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THE LAST DEGLACIATION IN THE SOUTH ADRIATIC SEA: BIOSTRATIGRAPHY AND PALEOCEANOGRAPHY

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RIASSUNTO - *L'ultima deglaciazione nel sud Adriatico: biostratigrafia e paleoceanografia* - Il Quaternario *Italian Journal of Quaternary Sciences*, **9**(2), 1996, 679-686 - Le variazioni percentuali di frequenza dei Foraminiferi planctonici presenti in quattro carote (AD91-14, AD91-16, AD91-17 e IN68-5) prelevate nel Sud Adriatico permettono di suddividere l'ultima deglaciazione in otto intervalli ben distinguibili. Tali intervalli tarati con datazioni radiometriche ^{14}C AMS e con la stratigrafia isotopica dell'ossigeno forniscono una biocronologia ad alta risoluzione per questo bacino. Le variazioni isotopiche dell'ossigeno misurate su *G.bulloides* nelle carote AD91-17, IN68-5 e IN68-9 evidenziano per il Sud Adriatico lo stesso *trend* paleoclimatico presente nel Nord Atlantico. Sono infatti ben riconoscibili le due tappe della deglaciazione (Terminazioni I_A e I_B) e l'evento freddo *Younger Dryas.* Invece, anomalie locali intervengono nel segnale isotopico $\delta^{13}C$. L'integrazione dei dati isotopici con quelli biostratigrafici e con le analisi radiometriche ^{14}C documentano l'inizio della deglaciazione in questa area a circa 13.500 anni, una suddivisione dell'evento *Younger Dryas* in due "fasi paleoclimatiche" e confermano la presenza del livello sapropelitico S_1.

ABSTRACT - *The last deglaciation in the South Adriatic Sea: biostratigraphy and paleoceanography* - Il Quaternario *Italian Journal of Quaternary Sciences*, **9**(2), 1996, 679-686 - The frequency patterns of planktonic foraminifera from four cores (AD91-14, AD91-16, AD91-17 and IN68-5), drilled in the South Adriatic Sea, allow us to subdivide the last deglaciation into 8 intervals. These intervals, calibrated with ^{14}C AMS dating and isotopic stratigraphy, provide a detailed biochronology for this basin. The oxygen isotopic records obtained from the planktonic foraminifera *G.bulloides* from the cores AD91-17, IN68-5 and IN68-9 show for the South Adriatic Sea the same palaeo-climatic trend documented in the North Atlantic ocean. In fact the two main steps of the deglaciation are very well identified, corresponding to Termination I_A and I_B as well as the Younger Dryas cold event. The $\delta^{13}C$ record is more sensitive to local oceanographic conditions. Furthermore, isotopic records, biostratigraphic curves and ^{14}C AMS datings record the beginning of deglaciation at 13.500 years B.P., the subdivision of the Younger Dryas into two "paleoclimatic phases", and confirm the presence of the sapropelitic layer S_1.

Key-words: Planktonic forams, organic carbon, oxygen and carbon isotopic curves, deglaciation time, South Adriatic Sea, Italy
Parole chiave: Foraminiferi planctonici, carbonio organico, curve isotopiche dell'ossigeno e del carbonio, deglaciale, Sud Adriatico, Italia

1. INTRODUCTION

Planktonic forams are one of the most widely used indicators of paleoceanographic variations for the Late Quaternary. In fact, the distribution pattern of living planktonic forams is related to different physical and geochemical proprieties of water masses (Cifelli, 1974; De Castro Coppa *et al.*, 1980; Pujol & Vergnaud-Grazzini, 1995). It has also been proved that a positive correlation exists between the living planktonic forams and the assemblages stored in the surface sediment (Vergnaud-Grazzini *et al.*, 1986).

In this study we have considered the distribution of the planktonic forams with respect to oxygen isotopic scale calibrated by ^{14}C AMS datings.

The aims of this study are twofolds: i) to provide a detailed biochronology for the South Adriatic Sea during the last deglacial time and ii) to characterize the oceanographic setting of this area as related to climatic fluctuations.

2. MATERIAL AND METHODS

During the cruise AD91, performed by the *R/V Minerva* from 5 to 21 March 1991, 3 gravity cores were collected in the Southern Adriatic Sea. Navigation was controlled with GPS and Loran-C navigation positioning system. Core location and the geographic position are listed in Table 1 and shown in Figure 1, respectively.

Cores IN68-5 and IN68-9 have been previously investigated by Jorissen *et al.* (1993).

The cores AD91-17, AD91-16 and AD91-14, consist of muddy sediments with several ash layers (Fig. 2). Two turbidite levels are present in core AD91-17 at 193 to 198 and 307 to 313 centimeter-depth. Two dark layers with high organic content have been correlated with the sapropel S_1, in cores AD91-17 and AD91-16.

The sediment–accumulation-rate curves for AD91-17 and AD91-16 are shown in Figure 3 and are based on the data listed in Table 2 together with ecozone boundaries.

In cores AD91-14, AD91-16 and AD91-17, a 1 cm-thick sample every 10 cm intervals was collected, and dried at about 60°C. Next, 10 g of bulk sediment were taken and sieved with a 63 µm mesh sieve. The >63 µm fraction was split to obtain a subsample containing at least 300 planktonic forams. Calcareous planktonic forams were identified and counted, in order to detect the down-core variation in relative frequency of the most significant taxa.

Isotopic records from cores IN68-5 and IN68-9 published by Jorissen *et al.* (1993) have been re-interpreted in this paper. Isotopic analyses of AD91-17 were performed by Dr. Cespuglio at the Laboratorio di Geochimica Isotopica, Trieste.

The time-stratigraphic framework is provided by the oxygen isotope record in combination with several uncalibrated AMS ^{14}C datings from cores IN68-5, IN68-9 (Jorissen *et al.,* 1993) and AD91-17, AD91-16.

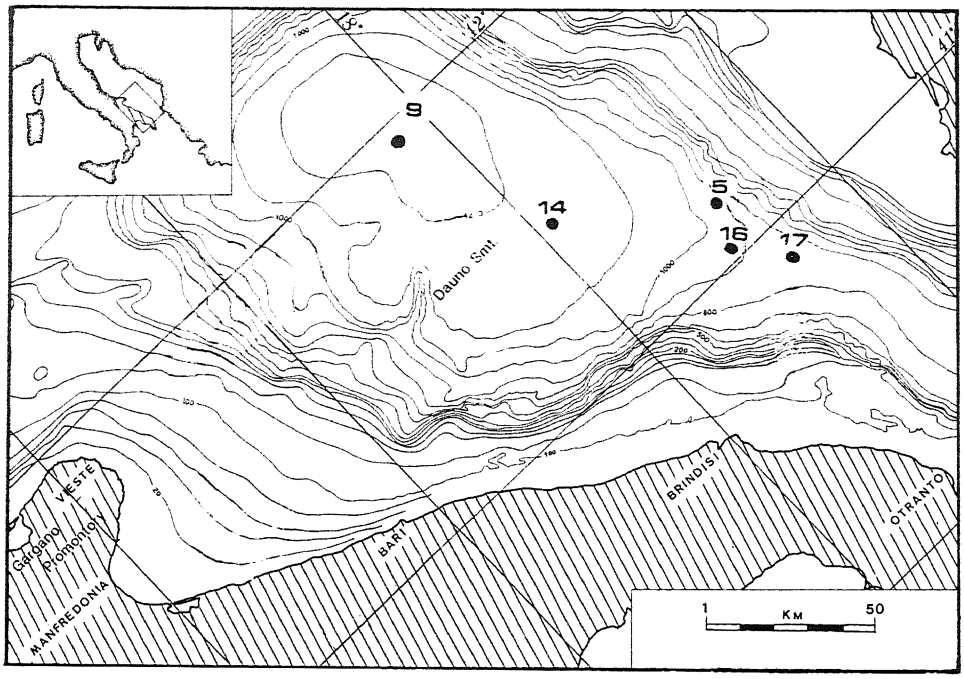

Fig. 1 - Generalized bathymetry for the South Adriatic Sea, together with the core locations from AD91 cruise, and other cores referred to in the text.

Batimetria del sud Adriatico e posizione geografica delle carote prelevate durante la crociera AD91 e delle altre carote citate nel testo.

3. BIOSTRATIGRAPHIC RECORD

The major compositional changes, as well as temporary local disappearance or reappearance of planktonic forams have been used to reconstruct the biostratigraphic framework for the last deglacial time in the South Adriatic Sea. Diagrams with cumulative percentages against depth are shown in Figure 4.

As a result, eight intervals have been recognized:

i) Interval 8: between 18.000 and 13.500 yr B.P. - The planktonic foraminiferal assemblage is clearly dominated by subartic species (*G. scitula, N. pachyderma, G. bulloides* and *G. quinqueloba*), whereas subtropical species are absent. This association is coeval, and very similar, to that observed in the western Mediterranean Sea by Pujol & Vergnaud-Grazzini (1989) and Capotondi *et al.* (1994), and indicates a non-stratified water column rich in nutrients.

ii) Interval 7: between 13.500 and 11.000 yr B.P. - The abrupt decrease of *G. scitula* together with the occurrence of *G. inflata, G. truncatulinoides, G. ex gr. ruber* and *O. universa* are observed in this interval. The presence of grazing species such as *G. inflata* and *G. truncatulinoides,* suggests an increase in phitoplankton productivity. In detail, at 12.700-12.500 yr B.P. a warmer phase characterized by the increase of *G. ex gr. ruber* and *O. universa* is present.

iii) Interval 6: between 11.000 and 10.000 yr B.P. - This period corresponds to the Younger Dryas climatic event and is characterized by the total absence of subtropical species and by the occurrence of subartic species, such as *N. pachyderma* (maximum), *G. bulloides, G. quinqueloba* and *G. glutinata.* In detail, *N. pachyderma* yields a peak of maximum frequency at around 11.000 yr B.P., whereas *G. bulloides* at ca. 10.700 yr B.P.

The quantitative distribution of these species suggests a subdivision of this event: a first stage from 11.000 to 10.700-10.500 yr B.P. characterized by a colder phase with total absence of *G. ex gr. ruber* and *O. universa;* a second stage from 10.700-10.500 to 10.000 yr B.P. with a relative low frequency of *O. universa* and *G. inflata* and an increase of *G. ex gr. ruber,* suggesting a weak warming of the surface water masses.

iv) Interval 5: between 10.000 and 9.000 yr B.P. - The microfaunal assemblage shows presence of *G. inflata, G. ruber* and very few specimens of *G. truncatulinoides.* This

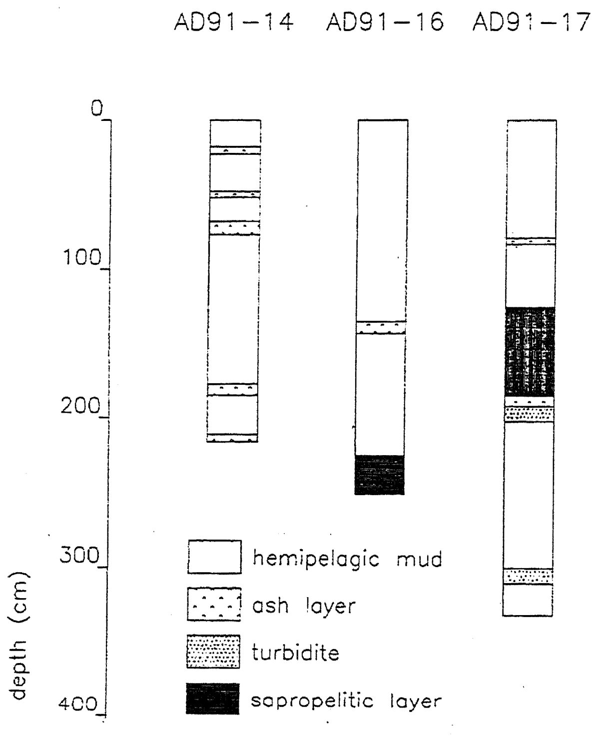

Fig. 2 - Lithology of the cores from AD91 cruise.

Litologia delle carote prelevate durante la crociera AD91.

Table 1 - Location, water depth, and length of studied cores.
Posizione, profonditá e lunghezza delle carote analizzate in questo studio.

Core	Latitude N	Longitude E	Water depth (m)	Length (cm)
AD91-14	41°26'.00	18°02'.50	1146	216
AD91-16	41°02'.50	18°30'.26	935	251
AD91-17	40°52'.17	18°38'.15	844	331
IN68-5	41°14'.00	18°32'.00	1030	643
IN68-9	41°47'.50	17°54'.50	1234	609

Table 2 - Uncalibrated ^{14}C ages in yr B.P.
Datazioni ^{14}C AMS, non calibrate.

Core	Depth (cm)	AMS ^{14}C Ages (yr B.P.)
IN68-5	10.5	5800 ± 100
	190.5	9870 ± 170
	330.5	11900 ± 300
	460.5	13700 ± 300
	617.5	14700 ± 300
IN68-9	11.5	3160 ± 120
	54.5	6390 ± 60
	156.5	9280 ± 180
	241.5	13100 ± 200
	322.5	14200 ± 300
	510.5	17200 ± 300
AD91-17	170.5	7750 ± 60
AD91-16	40.5	2590 ± 60
	170.5	5690 ± 60

association is similar to that found in the eastern Mediterranean, suggesting a significant change in the paleoceanographic circulation, characterized by an exchange of water between the Adriatic Sea and the Levantine Basin.

v) Interval 4: between 9.000 and 7.500 yr B.P. - The assemblage is dominated by subtropical, spinose species (*G. ruber* var. *rosea* and *alba, O. universa, G. aequilateralis* and *G. tenellus*) typical of surface water. This association is characterized by thin test specimens with pyrite crystals or granules of organic matter.

These planktonic forams are associated with a change in sediment colour and increase of organic carbon content that suggest the occurrence of disoxic conditions coeval with the deposition of the sapropelitic layer S_1 in the eastern Mediterranean Sea.

vi) Interval 3: between 7.500 and 6.500 (6.000) yr B.P. - The occurrence of *G. ruber* and *O. universa* with the occurrence of *N. pachyderma* and *G. inflata* suggest high seasonality. In fact, the first species are typical of surface water (Bouvier-Soumagnac & Duplessy, 1985), and the peak in abundance of *N. pachyderma* is usually found at the depth of maximum chlorophyll biomass. *G. inflata* requires, instead, a rather cool and homothermal water column (Fairbanks *et al.*, 1980; Pujol & Vergnaud-Grazzini, 1995).

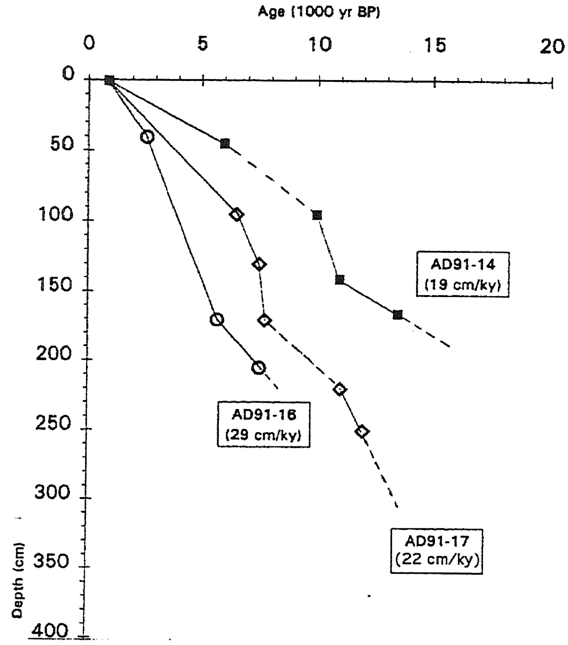

Fig. 3 - Sediment accumulation rates for the three cores from cruise AD91.
Tasso di sedimentazione relativo alle tre carote prelevate durante la crociera AD91.

vii) Interval 2: between 6.500 (6.000) and 5.000 yr B.P. - The foraminiferal assemblages are characterized by the disappearance of *N. pachyderma* and *G. inflata* and by the presence of tropical and subtropical species (*G. ex gr. ruber* and *O. universa*) together with *G. trilobus* and *G. sacculifer.* This planktonic association suggests warmer surface water dominated by oligotrophic conditions, which implies a stratified water column.

Accelerator Mass Spectrometry ^{14}C datings, (in progress) will allow us to better define the chronology in the last three intervals.

viii) Interval 1: between 5.000 yr B.P. and present - The observed association is mainly composed of subtropical species such as *G. ex gr. ruber* and *O. universa,* and of some species typical of high productivity zones, as *G. bulloides* and *G. glutinata.* This assemblage is similar to that found today in the Levantine basin (Pujol & Vergnaud-Grazzini,1995).

4. OCEANOGRAPHIC RECORD

Oxygen isotopic composition of *G. bulloides* measured in the cores AD91-17, IN68-5 and IN68-9 shows different steps during the transition between the Last Glacial maximum and the present interglacial. In particular, we can recognize the presence of two warming phases (Fig. 5) (from 580 to 300 cm in IN68-5; from 260 to 200 cm in IN68-9 and from 280 to 220 cm in AD91-17) which correspond to the Termination I_A, centered around 14,800 yr B.P. and to Termination I_B (from 202 to 140 cm in IN68-5; from 170 to 140 cm in IN68-9) centered around 8,500 yr

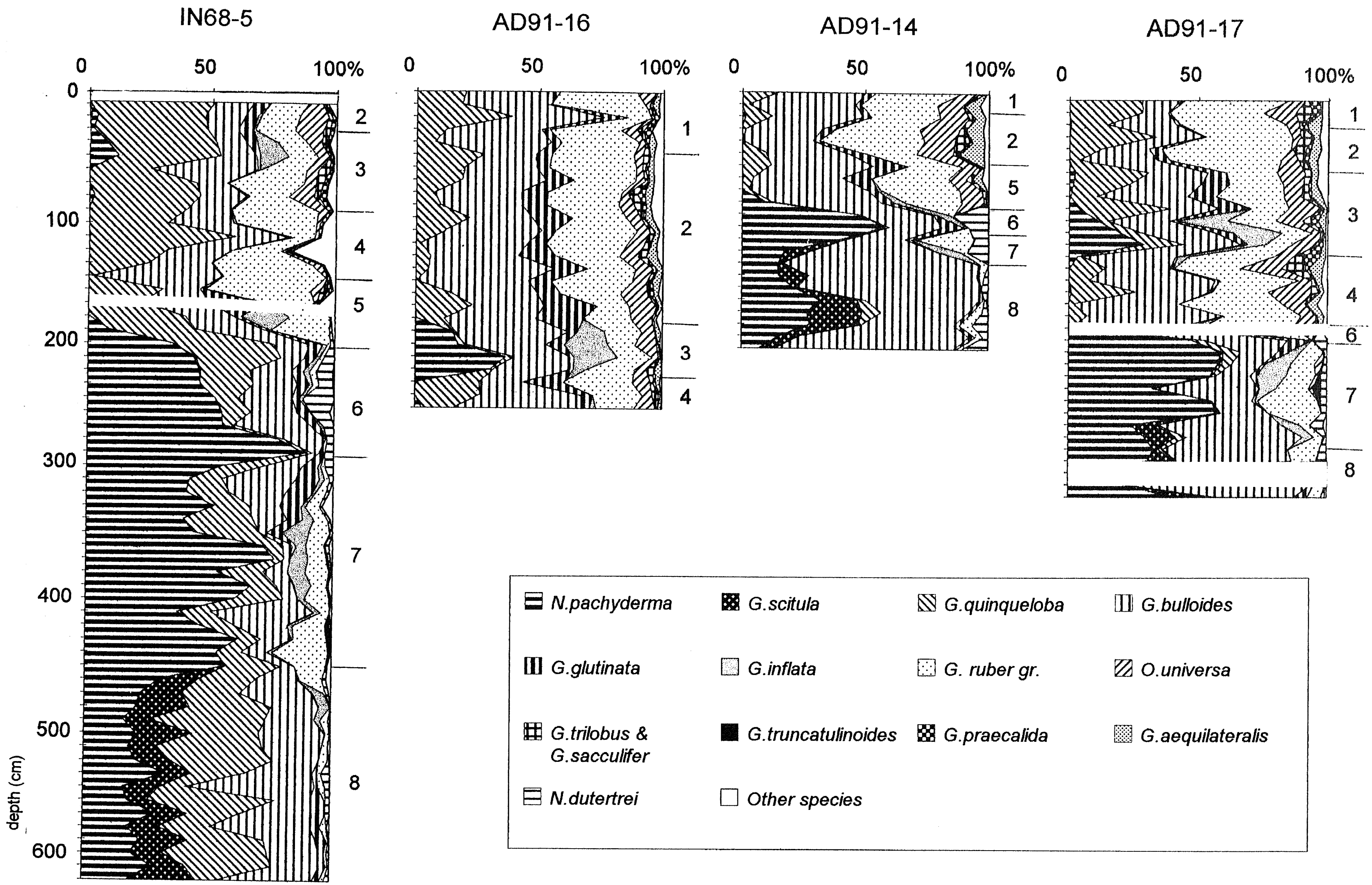

Fig. 4 - Relative abundance of planktonic Foraminifera. Biostratigraphic unit boundaries (dashed) are also shown.
Distribuzione in percentuale cumulativa dei Foraminiferi planctonici. Sono rappresentati i limiti degli intervalli biostratigrafici (tratteggio).

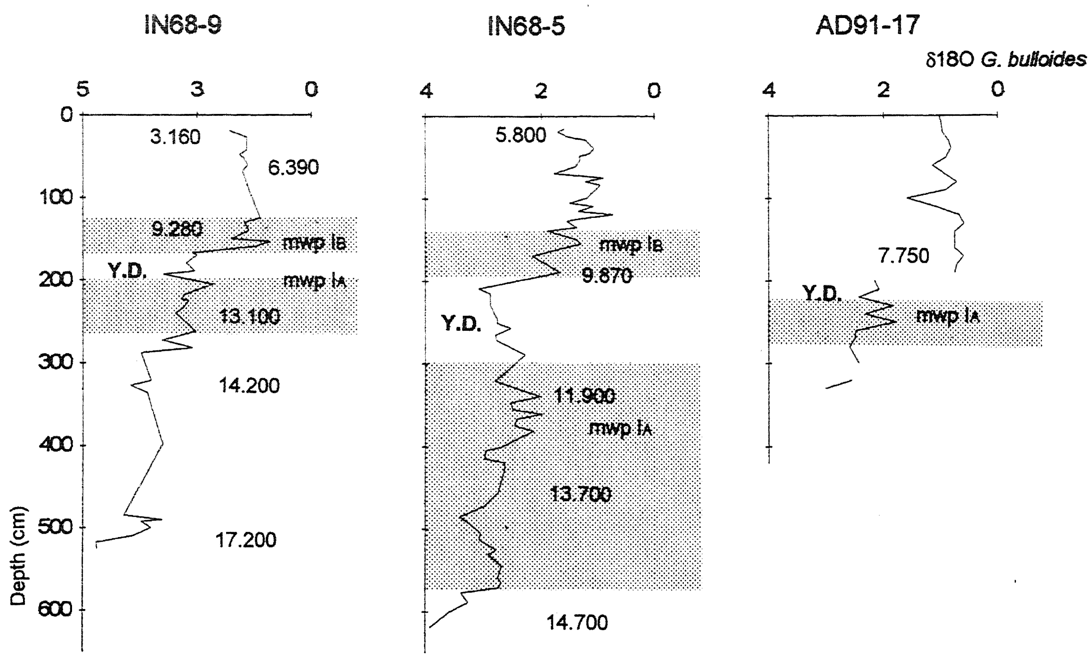

Fig. 5 - Oxygen isotopic variation of *G. bulloides* and ^{14}C dates of cores IN68-5, IN68-9 and AD91-17. The shadowed area identifies the Termination T_{1A} and T_{1B}. Younger Dryas (Y.D.), first and second melt water pulses (mwp I_A and mwp I_B, respectively) are also shown.

Variazioni del $\delta^{18}O$ in G. bulloides *e datazioni ^{14}C AMS nelle carote IN68-5, IN68-9 e AD91-17. L'area ombreggiata rappresenta le Terminazioni T_{1A} e T_{1B}. Sono indicati lo* Younger Dryas *(Y.D.), il primo ed il secondo* melt water *(rispettivamente, mwp I_A e mwp I_B).*

B.P. (Duplessy *et al.*, 1981) in the North Atlantic Ocean.

Two events of freshwater discharges are also evident from the isotopic curves (between 380 and 340 cm and at 150 cm of depth in the core IN68-5; at 205 and at 158 cm of depth in the core IN68-9 and at 250 cm of depth in AD91-17). They can be correlated to the meltwater pulses (mwp I_A and mwp I_B) reported for the Atlantic Ocean and dated to 12,000 and 9,500 yr B.P., respectively (Fairbanks, 1989).

The $\delta^{13}C$ records of *G. bulloides* indicate that shal-

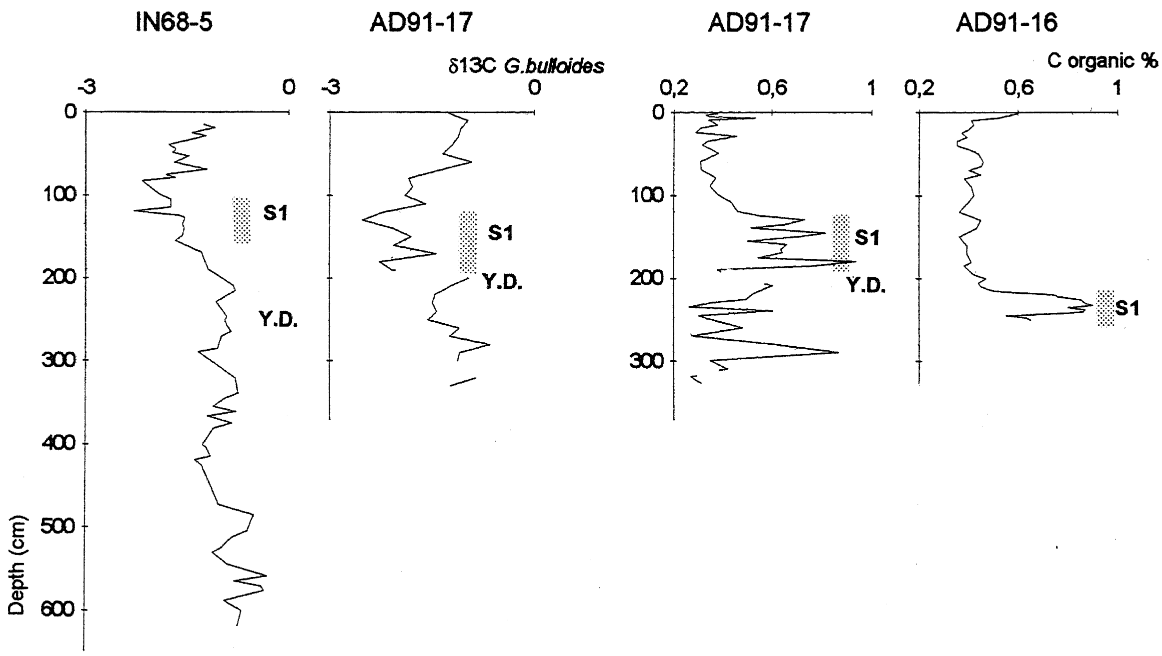

Fig. 6 - Carbon isotopic variation of *G. bulloides* in cores AD91-17 and IN68-5 and organic C contents of cores AD91-17 and AD91-16. The shadowed rectangles mark the sapropel S_1.

Variazioni del $\delta^{13}C$ in G. bulloides *nelle carote AD91-17 e* IN68-5 *e contenuto di carbonio organico nelle carote AD91-17 e AD91-16. Il rettangolo ombreggiato indica il sapropel S_1.*

low water $\delta^{13}C$ depletion was maximum between 14,000 and 11,000 yr B.P. (Fig. 6). Values from planktonic as well as benthonic foraminifera in all basins of the Mediterranean Sea (Vergnaud-Grazzini *et al.*, 1986) differ from the $\delta^{13}C$ records of the open ocean (Shackleton *et al.*, 1983), where deglaciation corresponds to an increase in the $\delta^{13}C$ values as a result of a decrease in the ocean productivity from glacial to the post-glacial time.

Vergnaud-Grazzini & Pierre (1992) interpreted this anomaly in the South Adriatic Sea and in the Eastern Mediterranean, as caused by factors which controlled the surface water primary production, the downward fluxes of organic carbon to the sediment and the deep ventilation.

The Younger Dryas event is marked by a $\delta^{18}O$ increase (values around +3.09, +3.03‰ *vs* P.D.B., maximum at 210 cm in the core IN68-5; at 197 cm in core IN68-9) and a $\delta^{13}C$ enrichment.

The depletion in $\delta^{18}O$ values corresponds to the deposition of the sapropel S_1 (from 140 to 98 cm in core IN68-5; from 140 to 54 cm in core IN68-9 and from 190 to 140 cm in core AD91-17) in agreement with the negative values recorded in the sapropel layers from the eastern Mediterranean (Vergnaud Grazzini *et al.*, 1977; Rossignol-Strick, 1985). For these layers the diagrams of the organic carbon content (Fig. 6) display the highest organic C contents (>0.5 %).

5. CONCLUSION

The oxygen isotopic values combined with the quantitative microfaunal analyses and ^{14}C AMS datings show that in the South Adriatic Sea the effects of glacial conditions ceased at about 13,500 yr B.P.

Between 13,500 to 11,000 yr B.P. the microfaunal assemblage suggest a first warming, which had a peak around 12,700-12,500 yr B.P. During this phase, fresh water discharges correlated with the first melt water spike reported for the Atlantic Ocean at about 12,000 yr B.P. (Fairbanks, 1989) probably caused a weak stratification of the water column. In the colder seasons, an intensification of the vertical mixing prevailed and resulted in the absence of the thermocline.

The Younger Dryas event, dated 11,000 and 10,000 yr B.P. ^{14}C ages (Fairbanks, 1989; 1990), is very well marked by the oxygen isotope record and by the planktonic foraminifera assemblage. These data agree with the pollen record for the same area (Rossignol Strick *et al.*, 1992; Zonneveld, 1996). In particular, the Younger Dryas can be subdivided into two climatic phases: from 11,000 to 10,700-10,500 yr B.P. with the coldest phase, and from 10,700-10,500 to 10,000 yr B.P. with gradual warming of the water column. This paleoclimatic trend is in agreement with the results of Dansgaard *et al.* (1989) and Hammer *et al.* (1986) who suggested that the end of Younger Dryas cooling event occurred at 10,700 years B.P.

During the Holocene, temperatures increased and a different oceanographic setting was established. The microfaunal assemblage, in fact, is similar to associations occurring in the eastern Mediterranean.

The presence of sapropel or sapropelitic sediments in the South Adriatic Sea, was already shown by Rohling *et al.* (1993), Rasmussen (1991) and Capotondi (1995) in other regions of the western Mediterranean Sea. This fact demonstrates that oceanographic conditions leading to sapropel formation were not confined to the eastern Mediterranean, but occurred also outside the eastern basin, and may have influenced the sedimentation of the entire Mediterranean sea during the Late Pleistocene and Pliocene (Emeis *et al.*, 1991).

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