999)
75	Ecozones 3-2 boundary	4.0	3.9	Capotondi <i>et al.</i> (1999)
125	Ecozones 6-5 boundary	10.0	10.9	Capotondi <i>et al.</i> (1999)
165	Ecozones 7-6 boundary	11.4	12.9	Capotondi <i>et al.</i> (1999)
170	<sup>14</sup> C AMS dating	12.030±0.100	13.45 (intercept)	

show the loadings for the components corresponding to eigenvalues greater than 1, computed respectively from the correlation matrix of the raw and the log transformed data. The most important difference between raw data and logratio data rests in the behaviour of *N. pachyderma* which in the first case, unlike the second, does not have significant loading on the first component. A minor

difference regards the third component obtained with the logratio transformations, which corresponds to the fourth component of the original data. In Figure 2 the scores of the first three components computed from the logratio transformed data are plotted along core G93-C9. The following discussion is based on the results achieved with the logratio transformation.

Table 2. Percentages of planktonic foraminifera within Core G93-C9.  
*Percentuali dei foraminiferi planctonici della Carota G93-C9.*

cm	<i>Turbotalia quinqueloba</i>	<i>Globigerina bulloides</i>	<i>Globigerinoides ruber</i>	<i>Globorotalia inflata</i>	<i>Neogloboquadrina pachyderma</i>	<i>Globigerinita glutinata</i>	<i>Neogloboquadrina dutertrei</i>	<i>Globoturborotalia</i>	<i>Globorotalia scitula</i>	<i>Orbulina universa</i>	<i>Globorotalia truncatulinoides</i>	<i>Globigerinoides sacculifer</i>	<i>Globigerinella siphonifera</i>	Indeterminabile
2	6,93	19,1	41,9	7,59	0,33	1,32	0	4,29	0	2,97	8,91	0	1,32	5,28
10	4	21	47,3	5,67	0	2,33	0	1,33	0	5	8,33	0	1	4
20	1,97	24	33,2	6,25	1,64	0,33	0	13,8	0	1,97	4,61	0,66	1,97	9,54
30	8,12	27,9	35,4	6,82	0	3,25	0,65	1,95	0	2,6	1,95	1,95	2,92	6,49
40	4,26	12,8	33,4	5,9	0	0,66	0	10,8	0	5,57	5,25	1,31	5,57	14,4
50	27,2	10,6	27,2	4,32	3,65	8,31	0	6,31	0	2,33	1,99	2,33	1	4,65
60	9,24	19,8	34,3	6,6	0,33	2,31	0	1,32	0	4,95	2,97	12,2	1,32	4,62
70	12,6	27,2	27,5	6,62	0,99	3,31	1,66	0,99	0,33	1,99	2,65	6,62	1,32	6,29
80	5,94	13,2	30,4	11,6	12,9	2,31	1,32	3,63	0	4,62	0,66	1,65	2,64	9,24
90	13,4	21,2	22,7	14	14,3	2,49	0,62	1,56	0	2,8	0	0,93	1,25	4,67
100	9,78	19,9	26,8	18	8,2	0,95	0	2,21	0,95	2,52	0	1,58	0,63	8,52
110	17,4	17,1	22,9	11,3	5,12	4,1	3,41	2,39	2,39	0,68	1,02	1,02	0,34	10,9
120	10	20,7	35	12,3	5	1,33	1	1	0	1	3	0,33	0	9,33
130	26,2	43,7	6,47	9,39	6,47	1,29	0,32	0,65	0,32	0,32	0,32	0	0,32	4,21
140	19,3	19,6	23,5	11,8	8,5	3,59	1,96	0	0	0,33	0	0,98	0,33	10,1
150	27,4	18,2	18,5	7,96	3,18	5,73	8,28	1,27	1,59	0,96	0	0,32	0	6,69
160	24,5	21,2	15,4	13,7	5,23	1,96	3,59	2,61	0,33	0,33	0,65	0	0,65	9,8
170	32,7	14,7	18,7	15	6,67	2,67	0	2,67	0	2	0,33	0,33	0,33	4
180	16,8	22,7	25,3	12,8	1,32	2,63	1,32	1,64	0	2,3	0	0,99	0,33	11,8
190	15,4	19,7	33,1	13,1	0,66	0,98	2,95	0,98	1,31	3,28	0,33	0,66	0,66	6,89
200	20,7	17,7	23	11,7	8,33	1,67	1,33	2,33	0	0,67	0	0	0	12,7
210	28,9	28	9,21	6,58	10,5	5,59	1,32	3,62	1,32	0,66	0,66	0	0	3,62
220	30,8	17,5	8,9	2,05	3,42	9,93	4,45	6,85	5,48	0,68	0	0	0	9,93
230	32	27,5	12	2,27	1,29	5,5	5,5	0	2,59	0	0	0,97	0	10,4
240	33,1	20,4	15,3	5,73	10,5	2,55	2,55	0,96	0,64	0	0	0,32	0	7,96
250	46,5	32,9	1,99	2,99	7,31	1,33	2,33	0,33	1,66	0	0,33	0	0	2,33
260	38,4	22,9	4,52	1,94	1,61	7,42	4,84	4,19	3,87	0,32	0,32	0	0	9,68
270	37,3	26,9	3,57	1,3	5,84	5,84	6,82	0,32	2,27	0	0	0	0	9,74
280	48,4	22,5	3,27	3,59	4,9	0,65	1,96	1,31	0	0	0,33	0	0	13,1
290	42,3	28	6	2,33	4,67	3,33	4,33	0	3,33	0,33	0,33	0	0	5
300	46,4	18,8	0	2,96	1,97	7,89	2,96	1,97	4,93	0	0	0	0	12,2
310	36,2	32,1	2,52	2,83	1,57	6,29	7,23	0,94	1,57	0,31	0	0	0	8,49
320	39,4	38,1	1,28	3,21	7,37	1,92	2,24	0	0,96	0	0	0	0	5,45
330	54	27	1,67	1,67	5,67	4,33	0,33	0,33	2,33	0	0	0	0	2,67
340	31	44,8	5,36	1,53	1,15	5,75	0,77	1,92	2,3	0	0	0	0	5,36
350	34,4	34,1	1,3	1,3	5,19	7,79	6,17	0,97	1,3	0	0	0,32	0	7,14
360	42,7	42,7	1,95	0,65	1,95	2,28	0,98	0	1,3	0	0	0	0	5,54
370	31,9	37,2	7,89	2,84	7,57	5,36	1,26	1,26	0,32	0	0,95	0,63	0	2,84
380	51,5	24,1	0,98	0	1,95	3,58	2,61	0,65	2,28	0	0,33	0	0	12,1
390	34,6	35,9	5,08	0,95	4,44	3,81	7,94	1,59	0,95	0	0	0	0	4,76
400	50,8	31,8	0,66	0,98	5,57	1,31	0,98	0	1,64	0	0	0	0	6,23
410	42,5	31,9	2,66	1,66	6,98	2,66	2,33	1	2,99	0	0	0	0	5,32
420	19,4	37	1,42	2,84	7,11	3,79	1,9	1,42	3,32	0	0	0,47	0	21,3
430	36,5	24,3	2,63	1,64	3,29	15,5	6,25	0,66	3,62	0	0	0,33	0	5,26
440	36,9	39,5	2,33	1,99	7,97	2,66	1,33	0	2,99	0	0	0	0	4,32
450	37,3	38	0,95	2,22	6,65	6,01	0,95	0	3,16	0	0	0	0	4,75
460	31,1	26,2	1,97	5,9	7,54	6,89	0,66	1,31	5,25	0	0	0,66	0,66	11,8
470	47	22,8	0,99	0	2,98	10,6	3,97	1,32	3,97	0	0,33	0	0	5,96

## 5. DISCUSSION

The first three components, corresponding to eigenvalues greater than 1, take into account respectively 55.48%, 10.64% and 8.26% of total variance. The cumulative variance retained is 74.38% of the total variance. As shown in Table 3b, the first component clearly individualizes two groups of species, the first of which, characterised by high positive loadings, is constituted by warm water species. The second group consists mainly of cold water species, with high negative loadings. This structure suggests a relation between this component and sea surface temperatures (SST).

It can be also observed that in core G93-C9 *Globigerina bulloides* and *Globigerinita glutinata* are grouped with cold water species, while *Globorotalia inflata* is grouped with warm species, as a consequence of its absence during the LG. The comparison of first component scores with algebraic climatic curves for pollen and calcareous nannofossils (Figure 3), points out a good agreement in the general trends, supporting the interpretation of the first component in terms of changes in SST. The scores of the first component are lower in the interval corresponding to the LG. The following trend in PC scores points out changes in SST corresponding to the Bølling-Allerød and

Younger Dryas events of the last deglaciation. The Holocene is characterised by increasing values of first component scores.

The second component is characterised by high loadings of grazing species, negative for *N. pachyderma* and *G. inflata* and positive for *Globorotalia truncatulinoides* (Table 3b). The abundance of *N. pachyderma*, which is usually considered a polar-subpolar species, has been related in the Mediterranean sea to the development of eutrophic conditions and a deep chlorophyll maximum (DCM) (Rohling and Gieskes, 1989; Rohling, 1994). The present distribution within the Mediterranean sea of *G. inflata* appears to be related to a rather cool and deep mixing as well as high primary production levels (Pujol and Vergnaud Grazzini, 1995). Moreover although *G. inflata* is mainly a mesopelagic species, it reaches high abundances in shallow water when phytoplankton blooms occur in the mixed layer (Pujol and Vergnaud Grazzini, 1995). In the fossil record this species reaches high abundances during glacial-interglacial transitions (Blanc-Vernet *et al.*, 1984). As regards *G. truncatulinoides*, Pujol & Vergnaud Grazzini (1995) suggest that vertical mixing and winter convection are the primary factors controlling the distribution of this species within the Mediterranean. In the Gulf of Salerno *G. truncatulinoides*, although its percentages never exceed 13%, it is the only grazing species whose abundance increases during the last 5000 yr, when fossil assemblages evidence a decrease in palaeoproductivity (Buccheri *et al.*, 2002).

On the basis of the above mentioned remarks, the second component may be likely related to trophic conditions and convection in the water column. In practice the highest negative scores reached during the last deglaciation-early Holocene interval (Fig. 2) could indicate the establishment of eutrophic conditions in the Gulf of Gaeta. On the contrary positive scores characterise the late Holocene, suggesting a decrease in palaeoproductivity. Besides the "open water" system of the modern Tyrrhenian sea has oligotrophic characteristics (Margalef *et al.* 1966). The opposite relationship between *G. inflata* and *G. truncatulinoides* may appear unexpected, as these species are often associated within the Mediterranean sea (Pujol & Vergnaud Grazzini, 1995). The positive loading of *G. truncatulinoides* does not imply an oligotrophic connotation for this species which does not reach high percentages in the late Holocene. Rather it evidences that during the early Holocene environmental conditions were unfavourable for this species. As regards *G. inflata*, its abundance during the last deglaciation has also been recorded in the shallow core C5 recovered in the Gulf of Gaeta at a depth of 111 m bsl (Amore *et al.* 2000). This means that during the last deglaciation, when the sea level was about 80-90 m lower than at present (Fairbanks, 1989), this species was also abundant in shallower water in the Gulf of Gaeta. This behaviour probably derived, in addition to advantageous conditions (such as the presence of transitional water masses), also from enhanced

primary productivity levels related to increased continental run-off. This is also supported by the high percentages of *Braarudosphaera bigelowii*, a calcareous nannofossil species related to turbidity of surface water and/or low salinity (Müller, 1979), recorded within the same interval (Esposito, 1999; Amore *et al.*, 2000). The composite effect on sea surface temperature changes and trophic regime is highlighted in a plot of core samples on the space defined by first and second components (Fig. 4). The plot allows two groups of samples to be distinguished, the first of which comprises samples from the LG and the deglaciation, with an upward trend towards negative scores for the second component. The second group is represented by late Holocene samples, with positive scores for both components.

The third component is characterised by high positive loadings of *Globigerinoides sacculifer* and negative loadings of *Globoturborotalita* and does not have a clear interpretation. The results of the standardized PCA seem to simply highlight the single peak of *G. sacculifer* within core G93-C9. At present, this tropical species is uncommon within the Mediterranean sea, apart from the Gulf of Lion where this species is very abundant at the

Table 3a - Component loadings, eigenvalues and percent of total variance for PCA computed from raw data.

Component loadings, autovalori e percentuale della varianza totale per l'analisi dei componenti principali relativa ai dati percentuali

	PC1	PC2	PC3	PC4
<i>Turborotalita quinqueloba</i>	-0,883	0,015	-0,105	0,062
<i>Globorotalia scitula</i>	-0,686	0,416	0,192	0,077
<i>Globigerina bulloides</i>	-0,563	-0,190	-0,671	0,017
<i>Neogloboquadrina dutertrei</i>	-0,544	0,336	0,362	-0,219
<i>Globigerinita glutinata</i>	-0,517	0,571	0,404	-0,131
<i>Neogloboquadrina pachyderma</i>	-0,180	-0,742	0,351	0,205
<i>Globigerinoides sacculifer</i>	0,456	0,121	-0,127	-0,724
<i>Globoturborotalita spp.</i>	0,543	0,421	0,142	0,554
<i>Globorotalia inflata</i>	0,631	-0,521	0,434	-0,087
<i>Globorotalia truncatulinoides</i>	0,723	0,347	-0,317	0,146
<i>Globigerinella siphonifera</i>	0,779	0,238	-0,053	0,203
<i>Orbulina universa</i>	0,909	0,133	0,029	-0,118
<i>Globigerinoides ruber</i>	0,944	0,025	0,087	-0,111
Eigenvalues	5,909	1,857	1,252	1,044
Percent of Total Variance Explained	45,452	14,288	9,633	8,032

Table 3b- Component loadings, eigenvalues and percent of total variance for PCA computed from logratio transformed data.

Component loadings, autovalori e percentuale della varianza totale per l'analisi dei componenti principali dei dati sottoposti a una trasformazione logratio.

	PC1	PC2	PC3
<i>Turborotalita quinqueloba</i>	-0,913	-0,025	0,045
<i>Globorotalia scitula</i>	-0,867	0,210	0,014
<i>Neogloboquadrina dutertrei</i>	-0,799	-0,041	-0,066
<i>Globigerinita glutinata</i>	-0,735	0,279	0,061
<i>Globigerina bulloides</i>	-0,692	0,076	0,265
<i>Neogloboquadrina pachyderma</i>	-0,620	-0,584	-0,163
<i>Globoturborotalita spp.</i>	0,493	0,351	-0,686
<i>Globigerinoides sacculifer</i>	0,538	-0,069	0,638
<i>Globorotalia inflata</i>	0,596	-0,678	-0,114
<i>Globorotalia truncatulinoides</i>	0,643	0,488	0,025
<i>Globigerinella siphonifera</i>	0,806	0,183	0,271
<i>Globigerinoides ruber</i>	0,829	-0,228	-0,042
<i>Orbulina universa</i>	0,904	0,020	-0,011
Eigenvalues	7,083	1,383	1,074
Percent of Total Variance Explained	54,481	10,638	8,259

end of summer (Pujol and Vergnaud-Grazzini, 1995). According to Bé and Tolderlund (1971) this species is more abundant in sea surface waters with intermediate salinities, while the maximum abundance of *G. ruber* occurs at more extreme salinities, as in the present-day Mediterranean sea. The highest abundances of *G. sacculifer* and consequently highest positive scores of the third component in core G93-C9 are reached around 3.5 kyr. This peak, which has been recognised throughout the western Mediterranean (Capotondi et al. 1999) coincides, in the Gulf of Salerno, with the re-entry of *Styliola subula*, a halophile pteropod. Buccheri *et al.* (2002) relate this event to the increase in sea surface salinity following the end of the sapropel S1 stagnation phase. The present distribution of *G. sacculifer* suggests that its abundance peak could be related to an enhanced influx of Atlantic waters after the end of the S1 stagnation phase, with sea surface salinities higher compared with the stagnation phase, but lower in comparison to the present.

### 6. CONCLUSIONS

The results of a PCA of planktonic foraminiferal assemblages of Gulf of Gaeta, applied first to the raw percentages data and then to the logratio transformed

data, differ primarily in the behaviour of *N. pachyderma*, which has no significant loading on the component related to SST if the PCA is computed from the raw data. This result is analogous to that obtained by Blanc-Vernet and Sgarrella (1989) in Tyrrhenian and Adriatic Sea cores. However if data are corrected for closure the same species achieves a negative loading on the same component.

Apart from the strong influence exerted by changes in SST, hydrography and trophic regime also play an important role in determining composition of assemblages. In particular second component scores indicate the establishment of eutrophic conditions during the last deglaciation and the early Holocene which allowed *G. inflata* to expand its distribution toward shallow waters of the Gulf of Gaeta. By contrast the Late Holocene is characterised by a tendency towards the establishment of oligotrophic conditions.

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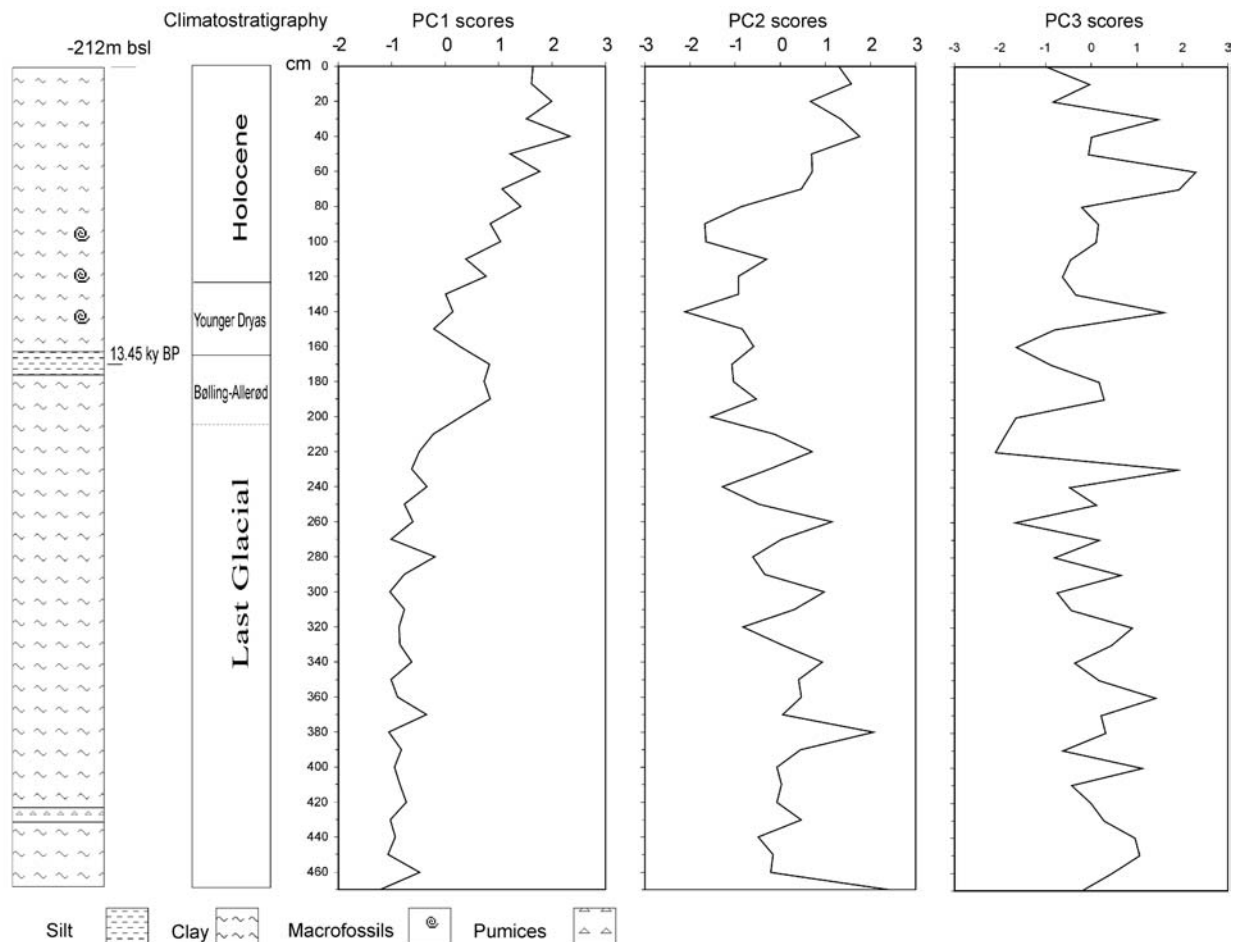


Figure 2 - Stratigraphy of core G93-C9 and scores of the first two component of foraminiferal assemblages. Carota G93-C9. Stratigrafia, climatostratigrafia e punteggi dei primi due componenti principali delle associazioni a foraminiferi planctonici.

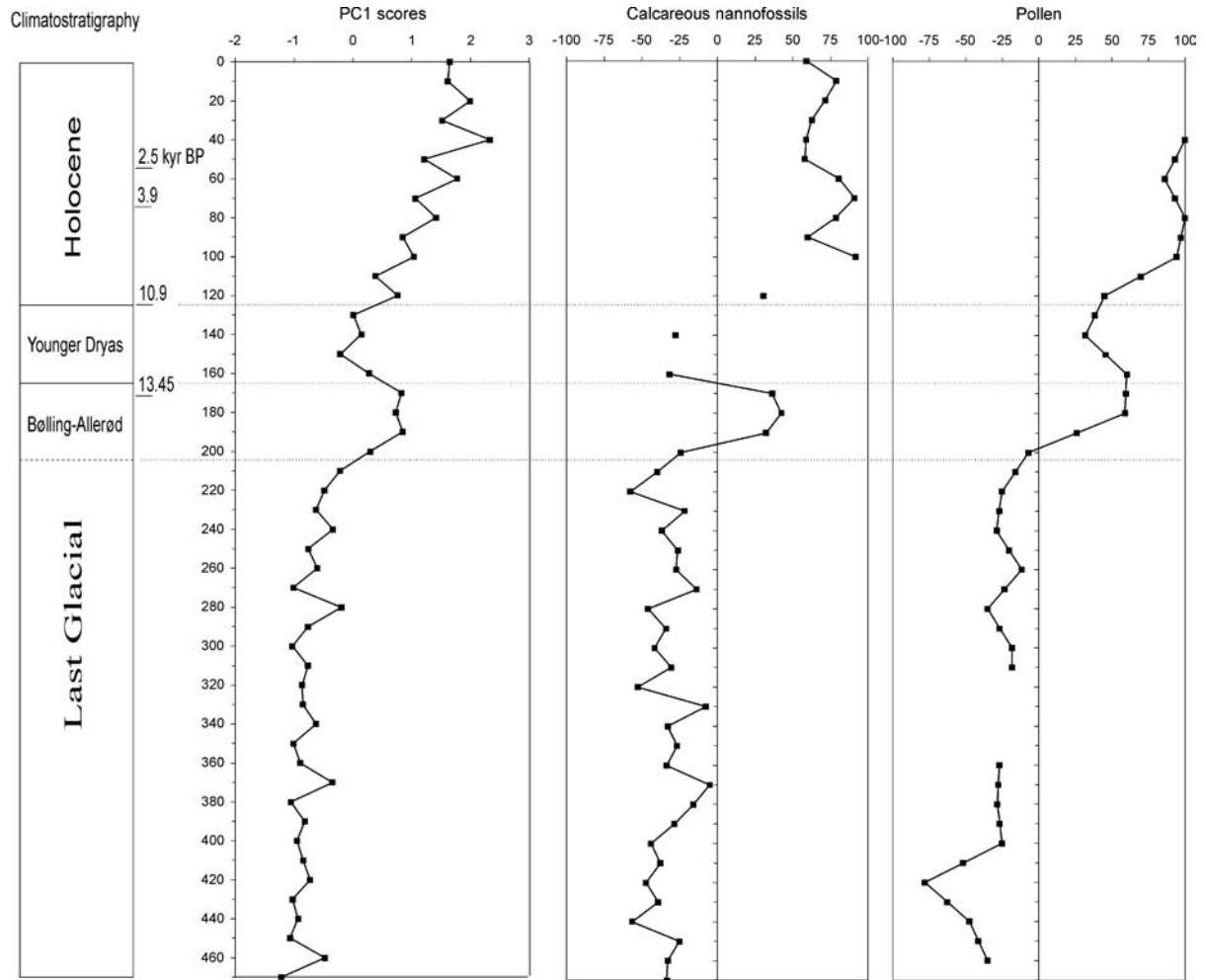


Figure 3 - First component scores of planktonic foraminiferal assemblages compared with algebraic climatic curves for pollen and calcareous nannofossils (from Amore et al. 2000).

Raffronto tra i punteggi del primo componente delle associazioni a foraminiferi planctonici e le curve climatiche algebriche di pollini e nanofossili calcarei.

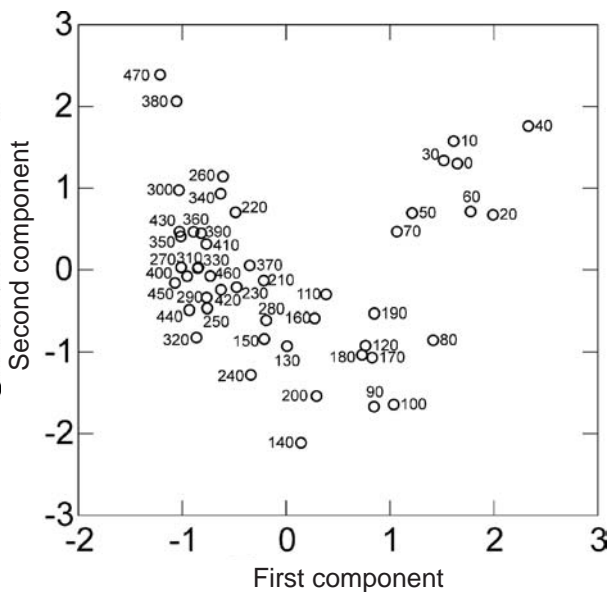


Figure 4 - Plot of core samples on the space defined by first and second components. Numbers refer to depth in core G93-C9.

Grafico dei campioni della carota G93-C9 nello spazio definito dai primi due componenti.

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