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The Younger Dryas–Sapropel S1 connection in the Mediterranean Sea (extended abstract)

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Introduction

In recent years the Younger Dryas, a short cold pulse interrupting the last deglaciation, has repeatedly been recognized in deep-sea cores from all major ocean basins (Ganssen, this issue). This finding allowed correlation of the event to the terrestrial record and confirmed its global character.

The oxygen-isotopic signature of the Younger Dryas is clearly reflected in Mediterranean deep-sea cores, where it occurs just below sapropel S1. Sapropels are dark-colored organic-rich (>2% organic carbon) intervals. They constitute characteristic levels in late Quaternary sediments of the Eastern Mediterranean. During the last 400ka twelve such intervals have been recognised, numbered in stratigraphical order S12–S1 (Cita et al. 1977). The youngest sapropel S1 was deposited between 9 and 7ka BP in the early Holocene.

It is generally accepted that a prerequisite for marine sapropel formation is the presence of a low-salinity surface layer causing density stratification. The resulting lack of deep-sea ventilation leads to reduced oxygen levels and ultimately to complete anoxia at the seafloor. The latter is reflected in sapropelic sediments by their laminated nature, indicating the absence of benthic life.

A typical sapropel sequence consists of a grey proto-sapropel, indicating progressing oxygen-deficiency, a black sapropel proper and a brown-reddish oxidized toplayer, above which normal conditions were restored.

Debates on the origin of the low-salinity layer still continue. Various scenarios have been postulated such as overflow of the Black Sea associated with deglaciation (Thunell et al. 1977) or increased run-off by the Nile and Po rivers caused by increased monsoonal activity (Rossignol-Strick et al. 1982). Anyway, a drastic change in the Eastern Mediterranean evaporation/precipitation balance is needed to maintain a low-salinity layer over a considerable length of time, implying a reversal of the present-day Mediterranean anti-estuarine circulation. The anti-estuarine system involves inflowing North Atlantic water of normal salinity, which through high evaporation rates in the eastern basin, becomes dense and sinks to intermediate depths. It leaves the Mediterranean through the Strait of Gibraltar as Levantine Intermediate Water (LIW). A branch of this watermass bends to the north and can be traced far into the Atlantic.

In this paper cores from the Eastern Mediterranean, containing sapropel S1, are compared with core-data from the Alboran Sea, close to the Atlantic–Mediterranean connection. Core-locations, water-depths and recoveries are listed in Table 1.

Age constraint is based on oxygen isotope stratigraphy coupled with AMS ^{14}C datings on selected samples. The Late Quaternary history of both areas will be reviewed in four time-slices: 1) the Late Glacial and the first step of deglaciation (Termination 1A), 2) the Younger Dryas, 3) the second step of deglaciation (Termination 1B) and 4) the 'modern' situation.

Changes in planktonic foraminiferal assemblages through the cores are used to reconstruct conditions in the water-column, while fluctuations in the benthic foraminiferal record reflect changing bottom conditions. Special attention is paid to the reproductive behaviour of selected planktonic species. In the modern oceans *Globorotalia truncatulinoides* (d'Orbigny) and *G. inflata* (d'Orbigny) show the strongest seasonal reproduction signal, while *Globigerinoides ruber* (d'Orbigny) reproduces bi-weekly (Hemleben et al. 1989). *Globigerinoides trilobus* (Reuss) is especially sensitive for lowered salinities (Hemleben et al. 1989).

Table 1. Mediterranean deep-sea cores discussed in the text.

Station	Latitude	Longitude	Depth (m)	Recovery (cm)
Eastern Mediterranean				
T87–14B	38°34′N	19°54′E	1999	42
T87–26B	34°44′N	16°48′E	2415	48
T83–10B	33°25′N	26°26′E	2445	36
T83–48P	33°50′N	25°59′E	2724	186
Alboran Sea				
T83–29B	33°38′N	28°26′E	3295	35
T91–11P	36°20′N	02°34′W	1817	558
T91–12P	36°19′N	03°18′W	856	764

B = Box-core, P = Piston-core

Results

Late Glacial and the first step of deglaciation, Termination 1A (17–11 ka BP)

Melting of the ice caps on the Northern Hemisphere and the introduction of glacial meltwater in the Mediterranean started ca 16ka BP. The early part of this time interval comprises the most arid phase in African lakes (Street & Grove 1979).

Alboran Sea. In both piston-cores the shift in oxygen isotopes towards lighter values takes place between 15 and 14 ka BP, which is in general agreement with Vergnaud Grazzini et al. (1991). Maximum excursion in this interval is 2‰ (Figs 1, 2). The 'cold' water species *Neogloboquadrina pachyderma* (Ehrenberg) is still a major constituent of the planktonic foraminiferal assemblage; the temperate form *Globorotalia inflata* is rare to absent in this section (Figs 1, 2).

In core 12P the benthic species *Nonionella turgida* (Williamson) increases in abundance, while in the deeper-water core 11P, low-oxygen-tolerant genera such as *Globobulimina*, *Chilostomella* and bolivinids flourish (Fig. 1). The number of benthic specimens per gram dry sediment reaches maximum values during both deglaciation steps, associated with the highest organic carbon values in the cores.

Eastern Mediterranean. ^{14}C analyses at the base of the proto-sapropel of cores 10B, 26B and 48P show that adverse conditions started at ca 16ka BP in the central part of the basin and at ca 14ka BP in the southern part.

Detailed analysis on box-core T87-26, north of the Gulf of Sirte, shows the planktonic foraminiferal oxygen isotope profile to have an amplitude of 3‰ which we interpret to be caused mainly by salinity fluctuations (Fig. 3). The initiation of deglaciation is not recovered within this core; from its base at 13 800 BP a gradual shift to lower $\delta^{18}O$ values is observed, interrupted by the Younger Dryas cold pulse. The seasonally reproducing planktonic species *Globorotalia truncatulinoides* and *G. inflata* are present in minor quantities.

Younger Dryas (11–10ka BP)

This short cold pulse represents a return to glacial-style conditions. Northwest European terrestrial records indicate a two-fold subdivision of the event in a lower humid and an upper dry phase.

Alboran Sea. In core 11P, the deglaciation is characteristically interrupted by the Younger Dryas cold pulse (Fig. 1). In core 12P this event is less clear, because of the wider sampling interval; the isotope curve just shows a platform (Fig. 2). Benthic low-oxygen-tolerant foraminiferal species decrease in abundance. The number of benthic specimens per gram dry sediment in this interval is significantly lower than during Terminations 1A and B.

Eastern Mediterranean. In core 26B the Younger Dryas is clearly reflected between 10 700 and 10 500 BP (Fig. 3). From this level upcore the strongly seasonally reproducing species *Globorotalia inflata* and *G. truncatulinoides* decrease in abundance, while the bi-weekly reproducing *Globigerinoides ruber* shows increasing frequencies.

Termination 1B (10–7 ka BP)

This interval represents the second deglaciation step. In the Eastern Mediterranean, increased run-off from the Nile commenced at 9ka BP (Richie et al. 1985). During this time interval sapropel S1 (9–7ka BP) was formed.

Alboran Sea. Figure 2 shows a distinct relation between the second deglaciation step and the frequency increase of the benthic foraminifer *Gyroidina* sp. and agglutinants in core 12P. In the deeper core 11P, Termination 1B is clearly correlated with high frequencies of low-oxygen-tolerant forms such as *Globobulimina* sp., *Bolivina* spp and *Chilostomella* sp. (Fig. 1). The seasonally reproducing *Globorotalia inflata* is conspicuously absent from this interval.

Eastern Mediterranean. The base of sapropel S1 proper in the various cores is dated between 9 and 8ka

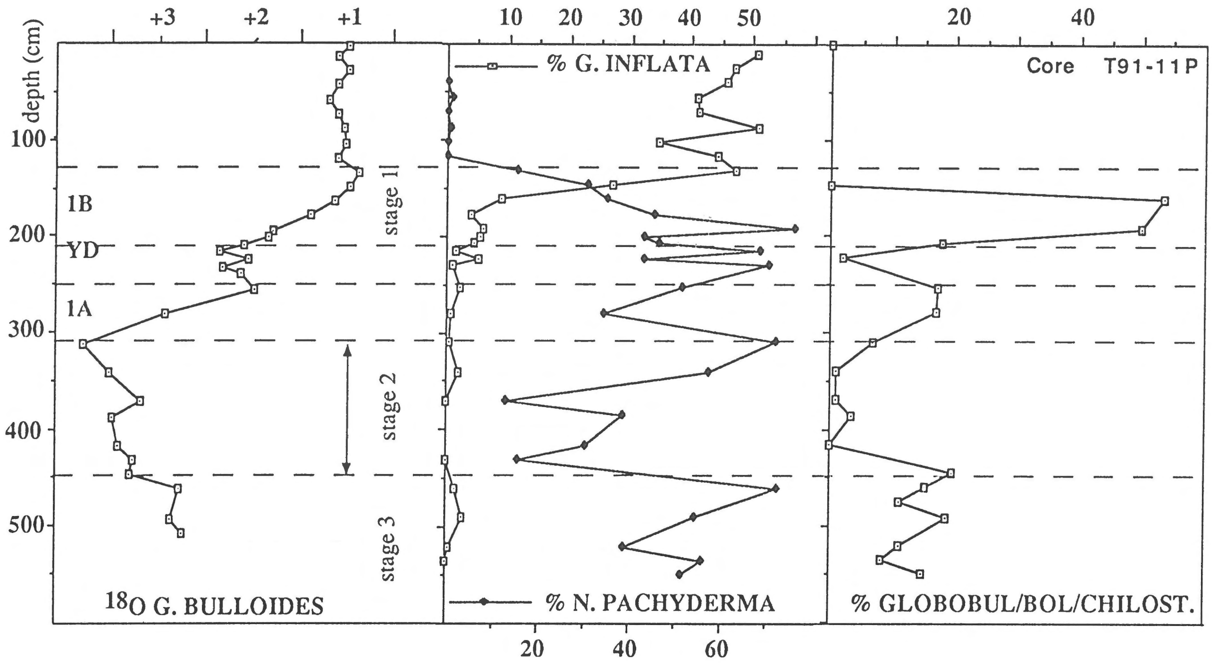

Fig. 1. Diagram of piston-core 11P from the Alboran Sea. Presented are the $\delta^{18}O$ curve of *Globigerina bulloides* (left), the frequency distributions of the planktonic foraminifera *Neogloboquadrina pachyderma* and *Globorotalia inflata* (center) and the frequency distribution of the low-oxygen-tolerant benthic foraminifera *Globobulimina* sp., bolivinids and *Chilostomella* sp. (right). Oxygen isotope stages, Terminations 1A and 1B and the Younger Dryas (YD) are indicated in the first column.

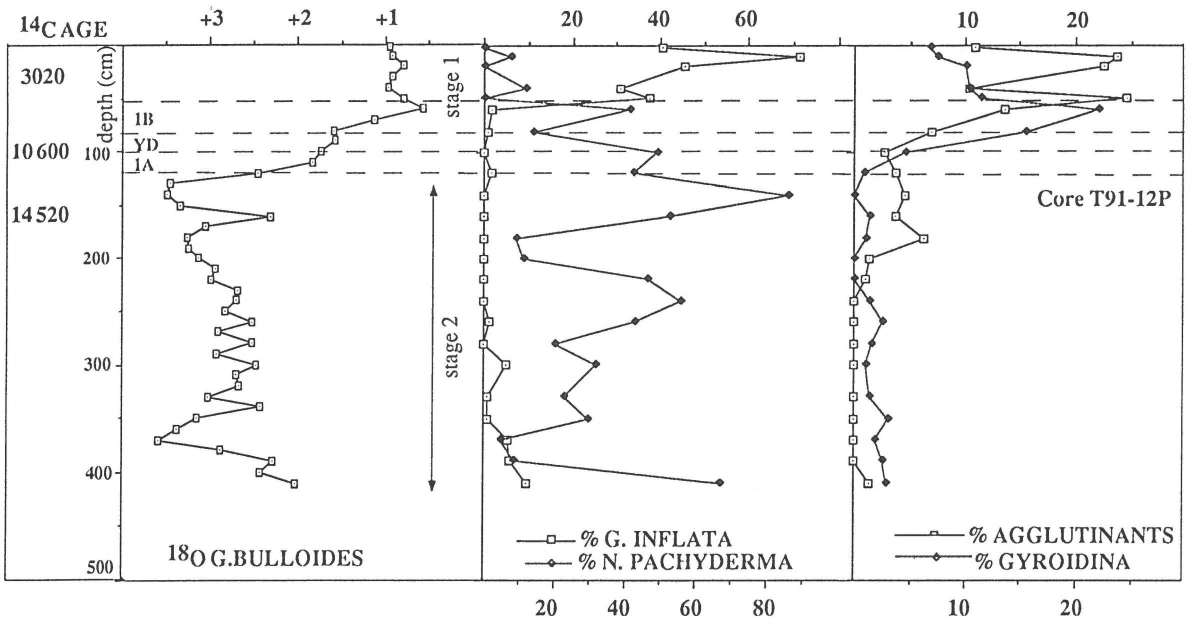

Fig. 2. Diagram of piston-core 12P from the Alboran Sea. Parameters presented are as in Fig. 1, with the exception of the third column, which gives the frequency distribution of benthic *Gyroidina* sp. and agglutinants. ^{14}C ages (in years BP) are shown on the left.

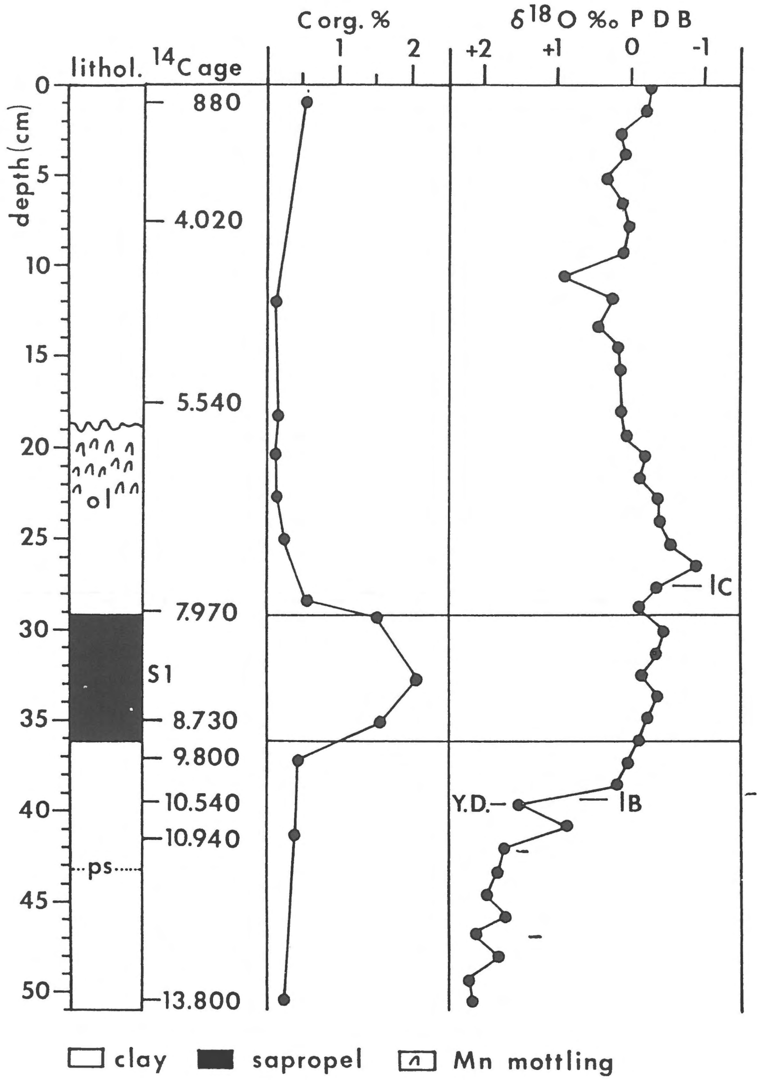

Fig. 3. Simplified lithology, ^{14}C age (in years BP), organic carbon content and oxygen isotope data on *Globigerinoides ruber* of Eastern Mediterranean box-core 26B. ps = protosapropel, S1 = sapropel S1, ol = oxidized layer. The tops of Terminations 1B and 1C are also indicated. YD = Younger Dryas

BP. Sediments are laminated and are devoid of benthic fauna, indicative of complete bottom anoxia The top of the sapropel proper is dated between 8.5 and 7.9ka for various box-cores respectively. Characteristically, the seasonally reproducing planktonic species *Globorotalia inflata* and *G. truncatulinoides* and the low-salinity-sensitive form *Globigerinoides trilobus* are absent from the sapropelic sediments.

Late Holocene (7 ka BP–Recent)

From 7ka BP onwards aridification of northeastern Africa started (Richie et al. 1985) and the present-day Nile-regime was established (Adamson et al. 1980). River input was low and precipitation belts moved away from the Mediterranean.

Alboran Sea. The oxygen isotope curves show the beginning of present-day Mediterranean conditions, dated between 7 and 8ka BP. Of interest is the sudden increase of *Globorotalia inflata* at the expense of *Neogloboquadrina pachyderma* from this level upcore (Figs. 1, 2). The same phenomenon was noted by Vergnaud-Grazzini & Pierre (1991) to occur between 9 and 7ka BP, indicating fluctuations in the depth of the deep chlorophyll layer.

Low-oxygen-tolerant foraminiferal species decrease strongly in abundance and likewise does the number of benthic foraminifera per gram dry sediment. In this section we observe the establishment of the modern Mediterranean microfauna.

Eastern Mediterranean. The initiation of present-day Mediterranean salinities took place between 7000 and 5800 BP. The microfaunal content (no benthics, absence of *Globorotalia truncatulinoides*) of the reddish-brown laminated oxidized layer indicates that this section still belongs to the sapropelic 'abnormal' conditions. The layer's color is due to the oxidation of iron and manganese (Troelstra et al. 1991). Sapropel deposition in core 26B thus lasted from 13.8 till 7–6ka BP, and even longer, beginning at 15.8ka BP in piston-core 48P.

Sediments above the oxidized layer yield benthic foraminifera and the planktonic *G. truncatulinoides*, indicative of a restored circulation.

Discussion and conclusions

The observed record can be understood by interpreting the changes in terms of changes in hydrographic regime. The following factors are of importance: 1) introduction of glacial meltwater from 16ka BP, 2) increased precipitation from 11–10ka BP, 3) increased run-off from the Nile river starting at 9ka BP, and 4) strongly reduced precipitation resulting in aridification and reduction of Nile influence from 6ka BP and in establishment of the present-day Mediterranean regime.

Introduction of glacial meltwater triggered the start of proto-sapropel deposition in the northern part of the eastern basin by the establishment of local low-salinity surface layers.

The effects of meltwater and of increased river run-off together cannot maintain a low-salinity surface for a considerable length of time. Instead a change in the evaporation/precipitation balance is needed. The southward migration of wet-climate belts during the second part of the Younger Dryas might have caused this change. A humid phase with little seasonality was the result, as evidenced by the absence of strongly seasonally reproducing planktonic species such as *Globorotalia truncatulinoides*. Rainfall increased the Nile River run-off from 9ka BP and established a permanent low-salinity surface (absence of *Globigerinoides trilobus*), resulting in the complete bottom anoxia of sapropel S1.

During this sequence of events, the circulation in the Mediterranean gradually changed from an anti-estuarine to estuarine mode or it even completely stagnated. This is especially obvious from the Alboran Sea cores, where increased numbers of (low-oxygen-tolerant) benthic foraminifera associated with highest values of organic carbon are found during this time interval.

Migration of the wet belts (7ka BP) and associated lowered run-off from rivers (6ka BP) caused the end of the low-salinity surface. Evaporation again exceeded precipitation and the modern anti-estuarine circulation and micro-faunas were established.

During the period 13–7ka BP the contribution of Levantine Intermediate Water to the Atlantic was weak or even absent. Already in an early phase this dense saline water did not reach the Norwegian Sea. A causal relationship between this changed circulation pattern and the return to glacial conditions (Younger Dryas) is worth investigating.

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