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THE LATE-QUATERNARY DEGLACIATION IN THE CENTRAL ADRIATIC BASIN

A. Asioli[1] - F. Trincardi[1] - A. Correggiari[1] - L. Langone[1] - L. Vigliotti[1] - S. Van Der Kaars[2] - J. Lowe[2]
[1]Istituto per la Geologia Marina, Bologna, Italy
[2]RHNC University of London, U.K.

RIASSUNTO - *La deglaciazione tardo-quaternaria nel bacino dell'Adriatico centrale* - Il Quaternario *Italian Journal of Quaternary Sciences,* 9(2), 1996, 763-770 - Vengono riportati i risultati di uno studio interdisciplinare della carota CM92-43 prelevata nella Depressione Meso Adriatica. Questo piccolo bacino è profondo 250 m e fornisce una successione marina continua che registra i mutamenti del clima dall'Ultimo Massimo Glaciale. Data la sua posizione molto vicina alle terre emerse, questa successione di mare relativamente poco profondo offre l'opportunità di stabilire correlazioni di dettaglio tra *records* paleoclimatici a terra e in bacini più profondi del Mediterraneo centrale. I nostri dati documentano che le associazioni polliniche e a foraminiferi bentonici e planctonici variano parallelamente e mostrano che la transizione tra condizioni glaciali e interglaciali non è stata continua, ma interessata da alcune oscilllazioni a breve termine. L'episodio freddo *Younger Dryas,* in particolare, è chiaramente registrato nei depositi continentali da un ritorno a condizioni piú aride accompagnate da un aumento della produttivitá e da un raffreddamento delle acque superficiali. Questo ritorno a condizioni più fredde è accompagnato da un sostanziale aumento del tasso di accumulo del sedimento, probabilmente generato da una caduta del tasso di risalita del livello marino. Durante l'Olocene forti variazioni nelle associazioni a foraminiferi riflettono l'allargamento del bacino Adriatico dovuto alla trasgressione e il progressivo annegamento della soglia meridionale che favorisce la connessione del bacino con il resto del Mediterraneo. L'influenza delle acque levantine sulla oceanografia del bacino è presente a partire da 9500 anni fa (età ^{14}C calibrata). La presenza di masse d'acqua con caratteristiche simili a quelle attuali (faune oligotrofiche) risale a circa 6000 anni fa (età ^{14}C calibrata).

ABSTRACT - *The late Quaternary deglaciation in the central Adriatic basin* - Il Quaternario *Italian Journal of Quaternary Sciences,* 9(2), 1996, 763-770 - Preliminary results of a multidisciplinary study on a core collected in the Meso Adriatic Depression (MAD) are discussed. This small basin is 250 m deep and provides a continuous marine section that has recorded climatic changes since the Last Glacial Maximum (LGM). Because of its location very close to a mainland, this relatively-shallow marine section provides a unique opportunity for establishing good correlations between paleoclimatic records on land and in deeper-water regions in the central Mediterranean. Foraminifera and pollen assemblages vary in good agreement showing that the transition from glacial to interglacial conditions was punctuated by several short-term oscillations. In particular, the Younger Dryas cold event is recorded by the return to more arid conditions on land, and by increased productivity and cooling of surface waters. This return to colder conditions is associated with a substantial increase of sediment accumulation rate, probably triggered by a drop in the rate of relative sea-level rise. During the Holocene, major shifts in foraminiferal assemblages reflect the transgressive widening of the Adriatic basin, and the progressive drowning of the southern sill that allowed for a better connection between the basin and the rest of the Mediterranean. The greatest influence of levantine waters on the basin oceanography commenced since 9,500 calibrated ^{14}C years BP. Modern circulation, marked by oligotrophic faunas, was established at about 6,000 calibrated ^{14}C years BP.

Key words: Paleoenvironmental reconstruction, Late-Quaternary, Foraminifera, palynology, radiocarbon datings, organic carbon, Central Adriatic, Italy
Parole chiave: Ricostruzioni paleoambientali, tardo-Quaternario, Foraminiferi, palinologia, datazioni ^{14}C, carbonio organico, Adriatico Centrale, Italia

1. INTRODUCTION

The Adriatic basin is a semi-enclosed marginal sea connected to the Mediterranean through a narrow sill (the Otranto Strait). Geophysical investigations in the Adriatic basin allow for the regional correlation of transgressive and highstand deposits across two complementary areas: the Meso Adriatic Depression (MAD), and the surrounding shelf area that was subaerially exposed at the onset of the last deglaciation (Trincardi *et al.*, 1994). The first area yields a continuous marine succession, whereas the second provides a discontinuous record consisting of backbarrier, coastal and offshore deposits (Trincardi *et al.*, 1994; Correggiari *et al.*, 1996). In the 250-m-deep MAD (Fig. 1), a stratigraphically complete and continuous marine section has been deposited below the shelf break since the Last Glacial Maximum (LGM). During this interval, however, sediment accumulation rates were not constant, but varied significantly in response to changes in the balance between relative sea-level rise and sediment supply. A combination of geochemical and biological data allows for a detailed paleoceanographic reconstruction for the last deglaciation in the Central Adriatic basin. Because of the geographic location of the basin, the new data can be correlated with lake records at the same latitude in peninsular Italy. Because the basin is land-locked, changes in the local oceanographic regime reflect also a varying degree of connection and water-mass exchange with the rest of the Mediterranean.

The main goal of the present work is to present marine records for the Central Adriatic and to establish a link between the paleoceanographic evolution of the basin and the changes in temperature and precipitation on land. We try to reconstruct climatic oscillations that affected the Central Mediterranean region during the deglaciation and concurrent relative sea-level rise by combining information on terrestrial (pollen) and marine (benthic and planktonic foraminifera) proxies. However, decreased sediment accumulation rates and increased sampling interval, still do not allow for the resolution of shorter-term oscillations within the late-Holocene interval.

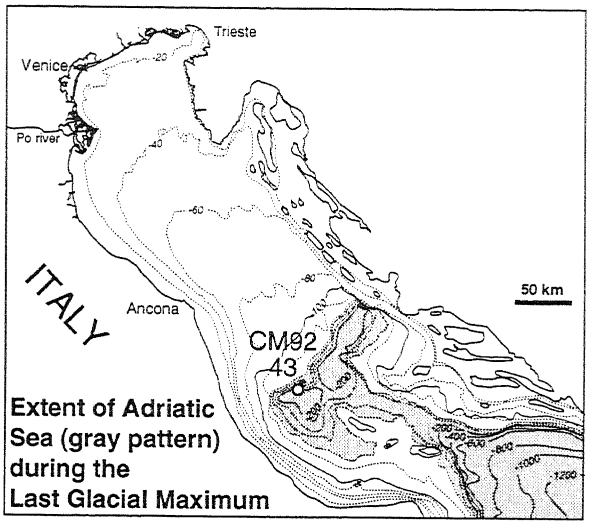

Fig. 1 - Scheme of the bathymetry for the modern Adriatic sea showing the basin extent (gray pattern) at the end of the Last Glacial Maximum (LGM). Note that the connection to the deeper South Adriatic basin was controlled by a narrow sill less than 50 m deep. Core CM92-43 was raised in 252 m water depth in the Meso Adriatic Depression (MAD).

Batimetria dell'attuale mare Adriatico con evidenziata in grigio l'estensione del bacino alla fine dell'Ultimo Massimo Glaciale. Si noti che la connessione con il più profondo bacino Adriatico era controllata da una stretta soglia profonda meno di 50 m. La carota CM92-43 è stata prelevata a 252 m di profondità nella Depressione Meso Adriatica.

2. METHODS

Core CM92-43 is 975 cm long, was raised in 250 m of water in the MAD (Fig. 1) and was precisely positioned (D-GPS) where digitally-recorded high-resolution seismic profiles indicated the highest stratigraphic expansion of the section deposited during the last deglaciation (Trincardi *et al.*, 1994). The core was recovered onboard the *R/V Urania* using a 12-m-long Kullenberg device and studied within the EU project PALICLAS (EU5V-CT93-0267) focused on the Last Glacial-Interglacial transition. The chronological framework is based on 12 AMS ^{14}C dates performed on tests of planktonic foraminifera for the upper 650 cm of core. Foraminifera were counted on the >63 μm fraction after splitting into aliquots of at least 300 planktic and 300 benthic foraminifera. Both foraminifera and pollen abundances (400 counts per sample, on average) are reported in percentage form. We measured total organic carbon and magnetic susceptibility at 10 cm steps. Changes in organic carbon content were measured by means of a Fison CHN Elemental Analyser after a 2N HCl treatment to eliminate the carbonate fraction. Magnetic susceptibility was measured on 103 discrete samples by using a Burtington MS2 susceptibility meter.

3. CHRONOLOGICAL FRAMEWORK

Twelve AMS ^{14}C dates constrain the major changes in sediment accumulation rates and microfaunal variation. All dates given in the present paper are corrected for a 570-years reservoir effect (based on unpublished measurements on modern Adriatic molluscs) and calibrated to calendar years through the polynomial function of Stuiver & Reimer (1993). The reference to calendar years provides a linear time scale and an easier basis for comparison to high-resolution paleoclimatic records on land and in other oceanic basins (Lowe *et al.*, 1995). Figure 2 shows the age-depth relation for core CM92-43. In this diagram, sediment accumulation rates are assumed to be constant between successive dates. No dates are available for the lower 3.2 m of the core where planktonic foraminifera are scarce or absent. Fort the extrapolation downcore, we assumed the same sediment accumulation rate that we interpolated between the two deepest available dates. Figure 2 and 3 report a synthesis of the main lithologic information and biostratigraphic data referred to calibrated ^{14}C ages.

4. LITHOLOGY AND MAGNETIC SUSCEPTIBILITY

The lower 3.2 m of core are composed of clayey sediment with dark stains or laminations. Based on seismic correlation, this portion of the core encompasses a relatively short time dominated by extremely high sediment accumulation rates (Fig. 2). Another interval of dark laminated mud occurs between 5 and 4 m, whereas the rest of the core appears as a light brown or yellowish mud (Fig. 2).

Magnetic susceptibility and preliminary geochemical analyses document two tephra layers at 1.5 and 6.8 m depth (Fig. 2). These tephra correlate to the Agnano-Monte Spina and Tufo Giallo eruption, respectively (Calanchi, Dinelli & Lucchini, pers. comm.). The core does not extend to the Et1 tephra from the Etna volcano (14,100 uncalibrated ^{14}C years BP; Paterne *et al.*, 1988) reached in other cores collected in sectors of the MAD where sediment accumulation rates are lower (Calanchi *et al.*, in press). Therefore, core CM92-43 provides an expanded record of the last ca.15,000 sidereal years BP. This figure is consistent with our interpolation of the sediment accumulation rates downcore.

Magnetic susceptibility exhibits a quite consistent decrease at 13,000 years BP (Fig. 3). Increasing values of magnetic susceptibility are found between 13,000 and 11,300 years BP (Fig. 3) and may be related to a change in the source of terrigenous input or to a change in sediment dispersal within the basin. Above this interval, the trend is again towards lower values of magnetic susceptibility between 8,500 and 8,000 calibrated years BP (Fig. 3). Above this absolute minimum, magnetic susceptibility increases again reflecting a different source for the magnetic minerals, probably related to a change in the paleocirculation of the basin.

5. ORGANIC CARBON

Organic carbon concentrations are low and range between 0.3 and 0.6 %. The lower interval (from 6.6 m to the bottom of the core) is characterised by the lowest organic carbon values. Short-term oscillation in organic

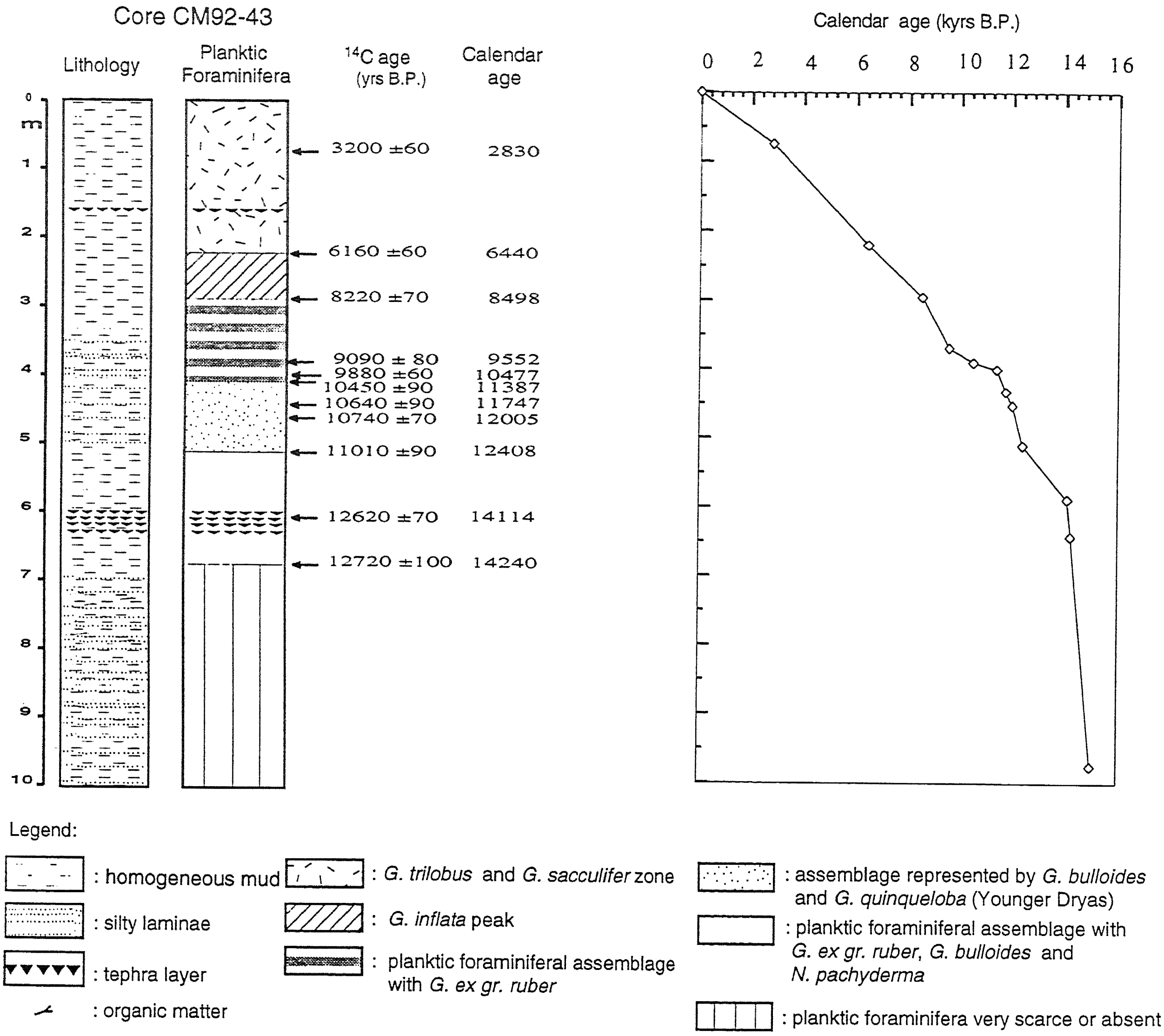

Fig. 2 - Lithology and synthetic biostratigraphy based on planktonic foraminifera assemblages. The chronological framework is based on tephra correlation and twelve AMS ^{14}C dates on planktonic foraminifera corrected for reservoir effects and calibrated following Stuiver & Reimer (1993). Sediment accumulation rates were calculated through linear interpolation between successive dates. This function allowed for the transformation of biologic and chemical data measured at increasing depths downcore into a time frame of thousands of sidereal years BP.

Schema litologico e biostratigrafico basato sulle associazioni a foraminiferi planctonici. La cronologia è fondata su correlazioni di teph-ra *e su dodici datazioni ^{14}C su foraminiferi planctonici, corrette per l'effetto* reservoir *e calibrate secondo Stuiver & Reimer (1993). Il tasso di accumulo del sedimento è ottenuto attraverso l'interpolazione lineare tra date vicine. Questo calcolo ha permesso la lettura dei dati chimici e biologici ottenuti a profondità crescenti secondo il tempo (anni siderali).*

carbon values characterises the lower 3 meters and corresponds to cm-scale colour bands, but the sampling interval (10 cm) and the sample size (1 cm) are not adequate to resolve them. An overall increase in organic carbon concentration is concurrent with the deglaciation and is punctuated by two distinct peaks in concentration centred between 10.5 and 11 calibrated ka BP and 8.2 and 9 calibrated ka BP, respectively.

Organic carbon burial rates, obtained by deconvolving the mass sediment accumulation rates and the organic carbon concentrations, indicate three distinct intervals of relatively high organic carbon fluxes. Such peaks match closely the changes in sediment accumulation rate. In particular, the lowest section before 14,100 calibrated years BP shows the highest fluxes and likely reflects the location of the Po delta at the northern edge of the MAD.

6. POLLEN RECORD

Core CM92-43 allows to determine the fluctuations that affected the late glacial in the land areas that surround the Adriatic basin. The record of the deglaciation is characterised by an overall decrease in *Pinus* and *Juniperus* abundances and by an increment of *Quercus* and broad-leaves trees. This trend is punctuated by short-term oscillations in pollen spectra.

Core bottom to 14 ka BP - The assemblage is

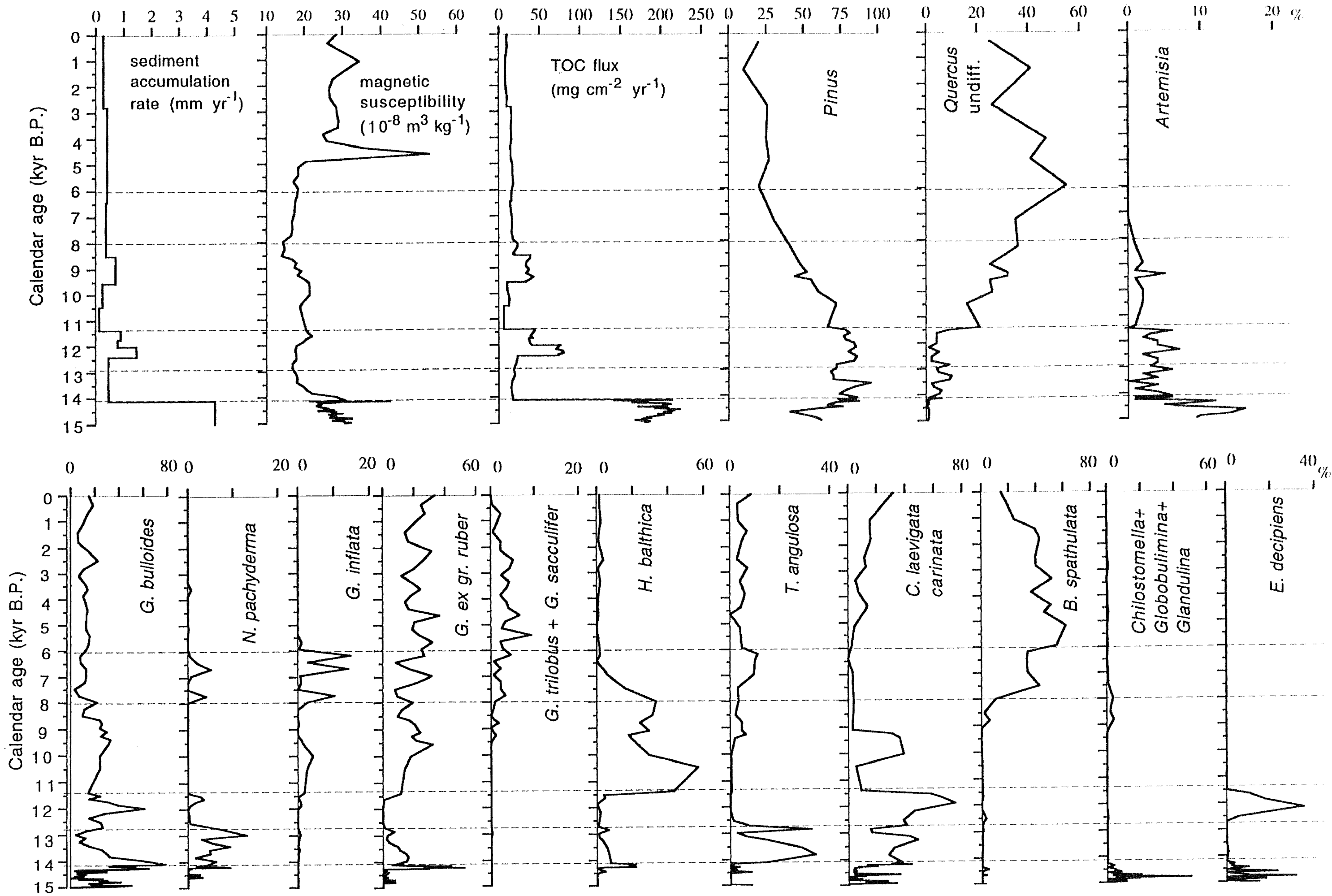

Fig. 3 - Synthetic representation of percent *vs.* time (sidereal years BP) of the main planktonic and benthic foraminifera and pollen species to mark major climatic shifts. Sediment accumulation rate, magnetic susceptibility and organic carbon fluxes are provided for reference and to help in defining the main stratigraphic intervals. These latter record major climatic changes for the central Mediterranean region, but also reflect changes in water circulation within the basin controlled by its transgressive widening and by the progressive improvement of its connection to the rest of the Mediterranean.

Curve di frequenza delle principali specie polliniche e di foraminiferi planctonici e bentonici in funzione del tempo (anni siderali) per evidenziare i maggiori mutamenti climatici. Il tasso di accumulo del sedimento, la suscettività magnetica e il flusso di carbonio organico sono riportati per una migliore definizione dei principali intervalli stratigrafici. Questi ultimi riflettono i maggiori mutamenti climatici del Mediterraneo centrale e le variazioni nella circolazione delle acque nel bacino. Tali variazioni sono controllate dall'allargamento del bacino e dalla progressiva apertura della sua connessione con il resto del Mediterraneo.

dominated by shrubs and herbs. *Pinus, Juniperus* and *Artemisia* are well represented indicating the persistence of cold and dry conditions similar to those documented for the Last Glacial Maximum in the central Mediterranean (Rossignol-Strick & Planchais, 1989).

14-12.8 ka BP - The base of this interval is defined by the decrease of *Artemisia* and the appearance and subsequent increase of *Quercus* (undifferentiated). The Bølling-Allerød interval is recorded between 12.8 and 13.5 ka BP by an increase of *Quercus,* indicating rising moisture, and a lowering in *Pinus* abundance.

12.8-11.4 ka BP - The Younger Dryas event is recorded by a marked decrease of *Quercus* and relative peaks in *Artemisia* and *Pinus,* indicative of a return to more arid and harsh climate.

11.4 ka BP to core top - The Preboreal is characterised by decreasing *Pinus* and increasing *Quercus.* Maximum abundance of *Quercus* is encountered in this interval close to 6,000 calendar years BP testifying the establishment of full interglacial conditions. This interval is accompanied by the proliferation of broad leaf trees, which require increased moisture during summer periods.

7. FORAMINIFERA RECORD

The following intervals have been distinguished:

Core bottom to 14 ka BP - Planktonic foraminifera are quite scarce and the percent diagrams in Figure 3 should be taken with caution for this interval. *Globigerina quinqueloba* is the dominant species. Deep dweller species, present in the southern Adriatic sea, as *Neogloboquadrina pachyderma* and *Globorotalia scitula* (Jorissen *et al.*, 1993), are absent because of the shallow paleo-depth of the MAD (approximately 130 m in its deepest portion) and of its reduced connection to the southern Adriatic basin (through a sill less than 40-50m deep; Fig. 1). The benthic assemblage is composed of *Sigmoilina sellii* and *Glandulina laevigata* and indicates cold bottom water and stagnation episodes. These events are probably related to fresh water runoff when the Po river mouth was located at the northern edge of the MAD.

14 - 12.8 ka BP - The appearance of *Globigerinoides ex gr. ruber* records the warming of surface waters. *N. pachyderma* is present (< 8 %), with *G. quinqueloba* and *Globigerina bulloides.* The absence of *Globorotalia truncatulinoides* and *Globorotalia inflata* may reflect the shallow depth of the sill, which hindered the entrance of these deep dwellers from the southern Adriatic sea into the MAD (Jorissen *et al.*, 1993). The dominance of *Hyalinea balthica* and *Trifarina angulosa* in the benthic assemblage suggests cold bottom water and currents impinging on the sea floor (Ross, 1984; Mackensen *et al.*, 1993; Schmiedl & Mackensen, 1995). In the uppermost part of this time interval, the planktonic herbivorous species *N. pachyderma* peaks and suggests phytoplancton blooms, whereas high productivity/low oxygen tolerant benthic species as *Fursenkoina* spp. occupies the 60% of the total assemblage.

12.8 - 11.4 ka BP - Subtropical surface species disappear during this interval. The planktonic assemblage, composed of *G. bulloides* and *G. quinqueloba,* indicates cold and productive waters. A sharp change of the water mass is also recorded by the benthic assemblage commonly composed of *Cassidulina laevigata carinata* and *Elphidium decipiens,* indicative of cold and productive waters (Van der Zwaan & Lourens, 1995).

11.4 - 8 ka BP - This interval is defined by the reoccurrence of *G. ex gr. ruber* that indicates a return to warm surface waters, whereas the benthic assemblage (*H. balthica* and *C. laevigata carinata*) indicates persisting cold bottom waters. *G. inflata* is present at the base of the warming but almost disappears between 9.2 and 8 ka BP. Between 9 and 7.5 ka BP the benthic assemblage records the reoccurrence of low oxygen tolerant species, such as *Chilostomella oolina* and *Globobulimina* spp. (Corliss, 1985), although they show very low frequencies (<4%).

8 - 6 ka BP - This interval is characterised by the last occurrence of *G. inflata. G. ruber* together with *Orbulina* and low percentages of *Globigerinoides trilobus* represent the intermediate season, as well as levantine species such as *Globigerina praecalida* and *Globigerinella aequilateralis,* which appeared in the uppermost portion of the underlying interval. The decrease of *H. balthica* and the increase of *Brizalina spathulata* suggest progressively warmer and less oxygenated bottom water.

6 ka to core top - The disappearance of *G. inflata,* the presence of symbiont bearing species such as *G. trilobus* and *Orbulina* indicate oligotrophic conditions of the surface waters (Pujol & Vergnaud-Grazzini, 1995). *Brizalina spathulata* dominates the bottom water assemblage.

8. DISCUSSION

Sedimentologic, paleontologic, and magnetic susceptibility data, supported by AMS ^{14}C calibrated dates, allow for a detailed reconstruction of the late-Quaternary deglaciation in the 250-m-deep Central Adriatic slope basin (MAD; Fig. 1). Changes in pollen and foraminifera association occur as a locked phase during the late glacial and are accompanied by fluctuations in sediment accumulation rate and organic carbon. These data confirm that during the early part of the late-Quaternary sea-level rise event, climate in the Central Adriatic basin was cold and dry, as observed in other Mediterranean sites (Rossignol-Strick & Planchais, 1989).

The lower portion of the core, up to 14 ka BP, indicates restricted circulation with high organic carbon fluxes. A poor connection with the Mediterranean is proved by the rare planktonic foraminifera. Fresh water runoff, when the Po river mouth was close to the edge of the MAD (Fig. 1), caused stagnation episodes and accumulation of organic matter. The presence of *Ammonia perlucida* in cores collected at shallower depths on the basin margin confirms the impact of large amounts of fresh water (Jorissen, 1988; Asioli *et al.*, 1995).

In the Central Adriatic, the Bølling/Allerød interval is defined by increased temperature and moisture on land and concurrent rise of sea surface temperatures (appearance of *G. ruber*) compared to the underlying interval. A decrease in sediment accumulation rate reflects a concurrent increase in the rate of relative sea-level rise, as observed elsewhere for this interval (Fairbanks, 1989). The rapid base-level rise and landward shift of sediment entry points caused sediment storage in aggrading alluvial plains, and sediment starvation in the adjacent shelf and basin.

During the Younger Dryas cold episode, pollen abundances oscillate in phase with the planktonic foraminifera assemblages. A decrease in sea surface temperatures accompanies a moisture drop on land. The cold water planktonic assemblage (*G. bulloides,* up to 80%, with *G. quinqueloba* and *N. pachyderma*) correlates with a peak in *Artemisia* and *Pinus* and a marked decrease of *Quercus* with respect to the underlying portion of the deglacial record (Bølling/Allerød). The return to arid conditions as indicated by the pollen record is concurrent with a marked increase in sediment accumulation rates, which may reflect a decrease in vegetation and soil cover on land (Fig. 3). However, increased sediment accumulation rates are also consistent with slower rates of relative sea-level rise or a still stand (Fairbanks, 1989; Duplessy *et al.*, 1981).

Organic carbon flux and sediment accumulation rate show a parallel trend throughout the core and during the Younger Dryas interval (Fig. 3). Increased organic carbon fluxes during this interval may indicate either enhanced delivery of organic matter to the sea floor or increased sea-bed preservation of organic matter, favoured by higher sediment accumulation rate. In the first case, organic carbon fluxes may reflect higher productivity, increased supply of terrestrial organic carbon from weathering or decreased degradation of organic matter in the water column. Planktonic and benthic foraminifera mark a productivity maximum during the Younger Dryas, possibly enhanced by increased nutrient supply through weathering. No $\delta^{13}C$ analyses are available at the moment on core CM92-43. However, in the adjacent South Adriatic basin, Vergnaud-Grazzini & Pierre (1992) attributed a $\delta^{13}C$ enrichment in surface waters during the Younger Dryas to increased primary productivity, possibly enhanced by the insulation maximum that occurred during this interval at mid latitudes in the Northern Hemisphere (Fairbanks, 1989). Finally, the abrupt change observed in all parameters indicates that the end of this cold episode was extremely rapid, as observed in other high-resolution records (Alley *et al.*, 1993; Lowe *et al.*, 1995). After this cold event an abrupt warming is simultaneously recorded by pollen and foram-inifera records (Fig. 3); this warming correlates to the second step of the deglaciation (Duplessy *et al.*, 1981; Fairbanks, 1989). As for the Bølling-Allerød interval, the high rate of sea-level rise leads to a landward shift of the sediment entry points, documented by the second minimum of sediment accumulation rate between 11.5 and 10.5 ka BP.

Between 9.5 and 8 ka BP the third and smallest peak in organic carbon flux is recorded. Organic carbon reaches the highest concentration at the end of this interval and it is paralleled by a marked minimum in the magnetic susceptibility curve (Fig. 3). This relative minimum may indicate a decrease in supply of magnetic minerals, or the post-depositional dissolution of the original titanomagnetite in suboxic condition (Canfield & Berner, 1987). Similar trends of organic carbon and magnetic susceptibility are found in Mediterranean cores across the S1 sapropel (Thompson & Oldfield, 1986). A decreased O_2 content in pore water, as documented by the presence of low-oxygen-tolerant deep infaunal species, indicates better preservation of organic matter. This situation possibly reflects weak water stratification. Finally, the scarcity of foraminifera species indicative of productive surface waters suggests that increased productivity did not play a key role in the organic carbon accumulation. According to Asioli *et al.* (1990) and Borsetti *et al.* (1992), the occurrence of levantine species indicates the first input of Eastern Mediterranean waters.

During the interval between 8 and 6 ka BP, the Adriatic basin is characterised by strong seasonality and vertical mixing in winter (Borsetti *et al.*, 1992). This is indicated by the presence of *G. inflata,* an herbivorous species that is an important component of the winter assemblage. This species prefers, in fact, cool water and a deep, mixed layer, therefore suggesting the disappearance of the thermocline in winter (Pujol & Vergnaud-Grazzini, 1995). Finally, planktonic associations during the interval above 6 ka BP indicates oligotrophic mixed layers (*G. trilobus* and *G. sacculifer*) whereas the benthic *B. spathulata* suggests low-oxygen bottom water.

9. CONCLUSIONS

The multiproxy data extracted from core CM92-43 indicate the followings: 1) foraminifera and pollen assemblages vary in locked phase, consequently the surface waters in the shallow Adriatic basin responded immediately to changes in temperature and moisture in the surrounding regions; 2) the transition from glacial to interglacial conditions was not monotonic, but punctuated by several short-term oscillations; 3) the Younger Dryas cold event was characterised by both a return to more arid conditions on land and sea-water cooling and increased productivity possibly triggered by land-derived nutrient supply during a return to very high sediment accumulation rates; 4) the end of the Younger Dryas cold event was extremely rapid; 5) water masses reflected the overall climate change of the central Mediterranean region, but also recorded the gradual widening of the shallow Adriatic shelf and the progressive drowning of the sill that connected the basin to the rest of the Mediterranean; 6) sediment accumulation rates were extremely variable (0.1 to 4.3 mm yr^{-1}), with two major intervals of very reduced supply to the MAD corresponding to two distinct phases when the rates of sea-level rise were highest; 7) the definitive drowning of the sill to the south after the Younger Dryas allowed for the full exchange of water masses and the entrance of eastern Mediterranean waters into the basin; 8) the available proxies show weak evidences of the sapropel S1; 9) modern circulation was established about 6 ka BP when the basin reached its maximum extent.

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