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LATE QUATERNARY PALEOCEANOGRAPHIC CHANGES RECORDED BY DEEP-SEA BENTHOS IN THE WESTERN MEDITERRANEAN RIDGE

ABSTRACT: PARISI E. & CITA M. B., *Late Quaternary paleoceanographic changes recorded by deep-sea benthos in the Western Mediterranean Ridge* (IT ISSN 0084-8948, 1982).

Paleoceanographic changes occurred in the Eastern Mediterranean in the last 400 000 y are reconstructed on the basis of a quantitative study of benthic foraminifers from the upper 9 m of a sediment core (KS 09) from the crestal area of the Mediterranean Ridge whose climatic record was already investigated through changes recorded in planktonic foraminiferal faunas, composition in stable isotopes, and clay mineralogy.

Benthic foraminifers represent a minor constituent of the faunal assemblages, which are essentially planktonic. Species recorded are 92, with a maximum of 27 in a single sample. Twelve samples out of 69 do not contain any benthic form. Number of specimens recorded in a single sample ranges from 0 to 679. Peaks of abundance are always related to catastrophic paleoceanographic events.

Peaks of abundance related to re-colonization of the bottom after a faunal annihilation were already known, but for the first time we discovered peaks of abundance in layers immediately predating the onset of stagnant conditions. They are limited to the lower part of the stratigraphic column, older than approximately 200 000 y BP.

A strong decrease in faunal density results from the frequently repeated (approximately 20 000 y cycles) stagnation of the later part of climatic zone V (here defined as « subzone V″ ») which correlates with isotopic stage 7. These stagnations were originated by density stratification resulting from excess meltwater from the North European and Siberian grounded ice-sheets.

The composition of the fossil assemblages also record drastic changes. The best and most evenly represented species is the abyssal *Articulina tubulosa.* Species occasionally represented by 20 or more specimens are 15: they include *Bulimina aculeata*, *B. exilis*, *Fursenkoina complanata*, *Ellipsopolymorphina* sp. and *Cassidulinoides tenuis*, which are present only in a limited number of samples characterized by quite unusual ecologic conditions. We recorded in abundance beneath the older sapropels (of zone V) *Bulimina aculeata* which is known to tolerate and prefer low oxygen levels, associated with large-sized *Pyrgo* like *P. murrhyna*, *P. serrata*, *P. lucernula* and *P. depressa*, whose preference for such habitats was previously unknown.

The drastic downcore fluctuations in faunal density and the unexpected changes in the composition of the fossil assemblages display striking similarities with those recorded at exactly the same stratigraphic levels in Core Alb 189 from the Levantine Basin, some 1000 km to the East of Core KS 09.

Spacial homogeneity versus temporal instability suggests large oceanographic changes, of more than local significance.

RIASSUNTO: PARISI E. & CITA M. B., *Cambiamenti paleoceanografici del tardo Quaternario testimoniati dal benthos batiale della Dorsale Mediterranea Occidentale* (IT ISSN 0084-8948, 1982).

Studi quantitativi condotti sulle associazioni a Foraminiferi bentonici dei 9 metri superiori di una carota prelevata sulla cresta della Dorsale Mediterranea e il cui record paleoclimatico era già stato decifrato per mezzo di studi sul contenuto in Foraminiferi planctonici, composizione isotopica di due diverse specie, e minerali argillosi, hanno messo in luce variazioni paleoceanografiche verificatesi negli utimi 400 000 anni.

La fauna bentonica, sempre scarsa, è stata distrutta ripetutamente da episodi euxinici. Sono state identificate 92 specie con un massimo di 27 in un singolo campione. Dodici campioni su 69 sono privi di Foraminiferi bentonici. Il numero di esemplari trovati in un singolo campione varia da 0 a 679. I picchi di abbondanza si trovano immediatamente sotto o immediatamente sopra a sapropels. Picchi di frequenza legati alla ricolonizzazione del fondo erano già stati osservati, mentre non erano noti incrementi di frequenza in livelli immediatamente precedenti condizioni anossiche. Tali picchi sono limitati alla parte inferiore della colonna stratigrafica, più antica di 200 000 anni. Al frequente ripetersi di stagnazioni nella parte superiore della zona climatica V (qui definita, « subzona V″), correlabile allo stadio isotopico 7, cicli la cui durata è di circa 20 000 anni, segue un brusco decremento della densità faunistica. Queste stagnazioni si sarebbero verificate in seguito alla stratificazione delle masse d'acqua causata dalla fusione della calotta glaciale nord-europea e siberiana, che alimentava il Mediterraneo Orientale attraverso il Mar Nero.

Anche la composizione delle associazioni presenta drastiche variazioni. Le specie meglio rappresentate sono *Articulina tubulosa*, che sembra insensibile alle variazioni ambientali, *Bulimina aculeata*, *B. exilis*, *Fursenkoina complanata*, *Ellipsopolymorphina* sp. e *Cassidulinoides tenuis*, che compaiono solo in un limitato numero di campioni caratterizzati da condizioni ecologiche insolite. Nei livelli precedenti le stagnazioni della zona V è molto frequente *Bulimina aculeata*, che tollera bassi livelli di ossigeno, associata a *Pyrgo* di grosse dimensioni (*P. murrhyna*, *P. serrata*, *P. depressa*, *P. lucernula*), la cui preferenza per simili condizioni ambientali era finora sconosciuta.

Le drastiche variazioni della densità e della composizione faunistica sono strettamente correlabili con quelle riscontrate negli stessi orizzonti stratigrafici in una carota prelevata nel Bacino Levantino, circa 1000 km ad Est di quella qui considerata. Questa osservazione suggerisce che le variazioni oceanografiche avessero ampiezza e significato più che locali.

TERMINI-CHIAVE: Quaternario; Foraminiferi bentonici; sapropel; Mediterraneo orientale.

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BACKGROUND AND MOTIVATION

Core KS 09 from the Western Mediterranean Ridge has a climatic record extending back in time to approximately 700 000 (Cita, Bigioggero & Ferrario, 1975). This record was investigated by means of studies on planktonic foraminifers, on isotopic geochemistry, and on clay mineralogy (Cita & *alii*, 1977). As a result of this research, and of similar investigations carried out on Eastern Mediterranean deep-sea cores (Thunell & *alii*, 1977; Vergnaud-Grazzini & *alii*, 1977; etc.) we can state that the climatic record of the Mediterranean is similar in character, phases and chronology to the record investigated in the Caribbean (Emiliani, 1966; Broecker & van Donk, 1970) and in the equatorial Pacific (Shackleton & Opdyke, 1973; 1976). Studies on the isotopic composition of 0 on epipelagic foraminifers indicate that temperature changes in the surficial water layers in the Eastern Mediterranean never exceeded 8 °C during the late Pleistocene glacial stages, the greatest isotopic excursion being recorded at the stage 6/stage 5e boundary or Termination II (Vergnaud-Grazzini & *alii*, 1977).

The Eastern Mediterranean deep-sea record is characterized by cyclically repeated stagnant episodes resulting in the deposition of black, organic-rich layers containing up to 16 % by weigth organic C, the organic matter being mostly pelagic in origin (Cita & Grignani, 1980; Kidd & *alii*, 1978).

Sapropels, sedimentary expression of basin-wide stagnations (Ryan & Cita, 1977), and tephra layers, sedimentary expression of explosive volcanic activity (Keller & *alii*, 1978), represent isochronous lithologies: they al-

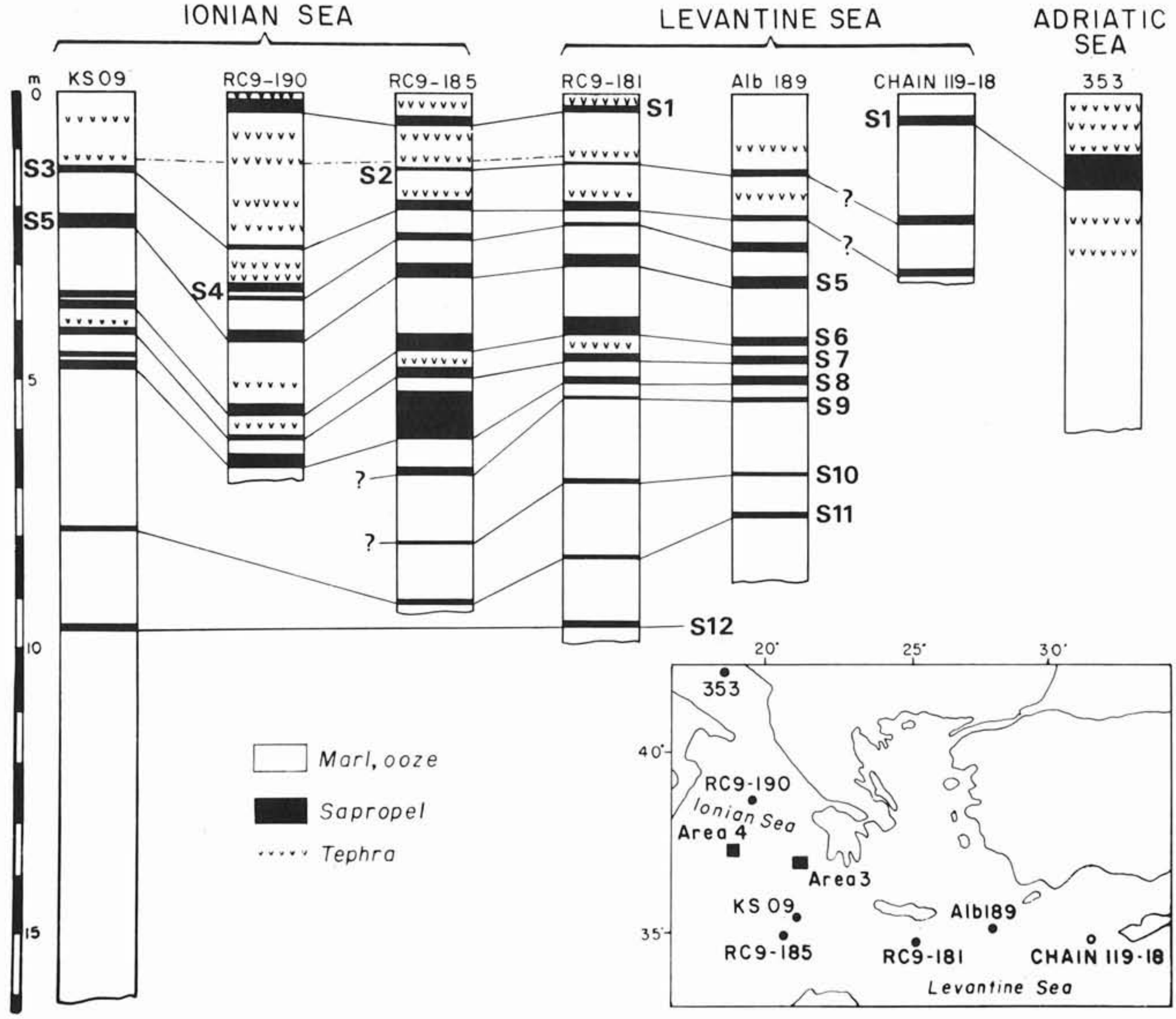

Fig. 1 - Lithostratigraphic correlation of Core KS 09 with other Eastern Mediterranean deep-sea cores by means of isochronous lithologies (sapropels and tephra layers). The insert shows the location of the cores, and two areas explored in great detail in 1978 (Cobblestone Area 3, and 4).

low a precise layer-by-layer correlation of piston cores (fig. 1) and permit to extrapolate the climatic record from the cores investigated in detail to a number of other deep-sea cores.

The present study concerns the distribution of benthic foraminifers in the upper 9 m approximately of Core KS 09; according to the chronology of Cita & *alii* (1977) this interval corresponds to a duration of approximately 400 000 y.

Little attention has been paid so far to changes occurred in benthic assemblages (Cita & Podenzani, 1980; van der Zwaan, 1980; Mullineaux & Lohmann, 1981) although the bottom-living fauna should record paleoceanographic changes leading to stagnation more carefully than do planktonic foraminifers or other planktonic organisms.

Our recent investigations on the distribution of benthic foraminifers in the deeper parts of the Mediterranean (Cita & Zocchi, 1978; Massiotta, Cita & Mancuso, 1976; Parisi, 1981) were essentially oriented to check the influence of bathymetry on the composition of the benthic fauna. They demonstrated beyond any doubt that faunal density decreases as a function of increasing depth; they also demonstrated that the Western Mediterranean and the Eastern Mediterranean behave as two discrete bioprovinces, the latter being much more impoverished than the former, and yielding more specialized foraminiferal faunas.

TABLE 1

Location and water depth of all the Eastern Mediterranean deep-sea cores discussed in this paper.

ADRIATIC SEA			
353	43°58'	17°51'	1207
IONIAN BASIN			
KS 09	35°09'	20°09'	2800
RC9-190	38°39.3'	19°13.7'	1712
RC9-185	34°27.1'	20°06.9'	2858
Cobblestone Area 4			
6	36°14.9'	17°04.9'	3613
10	36°14.7'	17°46.1'	3832
40	36°15.2'	17°42.3'	3630
42	36°16.6'	17°43.4'	3806
44	36°17.3'	17°43.3'	3706
45	36°16.2'	17°43.5'	3692
Cobblestone Area 3			
23	35°50.7'	20°50.4'	3001
28	35°51.5'	20°47.6'	3150
29	35°50.1'	20°49.6'	2866
30	35°50.5'	20°50.7'	2864
32	35°51.0'	20°52.1'	3243
39	35°52.8'	20°47.6'	3021
LEVANTINE BASIN			
RC9-181	33°25'	25°01'	2286
Alb 189	33°54'	28°29'	2664
Chain 119-18	32°09'	34°03'	2484

One of the purposes of the present study is to clarify which other factor, beyond bathymetry, affects the density, and the composition of the foraminiferal faunas.

A study still unpublished on the distribution of benthic foraminifers in core tops from the Ionian Basin (Cobblestone Area 3 on the Western Mediterranean Ridge and Cobblestone Area 4 in the Southern Calabrian Ridge, see location in fig. 1) revealed that the two areas yield two entirely different foraminiferal faunas, with no species and no genera in common: that from the Southern Calabrian Ridge (Cobblestone cores 6, 10, 40, 42, 44, 45, see table 1) entirely consisting of Miliolids; that from the Western Mediterranean Ridge (Cobblestone cores 23, 28, 29, 30, 32, 39) characterized by the agglutinated *Glomospira* and by *Anomalinoides minimus*, with no Miliolids (Vignali & Cita, in press). We wanted to investigate the time, and eventually the causes, of this differentiation in two areas of similar bathymetry, which are not separated by any physical barrier.

One more problem we were addressing is related to stagnation. Our studies on sapropel S-1 (Cita & Podenzani, 1980) had shown that the re-colonizing fauna after the youngest (Holocene) stagnation of the Eastern Mediterranean is entirely different from the pre-stagnant assemblage, and that the latter progressively changed composition as a response to decreasing oxygen levels at the sediment/water interface. Although the frequency of our sampling interval was inadequate for a detailed study (see below), we planned to reconstruct the general framework of benthic faunal changes related to oxygen starvation for the late Pleistocene sapropels, especially those cyclically repeated of climatic zones X (sapropels S-3, S-4 and S-5) and of the later part of zone V (sapropels S-6, S-7 and S-8). Our studies on sapropels (Vergnaud-Grazzini & *alii*, 1977; Cita, Broglia & *alii*, 1982; Cita & Grignani, 1980) had shown that most sapropels in cores KS 09, Cobblestone 6, 29 and 45 occur on the warming trend of climatic faunal curves, but that some sapropels were induced by density stratification originated by strong dilution by fresh water without any detectable warming (S-6, S-8). We hoped to be able to detect in the bottom-living fauna some evidence of the different mechanisms leading to stagnation.

STRATIGRAPHIC FRAMEWORK

The basic stratigraphic information available for the late Quaternary of the Eastern Mediterranean is summarized in fig. 2.

The column to the left shows the isotopic record of oxygen measured on *Globigerinoides ruber* in Core RC9-181 (after Vergnaud-Grazzini & *alii*, 1977). This core from the crestal area of the Mediterranean Ridge is the most complete known: its columnar log, which contains all the twelve sapropels identified in the Holocene (S-1) and in the late Pleistocene (S-2 through S-12) is shown in the second column from the left. Isotopic stages 1 through 11 are well recognizable in the isotopic curve, with three distinct negative peaks recorded in stages 5 and 7. The amplitude of isotopic fluctuations is approximately three times greater in the Mediterranean than in the open ocean. In Core RC9-181 the range of change exceeds 5 per mil, from +3 ‰ (the most positive peak recorded in stage 2) to −2.23 ‰ (the most negative peak of substage 5e).

Column three shows the climatic zones identified by ERICSON & WOLLIN (1968), frequently used in studies on the Eastern Mediterranean (RYAN, 1972; MCCOY, 1974, KELLER & *alii*, 1978). Numerical ages assigned to climatic zonal boundaries are based on the cited papers, and on the chronology of Eastern Mediterranean sapropels proposed by CITA & *alii* (1977).

We subdivided zone V, whose duration is much longer than the duration of other climatic zones, in two subzones: V′) correlates with isotopic stages 11 through 8, and includes sapropels S-11, S-10 and S-9; V″) correlates with isotopic stage 7 and includes sapropels S-8, S-7 and S-6.

The numerical age of 225 000 y BP assigned to the V″/V′ subzonal boundary is based on interpolation of sedimentation rates calculated for Core KS 09 (see fig. 9 of CITA & *alii*, 1977).

Column four contains the nannofossil biostratigraphy used for the Eastern Mediterranean by BLECHSCHMIDT & *alii* (1982). Numerical ages given to the zonal boundaries are after GARTNER (1977) and BERGGREN & *alii* (1980). A few comments are required: the *Gephyrocapsa oceanica*/*Emiliania huxleyi* zonal boundary is assigned an age of 220.000 y BP, which is definetly younger than the age used by other authors for the open ocean (270 000 y BP in BERGGREN & *alii*, 1980). The later entrance of *E. huxleyi* in the Mediterranean Pleistocene seems well founded, since the first occurrence of this species has been consistently recorded in between sapropels S-8 and S-7 in three cores from Cobblestone Area 3 on the Mediterranean Ridge (MAZZEI, in BLECHSCHMIDT & *alii*, 1982) and in two additional METEOR cores (MÜLLER, in SIGL & MÜLLER, 1975).

More doubtful is the location of the *Pseudoemiliania lacunosa*/*Gephyrocapsa oceanica* zonal boundary in the Mediterranean. The extinction level of *P. lacunosa* has been identified by THIERSTEIN H. just beneath sapropel S-11 in Core RC9-181 (see VERGNAUD-GRAZZINI & *alii*, 1977, p. 227) but this finding was never replicated in other cores. The age of 375 000 y BP is according to CITA & *alii* (1977). Older ages for non-Mediterranean deep-sea cores are recorded in the literature: 400 000 in fig. 8 of BERGGREN & *alii* (1980); 474 000 in GARTNER (1977).

When, in the following pages, we will refer to climatic zones, it is within the stratigraphic framework discussed here.

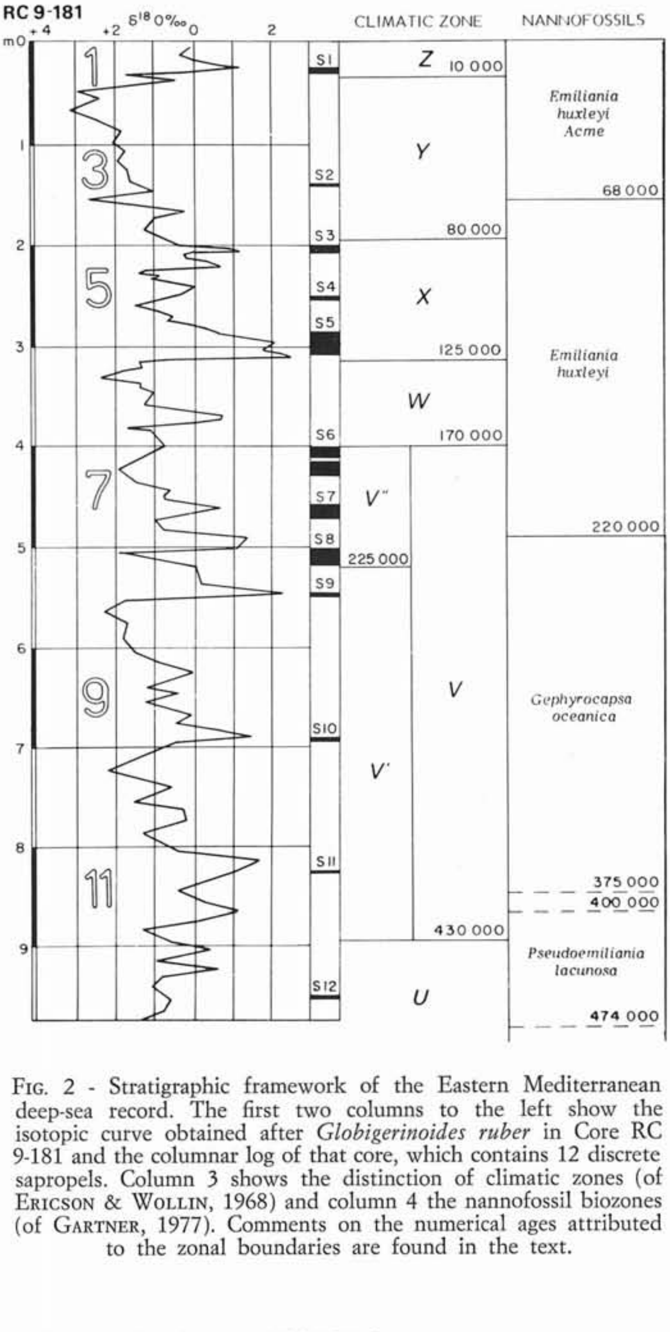

FIG. 2 - Stratigraphic framework of the Eastern Mediterranean deep-sea record. The first two columns to the left show the isotopic curve obtained after *Globigerinoides ruber* in Core RC 9-181 and the columnar log of that core, which contains 12 discrete sapropels. Column 3 shows the distinction of climatic zones (of ERICSON & WOLLIN, 1968) and column 4 the nannofossil biozones (of GARTNER, 1977). Comments on the numerical ages attributed to the zonal boundaries are found in the text.

MATERIAL AND METHODS

We used for this study the same of samples processed for Micropaleontology in the research published in CITA & *alii* (1977). Samples investigated are 69, from the upper 9 meters of this 16 meters long piston core. Sampling interval is 10-12 cm. Sample size is approximately 10 cc.

All the benthic foraminifers from the sediment fraction greather than 105 microns were picked, and identified specifically whenever possible, or at a generic level.

Fiftyseven samples out of the 69 investigated contain one or more specimen of benthic foraminifers: those devoid of bottom-living forms are from sapropel layers, from tephra layer, or from an interval of whitish, apparently well oxygenated sediment from 700-780 cm from core top.

Table 1 contains the coordinates and water depth of Core KS 09 and of other Eastern Mediterranean deep-sea cores discussed in this paper.

RESULTS

The list of taxa identified includes:

Angulogerina sp.
Anomalina sp. 1
Anomalina sp. 2
Anomalinoides minimus VISMARA, SCHILLING & PARISI
Amphycoryna scalaris (BATSCH)
Articulina tubulosa (SEGUENZA)
Astigerinata sp.
Astrononion sp.
Biloculinella cylindrica TODD
Biloculinella globula (BORNEMANN)
Biloculinella labiata SCHLUMBERGER
Bolivina advena CUSHMAN
Bolivina difformis (WILLIAMSON)
Bolivina pseudoplicata HERON-ALLEN & EARLAND
Bolivina spathulata WILLIAMSON
Bolivina subaenariensis CUSHMAN
Bolivina subspinescens CUSHMAN
Bolivina sp.
Bulimina aculeata D'ORBIGNY
Bulimina exilis BRADY
Bulimina marginata D'ORBIGNY
Bulimina sp.
Cassidulina laevigata D'ORBIGNY
Cassidulina subglobosa BRADY
Cassidulinoides tenuis PHLEGER & PARKER
Chilostomella ovoidea (REUSS)
Chilostomella elongata LAGOE
Cibicides sp.
Cyclogira involvens (REUSS)
Dentalina guttifera D'ORBIGNY
Dentalina leguminiformis (BATSCH)
Discorbis sp.
Elphidium complanatum (D'ORBIGNY)
Eponides bradyi EARLAND
Eponides tumidulus (BRADY)
Eponides sp.
Ellipsopolymorphina sp.
Fissurina annectens BURROWS & HOLLAND
Fissurina cavea (BUCHNER)
Fissurina circumvallata (BUCHNER)
Fissurina cucullata (SILVESTRI)
Fissurina granifera (BUCHNER)
Fissurina lateralis (CUSHMAN)
Fissurina marginata (MONTAGU)
Fissurina mennellae (BUCHNER)
Fissurina orbignyana (SEGUENZA)
Fissurina simplex (BUCHNER)
Fissurina staphyllearia (SCHWAGER)
Fissurina sp. 1
Fissurina sp. 2
Fissurina sp. 3
Fursenkoina complanata (EGGER)
Fursenkoina sp.
Glandulina laevigata D'ORBIGNY
Glandulina obesa (LOEBLICH & TAPPAN)
Glandulina gibba D'ORBIGNY
Glomospira charoides (PARKER & JONES)
Gyroidina delicata PARKER
Gyroidina neosoldanii BROTZEN
Gyroidina umbonata (SILVESTRI)
Lagena nebulosa CUSHMAN
Lagena radiata SEGUENZA
Lagena striata D'ORBIGNY
Lagena sp. 1
Lagena sp. 2
Lenticulina cultrata (MONTFORT)
Lenticulina sp.
Miliolinella subrotunda (MONTAGU)
Nodosaria sp.
Nonion padanum PERCONIG
Nonionella turgida
Oolina acuticosta REUSS
Oolina hexagona (WILLIAMSON)
Oolina sp.
Ophthalmidium acutimargo (BRADY)
Parafissurina turgida (BUCHNER)
Pullenia quinqueloba (REUSS)
Pyrgo depressa (D'ORBIGNY)
Pyrgo lucernula (SCHWAGER)
Pyrgo murrhyna (SCHWAGER)
Pyrgo serrata (BAILEY)
Quinqueloculina bicostata D'ORBIGNY
Quinqueloculina sp. 1
Quinqueloculina sp. 2
Robertina translucens CUSHMAN
Sigmoilina sp.
Spiroloculina sp.
Triloculina tricarinata D'ORBIGNY
Triloculina trigonula (LAMARCK)
Textularia sp.
Valvulineria sp.

The species recorded, with special attention to those which are best represented in the samples, are, with a few exceptions, either deep bathyal forms (i.e. *Articulina tubulosa*, *Miliolinella subrotunda*, *Anomalinoides minimus*, *Robertina translucens*) or species with a wide bathymetric range (i.e. *Glomospira charoides*, *Fissurina* spp., *Gyroidina* spp., *Biloculinella* spp.). The few exceptions are represented by *Asterigerinata* sp., *Discorbis* sp., *Elphidium complanatum* and *Valvulineria* sp., which are recorded with single specimens (one specimen) in a few samples, and are interpreted as downslope displaced.

Downslope displacement and in general resedimentation which could eventually obscure the paleoecologic signal of benthic foraminifers, is exceptionally rare in Core KS 09 which is located in the crestal area of the Mediterranean Ridge, far enough from the continental margin as not to be contaminated by terrigenous input and elevated enough above the adjacent abyssal plain as to escape turbidites.

Table 2 shows the distribution of a selected number of species or groups of species which are particularly well represented.

TABLE 2

DISTRIBUTION OF SELECTED SPECIES, OR GROUPS OF SPECIES, IN THE UPPER 9 METERS OF CORE KS 09.

SAMPLES	*Pyrgo depressa*	*Pyrgo murrhyna*	*P. serrata+P. lucernula*	*Miliolinella subrotunda*	*Articulina tubulosa*	*Miliolidae*	*Bolivina spp.*	*Cassidulinoides tenuis*	*Bulimina aculeata*	*Bulimina exilis*	*Eponides tumidulus*	*Ellipsopolymorphina sp.*	*Fursenkoina complanata*	*Fursenkoina sp.*	*Cassidulina spp.*	*Gyroidina delicata*	*Gyroidina neosoldanii*	*Other*	*TOT. no. specimens*	*TOT. no. species*
8-11					16	2									1				19	5
16-19	5			8	32	9									4			5	63	14
30-33																				
42-45				1	1														3	3
60-63				22	30						2				5			10	69	9
70-73		1		13	27	2									2			7	52	11
80-83				10	1														11	2
90-93				9	63		1								2			14	89	12
100-103																				
112-115					178													7	185	5
120-123					5														5	1
130-132					7	1												12	20	12
140-143																1			1	1
150-153				1	12													1	14	3
160-164					6	3										1		1	12	6
170-175					14													2	16	3
185-190					87						5							6	98	5
224-230																				
236-239																				
255-259	2	1	1	1	2	4			2							1		2	16	11
268-272						2													2	1
292-296	2				13	3			1									4	23	9
310-314					11	10											2	4	27	8
320-324				1	12	6												1	20	5
332-336		2		7	9	15												10	43	12
343-346					8	3												7	18	8
355-357																15	1	1	18	4
366-368	3				113			78		47	2	91	34			8	32	5	413	12
374-378																				
388-392					1													2	3	2
406-409				5	4	3					6							3	21	6
418-421																		1	1	1
440-444					2													2	4	3
455-458		1			1	1		15			3							2	23	7
467-471					52		1	9			11	1	3					12	89	13
484-488					35		1	1				1						2	40	5
493-497					52	1												5	58	5
510-514					663	1					2							13	679	7
524-527				25	63	4												15	107	14
538-542		3		27	150	4							1			1		24	210	20
550-554				17	99	3									1			12	132	13
562-566	36	20		1	60	15	2				1			1				29	165	24
574-577				32	131		1											15	179	11
587-589					83	1												9	93	9
597-599					38	1					1			1				6	48	9
610-613					5														5	1
623-626					2													3	5	2
637-640					14		1											1	16	3
649-653									1									2	3	2
660-663	1					2	2		78		4			7		21		7	122	13
671-675		24				8	6		371		8			4	1	9	3	34	468	26
683-687		6	1		2	3	1				1				3	4		7	29	16
695-699		10	2			6	1		1									7	27	13
708-712																				
720-724																				
733.5-736																				
745.5-749																				
759-762																				
772-778																				
782-785																				
786-788			1															1	2	2
800-804		35				1	1		269		12			27	2		10	29	386	22
815-819	4	23	18	3	122				12					3				43	291	27
827-830		39	6		1	10	7									10	19	11	104	20
842-846					25	1	1		1		51				1	9	4	17	113	18
857-861			4		61	4	2				36				2	40		26	184	23
871-873					3						6					14		8	34	7
883-886		1			2						3					2		7	20	8
883-903		1			76				1		3							9	106	11

A plot of all the findings of benthic foraminifers in Core KS 09, illustrations of 18 species and taxonomic notes are to be found in the paper by PARISI (in press), to which reference is made.

Fig. 3 is a photograph of a portion of Core KS 09 from approximately 430 to 500 cm from core top, encompassing sapropels S-7 (in part only) and S-8.

DISCUSSION

FAUNAL DIVERSITY

The total number of taxa identified is 92, however they never co-occur all at the same time. The maximum number of taxa identified in a single sample is 27. Most of the samples (23) contain 10-20 species. Eighteen samples contain 5-9 taxa. Twelve are barren.

There is no obvious trend in faunal diversity (= number of species), as shown by fig. 4. The older assem-

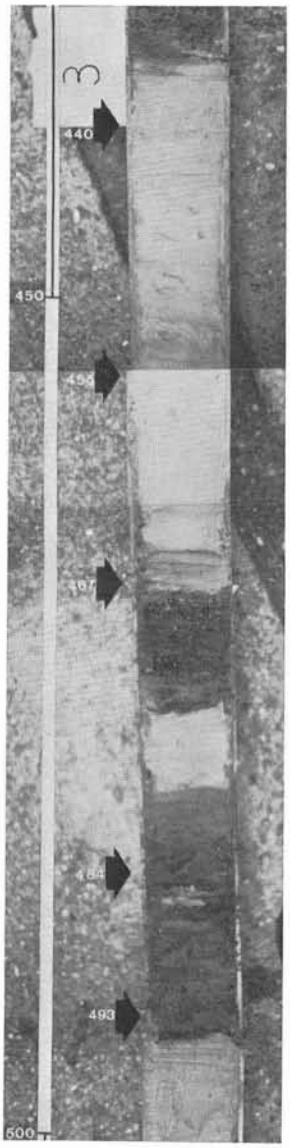

FIG. 3 - Photograph of a portion of Core KS 09 encompassing sapropels S-8 and S-7. Arrows point to the top cm of sampled intervals.

blages (deeper than 800 cm in the core) appear more uniformly diversified than the younger ones, suggesting more uniform ecologic conditions at the bottom. The mean values of species number calculated for each climatic zone/subzone show fluctuations in the later part of the time-interval considered, with higher species numbers in the cold intervals (Y, W) and lower species numbers in the warm intervals (X).

FAUNAL DENSITY

The number of specimens from a single sample ranges from 0 to 679. Mean value (4 994 counted specimens divided by 69 samples) is 72.3. If we exclude from the countings the barren samples, mean of the fossiliferous samples is 87.6.

The peaks of abundance are very unevenly spaced (fig. 4). Of the 16 specimens yielding 100 or more benthic foraminifers, all but two are from the V zone. These two peaks of abundance are ephemeral in duration and document the recolonization of the bottom after an ash fall (sample at 122 cm in climatic zone Y) and after a stagnant episode (sample at 366 cm above sapropel S-6 in the basal part of climatic zone W).

A first conclusion can be drawn that the strong, cyclically repeated stagnations of the later part of zone V had drastic effects on the population levels of the deep Mediterranean floor.

FAUNAL COMPOSITION

The composition of the fossil assemblages records drastic changes. *Articulina tubulosa* is recorded in most samples investigated and is the best represented species (fig. 5). High percentages are recorded both in samples poor in benthic foraminifers, and in samples rich in benthic forms.

The conclusion can be drawn that the frequent stagnations of subzone V″ did not affect *A. tubulosa.*

Fourteen out of the 69 samples investigated contain > 100 benthic foraminifers. In seven of these 14 samples *A. tubulosa* represents > 50 % of the population, whereas this species is absent altogether in 4 samples. All these layers rich in benthic foraminifers but devoid of *A. tubulosa* are from the lower part of the sediment core, predating sapropel S-9.

A group of species which includes several Miliolids such as *Quinqueloculina* spp., *Triloculina trigonula*, *T. tricarinata*, *T.* sp., *Pyrgo depressa*, *Miliolinella subrotunda* and the *Lagenidae* (*Lagena striata*, *L. nebulosa*, *L.* spp., *Fissurina lateralis*, *F. staphyllearia*, *F. annectens*, *F. simplex*, *F. circumvallata*, *F. mennellae*, *F.* spp., *Oolina acuticosta*, *O. hexagona*) have a fairly uniform distribution in the samples, but are never abundant.

A group of species including *Bulimina aculeata*, *Pyrgo murrhyna*, *P. serrata*, *Eponides tumidulus*, *Gyroidina delicata* is fairly well represented in the interval from 649 to 800 cm from core top (zone V′) whereas it is only occasionally recorded above 649 cm.

A few species are exceptionally well represented at definite levels (see table 2): they are *Bulimina exilis*, *Fursenkoina complanata*, *Ellipsopolymorphina* and *Cassidulinoides tenuis*, which co-occur at 366 cm just above sapropel S-6 with percentages of 11.38 %, 82.32 %, 22.03 % and 18.88 % respectively. This quite anomalous sample contains the third from the richest benthic foraminiferal assemblage from our data set. *Bulimina exilis* in only recorded in this sample. *F. complanata* and

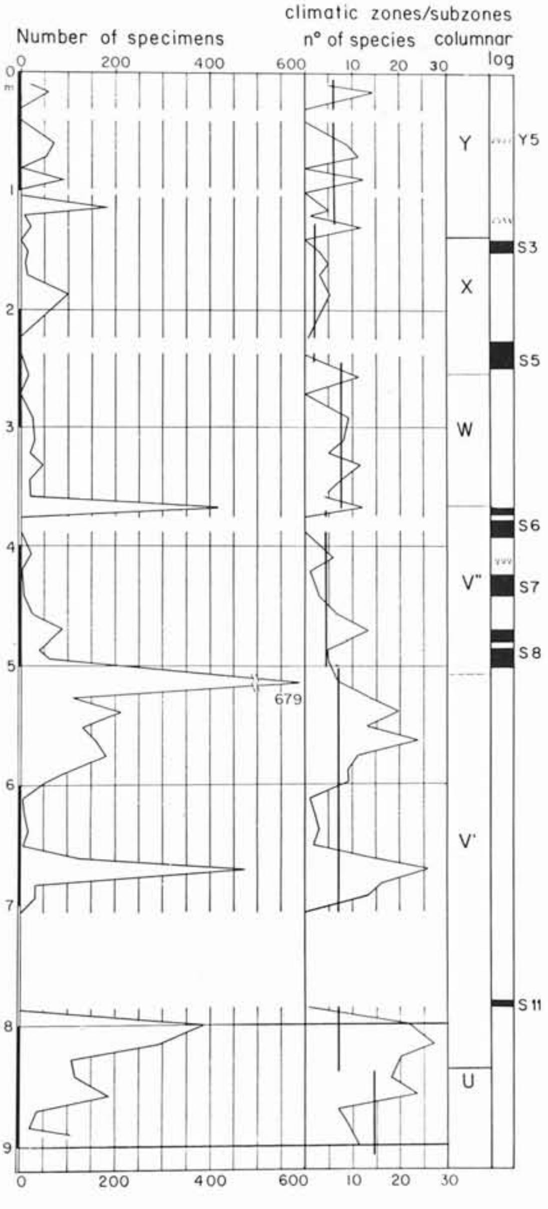

FIG. 4 - Changes recorded in faunal density (number of specimens per sample of approximately 10 cc, left column) and in faunal diversity (number of species identified, right column) in the upper 9 meters of Core KS 09. Mean values of the species number calculated for each climatic zone/subzone are also shown. To the right of the figure one can see the columnar log of Core KS 09 and the distinction of climatic zones. White areas indicate intervals devoid of benthic fauna. The position of samples investigated is precisely indicated in table 2. Here and in fig. 5 the location of the samples corresponds to the top cm of the sampled interval.

Ellipsopolymorphina in two additional ones; *C. tenuis* in four additional ones.

Buliminids are known as the benthic foraminifers most tolerant to low oxygen levels (BOLTOVSKOY & WRIGHT, 1978). They are poorly represented in Core KS 09, with a few exceptions. *Uvigerina* is absent altogether. *Bolivina* spp. are scanty or absent, their percentages never reaching 10 % of the fauna. *Bulimina* (with *B. exilis* and *B. aculeata* as the best represented species) is uneven in its distribution (table 2). Percentages exceed 70 % in two levels (800 cm and 671 cm). The first is immediately beneath sapropel S-11. The second is not

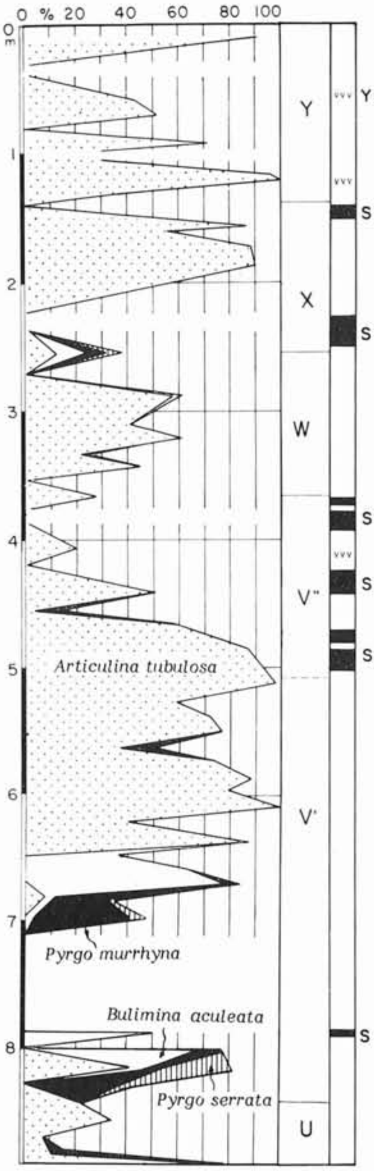

FIG. 5 - Distribution of the four species of benthic foraminifers best represented in the upper 9 m of Core KS 09. White areas indicate intervals devoid of benthic fauna. To the right, columnar log of Core KS 09 and climatic zones.

TABLE 3

DISTRIBUTION OF SELECTED SPECIES, OR GROUPS OF SPECIES, IN CORE ALB 189 AFTER PARKER, 1958 (1).

SAMPLES	*Pyrgo murrhyna*	*Pyrgo serrata*	*Miliolinella circularis*	*Articulina tubulosa*	Miliolidae	*Cassidulinoides tenuis*	*Bulimina aculeata*	*Bulimina exilis*	*Globobulimina ? sp.*	*Virgulina complanata*	*Cassidulina spp.*	*Pullenia spp.*	*Gyroidina delicata*	*Gyroidina neosoldanii*	Other	TOT. no. specimens	TOT. no. species
2.5-3	1														1	2	2
9.5-10	7		3	10	2						2				6	30	9
59.5-60	7		5	13	1										15	41	7
99.5-100			1	7	1						1				1	11	5
109.5-110			1	8	2						1				2	14	6
119.5-120			6	5							3				13	27	6
129.5-130			8	5							3					16	3
149.5-150			5	3	1						2					10	7
159.5-160			23	17	1						5				8	54	7
169.5-170			36	77	2						11				10	136	11
179.5-180			34	72	2						12				1	121	5
189.5-190			33	52	1						1				18	95	7
199.5-200			14	6											1	21	3
209.5-210				54										3	4	61	6
218-218.5				26											23	49	4
224-224.5																	
228.5-229																	
239.5-240				1										1		2	2
249.5-250				8											1	9	2
259.5-260														2		2	1
268.5-269				22											2	24	2
281.5-282																	
289.5-290														1		1	1
299.5-300				1												1	1
319.5-320				2										1	1	4	3
329.5-330				1										2	1	4	3
339.5-340																	
350.5-351													1		4	5	3
359.5-360			4		12					1			6		26	49	11
369.5-370				1	2										1	4	3
379.5-380				10	5							1			2	18	5
388.5-389				10	3										5	18	6
399.5-400			1	3	1										2	7	4
409.5-410				5	4										11	20	8
419.5-420				44	3			2							9	58	7
429.5-430				1		60		50	86			1	40		19	257	8
439.5-440																	
449.5-450				18									64	1	80	163	11
459.5-460				3	1										1	5	3
469.5-470				1											24	25	3
479.5-480																	
489.5-490				15	2										7	24	7
509.5-510				4								1	1		3	9	5
519.5-520	1			1								2			6	10	5
527.5-528																	
532.5-533				161								1		1	11	174	7
539.5-540				7											4	11	3
549.5-550				25								1		1	23	50	5
559.5-560			1												4	5	3
569.5-570				19	10										9	38	4
579.5-580				3	1										3	7	5
599.5-600	9			17	1							1			3	31	5
607.5-608				11											1	12	2
617-617.5										2					6	8	3
622-622.5				9										1	9	19	8
629.5-630				79						1		2			20	102	7
629.5-640				7										1		8	2
649.5-650				12							1			1	1	15	4
659.5-660														2		2	1
669.5-670				4												4	1
678.5-679				8											1	9	2
683.5-684																	
689.5-690				1			25							1	4	31	5
699.5-700	12			26	19		1280			1			3		7	1349	10
709.5-710	5			1	3										23	32	8
729.5-730				2											3	5	4
739.5-740				6						2				1	7	16	4
759.5-760							5								1	6	2
769.5-770																	
779.5-780	11	80		2			896			11			7	1	12	1020	10
789.5-790	32	38		15						1				2	18	106	11
809.5-810				4										1	19	24	5
818-818.5				5										1	2	8	3
829.5-830				6										4	18	28	6
839.5-840				1										1		26	8

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(1) The sediment fraction used by PARKER is slightly smaller than that used by us (93 microns instead of 105). This notwithstanding, there is a striking similarity in the record of benthic foraminifers in these two cores, which are almost 1000 km apart.

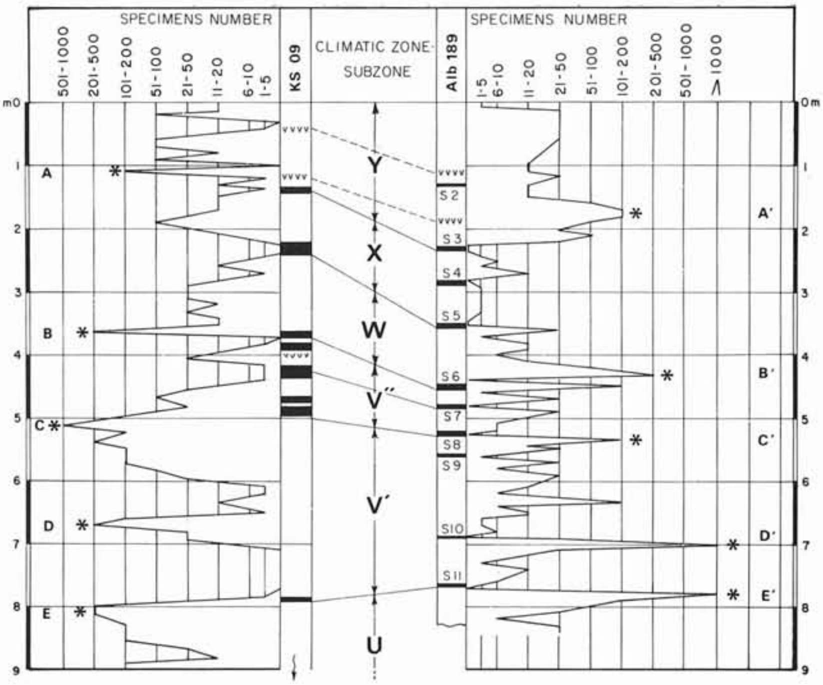

Fig. 6 - Plot of the number of specimens versus depth in Cores KS 09 and Alb 189. Notice that the scale is not linear. The columnar logs of the two cores are correlated by means of isochronous lithologies. Asterisks and letters permit to identify correlatable peaks of abundance in the two cores.

related to any sapropel. However, we point out that sapropels S-10 and S-9 could not be identified in Core KS 09. Their stratigraphic position (fig. 1) should be between 750 and 600 cm in the core. All the samples examined from 785 to 708 cm included are barren: this unusual finding might indicate anoxic conditions at the bottom, accompanied by low productivity at the surface. As a result, no organic-rich layer would accumulate no record of sapropel S-10). As far as sapropel S-9 is concerned, it is suggested that a minor hiatus resulted in its destruction. The position of the hiatus should be above 660 cm. If we compare the changes recorded in the composition of benthic assemblages, both qualitative and quantitative, in the interval from 805 and 785 cm (= i.e. across sapropel S-11) and from 671 and 649 cm (see table 2) we notice such a similarity that it seems reasonable to invoque a similar causative mechanism.

COMPARISON WITH THE DISTRIBUTION OF BENTHIC FORAMINIFERS IN THE SAME TIME SPAN (THE LAST 400 000 Y APPROXIMATELY) IN THE LEVANTINE BASIN

We used for this comparison the data presented by Parker F. L. in her classical study of Eastern Mediterranean foraminifers (1958) for Core Alb 189, which was investigated isotopically by Emiliani (1955).

Table 3 shows the distribution of a selected number of species which are particularly well represented in Core Alb 189, as well as in KS 09 (compare with table 2). Not only the faunal assemblages are similar, but the extrahordinary large changes recorded in the last 400 000 y as a response to changes in ocean paleoenvironment are also similar in these two cores, which are some 1000 km apart (figs. 1 and 6). Similarities include: *a*), faunal density and *b*), composition of the fossil faunas.

a) Fig. 6 is a plot of the number of specimens versus depth in the two cores considered. The column in the middle of the figure shows the lithostratigraphic correlation of the two cores, and the climatic zones. Core Alb 189 has a more complete record of sapropels than KS 09: its sedimentation rate is slightly higher than in KS 09 in the upper half of the sediment core, slightly lower in the lower half.

Asterisks mark the abundance peaks of benthic foraminifers which are well correlatable in the two cores, since they occupy the same stratigraphic position. From top to bottom they are:

peak A: in zone Y, just above a tephra layer;

peak B: in zone W, above sapropel S-6;

peak C: in subzone V″, beneath sapropel S-8;

peak D: in subzone V′, beneath sapropel S-10 or a correlatable layer (see previous discussion);

peak E: in subzone V′, beneath sapropel S-11.

The conclusion can be drawn that peak abundances of zone W or younger are re-population events, whereas peak abundances of zone V are related to deteriorating environmental conditions, leading to stagnation.

b) Figs. 7 and 8 illustrate the climatic faunal curve (a plot of percentages of warm water indicators minus cold water indicators) the salinity index (i.e. percentage abundances of *Globigerina eggeri*, a species of planktonic foraminifers which can stand considerable salinity changes, including lower-than-normal salinities), and the oxygen isotopic curve (on *Globigerinoides ruber*) obtained for Cores KS 09 and Alb 189 respectively (after Vergnaud-Grazzini & *alii*, 1977, using data from Emiliani, 1955; Parker, 1958; Ryan, 1972 and Cita & *alii*, 1977). Letters A-E indicate the peaks of abundance of benthic foraminifers discussed above. Symbols indicate the occurrence of characteristic faunal groups in abundance (tables 2 and 3).

The similarity of the two curves is striking: indeed the same major changes in faunal composition occur at exactly the same levels.

COMPARISON WITH THE DISTRIBUTION OF BENTHIC FORAMINIFERS IN OTHER EASTERN MEDITERRANEAN DEEP-SEA CORES

VAN DER ZWAAN (1980) recorded significant changes in the benthic assemblages in a 580 cm long core from the southern Adriatic (water depth 1 207 m). An upward decrease of *Pyrgo elongata, P. depressa, Quinqueloculina seminulina* accompanied by an increase in *Gyroidina* is compared to a similar trend observed in present day benthic faunas from the western to the eastern Mediterranean (CITA & ZOCCHI, 1978). Since the latter is poorer in oxygen and in nutrients than the former, this change is suggestive of unfavourable ecologic conditions at the bottom. VAN DER ZWAAN records an acme of *Globobulimina affinis* at the base of an organic-rich layer (at 105-188 cm from core top) which presumably corresponds to our sapropel S-1. If that is the case, the base of the core investigated should not exceed 40 000 y BP, which is close to the age of the top of KS 09.

For the same reason a close comparison cannot be established with Core RC9-180 investigated by CITA & PODENZANI (1980) with reference to changes in benthic foraminifers recorded across sapropel S-1. These authors noticed a distinct upward increase in abundance of *Bolivina* spp. approaching the base of the sapropel, whereas *Globobulimina* in inconspicuous.

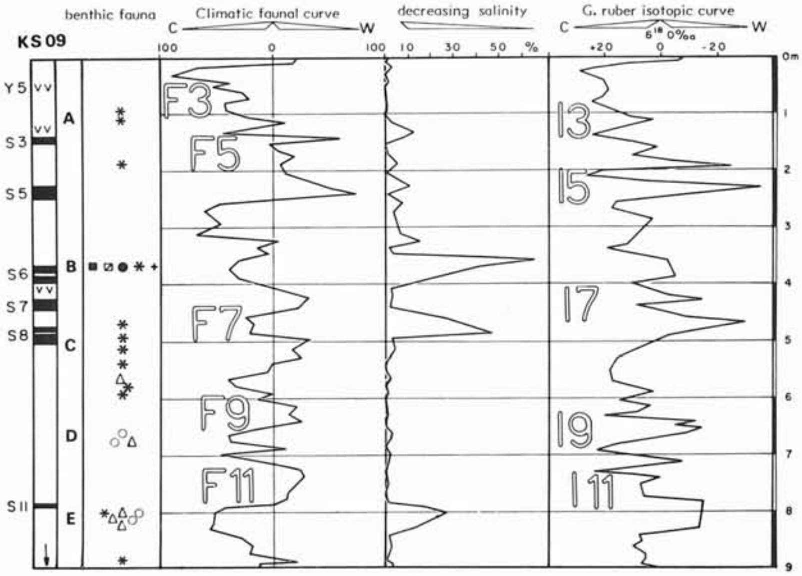

FIG. 7 - Columnar log, climatic faunal curve, salinity faunal index and isotopic curve (on *Globigerinoides ruber*) for Core KS 09 (after VERGNAUD-GRAZZINI & *alii*, 1977, mod.) and indication of: *a*) the major peaks of abundance of benthic foraminifers; *b*) occurrence of characteristic faunal groups. Legend as in fig. 8.

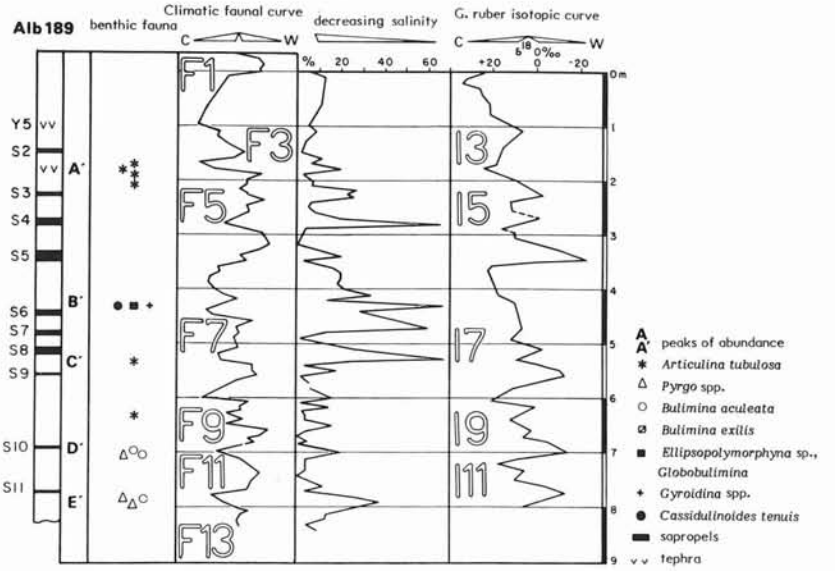

FIG. 8 - Columnar log, climatic faunal curve, salinity faunal index and isotopic curve (on *Globigerinoides ruber*) for Core Alb 189 (after VERGNAUD-GRAZZINI & *alii*, 1977 mod.) and indication of: *a*) the major peaks of abundance of benthic foraminifers; *b*) occurrence of characteristic faunal groups, as recorded by PARKER (1958).

The faunal assemblages recorded in an interval predating sapropel S-5 in another Ionian Sea Core (RC9-185) is rich in Miliolids and *Pyrgo*; these assemblages are comparable in composition as well as in diversity to the faunas from the same stratigraphic interval (later part of zone W, just prior to Termination II) of Core KS 09.

A 370 cm long core from the Levantine Sea (CHAIN 119-18) has been investigated in great detail by MULLINEAUX & LOHMANN, 1981). This sediment core contains three discrete sapropels, which have been carefully sampled (sampling distance approximately 2 cm). If these sapropels correspond to S-1, S-2 and S-3, the age of 80 000 y attributed to the base of the core by MULLINEAUX & LOHMANN is correct. However, we are not sure about the Stratigraphy of this core, since there is no agreement in the data concerning the distribution of benthic foraminifers during the last 80 000 y (i.e. from the present to the top of climatic zone X, or of isotopic stage 5, or to sapropel S-3) in cores CHAIN 119-18 and Alb 189, both from the Levantine Basin (see location in fig. 1).

It is pointed out that peak abundances of benthic foraminifers are recorded in two istances above individual sapropels (re-colonizing events), but not in the last (more recent) one, where the re-colonizing population is numerically poor. The *Globobulimina* assemblage, which presently lives in a relatively deep basin near the outlet of the Black Sea, is recorded above the second and third sapropel, and beneath the topmost one.

SUMMARY AND CONCLUSIONS

Benthic foraminiferal faunas underwent drastic changes in the last 400 000 years, as revealed by our quantitative studies on Core KS 09 from the crestal area of the Mediterranean Ridge in the Ionian Basin, and from data published by PARKER (1958) on Core Alb 189 from the Levantine Basin. Both cores are well known in their Stratigraphy and climatic history on the basis of previous studies.

Changes are recorded: *a*), in the faunal diversity, as expressed by the number of foraminiferal species; *b*), in the faunal density, as expressed by the number of specimens recorded in each sample treated and especially; *c*), in the composition of the faunal assemblages.

a) The most obvious factor affecting the diversity is availability of oxygen at the bottom. Sapropel layers are either entirely barren, or contain a limited number of specimens belonging to a few taxa (5 is the maximum number of species recorded, in sapropel S-8). There is some indication that diversity was slinghtly greater during cold periods (mean 6.1 in zone Y; 7.77 in zone W) than during warm periods (mean 2.28 in zone X), which agrees well with the scheme of increased bottom circulation during low sea-level stands (CITA & RYAN, 1978).

There is strong evidence that diversity was greater prior to the frequently repeated stagnations of substage V″, which were induced by strong dilution of sea water resulting from the deglaciation of the northeuropean and nortwest Asian ice sheets at approximately 200 000 y BP (VERGNAUD-GRAZZINI & *alii*, 1977; CITA, BROGLIA & *alii*, 1981). The trend towards lower diversification is clearly expressed by the decreasing mean values: 14.5 in the later part of zone U; 6.92 in subzone V′; 4.66 in subzone V″.

There is evidence that during the later part of stage U and the lower part of substage V′ ecologic conditions were more uniform than in younger times, as revealed by the more uniform diversification. Part of this diversification, however, is due to the presence of scattered displaced forms (*Discorbis* sp.) which in turn suggests the presence of thermo-haline circulation at the bottom more active than in later times.

b) The most obvious factor affecting faunal density is related to availability of oxygen and nutrients, whereas temperature plays a minor role. The four richests samples from our set of 69 contain 1946 individuals out of a grand total of 4 494. The mean value of benthic foraminifers/sample strongly decreases if we exclude from the countings these four extremely rich samples (46.12 instead of 72.3 including the barren samples; 56.56 instead of 87.6 excluding the barren samples). The four samples are from immediately above sapropel S-6 and from beneath sapropels S-8, S-9 equivalent and S-11.

Increases in faunal density in layers immediately predating the onset of stagnant conditions are unknown from the literature. Our pilot-study on faunal extinctions and repopulation rates (CITA & PODENZANI, 1980) did not show a similar trend in the younger part of the stratigraphic column, encompassing zones X and Z, nor did the recent study of MULLINEAUX & LOHMAN (1981). Frequency of sampling across the sapropels in these two studies was such that we can firmly state that no peaks of abundance of bottom-living forms exist beneath the sapropels in the last 125 000 y.

The case is different for the older part of the column, where faunal density is greater, and peak abundances are commonly recorded beneath sapropels. Our observations indicate that the strong, frequently repeated stagnations which were brought about by density stratification induced by excess meltwater from the North-European and Siberian grounded ice-sheets (cycles of approximately 20 000 y in subzone V″) drastically reduced the population levels of the deep Mediterranean floor.

Why most of the older sapropels are preceeded by blooms of benthic foraminifers remains basically unexplained. Indeed, if it is reasonable that some species which can tolerate low oxygen levels increase in number versus those species which do not tolerate such changes, and substitute them in their ecologic niches, it is totally unexpected that the total number of benthic forms actually increases, as it does. One possible explanation could be that, in agreement with BRADSHW's (1957) experiments on *Ammonia beccarii*, a change in salinity results in an increase of individual life, until the environmental conditions become prohibitive, and there is no more reproduction. Peak abundances could be the expression of main extinctions. Another explanation could be that incipient euxinification was accompanied by an increase of nutrients at the sediment/water interface, resulting in blooms of benthic foraminifers, whereas total anoxia soon followed, with annihilation of the bottom-living fauna.

Further studies are required to solve this puzzling problem, with a sampling interval much closer than that available for Core KS 09, to fully understand the process. Some deep-sea cores recently raised from tre Mediterranean Ridge in the Ionian Basin by the R/V BANNOCK (Cruise 14, 1981) seem suitable for this purpose.

c) The composition of the fossil assemblages records drastic changes. The best represented species is *Articulina tubulosa*, which is persistently distributed both in the lower part of the column, and in the upper one: the frequent stagnations of subzone V″ did not affect this highly stable species. Other stable species are poorly represented, and do not play any major role in the abundance peaks, which result from the extremely uneven distribution of species as *Bulimina aculeata*, *B. exilis*, *Cassidulinoides tenuis*, *Fursenkoina complanata* and a few others. Large *Pyrgo* (*P. murrhyna*, *P. serrata*, *P. lucernula*, *P. depressa*) increase in abundance along with *B. aculeata*, thus suggesting tolerance to low oxygen levels. All these species disappear after (above) subzone V″, which suggests:

1) that the low-salinity indicated by high percentages of *Globigerina eggeri* (see figs. 6 and 7) is not limited to the surficial water layers, but extends to the bottom layers;

2) that these species could not survive the decrease in salinity, and disappeared.

The drastic downcore fluctuations in faunal density and the unexpected changes recorded in the composition of the fossil assemblages are supported by similar findings documented in Core Alb 189 (Parker, 1958) from the Levantine Basin, some 1 000 km to the East of Core KS 09.

Spacial homogeneity versus temporal instability suggests large oceanographic changes, of more than local significance.

ACKNOWLEDGMENTS

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The identification of benthic foraminifers has been done by Elisabetta Parisi with reference to the collection of Mediterranean foraminifers of the Institute of Paleontology, University of Naples, created by prof. Maria Moncharmont Zei.

The picking was initiated several years ago by Mirna Zocchi, who generously allowed us to use her data.

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