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Paleoceanographic events associated with termination II in the Eastern Mediterranean

Foraminifera
Diatoms
Sapropel
Termination II
Stable isotopes

Foraminifères
Diatomées
Sapropêle
Terminaison II
Isotopes stables

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ABSTRACT

Pelagic sedimentary sequences accumulating in the Mediterranean Sea provide a record of regional or localized paleoclimatic changes superimposed on broadscale global events. A sequence of paleoceanographic changes associated with the glacial/interglacial transition at 127,000 years before present has been identified in the eastern Mediterranean Sea based on detailed microfossil and stable isotope studies. Specifically, these changes include a rapid increase in surface water temperature, the development of anoxic bottom conditions and a localized increase in productivity in the region around Crete. These events appear to be a response to the interplay of both a global warming at this time as well as changes in drainage patterns in the circum-Mediterranean.

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RÉSUMÉ

Événements paléocéanographiques associés à la Terminaison II en Méditerranée orientale

Les couches sédimentaires pélagiques accumulées dans la mer Méditerranée témoignent de changements paléoclimatiques régionaux ou localisés, superposés à des événements à l'échelle mondiale. L'étude détaillée des faunes de microfossiles et de leur composition isotopique permet de mettre en évidence en Méditerranée orientale une suite de changements paléocéanographiques associés à la transition glaciaire/interglaciaire datant de 127 000 ans. Ces changements comprennent, en particulier, une augmentation rapide de la température de l'eau de surface, le développement de conditions anoxiques en profondeur et une augmentation de productivité localisée autour de la Crète. Ces manifestations semblent résulter de l'interaction d'un réchauffement global avec des changements dans le drainage des eaux douces sur le pourtour de la Méditerranée.

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INTRODUCTION

Termination II at 127,000 years before present (yrs BP) marks a period of rapid change in global climatic conditions from a glacial maximum at approximately 132,000 yrs BP to a peak interglacial at 125,000 yrs BP (Broecker, van Donk, 1970; Shackleton, Opdyke, 1973; Ruddiman *et al.,* 1980). Termination II is also equivalent to the isotope stage 6/5e boundary (Emiliani, 1955 *a*). In terms of continental climatic changes, this event has been correlated with the Warthian/Eemian boundary in western Europe on the basis of pollen stratigraphy (Kukla, 1977). The warm conditions associated with interglacial substage 5e represent the only time during the last 700,000 years that the earth's climate has been as warm as or warmer than the present interglacial (Emiliani, 1966; Shackleton, 1969). It also represents a time at which sea level was slightly higher than its present stand (Mesolella *et al.,* 1969; Bloom *et al.,* 1974; Shackleton, Matthews, 1977).

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Within the eastern Mediterranean, a 3°C surface temperature increase has been estimated for this glacial/interglacial transition (Williams, Thunell, 1979), much lower than the 10°C increase estimated for parts of the North Atlantic (Sancetta *et al.*, 1973; Ruddiman *et al.*, 1977). Conversely, isotopic changes associated with the stage 6/5e boundary in the Mediterranean are significantly larger than those found in the open ocean. Oxygen isotopic changes of up to 5.0 ‰ have been observed in planktonic foraminifera by several workers in the Mediterranean (Vergnaud-Grazzini, 1975; Emiliani, 1955; Cita *et al.*, 1977), in comparison to average glacial/interglacial isotopic changes in planktonic foraminifera of approximately 1.9 ‰ for the Atlantic and approximately 1.1‰ for the Pacific (Erez, 1979). Such a substantial difference demonstrates that Mediterranean oxygen isotopic records reflect much more than Northern Hemisphere ice volume fluctuations, although the mechanism for such large isotopic fluctuations remains unresolved.

In the present study, we have attempted to document the sequence of paleoceanographic events associated with the transition from glacial stage 6 to interglacial stage 5 in the eastern Mediterranean.

MATERIALS, METHODS AND STRATIGRAPHY

Detailed microfossil and stable isotopic analyses were carried out on a 100 cm section (470-370 cm) of core TR172-22 located east of Crete (35°19'N; 29°01'E). Samples were generally taken at 2 cm intervals with an average time resolution of approximately 300 years (Thunell *et al.*, 1979). In order to aid disaggregation, the sediment samples were soaked in a hot Calgon solution and then wet sieved through a 63-μm screen. Dry residues were sieved through a 150-μm screen and the greater than 150-μm fraction was then split into an aliquot of approximately 300 planktonic foraminifera. Quantitative estimates were made of planktonic foraminiferal species abundances, with the presence or absence of siliceous microfossils (diatoms and radiolarians) also being noted.

Oxygen and carbon isotopic analyses of *Globigerina bulloides* were performed on the same set of samples following the methods of Williams *et al.* (1977). All samples were roasted for one hour at 400°C *in vacuo* to remove any extraneous organic matter and then reacted with 100% phosphoric acid at 50°C *in vacuo*. The isotopic difference between the sample CO_2 and the PDB standard was determined with an on-line VG micromass 602 mass spectrometer. All values are reported in conventional δ notation relative to the PDB-1 standard (Epstein *et al.*, 1953).

Thunell *et al.* (1979) have previously demonstrated that sedimentation rates in core TR172-22 are nearly uniform thoughout its length, averaging about 3.5 cm/1 000 years. This was based on recognition of events in the oxygen isotopic record of this core which have also been identified and dated in other deep-sea cores (Shackleton, Opdyke, 1973) and land-based marine records (Shackleton, Matthews, 1977). Using this average sedimentation rate and placing isotope stage 5e (125,000 yrs BP) at approximately 437 cm allows us to estimate tentative ages for all samples between 370-470 cm. Our calculations indicate that this interval of the core represents the period from approximately 135,000 to 120,000 BP. This chronologic interpretation is supported by the Io/Th work of Dominik and Mangini (1978). This then provides the basis for interpreting the sequence of paleoceanographic events within a relatively firm time-stratigraphic framework.

RESULTS AND DISCUSSION

From our faunal and isotopic data, the following sequence of climatic and oceanographic events is inferred for this region between 135,000 and 120,000 yrs BP: 1) a rapid increase in surface-water temperatures at Termination II; 2) the deposition of an organic-rich mud layer (sapropel D) characteristic of anoxic environments beginning at approximately 125,000 yrs BP; 3) a localized increase in surface-water productivity also beginning at 125,000 yrs BP; 4) the total disappearance of planktonic foraminifera approximately half-way through the period of sapropel formation; and 5) the return to normal marine conditions by around 120,000 yrs BP. In addition, a previously undescribed ash layer was found at 408 cm depth in this core. Unfortunately, this 2 cm thick ash layer is completely altered (Federman, pers. comm.) preventing geochemical identification of its source.

Changing surface water conditions at the rapid deglaciation 127,000 yrs BP are clearly reflected in the planktonic foraminiferal succession observed at this location (Fig. 1). Within an interval of less than 10 cm, a fully glacial fauna at 445 cm is completely replaced by an interglacial fauna at 435 cm in response to increasing surface water temperatures. Using a sedimentation rate of 3.5 cm/1 000 years for the non-sapropel interval of core (Thunell *et al.*, 1979), it is estimated that most of the surface water warming through this glacial/interglacial transition occurred within a period of approximately 2,500 to 3,000 years. The estimated duration of this change is consistent with the results of Ruddiman *et al.* (1977) for the North Atlantic in which they found that 75% of the warming at the stage 6/5e deglaciation occurred in less than 2,000 years.

The glacial fauna is characterized by high abundances (maximum of 45%) of *Neogloboquadrina pachyderma*. The dominance of this polar-subpolar species ends abruptly at approximately 130,000 yrs BP and is replaced by *Globorotalia inflata* at approximately 128,000 yrs BP (Fig. 1). *Globoratalia inflata*, which is characteristic of surface water temperatures transitional between subpolar and subtropical water masses in both the Atlantic (Be, Tolderlund, 1971) and the Mediterranean (Thunell, 1978), is abundant for approximately 1,000 years before it is replaced by *Globigerinoides sacculifer* and finally by the tropical species *Globigerinoides ruber* at approximately 125,000 yrs BP.

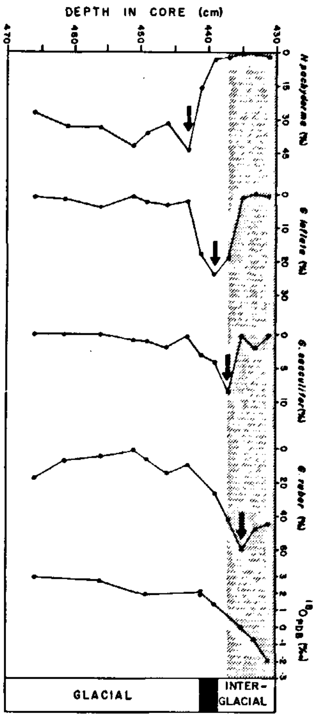

Figure 1

Variation in the percent abundance of four temperature diagnostic planktonic foraminiferal species, as well as change in the oxygen isotopic composition of Globigerina bulloides *across the glacial/interglacial transition at 127,000 yrs BP in core TR172-22. Each arrow indicates the level of maximum abundance for a particular species within this section of the core. Depth in core is indicated on the left. Sapropel D is represented by the stipled zone.*

The establishment of interglacial conditions marks the point at which sapropel deposition commences within this interval. The sapropel is approximately 47 cm thick and is equivalent to « sapropel D » (Thunell *et al.*, 1977) or "S5" (Cita *et al.*, 1977). Sapropels are black, organic-rich muds (Kullenberg, 1952; Olausson, 1961) that have been deposited periodically in the eastern Mediterranean during the late Quaternary. Of the mechanisms invoked to explain these anoxic conditions, a number of studies have advocated a density stratification produced by a low-salinity surface layer from glacial meltwater run-off (Ryan, 1972; Cita *et al*, 1977; Thunell *et al.*, 1977; Vergnaud-Grazzini *et al.*, 1977; Thunell, Lohmann, 1979; Stanley, Blanpied, 1980). In addition, there is substantial support for an association between increased discharge from the Nile region and sapropels deposited during the transition from glacials to interglacials (Rognon, Williams, 1977; Street, Grove, 1979; Adamson *et al.*, 1980).

The transitional or gradational changes in the planktonic foraminiferal assemblage within the sapropel (437-408 cm) suggest that surface water conditions were rapidly changing during its deposition (Fig. 2). *Neogloboquadrina dutertrei*, a salinity-sensitive species that usually occurs in abnormally high abundance within sapropel layers (Kullenberg, 1952; Cita *et al.*, 1977; Thunell *et al.*, 1977; Vergnaud-Grazzini *et al.*, 1977), is not consistently abundant in sapropel D but rather occurs as distinct peaks. Other planktonic foraminiferal species also show large oscillations in abundance within the anoxic layer suggestive of a faunal succession. For example, the peak abundances of *G. ruber, N. dutertrei, G. bulloides, G. glutinata* and *G. sacculifer* form a definite time-transgressive sequence (Fig. 2). These faunal changes are most likely a reflection of changes in both the salinity and temperature characteristics of the prevailing surface water masses. *Neogloboquadrina pachyderma,* which was very abundant during the preceding glacial interval, is virtually absent within the sapropel (Fig. 2).

A comparison of the faunal and isotopic trends within the sapropel reveals a close relationship between fluctuations in the salinity-sensitive *N. dutertrei* and large depletions in both $\delta^{18}O$ and $\delta^{13}C$ (Fig. 2). Maximum isotopic anomalies of greater than 4‰ are recorded at 430 cm for both oxygen and carbon. The magnitude of these changes is similar to those previously reported for this particular sapropel layer (Vergnaud-Grazzini *et al.*, 1977; Williams, Thunell, 1980). A −2‰ change in $\delta^{18}O$ occurs from below the sapropel within glacial stage 6 to the base of the sapropel. This depletion is roughly equivalent in timing and magnitude to the glacial stage 6/interglacial stage 5e transition in the Atlantic and Caribbean (Emiliani, 1955 and 1966; Erez, 1979). The $\delta^{13}C$ of *G. bulloides* remains constant through the stage 6/5e transition. Within the first 7 cm of the sapropel, $\delta^{18}O$ becomes negative by an additional −3‰, and $\delta^{13}C$ concurrently became depleted by greater than −4‰. These $\delta^{18}O$ and $\delta^{13}C$ changes slightly lead the increase in *N. dutertrei,* which peaks approximately 2 cm after the maximum isotopic anomalies. $\delta^{18}O$ and $\delta^{13}C$ continue to covary throughout the sapropel, dropping rapidly from their respective peak depletions at 430 cm but remaining

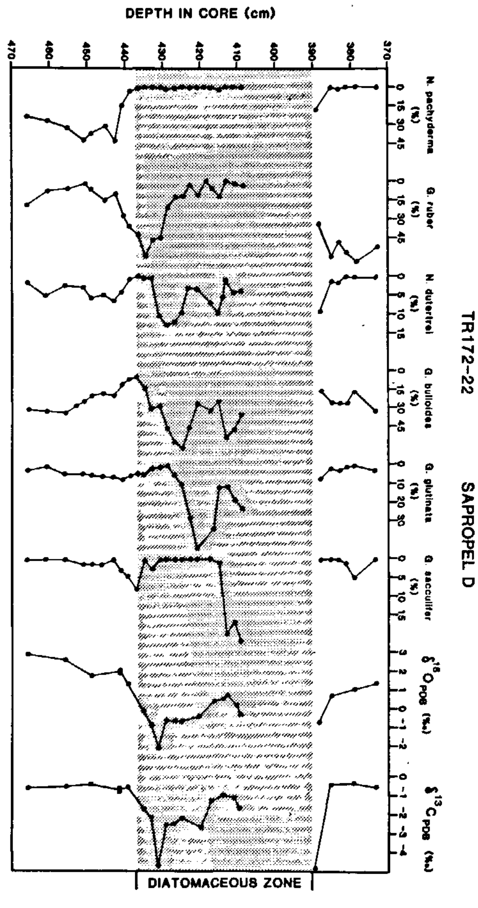

Figure 2

Variation in the percent abundance of six planktonic foraminiferal species across Sapropel D in core TR172-22, as well as change in both the oxygen and carbon isotopic composition of Globigerina bulloides. *Sapropel D is represented by the stipled zone. Depth in core is indicated on the left.*

depleted relative to both normal stage 5 and stage 6 isotopic values. A 2 cm lag is again found between the rapid $\delta^{18}O$ and $\delta^{13}C$ enrichment and the sharp decrease in *N. dutertrei* abundance. The total absence of planktonic foraminifera between 408 and 390 cm prevents further isotopic analyses within this sapropel. Within 5 cm above the sapropel, *N. dutertrei*, $\delta^{18}O$ and $\delta^{13}C$ return to normal stage 5 values (Thunell *et al.*, 1977).

Just above the base of the sapropel, a noticeable increase occurs in the abundance of siliceous microfossils (Fig. 2). In particular, diatoms are virtually absent below the sapropel and increase rapidly from 0 diatoms/g dry sediment to approximately 10^8 diatoms/g dry sediment within the first five centimeters of this sapropel (Schrader, Matherne, 1981). Diatoms, as well as radiolarians, remain abundant throughout the entire sapropel, whereas the abundance of planktonic foraminifera decreases gradually until they disappear altogether at 408 cm. This loss of foraminifera is not considered to be due to post-depositional dissolution because calcite should be readily preserved within anoxic porewaters (Berger, Soutar, 1970) and the foraminifera do not exhibit the breakage and loss of spines characteristic of dissolution. As a result, this disappearance is considered to be an ecologic response to the establishment of surface-water conditions in which planktonic foraminifera could not survive.

The sudden appearance of diatoms in high abundance at the base of the sapropel correlates well with the increase in *N. dutertrei* and the $\delta^{18}O$ and $\delta^{13}C$ depletions, and is most likely due to an increase in surface productivity. This increase in productivity is most likely related to either upwelling on enhanced continental run-off rich in nutrients. If sapropel deposition is induced by a density stratification of the water column, it would be oceanographically impossible to have upwelling at the same time. The second alternative of having nutrients beign carried in with continental run-off, not only can account for the increased productivity but would also produce the low-density surface layer needed to establish density stratification. The large depletions in $\delta^{13}C$ at the base of the sapropel are also indicative of the input of isotopically light terrestrial organic matter. A similar situation has been documented in the Gulf of Mexico (Leventer *et al.*, 1981) where the input of nutrient-rich glacial melt-water resulted in increased siliceous productivity and large depletions in $\delta^{13}C$.

Sapropel D is geographically widespread, covering most of the eastern Mediterranean (Cita *et al.*, 1977; Thunell *et al.*, 1977; Vergnaud-Grazzini *et al.*, 1977). However, our data as well as that of Cita (pers. comm.) and Schrader and Matherne (1981) suggest that the association of diatoms with this layer is restricted to a small region immediately south and east of Crete (Fig. 3). The lack of an association between high abundances of diatoms and sapropel D over most of the eastern basin precludes an interpretation that the origin of sapropel D is directly related to increased surface productivity. The previously proposed idea of density stratification brought on by a low-salinity surface layer from continental run-off (Cita *et al.*, 1977; Thunell *et al.*, 1977; Kullenberg, 1952; Vergnaud-Grazzini *et al.*, 1977; Thunell, Lohmann, 1979) still appears to be the most plausible mechanism for the formation of this sapropel. The large oxygen isotopic anomalies associated with this sapropel strongly suggest that a low salinity surface layer existed at the same time deposition of sapropel D was initiated.

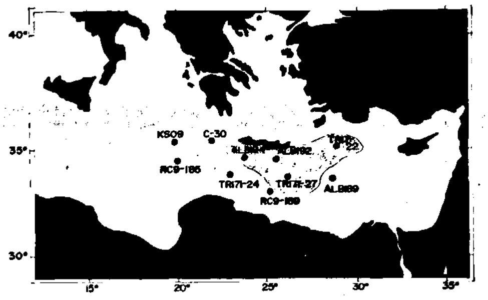

Figure 3

The areal distribution of piston cores containing a diatomaceous Sapropel D (stipled area). This is based on data from Cita et al. (1977), *Cita (pers. comm.), Thunell* et al. (1977) *and Schrader and Matherne* (1981).

As previously stated there appear to be two major sources of fresh water. Both glacial melt-water (Cita *et al.*, 1977; Thunell *et al.*, 1977; Lohmann, 1979; Stanley, Blanpied, 1980) and Nile discharge (Rognon, Williams, 1977; Street, Grove, 1979; Adamson *et al.*, 1980) could produce sapropel forming conditions during glacial/interglacial transitions. An examination of the areal distribution of the diatomaceous sapropel D indicates that there is very good control on determining the southern extent of this zone (Fig. 3).The lack of Aegean Sea cores containing sapropel D prevents us from determining the northern limit of this diatomaceous zone. If the Nile region was the primary source for the input of nutrient-rich run-off, we would expect to find a diatomaceous sapropel D in cores closest to the Nile Core. Figure 3 shows that this is clearly not the case. However, the observed distribution pattern of diatoms in sapropel D is still compatible with the previously proposed idea that the major source of fresh water is the Black Sea (Thunell *et al.*, 1977; Vergnaud-Grazzini *et al.*, 1977; Thunell, Lohmann, 1979; Stanley, Blanpied, 1980; among others).

CONCLUSIONS

Detailed faunal and stable isotope studies across Termination II in an eastern Mediterranean piston core reveal a distinct sequence of paleoceanographic events associated with this glacial/interglacial transition. These include :

1) a rapid increase in surface water temperatures at approximately 127,000 yrs BP with a fully glacial fauna being replaced by an interglacial fauna in less than 3,000 years;

2) the onset of sapropel deposition at 125,000 yrs BP, most likely induced by a density stratification of the water column;

3) a localized increase in surface productivity at 125,000 yrs BP as evidenced by the high abundance of diatoms;
4) the disappearance of planktonic foraminifera approximately half-way through the period of sapropel formation; and
5) the return to normal marine conditions by 120,000 yrs BP.

The carbon isotopic results indicate that the increase in surface productivity at 125,000 yrs BP may have been related to increased continental run-off containing a high level of nutrients. The restricted areal relationship between sapropel D and the presence of diatoms suggests that the development of anoxic conditions can not be related simply to increased surface productivity and subsequent depletion of oxygen in bottom waters by the oxidation of organic matter.

Acknowledgements

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Congrès-Assemblée Plénière de la Commission Internationale pour l'Exploration Scientifique de la Méditerranée

Cannes, 2-11 décembre 1982

A l'aimable invitation du gouvernement français, le 28^e Congrès-Assemblée Plénière de la Commission Internationale pour l'Exploration Scientifique de la Mer Méditerranée (C.I.E.S.M.) aura lieu, à Cannes, du 2 au 11 décembre 1982.

Au cours de ce congrès se tiendront notamment :

— les sixièmes journées d'études sur les pollutions marines en Méditerranée, en collaboration avec le Programme des Nations Unies pour l'Environnement;

— une réunion interdisciplinaire « aspects scientifiques concernant les récifs artificiels et la mariculture suspendue »;

— des tables rondes et les réunions ordinaires des 12 comités scientifiques.

Pour tous renseignements, s'adresser au secrétariat de la C.I.E.S.M. (16, Bd de Suisse, MC 98000, Monaco).

Congress and Plenary Assembly of the International Commission for the Scientific Exploration of the Mediterranean

Cannes, 2-11th December 1982

On the kind invitation of the French government, the 28th Congress and Plenary Assembly of the International Commission for the Scientific Exploration of the Mediterranean will take place, at Cannes, from December 2 to 11, 1982.

Several meetings will be held during this congress :

— sixth workshops on marine pollution in the Mediterranean, co-sponsored with the United Nations Environment Program;

— an interdisciplinary meeting on « scientific aspects concerning the artificial reefs and suspended mariculture »;

— round table discussions and regular sessions of the 12 scientific committees.

Information can be obtained from ICSEM secretariat (16, bd de Suisse, MC 98000, Monaco).