Late Quaternary climatic variations on the Latium and Campanian Margin of the Tyrrhenian SeaVariazioni climatiche tardo quaternarie nel Margine Campano e Laziale, Mar Tirreno

Rend. Fis. Acc. Lincei
s. 9, v. 9:293-313 (1998)

Geologia. — *Late Quaternary climatic variations on the Latium and Campanian Margin of the Tyrrhenian Sea.* Nota (*) di Federica Tamburini, Laura Sbaffi, Forese Carlo Wezel e Judith A. McKenzie, presentata dal Corrisp. F. C. Wezel.

Abstract. — A multidisciplinary investigation was carried out on two cores, MC 82-12 (Palinuro intraslope basin) and ML 83-21 (Pontinia intraslope basin), recovered during a cruise carried out in 1983, in the eastern part of the Tyrrhenian Sea, funded by C.N.R. Quantitative analyses of planktonic foraminifers, along with oxygen and carbon stable isotopes analyses, and mineralogical and petrological studies on tephra layers allowed to recognize and date, by means of isotopic stratigraphy, the main climatic events of the Late Quaternary: the Last Glacial Maximum, the Younger Dryas event, as well as Termination IA and IB. The planktonic assemblages recognized in the two cores correlate well between them and with the oxygen isotopic signal, even if there are some discrepancies, related to oceanographic factors other than temperature influencing the foraminifers distribution.

Key words: Tyrrhenian Sea; Planktonic foraminifers; Oxygen stable isotopes; Late Quaternary.

Riassunto. — *Variazioni climatiche tardo quaternarie nel Margine Campano e Laziale, Mar Tirreno.* Uno studio multidisciplinare è stato condotto su due carote sedimentarie, MC 82-12 (bacino di Palinuro) e ML 83-21 (bacino di Pontinia), recuperate durante una crociera del 1983, finanziata dal C.N.R., lungo il margine orientale del Mar Tirreno. Le analisi quantitative sui foraminiferi planctonici, unite alle analisi degli isotopi stabili dell'ossigeno e del carbonio e a studi mineralogici e petrografici di strati sabbiosi di origine vulcanica, hanno permesso di riconoscere e datare, per mezzo della stratigrafia isotopica, gli eventi climatici principali del Tardo Quaternario: l'ultimo massimo glaciale, l'evento *Younger Dryas*, così come le due fasi della deglaciazione (*Termination* IA e IB). Le associazioni planctoniche riconosciute nelle due carote si correlano bene tra di loro e con le curve dell'ossigeno, e le differenze esistenti sono da mettere in relazione, oltre che alla temperatura, ad altri fattori oceanografici, come la salinità, che influenzano la distribuzione dei foraminiferi.

Introduction

The principal oceanographic factors, as temperature, salinity, oxygen and nutrient amounts, vary in a very sensitive way from the west to the east of the Mediterranean Sea, according to the inflow of the Atlantic water and to the complex physiography of the basin, strongly influenced by the tectonic evolution of the area (Vergnaud-Grazzini, 1985).

Several minor basins can be recognized, connected each other by small and shallow sills that affect the hydrographic circulation of the sea and control the quality and quantity of water interchange. One of these basins, the Tyrrhenian Sea, is an epirogenic interarc basin laying within the concave side of the Apennine and Sicilian mountain belts of Neogene and Quaternary age. It's a young, small and triangular shaped basin, with a central deep abyssal plain, where new oceanic crust forms, and a shallow and narrow continental platform, bordering the basin plain and affected by normal faulting,

(*) Pervenuta in forma definitiva all'Accademia il 4 novembre 1998.

leading to the presence of several little basins (Circum-Tyrrhenian basins or intraslope basins; Vanney and Gennesseaux, 1985). These basins actively control the flow of terrigenous sediment to the abyssal plain (Wezel, 1981).

The Tyrrhenian Sea is connected to the Ionian Sea through the Messina Strait (Southeast), to the Western Mediterranean Sea through Sardinia Channel (Southwest) and through Bocche di Bonifacio (West) and to the Ligurian Sea through Piombino and Corsica channels (North). So, it principally receives water from the Western Mediterranean Sea and the Ligurian Sea (Selli, 1985).

This paper focuses on the Tyrrhenian Sea, in particular on two little intraslope basins located in its eastern margin (Latium-Campanian margin).

During the period 1977-1983 several C.N.R. cruises in the Tyrrhenian Sea were organized to study the morphostructural and sedimentary framework of the Circum-Tyrrhenian basins. These cruises were organized within the framework of the C.N.R. project «Oceanografia e Fondi Marini».

Two gravity cores, MC 82-12, 263 cm long (Palinuro basin, Campanian margin; 39°43.74′ N, 14° 25.14′ E, 1657 m water depth, 75 km offshore), recovered during R/V *Marsili* cruise of 1982, and ML 83-21, 340 cm long (Pontinia basin, Latium margin; 41°03.8′ N, 12°16.3′ E, 1720 m water depth, 50 km offshore), collected during R/V *Bannock* of 1983, are studied here (Wezel, 1981; Savelli *et al.*, 1988; fig. 1). The cruises were organized by the group «Bacini Sedimentari», co-ordinated by F. C. Wezel, from University of Urbino (Italy), where the cores are now stored.

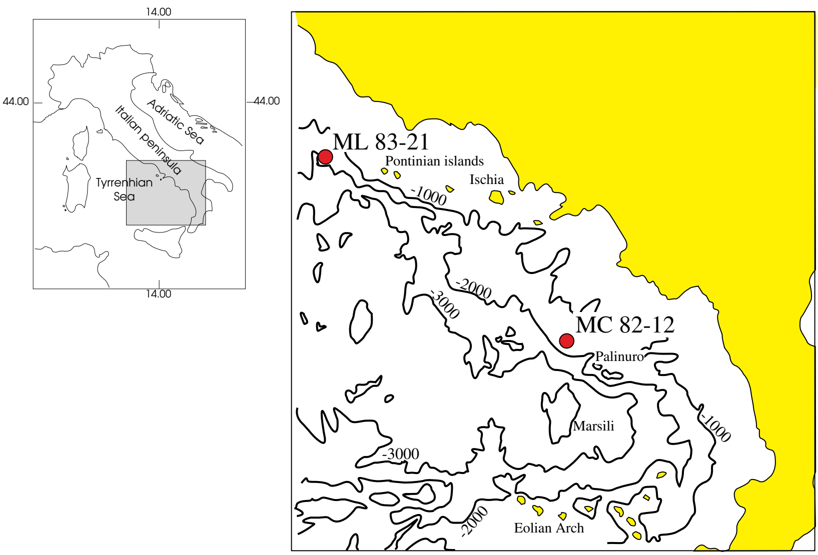


Fig. 1. – Location of C.N.R. cores MC 82-12 and ML 83-21 in the Tyrrhenian Sea.

Previous works (Borsetti *et al.*, 1985; Capotondi *et al.*, 1989) on the Tyrrhenian area have demonstrated that these small intraslope basins are not as disturbed by reworking processes as the central abyssal plain, and that very often they show an almost continuous Late Quaternary geological record (Wezel *et al.*, 1982).

Because of all these considerations, a detailed study of the two cores was carried out, in order to provide new information on the Late Quaternary climatic variations in the Tyrrhenian Sea.

Materials and methods

Lithologic description of the cores.

- MC 82-12.

Core MC 82-12, 263 cm long, consists mainly of grey mud and silty mud. Some sandy levels, more or less continuous, occur in the core. The thickest one (134-144 cm from the core top) is normally graded and constituted by black sand, rich in volcanic glass. Thinner sandy levels are present at 258-262, 98-99, 62-65 and 25-30 centimetres from the core top. The interval between 50 and 63 cm is bioturbated. From 107 to 120 cm patches of organic matter occur (fig. 2).

- ML 83-21.

Mud and silty mud are the dominant lithology of core ML 83-21, 340 cm long. Intercalations of thin silty and sandy levels are also present (309-312, 279-280 and 49-51 cm from the core top).

A 8 centimetres thick sandy layer, composed of dark volcanic sand, rich in glass and biotite, normally graded and with sharp lower contact, occurs at 330 cm from the core top. A large pumice fragment (ø 2.5 cm) is found at 130 cm from the core top.

The interval between 148 and 150 cm contains abundant pteropods. From 170 to 250 cm brown to black organic patches are present, more or less continuous (fig. 2).

Apart from the sandy and/or silty levels described above, the lithology of both cores seems to be homogeneous, mainly characterized by pelitic sediments, testifying a continuous sedimentation, with scarce terrigeneous supply (fig. 3).

Sedimentation rates, extrapolated from $\delta^{18}O$ stratigraphy, are in average around 8-10 cm/kyr for both cores.

Five different chromatics intervals are observed in the cores. In particular, from bottom to top, the following chromatic units can be identified:

i) olive-grey unit (5Y6/3, Munsell Soil Colour Chart): its thickness varies from 161 cm (MC 82-12) to 270 cm (ML 83-21). It's the thickest unit.
ii) olive-brown unit (5Y6/4): from 11 cm (ML 83-21) to 82 cm (MC 82-12).
iii) hazel-brown (10YR6/3): from 4 cm (MC 82-12) to 16 cm (ML 83-21).
iv) light brown (10YR5/4): from 12 cm (ML 83-21) to 38 cm (MC 82-12).
v) dark brown (2.5Y5/4): from 21 (ML 82-12) to 27 cm (ML 83-21).

A multiproxy investigation, including micropaleontological, geochemical and mineralogical analyses, has been carried out on these two cores.

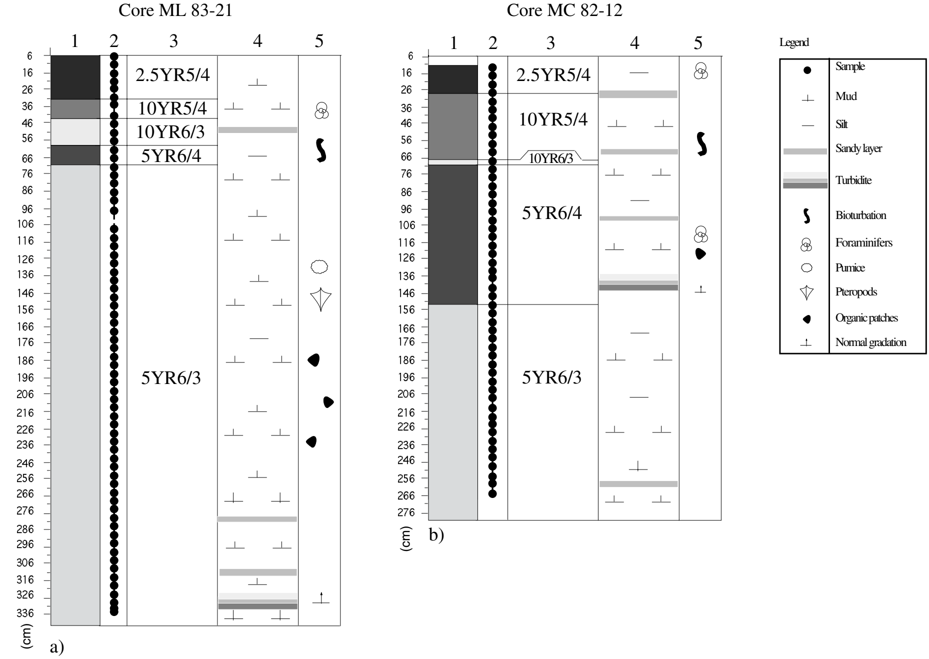


Fig. 2. – Cores ML 83-21 (*a*) and MC 82-12 (*b*); 1: schematic representation of the cores; 2: sampling intervals; 3: Munsell colors of the sediment; 4: lithology; 5: sedimentary structures.

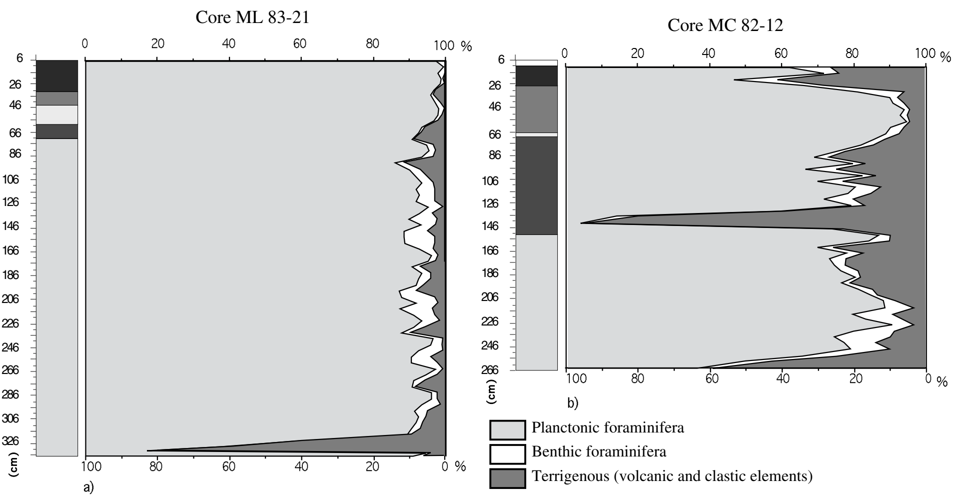


Fig. 3. – Percentages of planktonic and benthic foraminifers and terrigenous elements in the sediments from cores ML 83-21 (*a*) and MC 82-12 (*b*).

Samples were taken at intervals of about 5 centimetres, to a total of 51 samples for core MC 82-12 and 67 for the core ML 83-21. The sampling distance varies depending on lithology variations (fig. 2).

Samples from sandy layers (samples 26 and 27, core MC 82-12 and samples 64 and 65, core ML 83-21) were taken to allow petrographical and qualitative mineralogical analyses, performed by Dr. W. Winkler at the ETH-Zentrum in Zürich.

For micropaleontological analyses, performed by F. Tamburini and L. Sbaffi, the samples were washed with distilled water, using a 40 microns sieve, dried at 40° and then wet sieved with a mesh width of 125 microns.

For each sample the size fraction larger than 125 microns was spread over a tray and about 300 planktonic foraminifers (minimum 213, maximum 409) were identified and counted, to have an estimation of the total number of specimens of each species. The curves in figures 4 and 5 represent the taxa as percentages of the total number of planktonic foraminifers analysed in each sample.

Quantitative analyses were carried out on this size fraction (larger than 125 microns) to eliminate those juvenile forms very difficult to identify; the most important disadvantage of this methodology is the risk to underestimate the amount of the small species, like *Globorotalia scitula* and *Turborotalia quinqueloba*, considered as cold-water indicators.

About 10 to 20 specimens of *Globigerina bulloides* and *Globigerinoides ruber* were picked in all the samples for stable isotope analyses. About 7 to 10 specimens of *Cibicidoides pachyderma* were picked in selected samples.

Oxygen and carbon stable isotopes were measured using a PRISM Mass Spectrometer at the ETH-Zentrum in Zürich (F. Tamburini). The isotope data were corrected following the procedure of Craig (1957), modified for a triple collector and relative to the international standard Pee Dee Belemnite (PDB).

For the qualitative mineralogical analyses of the volcanic sands, organic material and carbonate coatings were dissolved in a 10% solution of HCl with small addition of H_2O_2. The samples were wet sieved and the size fractions <0.063 mm and >0.4 mm removed. Residues were dried in oven at 50 C°. Heavy and light minerals were separated with 100% bromoform (D = 2.82) in separation funnels and a small amount for each fraction of each sample was mounted in piperine resin.

Results and discussion

1. *Qualitative mineralogical and petrographical analyses on volcanic sandy layers.*

The main mineralogical components of the sandy layers are green and brown hornblende, aegirine-augite, olivine, biotite, sanidine and volcanic glass (W. Winkler, personal communication). The composition of these layers is typical of the Campanian province and it can be referred to a «Campanian trachyte», a very common petrogenic type in the Mediterranean tephras, related probably to the Late Quaternary activity of Phlegraean Fields (Paterne *et al.*, 1986; Keller *et al.*, 1978).

K-Ar analyses performed on sanidine coming from the tephra layer of core MC 82-12 did not allow a radiometric dating (I. Villa, personal communication), because the volcanic material is too young. But its mineralogical composition and its position can give indications about the stratigraphy of the core.

In fact, the layer is located just below the interval recognized as being Termination IA (figs. 5, 9) and dated at around 14.8 kyr (Duplessy *et al.*, 1981); so, it might be considered as the product of the latest activity of the first period of the Phlegraean Fields activity, dated at around 15 kyr (Keller *et al.*, 1978).

2. *Quantitative analyses on planktonic foraminifers and paleoclimatic curve.*

The two studied cores provide a very good record for paleoclimatic studies. Both planktonic and benthic foraminifers are present, although benthic foraminifers are less abundant and less continuos along the cores (figs. 2, 3).

There are many works on the climatic and environmental significance of planktonic foraminifers associations, and considering that all the planktonic species here considered still live in the modern oceans, there are also many works about their ecology, studying the factors influencing their presence and frequency; for this work we have used Thunell (1978) and Pujol and Vergnaud-Grazzini (1995), which refer to living planktonic foraminifers of the Mediterranean Sea. The taxonomy of Parker (1962), has been used in this study. Sinistral *N. Pachyderma* has been combined with the dextral form, being always <1%. The different morphotypes of *G. ruber* has not been differentiated in this study.

Using the quantitative analyses and correlating peaks of increasing and/or decreasing in the % of the species and the variations in the whole planktonic foraminifers assemblage (figs. 4, 5), informal biozones and some informal biostratigraphic events have been recognized; these events have a wide and known biostratigraphic meaning in the Tyrrhenian Basin (Capotondi *et al.*, 1989).

Recovered species have been subdivided as follows:

Warm water indicators:

Globigerinoides ruber, Globigerinoides trilobus, Globigerinoides quadrilobatus, Globigerinoides sacculifer, Globigerinoides elongatus, Orbulina universa, Truncorotalia truncatulinoides (including also *T. truncatulinoides excelsa*) and *Hastigerina siphonifera*.

Cold water indicators:

Globigerina bulloides, Globigerinita glutinata, Globorotalia scitula, Neogloboquadrina pachyderma.

The climatic curve of each core (fig. 6) has been determined as the algebraic sum of the percentages of warm-water indicators, considered as positive values, and cold-water indicators, negative values. Other identified species were not included because of their uncertain climatic significance, but they will be considered during the discussion of the paleoclimatic curve and the oxygen isotope curve, according to their paleoenvironmental signal.

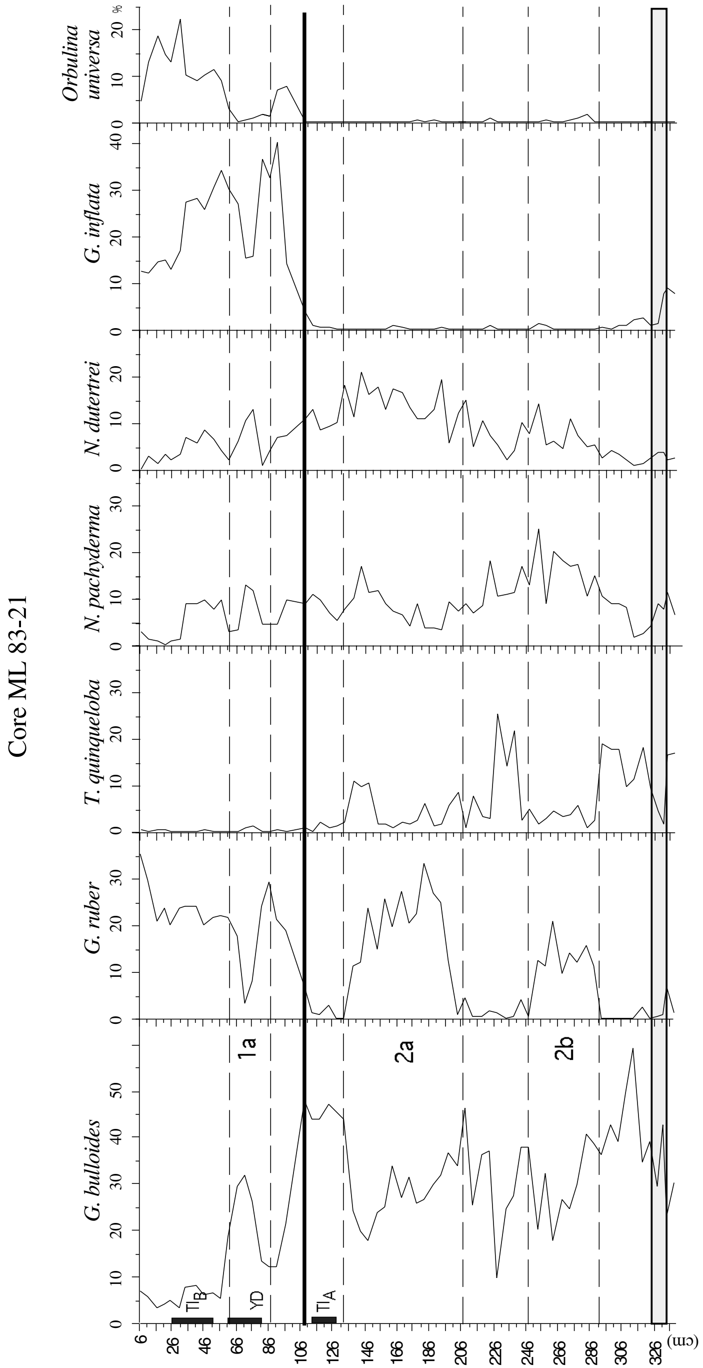


Fig. 4. — Frequency curves of planktonic foraminifers from core ML 83-21. The dashed area represents the volcanic sandy layer recognized in the core.

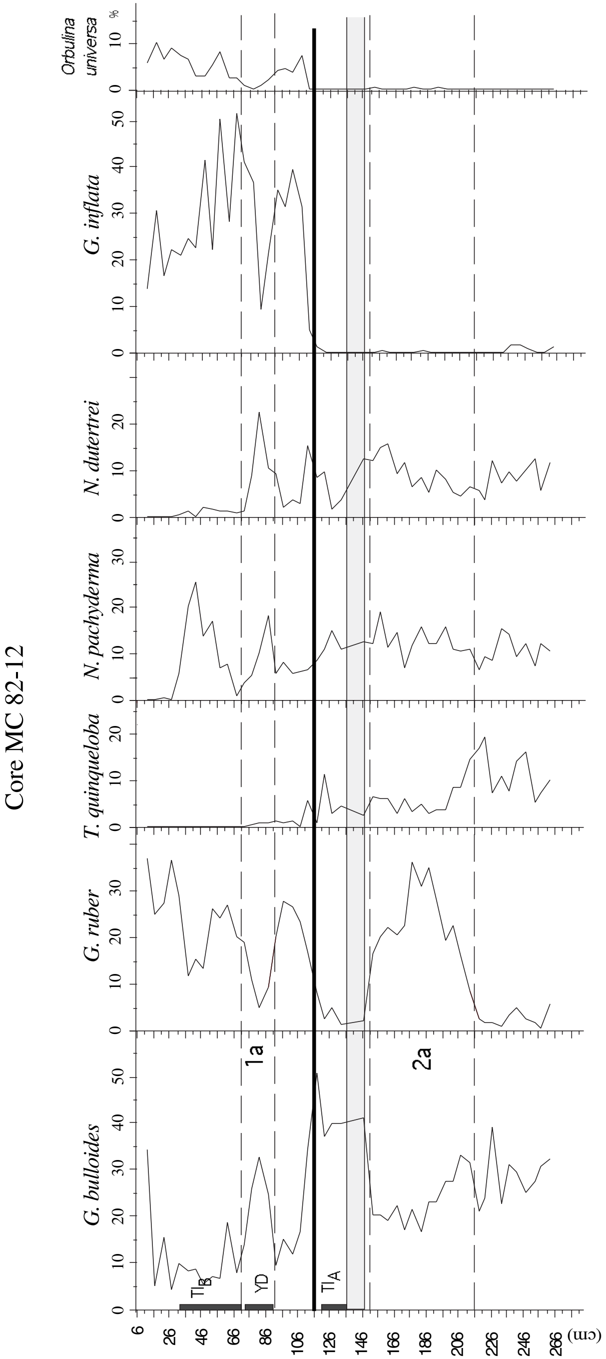


Fig. 5. —Frequency curves of planktonic foraminifers from core MC 82-12. The dashed area represents the volcanic sandy layer recognized in the core.

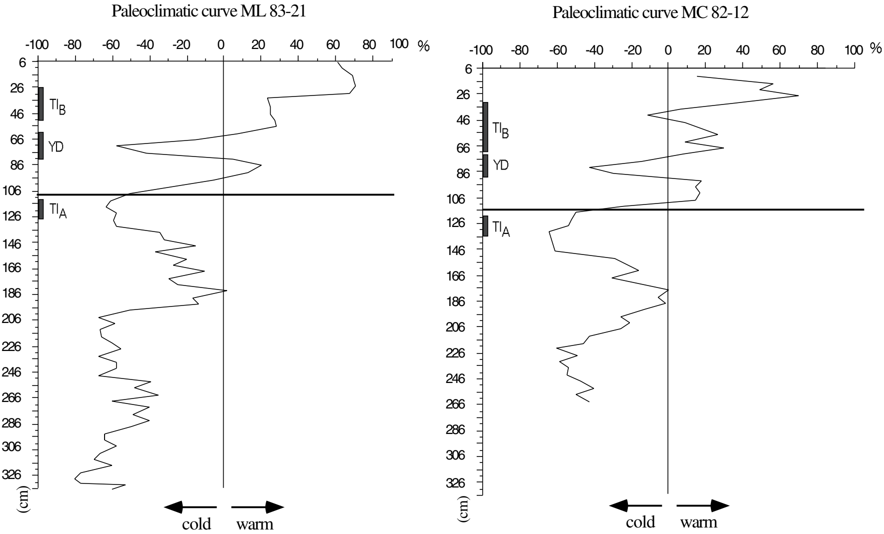


Fig. 6. – Paleoclimatic curves determined by means of the algebric sum of the percentages of planktonic foraminifers. Cold indices are considered negative, while warm indices positive (see text).

Studying the frequency curves of planktonic foraminifers of both cores, a major break in their relative abundances was noticed, located at about 116 cm depth in core MC 82-12 and at about 108.5 cm depth in core ML 83-21.

This break has been recognized also in other faunal records from cores recovered in different areas of the Mediterranean Sea, as Strait of Sicily, Ligurian Sea and Alboran Sea (Vergnaud-Grazzini *et al.*, 1988; Testa *et al.*, 1990).

In both cores this break separates two principal zones, zone 2 (MC 82-12/2, 262-116 cm; ML 83-21/2, 336-108.5 cm) and zone 1 (MC 82-12/1, 116-0 cm; ML 83-21/2, 108.5-0 cm), characterized by different faunal assemblages. Within these two and on the basis of foraminifers frequency fluctuations, it has been possible to define subzones that can be correlated between the two cores.

- ML 83-21 foraminifers frequency and paleoclimatic curves description.

Zone ML 83-21/2 (336-108.5 cm).

In this interval the paleoclimatic curve shows an almost constant trend, all with negative (cold) values.

Cold indices are dominant, *G. bulloides* shows its highest frequency (58%), together with *G. glutinata* (40%). *O. universa* and *T. truncatulinoides* are absent and *G. inflata* decreases to 0 just at the bottom of this interval.

N. dutertrei in this interval is at its highest frequency.

From 291 to 246 cm (2*b*) and from 206 to 131 cm from to top core (2*a*), there are two intervals in which the frequency of *G. ruber* increases towards quite high values (25-35% of the total assemblage) and then decreases. In these two intervals *G. ruber* and *T. quinqueloba* show an opposite trend, and *N. dutertrei* shows high percentages; the paleoclimatic curve is influenced by the frequency variations of *G. ruber*.

At the top of this zone all the cold species begin to decrease:

G. bulloides has its highest peak (about 50% of the total assemblage) and then decreases, *G. scitula* and *T. quinqueloba* show their minimum values, while all the warm indices start to increase.

- Zone ML 83-21/1 (108.5 cm to the top core).

This second zone is characterized by the dominance of tropical and subtropical species, as *G. ruber*, *G. inflata*, *T. truncatulinoides*.

G. ruber keeps on an average of 25%, with its highest peaks at 86 cm and at the core top (about 35% of the total assemblage).

G. inflata, *G. trilobus* and *sacculifer*, *O. universa* and *T. truncatulinoides* have their maximum frequency. *O. universa* appears at the base of the zone.

Cold indices show their minimum frequency, *G. scitula* and *T. quinqueloba* almost disappear.

The paleoclimatic curve shows positive values, with only one colder event.

From 86 to 61 cm from the top (1*a*) core an inverse trend of the frequencies of the species can be easily recognized:

this interval, centred around 71 cm from the core top, is characterized by the decrease of *G. ruber* toward values of 4%, with the warm indices making up only the 4.61% of the whole assemblage, and by the re-occurrence of cold indices, as *G. scitula* and *T. quinqueloba*, with peaks of *G. bulloides* (more than 30%) and of *G. glutinata* (about 15%).

After this event, all the cold species decrease. The last 20 cm of the core are dominated by a warm association with high percentages of *G. ruber*, *G. inflata*, *T. truncatulinoides* and *O. universa*. The paleoclimatic curve shows its more positive values.

- MC 82-12 foraminifers frequency and paleoclimatic curves description.

Zone MC 82-12/2 (262-116 cm).

The total assemblage is significantly dominated by cold water indicators (*G. bulloides*, *G. scitula*, *G. glutinata*, *N. pachyderma*); some of them reach in this interval the highest values.

G. bulloides is the dominant form (average 30%), *G. scitula* (20.30%), *T. quinqueloba* (19.10%) and *G. glutinata* (17.58%) in this interval show their maximum frequency.

G. inflata, *T. truncatulinoides*, *O. universa*, *G. trilobus* and *sacculifer* are almost absent from the assemblage.

From 216 to 151 cm from the core top (2*a*) the climatic curve shows a shift to more positive values (warmer), due to the increasing of *G. ruber*, with a maximum peak between 188 and 178 cm. This particular feature can be easily correlated to the peak of *G. ruber*, characterizing zone ML 83-21/2a.

In this subzone the cold indices decrease, except *N. pachyderma* which frequency keeps on the same values of the below interval. This peak is also associated to an increase (positive trend) of *N. dutertrei* frequency (around 20%).

At 116 cm *G. bulloides* shows its maximum peak (50%) and then begins to decrease. Other cold indicators decrease till the top of the interval. *T. quinqueloba* has the last positive peak (12%) at 121 cm, while *G. glutinata* disappears at 116 cm.

- Zone MC 82-12/1 (116 cm to the core top).

Here tropical and subtropical species are almost dominant.

G. ruber represents on average the 25% of the whole assemblage, *G. inflata* reaches its maximum frequency (51%) at 66 cm, *G. trilobus* and *sacculifer* have their maximum frequency between 76 and 16 cm (5%).

T. quinqueloba and *G. glutinata* strongly decrease till disappearing at 71 cm from the core top, while *G. scitula* shows its last positive peaks in the interval between 86 and 56 cm. The paleoclimatic curve shows a trend toward high values (warm), broken by two negative peaks (fig. 6).

The first one, between 91 and 71 cm from the core top (1*a*) and centred around 81 cm, is characterized by a decrease in all the warm species: *G. ruber* decreases (5%) and the warm water indices make up only the 6.02% of the entire association.

G. bulloides, *G. scitula* and *N. pachyderma* shift toward positive values, together with *N. dutertrei* (24%).

At around 41 cm from the top core we can observe another shift to negative values in the paleoclimatic curve, due to an increase of the frequency of *N. pachyderma*, along with an increase of *T. truncatulinoides* and *G. ruber*.

Then the assemblage is dominated by warm species, reflecting the modern association; the top of the core is characterized by an increase in the frequency of *G. bulloides*.

3. *Isotopic results on core MC 82-12 and core ML 83-21.*

G. bulloides and *G. ruber* are the planktonic foraminifers species used for stable isotopic composition analyses for core MC 82-12 and core ML 83-21.

Even if previous studies on living foraminifers have demonstrated that *G. bulloides* could represent an example of oxygen isotopic disequilibrium with the sea water (Deuser *et al.*, 1981), this species has been used because it is the most persistent one throughout the cores and it is also the most used planktonic species for isotopic studies in the Mediterranean Sea. This allowed to correlate the isotopic records with previous published and well-dated ones.

Isotopic measurements have been performed also on *G. ruber* to have information on the isotopic composition of the surface water layer.

The isotope records from both core of *G. bulloides*, *G. ruber* and of *C. pachyderma*, the benthic foraminifer species analysed for isotopic composition, show the same general trend, with lower values of $\delta^{18}O$ in the *G. ruber* records and higher in the *C. pachyderma* ones (figs. 7, 8).

$\delta^{18}O$ values (smoothed, 3 points moving average) from *G. bulloides* are compared with the isotopic records of core CS 70 5 (Strait of Sicily, Vergnaud-Grazzini *et al.*, 1988) and of core CH 73139C (North Atlantic, Duplessy *et al.*, 1981), to allow a

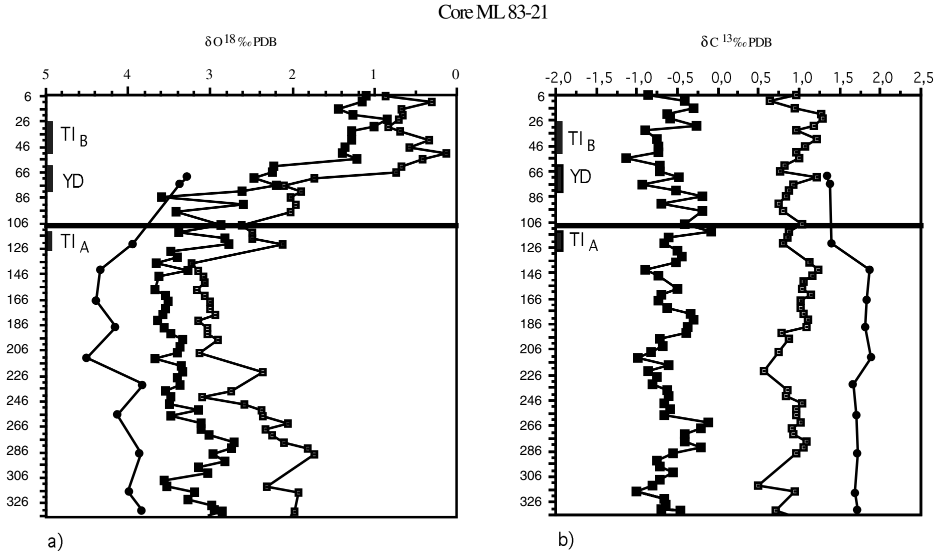


Fig. 7. – Oxygen (*a*) and Carbon (*b*) stable isotope curves from cores ML 83-21. *C. pachiderma* (•), *G. bulloides* (■), *G.des ruber* (⊡).

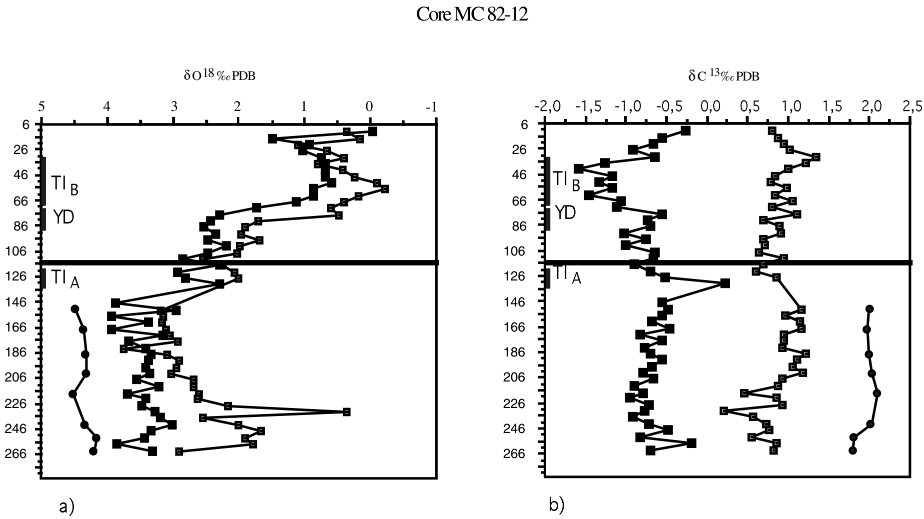


Fig. 8. – Oxygen (*a*) and Carbon (*b*) stable isotope curves from cores ML 82-12. *C. pachiderma* (•), *G. bulloides* (■), *G.des ruber* (⊡).

dating of the cores (fig. 9). These authors have recognized in the isotopic record of the cores the two steps of the last deglaciation, dated by means of C^{14} analyses.

The first step, corresponding to Termination IA (TI_A) is dated at about 14.8 kyr B.P., while the second one, Termination IB (TI_B), is centred around 8.5 kyr B.P. These

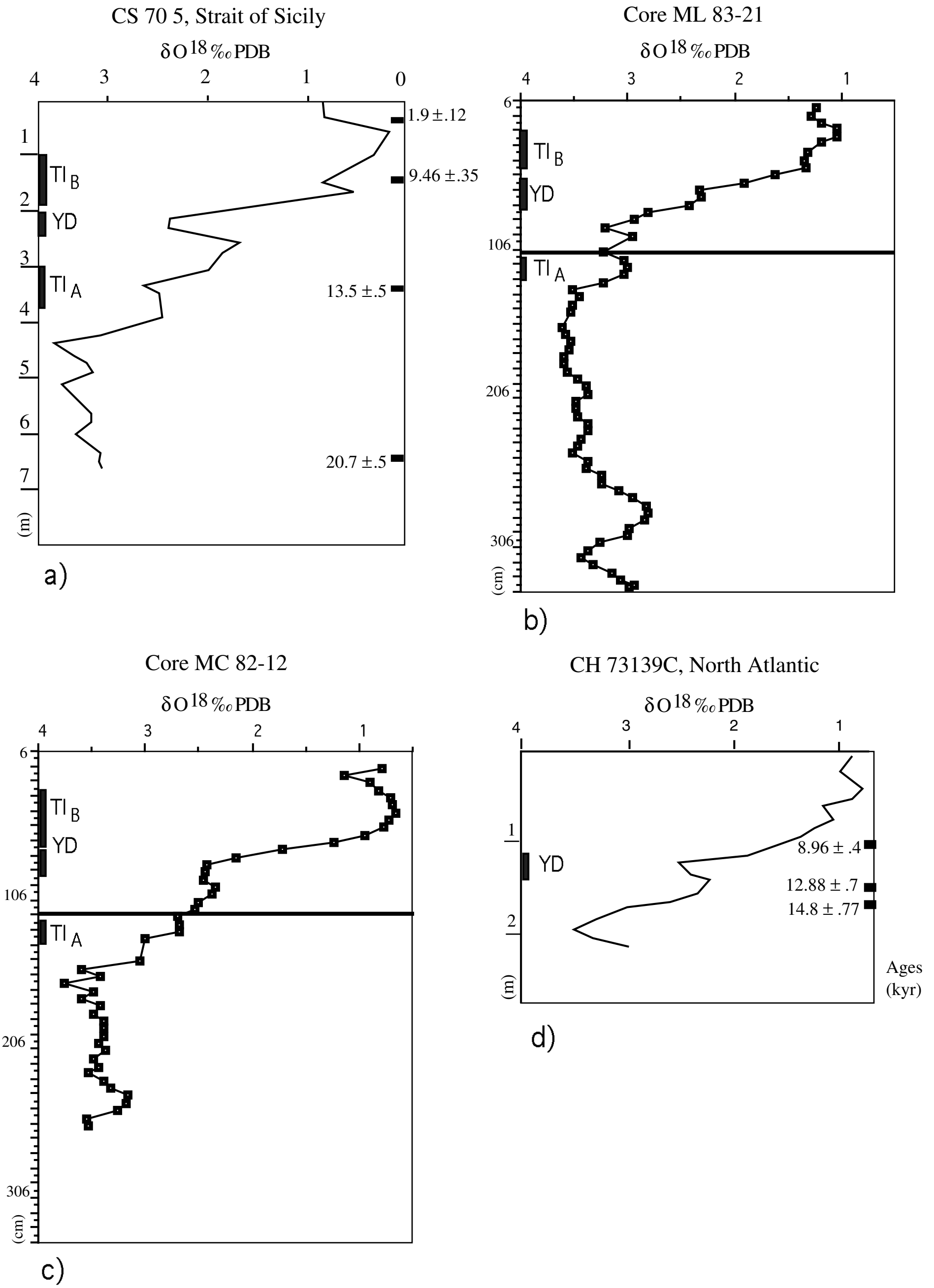


Fig. 9. – δ^{18}O (smoothed) of *G. bulloides* from cores ML 83-21 (*b*) and MC 82-12 (*c*), compared with δ^{18}O (*a*) from core CS 70 5 from Strait of Sicily (Vergnaud-Grazzini *et al.*, 1988) and δ^{18}O (*d*) from core CH 73139C from North Atlantic (Duplessy *et al.*, 1981).

coincide with decreases in the $\delta^{18}O$ values, interrupted by a sharp increase in the values, between 10 and 11 kyr B.P. (Duplessy *et al.*, 1981; Fairbanks, 1989); this event has been recognized as the Younger Dryas event (YD).

This trend is shown also in the oxygen stable isotope records from core ML 82-12 and MC 83-21, where isotopic Stages 1 and 2, along with the Younger Dryas event and the Last Glacial Maximum can be recognized (fig. 9).

The maximum values in the $\delta^{18}O$ (average of + 3.5‰ in *G. bulloides* and average of 3‰ in *G. ruber* in both cores), are present in the lower part of the cores, at 156 cm and 216 cm in core MC 82-12, and at 138 and 213 cm in core ML 83-21; the Late Glacial Maximum can be localised therefore in these two intervals.

The first step of deglaciation, Termination IA, is marked by a decrease in the $\delta^{18}O$ values (average of 2.6‰ in core MC 82-12 and 3.0‰ in core ML 83-21 of *G. bulloides*), and corresponds to the interval between 136 and 121 cm in core ML 82-12 and to interval between 128 and 113 cm in core ML 83-21.

The Younger Dryas event is located between 91 and 73 cm, centred around 86 cm, in core MC 82-12, and between 81 and 61 cm, centred around 71 cm, in core ML 83-21. The $\delta^{18}O$ values are about 2.5‰ .

The end of the Younger Dryas is emphasized by a strong decrease of the $\delta^{18}O$ values, characterizing the second step of deglaciation, Termination IB.

This latter is recorded between 71 and 31 cm in core MC 82-12 and between 51 and 26 cm in core ML 83-21. During Termination IB in the Eastern part of the Mediterranean Basin the deposition of Sapropel S1 (around 8-9 kyr B.P., Vergnaud-Grazzini, 1985) took place (Thunell *et al.*, 1977; Cita *et al.*, 1977).

Discussion

The above isotopic stratigraphy allows to date the bioevents recognized in the studied cores. Comparing the faunal and the isotopic records of the cores (fig. 10), it is possible to see that the principal break in the faunal assemblage, recognized at the onset of increasing of *G. inflata* seems to be younger than the one recognized in the Strait of Sicily (14 kyr B.P., Vergnaud-Grazzini *et al.*, 1988; 15 kyr B.P., Muerdter and Kennett, 1984).

As reported previously by many authors, during the last glacial period and also during the last deglaciation, many faunal events, as occurrence, non occurrence, and peak of abundance of certain species, are diachronous in the Mediterranean Sea (Vergnaud-Grazzini *et al.*, 1988; Testa *et al.*, 1990). Their trend and variations through space and time are related not only to temperature variations but also to circulation patterns (Bizon, 1985; Vergnaud-Grazzini *et al.*, 1988).

Comparing the faunal with the isotopic records from the Tyrrhenian cores, the onset of increase of *G. inflata* can be dated around 13 kyr B.P.; this is in agreement with the dating of the reappearance of *O. universa* after Termination IA, dated around 13 kyr B.P. (Muerdter and Kennett, 1984), and with the data given by the oxygen stable isotope record.

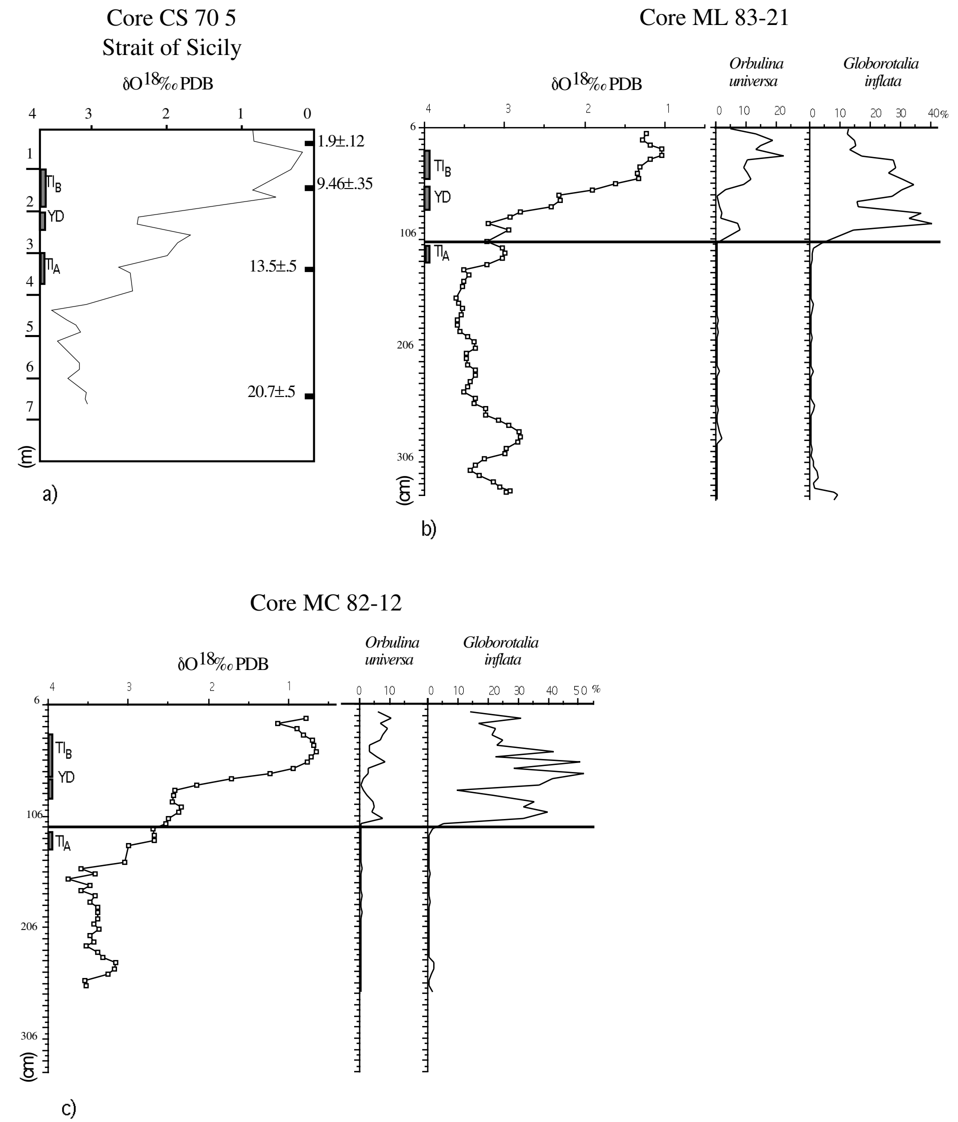
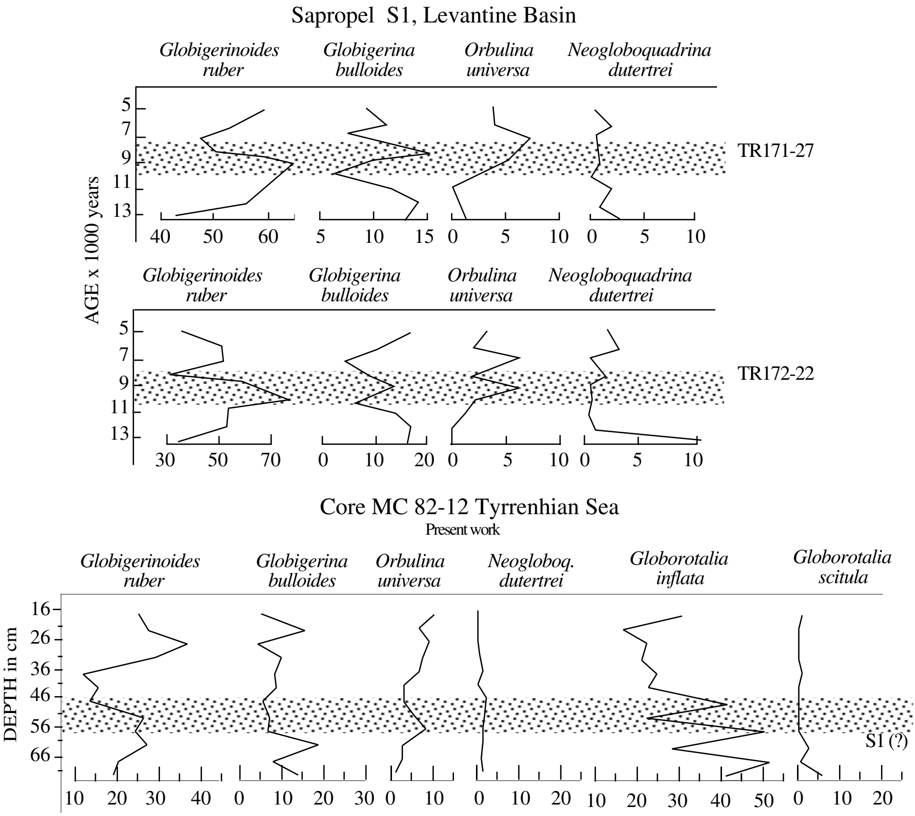


Fig. 10. – Oxygen stable isotope curves of *G. bulloides* from cores ML 83-21 (*b*) and MC 82-12 (*a*) compared to frequency curves of *O. universa* and *G. inflata*. (*a*) δ^{18}O curve from core CS 70 5 from Strait of Sicily (Vergnaud-Grazzini *et al.*, 1988). The two lines represent the onset of increasing percentage of *G. inflata* and the reapparence of *O. universa* (see text, quantitative analyses on planktonic foraminifers).

The cold interval recognized in the faunal records from both cores (ML 83-21/1b and MC 82-12/1b), corresponding to the one dated by Capotondi *et al.* (1989) around 10 kyr B.P., well correlates with the cold event recognized in the isotopic records as the Younger Dryas Event.

During Termination IB (8-9 kyr B.P.) in the Eastern Mediterranean basin the deposition of sapropel S1 took place. Although there is variability in the planktonic foraminifers assemblage of the various Quaternary sapropels, certain characteristic changes in the foraminifers frequencies have been recognized as reflecting the possible presence of a sapropel layer (Thunell *et al.*, 1977; Cita *et al.*, 1977; Williams and Thunell, 1979; Thunell *et al.*, 1984).

In the studied cores there is no lithologic evidence of sapropel deposition, maybe due to a complete post-depositional removal of the sapropel unit (De Lange *et al.*, 1997), but comparing faunal and oxygen and carbon stable isotopes records, it is possible to recognized an interval, located between 46 and 56 cm from the top in core MC 82-12 and between 41 and 51 cm from the top in core ML 83-21, corresponding, maybe, to sapropel S1 deposition (figs. 9, 11) and having faunal and isotopic signatures of a sapropel layer.



a)

b)

Fig. 11. – Frequency curves of planktonic foraminifers, showing the variation in percentages of the species during the deposition of sapropel S1 (*a*) from cores recoverded in the Levantin Basin (Williams and Thunell, 1979). Frequency curves from core MC 82-12 (*b*), showing the variation of the same species in the interval corresponding to the S1 interval. Frenquency curves of *G. inflata* and *G. scitula* are also shown. Dashed areas represent the sapropel S1.

The faunal assemblage of this interval is characterized by an increase of *N. dutertrei*, characteristic of low-salinity waters (Bé and Tolderlund, 1971), by the absence of *G. scitula* (bathypelagic specie, not present in sapropel layer) and by a significant drop in percentage of *G. inflata* (fig. 11; Williams and Thunell, 1979).

The stable isotope records show high depletion, both in oxygen stable isotope and in carbon stable isotope values in this interval (figs. 7, 8). The co-occurrence of depletion both in the oxygen and in the carbon stable isotope record, considered as characteristic of sapropel horizons (Thunell and Williams, 1983), can be explained in fact by means of surface salinity changes.

The $\Delta\delta^{18}O$ between the Last Glacial (about 18 kyr B.P.) and Termination IB (about 8 kyr B.P.) is around +3.5‰ (data from oxygen isotopic record from *G. bulloides*, core MC 82-12) in the Tyrrhenian cores, too high to be completely attributed to temperature changes and ice-volume effect. In fact, considering the equation from Shackleton and Kennett (1975) to estimate paleotemperatures from oxygen isotope data, this difference could be explained by a temperature change of about 13 °C, greater than the one (about 8°C) foreseen by Cita *et al.* (1977) for the eastern Mediterranean Basin.

Therefore, the oxygen and also the carbon isotopic depletion during the sapropel formation have been attributed not only to a temperature increase, but principally to a strong dilution of the upper layer of the water column (lower salinity layer), due to enhanced precipitation, runoff and increased fresh water input from the continent during the glacial-postglacial transition (Fairbridge, 1972; Cita *et al.*, 1977; Vergnaud-Grazzini *et al.*, 1977), and causing a stratification of the column water.

Discrepancies between the isotopic records and the calculated paleoclimatic curves from the Tyrrhenian cores have been observed in two intervals, ML 83-21/2a, MC 82-12/2a and ML 83-21/2b (fig. 12); they can be explained by the effects of oceanographic factors, locally more important than temperature, as productivity and salinity, influencing faunal assemblages.

In fact, the frequency of *G. ruber* (spinose carnivore species, living in the uppermost part of the water column), affecting the most the trend of the paleoclimatic curves in these intervals, is not affected only by temperature change, but also by salinity, nutrients and zooplankton amount (water column productivity). *N. pachyderma* and *N. dutertrei* (non spinose herbivorous species) are present in those intervals in quite high percentages (figs. 3, 4); their frequency can be also influenced by productivity and they indicate high fertility of the water column in response to upwelling events, periods of vertical mixing or river input.

Conclusion

The multidisciplinary investigation carried out on two cores collected in two Circum-Tyrrhenian intraslope basins has allowed to reconstruct the paleoclimatic record of the Late Quaternary in the area.

Even if absolute datings of the cores would have given a more precise and accurate temporal framework of the records, the isotopic stratigraphy allowed to recognize the

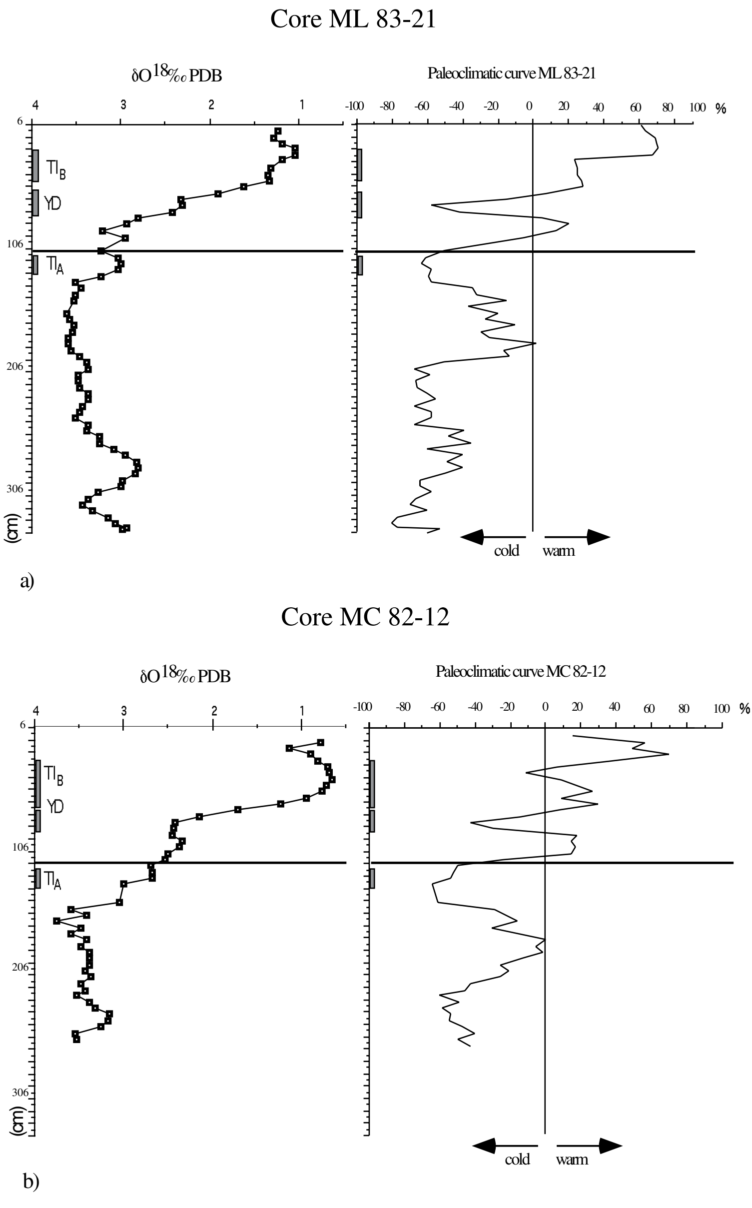


Fig. 12. – Oxygen stable isotope curves of *G. bulloides* and paleoclimatic curves from cores ML 83-21 (*a*) and MC 82-12 (*b*).

main climatic changes and their timing.

The oxygen isotope records from core MC 82-12 and ML 83-21 display the same trend shown by other isotopic records of cores both from the Mediterranean Sea (Vergnaud-Grazzini *et al.*, 1988) and from the open ocean (Duplessy *et al.*, 1981).

Isotopic stages 1 and 2 have been recognized in the Tyrrhenian records, as well as the Last Glacial Maximum and the two principal steps of deglaciation, Termination IA and IB, interrupted by the Younger Dryas cold event.

They also well correlate with the faunal assemblages and the bio-events recognized in the cores, and already studied in other parts of the Mediterranean Sea.

Some of these bio-events (see onset of *O. universa*) seem to be sinchronous with the events previously recognized in the Mediterranean Sea, while others (see onset of *G. inflata*), seem to be diachronous.

This and the discrepancies between the paleoclimatic curves and the oxygen isotopic records, due mainly to the presence of particular faunal assemblages, suggests that the foraminifers distribution records the climate changes occurred during the Late Quaternary, but with a strong overprint of local oceanographic factors, as circulation patterns, changes in salinity and productivity of the column water, due also to the proximity of the continent.

Acknowledgements

The authors are deeply indebted to S. Spezzaferri and D. Ariztegui, for helpful and stimulating discussions. Special thanks to S. Bernasconi and H. Paul for their vital help with the PRISM, and to W. Winkler.

Funding for this research were provided by C.N.R. 1996 grant and MURST 40% grant (responsible: F. C. Wezel).

References

Bé A. W. H., Tolderlund D. S., 1971. *Distribution and ecology of living planktonic foraminifera in surface waters of the Atlantic and Indian Oceans*. In: B. M. Funnel, W. R. Riedel (eds.), *The Micropaleontology of the Oceans*. Cambridge University, London: 105-149.

Bizon G., 1985. *Mediterranean Foraminiferal Changes as Related to Paleoceanography and Paleoclimatology*. In: D. J. Stanley, F. C. Wezel (eds.), *Geological evolution of the Mediterranean Sea*. Springer-Verlag: 453-470.

Borsetti A. M., Cati F., Colantoni P., D'Onofrio S., Tampieri R., Vergnaud-Grazzini C., 1985. *Changements observés dans les associations des faunes planctoniques du Canal de Sicile au cours de la dernière déglaciation*. Rapp. Comm. Int. Mer Méditerranée, 29: 167-168.

Capotondi L., Borsetti A. M., Vergnaud-Grazzini C., D'Onofrio S., 1989. *Biostratigrafia e stratigrafia isotopica della carota AC85-4: considerazioni sulla paleoceanografia tardo-quaternaria del Mar Tirreno orientale*. Giorn. Geol., 51 (1), ser. 3: 201-212.

Cita M. B., Vergnaud-Grazzini C., Robert C., Chamley H., Ciaranfi N., D'Onofrio S., 1977. *Paleoclimatic record of a long deep sea core from the Eastern Mediterranean*. Quaternary Research, 8: 205-235.

Craig H., 1957. *Isotopic standards for carbon and oxygen and correction factors for mass-spectrometric analysis of carbon dioxide*. Geochem. Cosmochem. Acta, 12: 133-149.

De Lange G. J., Van Santvoort P., Passier H., Langereis C., Dekkers M., Thomson J., Michard A., Corselli C., 1997. *Redox-related preservation of paleoceanographic proxies from initial sapropel sediments.* International Conference on *Neogene Paleoceanography,* Erice (Italy), 28-30 Sept. 1997. Abstract Volume: 26-27.

Deuser W. G., Ross E. H., Hemleben C., Spidler M., 1981. *Seasonal changes in species composition, mass, size and isotopic composition of planktonic foraminifera settling into the Deep Sargasso Sea*. Palaeogeogr., Palaeoclimat., Palaeoecol., 33: 103-127.

DUPLESSY J. C., DELIBRIAS G., TURON J. L., PUJOL C., DUPRAT J., 1981. *Deglacial warming of the Northeastern Atlantic Ocean: correlation with the paleoclimatic evolution of the European continent*. Palaeogeogr., Palaeoclimatol., Palaeoecol., 35: 121-144.

FAIRBANKS R. G., 1989. *A 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation*. Nature, 342: 637-642.

FAIRBRIDGE R. W., 1972. *Quaternary sedimentation in the Mediterranean region controlled by tectonics, paleoclimates and sea level*. In: D. J. STANLEY (ed.), *The Mediterranean Sea*. Dowden, Hutchinson and Ross, Stroudsburg: 99-113.

KELLER J., RYAN W. B. F., NINKOVICH D., ALTHERR R., 1978. *Explosive volcanic activity in the Mediterranean over the past 200,000 yr as recorded in deep-sea sediments*. Bull. Soc. Geo. American, 89: 591-604.

MUERDTER D. R., KENNETT J. P., 1984. *Late Quaternary planktonic foraminiferal biostratigraphy, Strait of Sicily, Mediterranean Sea*. Mar. Micropal., 8: 339-359.

PARKER F. L., 1962. *Planktonic foraminiferal species in Pacific sediments*. Micropaleontology, vol. 8, n. 2: 219-254.

PATERNE M., GUICHARD F., LABEYRIE J., GILLOT P. Y., DUPLESSY J. C., 1986. *Tyrrhenian sea tephrochronology of the oxygen isotope record for the past 60000 years*. Marine Geology, 72: 259-285.

PUJOL C., VERGNAUD-GRAZZINI C., 1995. *Distribution patterns of live planktic foraminifers as related to regional hydrography and productive systems of the Mediterranean Sea*. Mar. Micropal., 25: 187-217.

SAVELLI D., TRAMONTANA M., WEZEL F. C., TIBERI P., MAZZOLI S., 1988. *Recent sedimentation and basement rocks in the morphostructural context of the Campania-Latium margin (Tyrrhenian Sea): Preliminary report*. Boll. Oceanol. Teor. Applicata, 6: 91-100.

SELLI R., 1985. *Tectonic evolution of the Tyrrhenian Sea*. In: D. J. STANLEY, F. C. WEZEL (eds.), *Geological evolution of the Mediterranean Sea*. Springer-Verlag: 131-151.

SHACKLETON N. J., KENNET J. P., 1975. *Late cenozoic oxygen and carbon isotopic changes at DSDP Site 284: Implications for glacial history of the Northern Hemisphere and Antarctic*. In: J. P. KENNET, R. E. HOUTZ *et al.*, *Initial Reports of the Deep Sea Drilling Project*, 29. U. S. Govt. Printing Office, Washington, D. C.: 801-807.

TESTA S., MAROCCO R., PIRINI-RADRIZZANI C., PRINCIVALLE F., VERGNAUD-GRAZZINI C., 1990. *Paleoclimatic record of the past 30,000 years in the Ligurian Sea: evidence provided by Oxygen isotopes, foraminifera and clay minerals*. Boll. Oceanol. Teor. Applic., vol. VIII, 3: 177-195.

THUNELL R. C., 1978. *Distribution of recent planktonic foraminifera in surface sediments of the Mediterranean Sea*. Mar. Micropaleontol., 3: 147-173.

THUNELL R. C., WILLIAMS D. F., 1983. *Paleotemperature and paleosalinity history of the eastern Mediterranean during the Late Quaternary*. Palaeogeogr., Palaeoclimatol., Palaeoecol., 44: 23-39.

THUNELL R. C., WILLIAMS D. F., KENNETT J. P., 1977. *Late Quaternary paleoclimatology, stratigraphy and sapropel history in eastern Mediterranean deep-sea sediments*. Mar. Micropaleontol., 2: 371-388.

THUNELL R. C., WILLIAMS D. F., BELYEA P. R., 1984. *Anoxic events in the Mediterranean sea in relation to the evolution of the late Neogene climates*. Mar. Geol., 59: 105-134.

VANNEY J.-R., GENNESSEAUX M., 1985. *Mediterranean seafloor features: overview and assessment*. In: D. J. STANLEY, F. C. WEZEL (eds.), *Geological evolution of the Mediterranean Sea*. Springer-Verlag: 3-32.

VERGNAUD-GRAZZINI C., 1985. *Mediterranean Late Cenozoic Stable Isotope Record: Stratigraphic and Paleoclimatic Implications*. In: D. J. STANLEY, F. C. WEZEL (eds.), *Geological evolution of the Mediterranean Sea*. Springer-Verlag: 413-451.

VERGNAUD-GRAZZINI C., RYAN W. B. F., CITA M. B., 1977. *Stable isotopic fractionation, climate change and episodic stagnation in the eastern Mediterranean during the Late Quaternary*. Mar. Micropaleontol., 2: 353-370.

VERGNAUD-GRAZZINI C., BORSETTI A. M., CATI F., COLANTONI P., D'ONOFRIO S., SALIÈGE J. F., SARTORI R., TAMPIERI R., 1988. *Paleoceanographic record of the Last deglaciation in the Strait of Sicily*. Mar. Micropaleontol., 13: 1-21.

WEZEL F. C. (ed.), 1981. *Sedimentary basins of Mediterranean margins. CNR Italian Project of oceanography*. Tecnoprint, Bologna, 520 pp.

WEZEL F. C., SAVELLI D., TRAMONTANA M., 1982. *Sedimentazione sui margini tirrenici in relazione alla loro evoluzione tettonica*. Mem. Soc. Geol. It., 24: 401-426.

WILLIAMS D. F., THUNELL R. C., 1979. *Faunal and oxygen isotopic evidence for surface water salinity changes during sapropel formation in the eastern Mediterranean*. Sediment. Geol., 23: 81-93.

Pervenuta il 3 agosto 1998,
in forma definitiva il 4 novembre 1998.

J. A. McKenzie:
ETH-Zentrum
Sonneggstrasse, 56
CH-8092 ZÜRICH (Svizzera)

L. Sbaffi, F. C. Wezel:
Istituto di Dinamica Ambientale
Facoltà di Scienze Ambientali
Università degli Studi di Urbino
Campus Scientifico - 61029 URBINO
ls230@cus.cam.ac.uk
wezel@alma.unibo.it; wezel@fis.uniurb.it

F. Tamburini:
Institut de Géologie
Université de Neuchâtel
Rue Emile-Argand, 11
CH-2007 NEUCHÂTEL (Svizzera)
federica.tamburini@geol.unine.ch