Riv. It. Paleont. Strat.	v. 97	n. 3-4	pp. 677-694	Aprile 1992

CLIMATICALLY MODULATED ANOXIC EPISODES AND PRODUCTIVITY IN THE MIDDLE PLEISTOCENE (CROTONIAN) OF THE EASTERN MEDITERRANEAN

MARIA BIANCA CITA, ELISABETTA PARISI & MARIDA BAXIU

Key-words: Anoxic episodes, Middle Pleistocene, Eastern Mediterranean.

Riassunto. E' stata studiata una porzione di una carota di mare profondo prelevata sulla Dorsale Mediterranea a circa 32°14.20' lat. N, 19°42' long. E, che contiene una successione pelagica di età compresa fra circa 260.000 e 160.000 anni BP (Pleistocene medio). La velocità di sedimentazione è bassa, e sono presenti in questo intervallo quattro sapropels (da S-6 a S-9). Le analisi fatte comprendono calcimetrie, lavaggi pesati, studio microscopico delle componenti biogeniche e non biogeniche, contenuto in Carbonio organico, isotopi stabili di O e C.

Il tenore in Carbonio organico mostra un andamento bimodale, con valori compresi fra 0,2 e 0,9% nei sedimenti "normali", da 3,9 a oltre 9% nei sapropels.

I componenti biogenici sono sempre dominanti, e consistono essenzialmente di gusci di Foraminiferi planctonici: il loro numero varia da qualche migliaio di esemplari per grammo di sedimento fino a circa 30.000 esemplari nel sapropel S-6. Questo sapropel è ricchissimo di esemplari, ma la associazione, dominata da *Globigerina bulloides* e *Neogloboquadrina dutertrei* indicatrici di acque fredde ad alta produttività, è poco diversificata. Lo studio isotopico ha permesso di riconoscere gli stadi isotopici da 6 a 8: i tre sapropels inferiori corrispondono rispettivamente ai substadi 7a (S-7), 7b (S-8) e 7e (S-9).

Abstract. A portion of a deep-sea core that contains a purely pelagic low-sedimentation-rate succession, extends in time from approximately 260,000 to 160,000 y BP, includes the *Gephyrocapsa oceanica/Emiliania huxleyi* zonal boundary, and the four sapropels S-9 through S-6, was investigated in detail. Carbonate content, org C content, grain-size analysis, composition of the sand-size sediment fraction, isotopic composition of O and C were measured with an observation point every approximately 3000y.

Cyclicity represented by the sapropels is fairly regular and is of the order of 20,000 y (Milankovitch precession cycles).

The grain-size increases consistently in the sapropels, whereas the carbonate content usually decreases, with the exception of S-6.

Biogenic components are always dominant, whereas organic matter abounds in sapropels, especially in S-7 which records 9% org C. The number of planktonic foraminifers ranges around a few thousands per gram of sediment; increases of one order of magnitude are noticed in sapropels S-6 and S-8, thus supporting increased productivity, as suggested by the dominance of *Neogloboquadrina dutertrei.*

The consistent decrease in the number of pteropod fragments in all sapropel layers is attributed to dissolution of the easily dissolvable aragonitic tests in the deep-sea acidic environment.

- Dipartimento di Scienze della Terra dell' Università degli Studi di Milano, via Mangiagalli 34, 20133 Milano.

Inorganic components are essentially siliciclastic and small-sized; a consistent increase recorded immediately beneath each sapropel layer might suggest a change in wind pattern predating basin-wide stagnation.

The isotopic study (based on *Globigerinoides ruber* with the exception of S-6 where *Globigerina bulloides* was used instead) permits the identification of isotopic stage 7 with the substages 7a, 7c, and 7e corresponding respectively to sapropels S-7, S-8 and S-9, bracketed between stages 6 and 8.

Introduction.

The Pleistocene deep-sea record of the Eastern Mediterranean is characterized by a consistently low rate of sediment accumulation and by the occurrence of numerous centimetric layers of sapropels, that are interpreted as the sedimentary expression of basin-wide anoxic episodes (Olausson, 1961; Ryan, 1972; Thunell et al., 1977; Cita et al., 1977; Cita & Grignani, 1982 inter alias).

The duration of each anoxic episode is of the order of a few thousand years as opposed to persistent anoxia characterizing deposition beneath the level of the brines (Cita et al., 1985; Parisi et al., 1987; Cita, 1991a), that may last for hundred thousand years or more. In the latter case, anoxia is accounted to a geologic situation (submarine dissolution of Messinian evaporites), but in the former case forcing derives from paleoclimatic and/or paleoceanographic conditions (Rossignol-Strick, 1983; Parisi, 1987a).

Investigations carried out on the quantitative composition of planktonic foraminiferal faunas, and on the isotopic composition of Oxygen in the shell of planktonic foraminifers have shown that most sapropels fall on the warming trend of the curves and contain warm peaks, but not all. The late middle Pleistocene (Crotonian) sapropel S-6 in particular falls in the cold isotopic stage 6 (Thunell et al., 1983); S-8 in a cold episode of isotopic stage 7 (Vergnaud- Grazzini et al., 1977; Parisi, 1987b). Both sapropels contain a rich, but poorly diversified foraminiferal fauna dominated by *Globigerina bulloides* and *Neogloboquadrina dutertrei* that are considered indicative of low salinity (Vergnaud-Grazzini et al., 1977; Williams & Thunell, 1979) and/or of high productivity. Foraminiferal faunas are particularly abundant in these two sapropels.

In order to find out if changes in productivity of planktonic foraminifers are measurable, and to check if indeed sapropels S-6 and S-8 record a higher productivity than the intervening "odd" sapropels, a core was selected where the interval encompassing sapropels S-6 through S-9 is represented by a low-sedimentation rate pelagic succession, without any detectable sedimentary gap, any turbidite or debris-flow, any disturbance.

Materials and methods.

The study was carried out on Core BAN 86-41 GC, raised from a very steep slope of the Sirte transect, some 15 nm west of Bacino Bannock from a water depth of 3350 m (uncorrected). Coordinates are: 32°14.20' lat. N, 19°42' long E. Core recovery is 399 cm.

The sediment core contains two conspicuous hiatuses: one in the upper part (see Fig. 1, columnar log and close-up photo to the left), where sapropel S-5 is missing.

A second one in the basal part, that is referred to the *Pseudoemiliania lacunosa* nannofossil zone, with an age greater than 430,000 y BP. Sedimentary gaps are accounted to the tectonic processes active on the Mediterranean Ridge, that cause sediment losses in the upper parts of steep slopes, as the one where the core under discussion is located (Blechschmidt et al., 1982; Camerlenghi & Cita, 1987).

In the latest part of middle Pleistocene (pre-Termination II), sapropels S-6 through S-9 are very well expressed (columnar log of Fig. 1 and close-up photo to the right). Cyclicity represented by the sapropels is fairly regular: on the basis of the widely accepted Eastern Mediterranean Quaternary chronology, it is of the order of 20,000 y (Milankovitch precession cycles).

The interval investigated has a duration of approximatively 100,000 y, from 260,000 to 160,000 y BP. Sedimentation rate is very low, of about 1.2 cm/1000 y.

This interval was sampled at regularly spaced intervals, with an observation point every approximately 3000 y. Thirty three samples of approximately 10 cc were dried and then split.

a) One gram of sediment was used for calcimetric analysis, using a Dieter-Freeling calcimeter.

b) The remaining part was weighted, soaked in H_2O_2, washed, sieved through a 61 microns mesh. The washing residues were then weighted again, and the percentages of the sand-size fraction were calculated.

c) The sand-size fraction was split 32 times or 64 times (occasionally less) using a microsplitter in order to obtain several hundred particles to be microscopically identified, and counted. Numbers of particles counted range from 200 to over 1000, usually they range from 300 to 500.

The following categories were considered:

Biogenic	planktonic foraminifers
	fragments of pteropods
	benthic foraminifers
	echinoid spines
	plant debris
	spores
	organic matter
	otholiths
	other fish remains
	ostracods
	other
Terrigenous	quartz
	mica
	other
Authigenic	gypsum
	pyrite
	glauconite

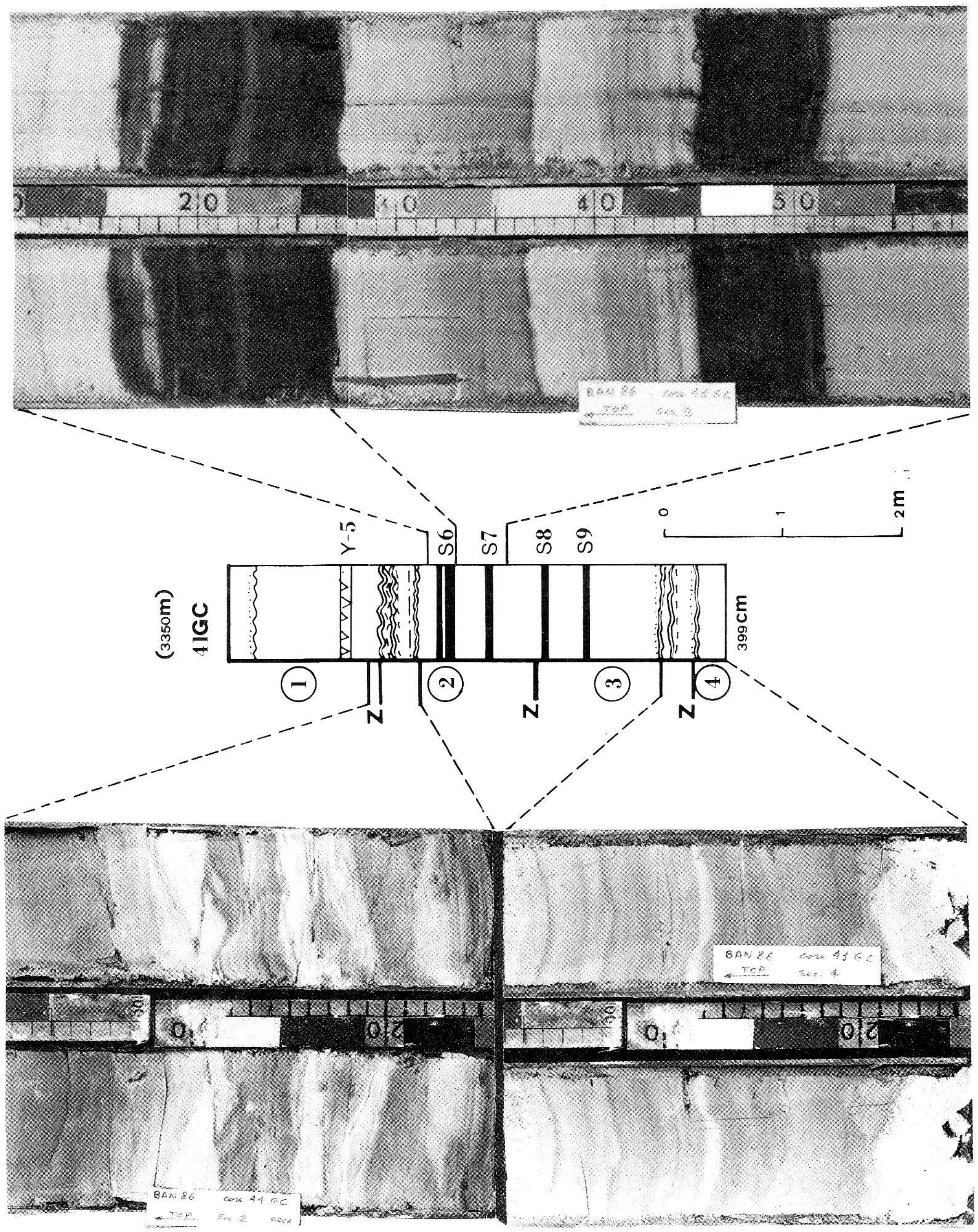

Fig. 1 - Columnar log of Core BAN 86-41 GC showing the main lithostratigraphic horizons: tephra Y-5, sapropels S-6, S-7, S-8 and S-9 included in the dominant lithology (marl). Undulated lines indicate erosional surfaces documenting hiatuses (see close-up photos to the left). Z indicates zonal boundaries separating nannofossil zones 1 (*Emiliania huxleyi* Acme), 2 (*Emiliania huxleyi*), 3 (*Gephyrocapsa oceanica*) and 4 (*Pseudoemiliania lacunosa*). A detail of the sediment core encompassing sapropels S-6 and S-7 is shown to the right.

d) Some 20 specimens of *Globigerinoides ruber* (whenever possible) or of *Globigerina bulloides* (in the upper seven samples, across sapropel S-6) were picked for isotopic measurements.

Carbon dioxide was obtained by reaction "in vacuo" with 100% ortophosphoric acid at 25°C for 12-24 h and analyzed in a Varian Mat 250 mass spectrometer. Isotopic measurements were carried out at the Geochemical Laboratory of AGIP-SGEL (S. Donato Milanese, Italy) under the supervision of dr. Ricchiuto.

Isotopic analyses are expressed in terms of δ notation as parts per mil (‰) relative to the isotopic composition of laboratory standard according to the equation:

$$\delta = \frac{R\ sample}{R\ reference\ -\ 1} \times 1000$$

where R is the isotopic ratio $^{18}O/^{16}O$ or $^{13}C/^{12}C$.

The results are reported relative to the PDB international standard (Epstein et al., 1953). Analytical precision on laboratory standard (periodically calibrated) is $\pm$ 0.03‰ for the $\delta^{13}C$ and $\pm$ 0.06‰ for the $\delta^{18}O$.

e) Eight additional samples (one from each sapropel and one from the underlying normal, non sapropelitic sediment) were used for measuring the organic Carbon content, using a LECO auto-analyser. Analyses were performed at AGIP Geochemical Laboratory.

Results.

Fig. 2 shows the columnar log of the interval investigated of Core BAN 86-41, the position of the samples and, from left to right:

1) the percentage of the sand-size fraction;
2) the percentage of $CaCO_3$;
3) the number of planktonic foraminifers/gr of sediment (expressed in thousands);
4) the number of fragments of pteropods/gr of sediment (expressed in hundreds);
5) the percentage of org C.

A few comments are provided.

1) The sand-size fraction ranges from 2% to over 30% (see Table 1 and Fig. 2), the average of 33 measurements being 15%. This mean value is much higher than that recorded in other eastern Mediterranean deep-sea sediment cores (Cita, Broglia et al., 1982), and is accounted to the high number of sapropel samples investigated. Sapropels are characterized by consistently high sand-size fractions that consist of biogenic particles (planktonic foraminifers dominate in sapropels S-6 and S-8; lumps of organic matter in sapropels S-7 and S-9; see Fig. 2).

Normal pelagic sediments intercalated in between the sapropels instead are characterized by very low (biogenic) sand-size fractions, usually only a few percent.

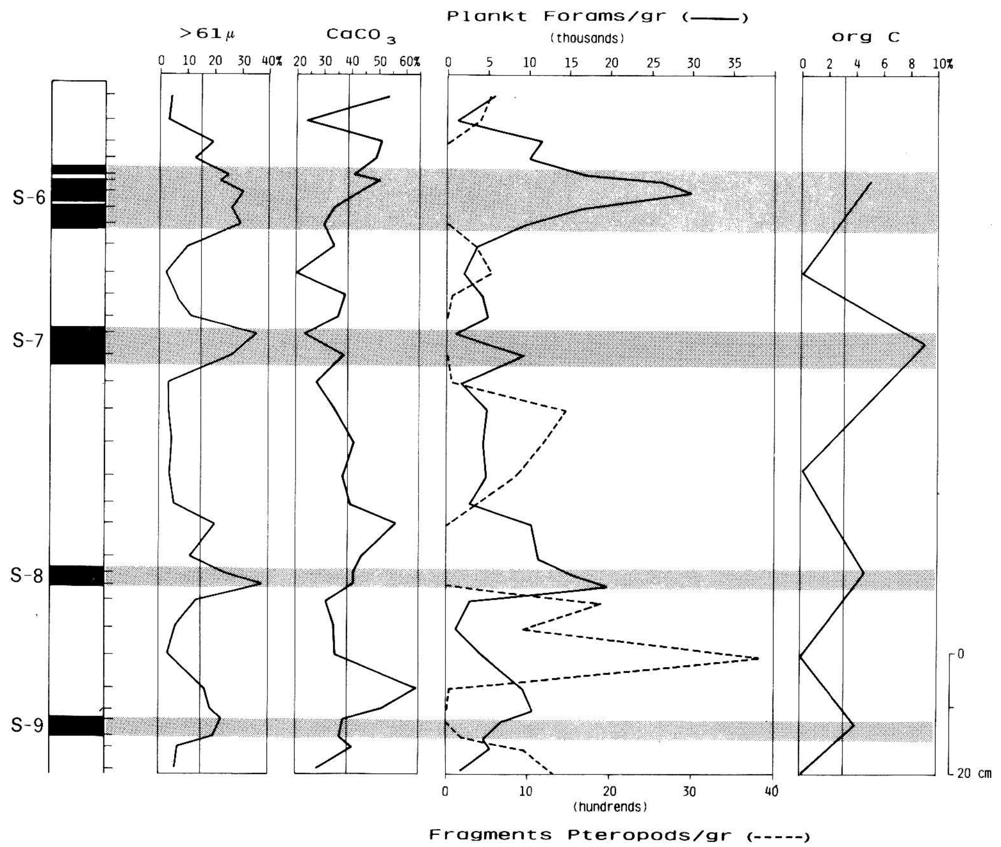

Fig. 2 - Simplified columnar log of the interval investigated, showing sample position and, from left to right: percentage of the sand-size sediment fraction and mean value; percentage of $CaCO_3$ content and mean value; number of planktonic foraminifers/gr of dry sediment (in thousands) and of pteropod fragments/gr of dry sediment (in hundreds); percentage of organic C (in weight) and mean value.

2) The carbonate content ranges from approximately 20% to 60%, the average being 38%, a value consistent with other records in the eastern Mediterranean (Cita, Broglia et al., 1982; Parisi, 1987a). Cold intervals (i.e. above S-6) are higher in carbonates than warm intervals, but the difference is not very strong.

Sapropels S-6 and S-8 display values higher than the average, whereas S-7 and S-9 display lower values.

3) The number of planktonic foraminifers was calculated from the number of actually counted specimens multiplied for how many times the sample was split, and corrected for the weight of the sediment treated.

4) Pteropod shells are usually represented by small flat fragments or by the embryo. Thus the numbers counted are only broadly indicative, since one specimen

Tab.1 - Quantitative distribution of various parameters in Core BAN 86-41.

Section	cm from top of section	sed. fraction >61μ%	$CaCO_3$ %	n.plankt foram/ gr.sed.	n.pter. fragm./ gr.sed.	orgC %	Sapropels
3	2.5	4.1	54.1	5.890	500		
3	7	3.4	23.7	1.200	400		
3	11	19.4	51.3	11.500			
3	14	12.9	49.4	10.000			
3	17	25.7	40.8	17.000			S6
3	18	22.8	50.3	26.000		5.77	S6
3	20	30.5	43.7	29.600			S6
3	23	26.8	34.2	16.500			S6
3	26	29.5	30.4	9.500			S6
3	30	10.5	34.2	3.500	340		
3	35	2.3	19.9	2.300	530	0.66	
3	39	6.0	38.0	4.100	40		
3	43	11.2	35.5	4.900			
3	46	36.1	23.2	1.100		9.05	S7
3	50	26.5	37.8	9.200			S7
3	55	3.2	27.1	1.700	40		
3	60	3.5	33.9	4.900	1440		
3	66	4.5	40.7	4.400	1180		
3	72	3.8	36.8	4.700	840	0.98	
3	77	5.2	39.7	2.700	380		
3	82	20.5	56.2	10.500			
3	87	11.6	43.6	11.000			
3	90	25.7	40.7	15.200		4.68	S8
3	92	42.7	40.7	20.700			S8
3	95	13.2	31.0	2.900	1880		
3	100	6.1	33.9	1.200	940		
3	105	3.4	33.9	4.600	3820	0.29	
3	111	16.3	64.0	9.300	20		
3	115	18.7	51.4	10.600			
3	117	22.9	36.8	6.800		3.90	S9
4	1	19.7	35.9	4.700	170		S9
4	3	6.4	40.7	5.300	980		
4	7	5.6	27.5	2.000	1300	0.29	

may well be represented by numerous fragments.

Pteropod fragments are conspicuously absent in all the sapropel samples; this observation is interpreted as the result of the dissolution of aragonitic tests in the acidic environment created by the org C rich sediments. At a water depth of 3350 m the aragonitic CCD is not that far, and may well be reached when local CO_2 rich conditions are established during temporary anoxic conditions.

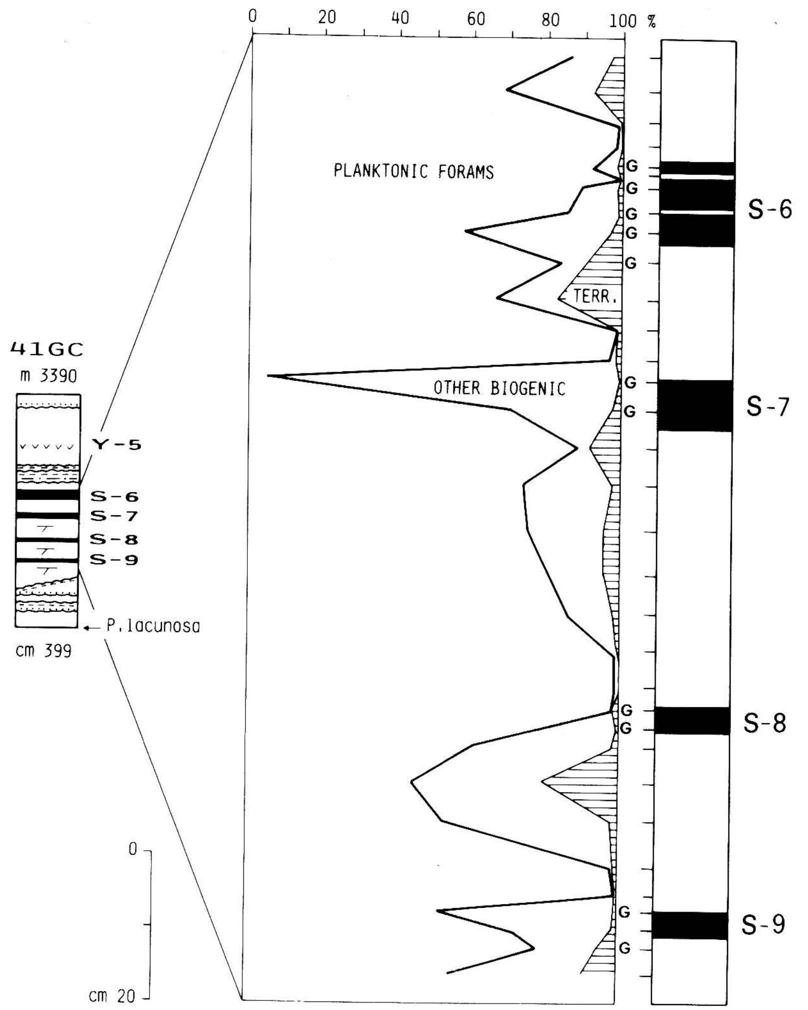

Fig. 3 - Columnar log of Core BAN 86-41 GC (left) and percent composition of the sand-size sediment fraction investigated in the interval encompassing sapropels S-6/S-9 (late middle Pleistocene or Crotonian). Planktonic foraminifers are always dominant with one exception (top of sapropel S-7) where organic matter prevails. Terrigenous components are minor, and consistently increase beneath the sapropels.

Indeed in all the cores raised from Bacino Bannock and vicinity, the only sapropel rich in Pteropods is the Holocenic sapropel S-1. The current interpretation is that Pteropods are present here (often abundant, with entire shells) because they have not been dissolved yet.

5) A bimodal distribution of org C is clearly shown in the curve: normal sediments are consistently very poor in org C whereas all the sapropels are well above the 2% content in weight, that is considered by Kidd et al. (1978) the boundary value to distinguish true sapropels from sapropelitic layers.

It peaks to 9% in sapropel S-7, in agreement with previous findings (Cita & Grignani, 1982) that record the highest values in S-7and/or S-5.

The mean value of the 8 measurements in excess of 3% is well above the mean value recorded by Cita, Broglia et al. (1982), that is 0.30%: it clearly results from the relatively high number of sapropels measured.

Composition of the sand fraction.

Fig. 3 summarizes the composition of the sand-size fraction, which is always dominated by biogenic components.

Benthic forams are sparse to absent, and are percentually insignificant, as well as echinoid spines, and ostracods.

Pteropod fragments are highly variable in abundance, and disappear in the sapropels (see above).

Organic matter may be the dominant biogenic component in some sapropel samples where planktonic forams are poorly represented, as in the topmost part of sapropel S-7 (compare Fig. 2 and 3). Fish otholiths, vertebrae and scales are often recognized in sapropel layers, as well as plant debris and spores.

The curves representing (a) the percentage abundance of planktonic forams (in Fig. 2) and (b) the number of planktonic forams/gr sediment (in Fig. 3) vary sympathetically, however they differ in shape: in normal hemipelagic sediments planktonic forams are always dominant (with just one exception underneath S-8, where a low peak in planktonic forams corresponds to the highest peak in pteropods), although their numbers may be low.

The terrigenous components consist of mica flakes and of small (less than 100 microns) subangular quartz grains, that may be wind-blown. In most samples the terrigenous components represent a few percent of the sand-size fraction. Only two samples record >10% terrigenous components: they are located just beneath sapropels S-8 and S-6. The probable eolian origin of the quartz (which is the dominant component in both instances) suggests a change in the wind patterns predating the onset of euxinic conditions, in agreement with the model proposed by Parisi (1987a) and with the new results on clay mineralogy of sapropels S-6 and S-8 (Tomadin & Landuzzi, 1991).

Tab.2 - Isotopic composition of *Globigerinoides ruber* and of *Globigerina bulloides** in Core BAN 86-41.

Section	cm from top of section	$\delta^{18}O$	$\delta^{13}C$	Sapropels
3	7	-0.85	-2.93	
3	11*	+0.51	-1.67	
3	14*	-0.81	-2.60	
3	17*	-2.76	-3.25	S6
3	18*	-2.10	-3.34	S6
3	20*	-1.24	-2.31	S6
3	23*	-3.53	-3.66	S6
3	30	+0.73	+0.51	
3	30*	-1.28	-2.41	
3	35	-0.56	-0.04	
3	35*	-1.33	-1.65	
3	39	-0.50	-0.03	
3	39	—	—	
3	43	-0.73	+0.03	
3	50	-3.17	-0.40	S7
3	55	+0.09	+0.74	
3	60	+0.41	+0.31	
3	66	-3.27	-3.58	
3	72	-0.99	-0.27	
3	77	+1.55	+1.54	
3	82	-0.65	+0.47	
3	87	-4.91	-5.31	
3	90	-3.72	-1.28	S8
3	92	-1.91	-0.18	S8
3	95	-1.50	-0.39	
3	100	+0.38	+0.18	
3	105	-1.31	-1.20	
3	111	-0.39	+0.45	
3	115	-2.17	-0.59	
4	117	-2.30	-0.31	S9
4	1	+2.58	+2.88	S9
4	3	-0.64	+0.47	
4	7	-0.10	+0.61	

The only authigenic mineral recorded in some abundance is gypsum (G in Fig. 3). It is present in all sapropels and/or immediately underneath. Gypsum crystals are rhombic in shape and range in size up to a few millimeters.

Isotopic study.

Table 2 and Fig. 4 summarize the isotopic data.

Most delta ^{18}O values are negative: indeed, only 7 positive values out of 32 were recorded, with positive peaks located at the base of sapropel S-9 and above S-8.

The values range from - 4.91 per mil to + 2.58 per mil with the maximum glacial/interglacial change at approximately 4.9 per mil occurring across sapropel S-9, at the transition between isotopic stages 8 and 7e (with reference to Core RC9-181, see Vergnaud-Grazzini et al., 1977) or Termination III.

Three marked negative peaks recorded just above S-9, above S-8 and within S-7 may be correlated with isotopic substages 7e, 7c and 7a respectively.

Eight samples from the upper part of Core BAN 86-41, encompassing sapropel S-6, did not contain enough specimens of *Globigerinoides ruber* to allow the isotopic study. *Globigerina bulloides* was measured instead (asterisks in Tab. 2; dotted line in Fig. 4). The measured values are consistently negative, ranging from -0.81 to -3.53 per mil, with just one exception (0.51 from 11 cm in section 3).

When both *Globigerina bulloides* and *Globigerinoides ruber* were measured from the same sample, more negative values were recorded in the former (-1.28; -1.33) than in the latter (+ 0.73; - 0.56 respectively).

Globigerina bulloides is an extant species with a mesopelagic habitat, whereas *Globigerinoides ruber* has a surficial, epipelagic habitat and for this reason is the preferred species - whenever present - for isotopic studies, being a sensitive indicator of changing temperature at the surface. The negative "warm" signal is thus related to non surficial water layers. More discussion on this subject will be found in the final part of this paper.

The isotopic signal of Carbon varies sympathetically with that of Oxygen, but the total excursion is even greater (from -5.31 per mil to +2.88) and the rate of change is not the same. Peak values, both positive and negative, are recorded at exactly the same levels (see Tab. 2 and Fig. 4).

Positive values are numerous (11 out of 32) especially in the lower part of the section investigated, from its base to sapropel S-8.

The overall excursion is much higher than that recorded in Core BAN 82-15 from the Levantine Basin (Parisi, 1987b), measured in the same laboratory.

A strong excursion of 3.19 per mil is recorded across the 8-7 isotope stage boundary (sapropel S-9). An even higher excursion from -5.31 per mil to +0.47 (5.78 per mil) is recorded in isotopic stage 7 (substage 7c ?). The anomalously negative values recorded in both $\delta^{18}O$ and $\delta^{13}C$ are considered with some hesitation (question marks in Fig. 4).

Again, strongly negative values were measured in *Globigerina bulloides* in the interval encompassing sapropel S-6.

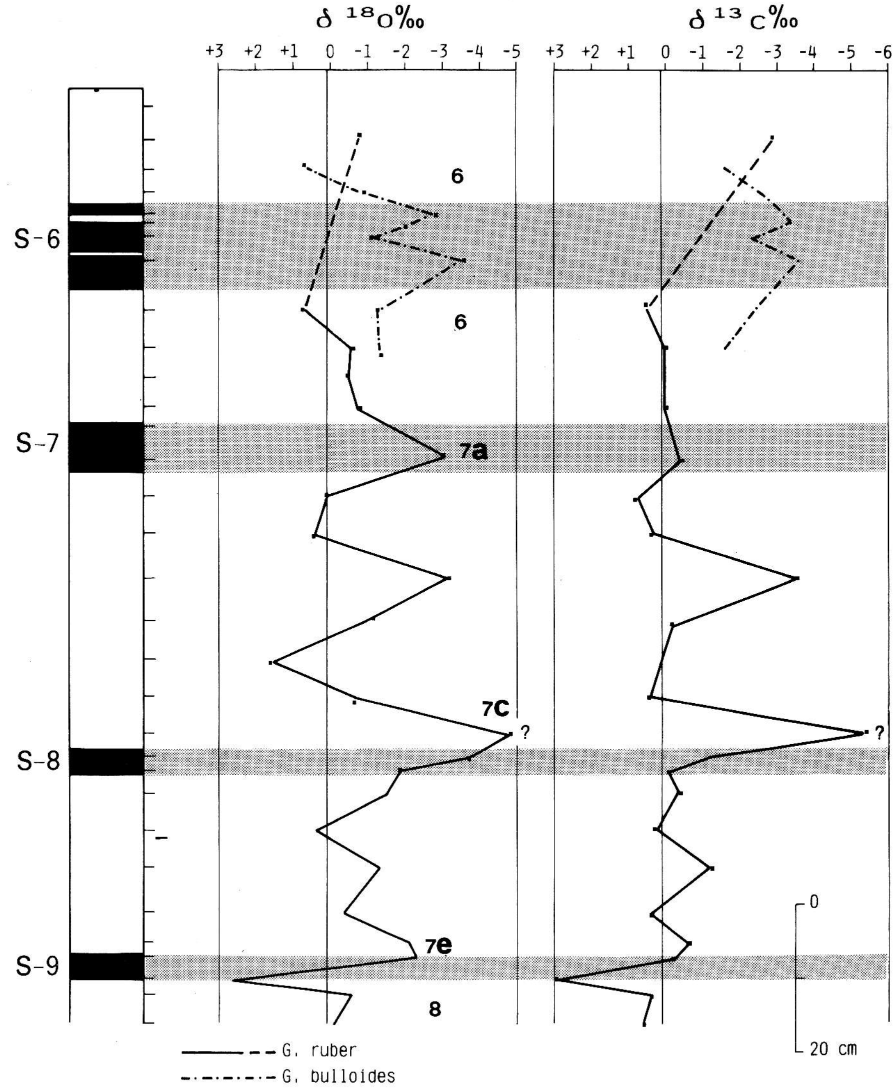

Fig. 4 - Isotopic composition of Oxygen and Carbon measured in the 32 samples investigated. The identification of isotopic stages 6, 7 (with the substages 7a, 7c and 7e) and 8 is based on correlation with other deep-sea cores published from the eastern Mediterranean (see discussion in text).

Discussion.

Late Quaternary Mediterranean sapropels represent a scientific dilemma since they were first discovered during the Swedish Deep Sea Expedition in 1947-48 (Kullenberg, 1952; Olausson, 1961), see Cita, de Lange and Olausson (1991). The classic interpretation, first proposed by Olausson (op. cit.) and followed by Ryan (1972), Cita et al. (1973) and many others, is that excess melt water during deglaciation resulted in stratification of the water column with the creation of a strong pycnocline, finally originating bottom anoxia (Fig. 5). Various features of the eastern Mediterranean morphology and oceanography are leading to stagnant conditions and consequently to anoxia: 1) the E-W elongation, 2) the existence of three shallow sills separating the Atlantic from the Mediterranean, the western from the eastern Mediterranean, and the latter from the Black Sea, 3) the low oxygen content of the eastern Mediterranean in general, and of the Levantine basin in particular, and 4) the strongly negative water budget (Cita, 1991b). A variant of this model, proposed by Rossignol-Strick (1983) considers the influence of the Nile more important than that of the Black Sea in creating a surface low-salinity, low-density layer.

An alternative model was meanwhile proposed by Calvert (1983) who considers sapropels as resulting from productivity related to up-welling, but unrelated to anoxia. This approach, visually represented in the bottom sketch of Fig. 5, necessarily involves a reversal of the currents at Gibraltar and in all the intervening sills during sapropel deposition, a situation which is far from being demonstrated, notwithstanding some recent attempts (Pride & Lohman, 1991).

Observational data in favor of episodic anoxia include the almost complete disappearance of the benthic fauna during sapropel deposition (Kidd et al., 1978; Parisi & Cita, 1982; Vismara Schilling, 1986; Oggioni & Zandini, 1987), whereas the high content in organic matter and the occurrence, in some peculiar sapropels, of foraminiferal assemblages indicative of high productivity (the so-called *G. bulloides / N. dutertrei* fauna) favor increased productivity. This fauna is conspicuously absent in the youngest, Holocene age sapropel (S-1), and the difference is attributed by Rohling and Gieskes (1989) to differences in food availability related to the development of a deep clorophyll maximum layer (DCM).

Our investigation carried out on a pelagic succession encompassing sapropels S-6 through S-9 documents sharp productivity increases coincident with sapropel S-6, which developed during isotopic stage 6 (Vergnaud-Grazzini et al., 1977; Thunell et al., 1983, their "glacial anoxia") and with sapropel S-8, which falls during substage 7c, a warm episode. The problem is not that simple.

The isotopic measurements did not help much to solve the dilemma either, although Carbon isotopes are considered potentially useful for calculating paleoproductivity (Berger et al., 1989). Strongly positive values are suggestive of high productivity, or might be related to humidity increases in continental environments (Corona, 1991). No such trends are observable in our record, shown in Fig. 4.

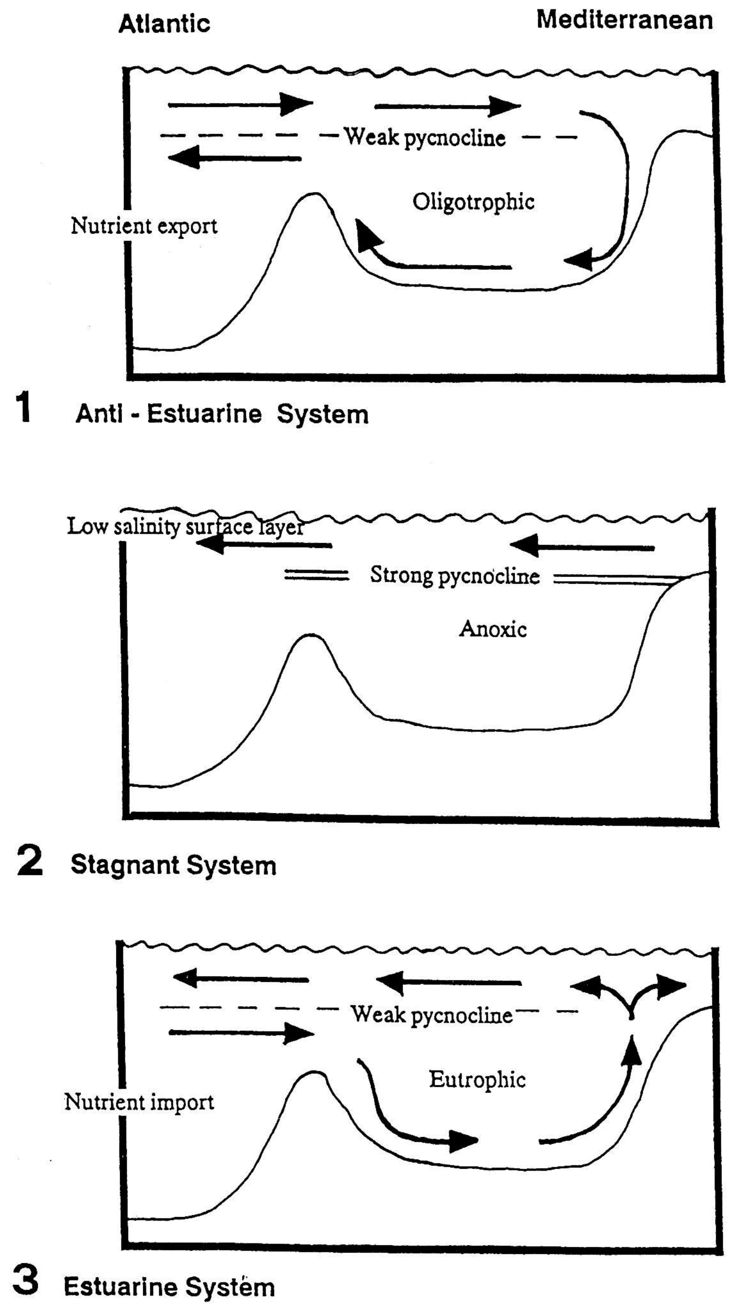

Fig. 5 - Schematic sections across the Mediterranean, showing three types of circulation: 1) anti-estuarine system, corresponding to the present situation; 2) stagnant system, according to Olausson (1961) model and 3) estuarine; high productivity system, according to Calvert (1983) model. The last model requires a reversal of the currents at Gibraltar.

The isotopic composition of Oxygen records strong changes, in agreement with previous findings (Parisi, 1987b; Olausson, 1991) thus supporting the generally accepted concept that the Mediterranean hehaves as an amplifier of the climatic signal due to its peculiarities in terms of physiography, circulation and climate (Cita, 1991b). Surprisingly enough the values measured on the mesopelagic species *G. bulloides* are negative, and in particular they are more negative than the values measured on the epipelagic *Globigerinoides ruber* in the two instances where both taxa were considered (compare Tab. 2 and Fig. 4). This observation might suggest a thermal inversion, with deeper waters warmer than surface waters during a time of strong glacial influx ("glacial anoxia"). We retain from making a strong case based on this meager evidence, however, because Olausson (1991) recently documented a very consistent trend, with *G. bulloides* more positive than *G. ruber*, in all the dozens samples analyzed from two cores from the area of Bannock Basin.

Acknowledgments.

Funding for the present research was provided by MURST 40%.

We gratefully acknowledge dr. Ricchiuto and prof. L. Mattavelli (AGIP, San Donato Milanese) for providing analytical data on stable isotopes and organic Carbon. Technical help was provided by G. Spezzi Bottiani, S. Antico and G. B. Sironi.

REFERENCES

Berger W. H., Smetacek V. S. & Wefer G. (1989) - Ocean Productivity and Paleoproductivity. An Overview. In Productivity of the Ocean: Present and Past, pp. 1-34, 9 fig., John Wiley and Sons Limited, Chichester.

Blechschmidt G., Cita M. B., Mazzei R. & Salvatorini G. (1982) - Stratigraphy of the western Mediterranean and southern Calabrian Ridges, eastern Mediterranean. *Marine Micropaleont.*, v. 7, pp. 101-134, 4 pl., 10 fig., Amsterdam.

Calvert S. E. (1983) - Geochemistry of Pleistocene sapropels and associated sediments from the eastern Mediterranean. *Oceanol. Acta*, v. 6, pp. 255-267, Paris.

Camerlenghi A. & Cita M. B. (1987) - Setting and tectonic evolution of the eastern Mediterranean deep-sea basins. *Marine Geol.*, v. 75, n. 1/4, pp. 31-56, 19 fig., Amsterdam.

Cita M. B. (1991 a) - Anoxic basins of the eastern Mediterranean. An overview. *Paleoceanography*, v. 6, pp. 133-141, 7 fig., New York.

Cita M. B. (1991 b) - Paleoclimatic and paleoceanographic evolution of the Mediterranean in the last 5 M. A. A Geological Perspective. Climate, Ocean and Man Intern. Symposium, Turin 1991 (in press).

Cita M. B. (1991 c) - Variazioni climatiche dopo l'ultima glaciazione. Ricostruzione in base allo studio dei sedimenti del Mediterraneo. *Accad. Naz. Lincei*, IX Giornata dell'Ambiente, Riassunti, Roma.

Cita M. B., Aghib F., Cambi A., Camerlenghi A., Corselli C., Erba E., Giambastiani M., Herbert T., Kastens K. A., Leoni C., Malinverno P., McCoy F. W., Nosetto A., Parisi E. &

Spezzi Bottiani G. (1985) - Precipitazione attuale di gesso in un bacino anossico profondo: prime osservazioni geologiche, idrologiche, paleontologiche sul Bacino Bannock (Mediterraneo orientale). *Giorn. Geol.*, v. 47, n. 1/2, pp. 143-163, 9 fig., Bologna.

Cita M. B., Broglia C., Malinverno A., Spezzi Bottiani G., Tomadin L. & Violanti D. (1982) - Late Quaternary pelagic sedimentation in the southern Calabrian Ridge and western Mediterranean Ridge (eastern Mediterranean). *Marine Micropaleont.*, v. 7, pp. 135-162, 14 fig., Amsterdam.

Cita M. B., Chierici M. A., Ciampo G., Moncharmont Zei M., d'Onofrio S., Ryan W.B.F. & Scorziello R. (1973) - Quaternary Record in the Ionian and Tyrrhenian Basins of the Mediterranean Sea. *Init. Rep. Deep Sea Drilling Project*, v. 13, pp. 1263-1340, 20 pl., 14 fig., U.S. Gov. Print. Office, Washington, D.C.

Cita M. B., De Lange G. J. & Olausson E. (1991) - Anoxic Basins and Sapropel deposition in the Eastern Mediterranean: Past and Present. *Marine Geol.*, v. 100, pp. 1-4, 1 fig., Amsterdam.

Cita M. B. & Grignani D. (1982) - Nature and origin of Late Cenozoic Mediterranean sapropels. In Schlanger S. O. & Cita M. B. (Eds.) - Nature and origin of Cretaceous Carbon-rich facies, pp. 165-198, 11 fig., Academic Press, New York.

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 Res.*, v. 8, pp. 205-235, New York.

Corona E. (1991) - La dendrocronologia come strumento di studio delle variazioni climatiche. *Accad. Naz. Lincei*, IX Giornata dell'Ambiente, Riassunto, Roma.

Epstein S., Buchsbaum R., Lowestam H. A. & Urey H. C. (1953) - Revised carbonate water isotopic temperature scale. *Geol. Soc. Am. Bull.*, v. 64, pp. 1315-1325, Boulder.

Kidd R. B., Cita M. B. & Ryan W.B.F. (1978) - The stratigraphy of eastern Mediterranean sapropel sequences as recovered by DSDP Leg 42A and their paleoenvironmental significance. In Hsü K., Montadert L. et al. - *Init. Rep. Deep Sea Drilling Project*, v. 42, pp. 421-443, 13 fig., U.S. Gov. Print. Office, Washington, D.C.

Kullenberg B. (1952) - On the salinity of water contained in marine sediments. *Medd. Oceanogr. Inst. Göteborg*, v. 21, pp. 1- 38, Göteborg.

Oggioni E. & Zandini L. (1987) - Response of benthic foraminifera to stagnant episodes: a quantitative study of core BAN 81-23, Eastern Mediterranean. In Van Hinte J. E., Cita M. B. & Van der Weijden C. H. (Eds.) - Extant and Ancient Anoxic Basin Conditions in the Eastern Mediterranean. *Marine Geol.*, v. 75, pp. 241-261, Amsterdam.

Olausson E. (1961) - Studies of deep-sea cores. *Rep. Swed. Deep-Sea Exped.*, v. 87, pp. 353-391, Göteborg.

Olausson E. (1991) - Carbon and Oxygen isotope composition of foraminifera in two cores from the Bannock Basin area, eastern Mediterranean. *Marine Geol.*, v. 100, pp. 45-52, 3 fig., Amsterdam.

Parisi E. (1987 a) - Carbon and Oxygen isotope composition of *Globigerinoides ruber* in two deep-sea cores from the Levantine Basin (eastern Mediterranean). *Marine Geol.*, v. 75, n. 1/4, pp. 201-219, 7 fig., Amsterdam.

Parisi E. (1987 b) - Evoluzione paleoclimatica e paleoambientale del Mediterraneo orientale dal Pleistocene all'Attuale. Tesi di dottorato inedita, pp. 1-413, Università di Milano.

Parisi E. & Cita M. B. (1982) - Quaternary paleoceanographic changes recorded by deep-sea benthos in the Western Mediterranean Ridge. *Geogr. Fis. Dinam. Quat.*, v. 5, pp. 102-114, 8 fig., 3 tab., Torino.

Parisi E., Erba E. & Cita M. B. (1987) - Stratigraphy and sedimentation in the anoxic Bacino Bannock (Eastern Mediterranean). Marine Geol., v. 75, n. 1/4, pp. 93-118, 2 fig., Amsterdam.

Pride C. J. & Lohman G. P. (1991) - Transitions between Lagoonal and Estuarine Circulation in the Eastern Mediterranean. *EOS*, AGU Spring Meeting 1991, Abstracts p. 152.

Rohling E. J. & Gieskes W.W.C. (1989) - Late Quaternary changes in Mediterranean Intermediate Water Density and Formation Rate. *Paleoceanography*, v. 4, n. 5, pp. 531-545, 6 fig., New York.

Rossignol-Strick M. (1983) - African monsoons, an immediate climate response to orbital insolation. *Nature*, v. 303, n. 5921, pp. 46-49, Basingstoke.

Ryan W. B. F. (1972) - Stratigraphy of Late Quaternary sediments in the Eastern Mediterranean. In Stanley D. J. (Ed.) - The Mediterranean Sea: A Natural Sedimentation Laboratory, pp. 149-170, Dowden, Hutchinson and Ross, Stroudsburg.

Thunell R. C. & Williams D. F. (1983) - Paleotemperature and paleosalinity of the eastern Mediterranean during the late Quaternary. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, v. 44, pp. 23-39, Amsterdam.

Thunell R. C., Williams D. F. & Cita M. B. (1983) - Glacial anoxia in the Eastern Mediterranean. *J. Foram. Res.*, v. 13, n. 4, pp. 283-290, Washington.

Thunell R. C., Williams D. F. & Kennett J. (1977) - Late Quaternary paleoclimatology, stratigraphy and sapropel history in Eastern Mediterranean deep-sea sediments. *Marine Micropaleont.*, v. 2, pp. 371-388, 9 fig., Amsterdam.

Tomadin L. & Landuzzi V. (1991) - Origin and differentiation of clay minerals in pelagic sediment and sapropels of the Bannock Basin (eastern Mediterranean). *Marine Geol.*, v. 100, pp. 35-44, 4 fig., Amsterdam.

Vergnaud-Grazzini C., Ryan W. B. F. & Cita M. B. (1977) - Stable isotopic fractionation, climate changes and episodic stagnation in the Eastern Mediterranean during the Late Quaternary. *Marine Micropaleont.*, v. 2, pp. 353-370, 7 fig., Amsterdam.

Vismara Schilling A. (1986) - Foraminiferi bentonici profondi associati a eventi anossici del Pleistocene medio e superiore del Mediterraneo Orientale. *Riv. It. paleont. Strat.*, v. 92, n. 1, pp. 103-147, 2 pl., 9 fig., Milano.

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.*, v. 23, pp. 81-93, 5 fig., Amsterdam.