Climatic and oceanographic changes for the last 25 cal ky bp in the Alboran Sea. A diatom inference

Cambios climáticos y oceanográficos durante los últimos 25.000 años en el Mar de Alborán inferidos a partir de diatomeas

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ABSTRACT

The present work concerns the study of the Calypso piston core MD 95-2043 (36°09′N/2°37.269′W). In order to establish a stratigraphic time framework the age model is based on seventeen 14C-dates, AMS radiocarbon ages measured on monospecific foraminiferan samples (G. bulloides). 14C-dates were calibrated to calendar years in order to correct natural variations of 14C. The CALIB 4.1 program was used for the calibration of 14C-dates time record considered in this study that spans the last 26.5 cal ky BP. Average sedimentation rate for the time interval studied is 35.85 cm/ka. Based on the diatom record, paleoceanographic conditions favoured an increase in paleoproductivity during the Last Glacial Maximum (LGM) with a maxima occurred at ca. of Termination 1a (T1a), and during the Younger Dryas event (YD). During this period, meteorological conditions, with increased westernlies, would induce an intensified eastward flow which would displace the Western Anticyclonic Gyre (WAG) to the East. A possible displacement of the North Alboran upwelling system has also been considered. The major component of the diatom assemblage during the YD are the resting spores (RS) of Leptocylindrus danicus. The development of this species was probably favoured by the presence of the cooler and less saline Atlantic Surface Water (ASW) triggered by the diversions of meltwaters from the ice sheets surrounding the Atlantic.

The abundance of fresh-water diatoms was used as an aridity indicator, while opal ptyoliths were linked to relatively wet conditions on land. During marine isotopic stage 2 (MIS2) until 14 cal ky BP the region supported a gradual climatic deterioration with a belt-grass loosing. Wind intensification was also deduced. During the Bolling-Allerød (B-A) climatic conditions would be warmer and moister. This conditions prevails until ca. 8 cal ky BP. When the re-establishment of vegetation belts and replenish of lakes were deduced. Nevertheless, during the YD climatic conditions could be dryer and windy.

RESUMEN

El presente trabajo enfoca el estudio del testigo de pistón tipo Calypso MD 95-2043 (36°09′N/2°37.269′W). La estratigrafía del testigo está basada en 17 edades de radiocarbono medidas sobre el foraminífero planctónico G. bulloides mediante la técnica AMS. Las edades de 14C obtenidas fueron calibradas a edades de las correspondientes a los posibles variaciones naturales del 14C. Para la calibración se emplea el programa CALIB 4.1, el resultado fue un período que comprendía los últimos 26.5 ka de calendario. La tasa de sedimentación media se estimó en 35.85 cm/ka para este período de tiempo.

El registro de diatomeas parece indicar que las condiciones paleoceanográficas del Mar de Alborán favorecieron el incremento de la paleoproductividad superficial durante el Último Máximo Glacial (LGM), con máximos próximos a la Terminación 1a (T1a) y durante el Younger Dryas (YD). Durante el período comprendido en este estudio las condiciones meteorológicas, con vientos del Oeste más intensos, inducirían a una intensificación del flujo de entrada hacia el Este desplazando al Giro Anticiclónico Occidental (WAG). Se especula un posible desplazamiento del sistema de surgencia localizado al Norte del Mar de Alborán hacia posiciones más orientales. El componente principal de la asociación de diatomeas durante el YD son las esporas de Leptocylindrus danicus. El desarrollo de esta especie pudo ser favorecido por la presencia de un Agua Superficial Atlántica (ASW) más fría y menos salina, este agua de características especiales pudo tener su origen en la fusión de las plataformas heladas que rodeaban el Atlántico.

La abundancia de diatomeas de agua dulce ha sido empleada como Indicator de aridez, mientras que los fytolitos se han relacionado con condiciones húmedas en el continente. Durante el estadio isotópico 2 (MIS2) hasta 14 cal ka BP la región soportaba un deterioro climático gradual con pérdida del cinturón herbáceo. También se ha podido deducir una intensificación edáfica. Durante el periodo Bolling-Allerød (B-A) las condiciones climáticas pudieron ser templadas y suaves. Estas condiciones prevalecieron hasta cerca de los 8 ka de calendario, se ha deducido el restablecimiento de los cinturones de vegetación y el refanno de los lagos. No obstante durante el YD las condiciones climáticas pudieron ser más frías y ventosas.

Key words: diatoms, paleoproductivity, paleoclimatology, deglaciation, Late Pleistocene, Alboran Sea.

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Introduction

The Mediterranean behaves as a system of anticyclonic gyre circulation with surface water entering from the Atlantic and leaving the Mediterranean at depth (Bormans et al., 1986). The circulation of the Alboran Sea is energetic, and is subject to strong seasonal variations related to fluctuations in the intensity of water exchange through the Strait of Gibraltar (Pistolesi et al., 1985). The most striking oceanographic features in the Alboran Sea are the Western Anticyclonic Gyre (WAG) and the Almeria-Oran density front (Fig. 1). Their shape, position, and permanence depends on several factors such as thermohaline circulation, meteorological forcing, etc. (Parrilla and Kinder, 1987). Unlike most of the Mediterranean, the Alboran Sea has two systems of high biologic productivity which are associated with WAG and the Almeria-Oran density front. To the northern limb of the WAG, an upwelling of subsurface waters occurs, and thus a frontal system develops along the eastern gyre (Fig. 1). Moreover, the present-day climatic system over the Mediterranean Sea is characterised by the establishment of a very stable high-pressure system, related to the Intertropical Convergence Zone (ITCZ) (Cramp and O'Sullivan, 1999). Its position is critical in determining climatic and oceanographic patterns in the Alboran Sea (Parrilla and Kinder, 1987).

Variations in paleoproductivity related to variations in climatic and oceanographic conditions has been widely studied in the area (Abrantes et al., 1988; Carape, 1988; Weaver and Pujol, 1988; Turon and Londeix, 1988; Vergnaud-Grazzini and Pierre, 1991; Tar- garona et al., 1997; Sterro et al., 1998, Baezena and Abrantes (1998), Cacho et al., (in press), and Baezena et al. (submitted).

Recent SST studies on core MD95-2043 (Cacho et al., in press), Baezena et al. (submitted) show evidence of a clear connection between the Greenland 818O record in GISP2 and its Dansgaard Oeschger (D-O) events (Meesse et al., 1997) and Alboran SST, as well as a very good coherence among the temperature minima in both records. The influence of the Heinrich events in the Alboran Sea with important invasions of polar waters into the Alboran Sea have been documented by the presence of a peak in the foraminifer Neogloboquadrina pachyderma (s) sinistral (Cacho et al., in press; and Baezena et al., submitted).

Northern Hemisphere climate is clearly linked to that of high-latitude ice sheets, with glacial aridity and interglacial humidity (Sarnthein et al., 1982; Stabell, 1986). During glacials the ITCZ migrates to the south (Sarnthein et al., 1982) favouring the location of a low-pressure system over the Mediterranean and prevailing westerlies, and therefore favouring "red-rain" over the Mediterranean (Parrilla and Kinder, 1987). Previous studies by Baezena et al. (1997), Flores et al. (submitted), and Baezena et al. (submitted), have shown the different behaviours between two types of siliceous wind transported microfossils, freshwater diatoms and opal pycnothys.

The abundance of fresh-water diatoms was used as an aridity indicator, while opal pycnothys were linked to relatively wet conditions on land.

The present work is aimed at the understanding of the climatic and paleoceanographic changes during the last deglaciation, with previous observation from marine isotope stage 2 (MIS2) and the Last Glacial Maximum (LGM) to present day, in the Alboran Sea. Regional atmospheric patterns would induce paleoceanographic and paleoproduction changes displacing the Alboran's high fertility systems eastward. Besides, Northern Hemisphere climatic and oceanographic changes would also affect the Alboran Sea introducing fresh waters through the Strait of Gibraltar. Climatic changes in North Africa as well as wind regime have been also study base in continental microfossils.

Materials and methods

The present work concerns the study of a calypso piston core MD 95-2043 was taken during the 1995 IMAGES cruise at 36°09'N/27°37'W and 1841 m water depth.

Micropaleontological studies were carried out on samples spaced at 10 cm intervals in core MD 95-2043. Samples were prepared according to the method outlined in Baezena and Abrantes (1998). Magnification was x1000, and the recommendations of Schrader and Gersonde (1978) were used as a basis for diatom values counting. For evaluation of the state of preservation of diatom valves we followed the recommendations of Baezena and Flores (1991).

Results

In order to establish a stratigraphic framework, constant sedimentation rates were assumed between the age control points, and linear interpolation was used to obtain ages between the control points. The age model is based on seventeen 14C-dates, AMS radiocarbon ages measured on monospecific foraminiferal samples, it has been widely described in Cacho et al. (in press). To correct natural variations and improve time resolution 14C-dates were calibrated to calendar years using the CALIB 4.1 (Stuiver and Reimer, 1993). The approximate time recorded in the core is 26.5 cal ky. Resulting sedimentation rate have an average value of 35.85 cm/ky for the studied time interval.

The range of the variations in diatom number fluctuates from an absence of diatom valves to abundance of 3.9 x10^6 valves/g of dry sediment (Fig. 2). In the Alboran basin abundances are lower than normally observed in strong upwelling areas where the number of diatom valves in the sediments may reach millions. During marine isotope stage 2 (MIS2) diatoms are present, the occurrence of several peaks from MIS2/MIS3 boundary to Termination 1a (T1a) has been observed. During the deglaciation diatom abundance shows strong fluctuations. The Bolling-Allerod period (B-A), which spans about 2000 years, appears characterised by an important reduction in diatom numbers. Following the B-A related to the YD, diatoms reach the highest abundance. The diatom assemblage found at this peak in core MD95-2043 is dominated by resting spores of Leptocylindrus danicus (63 to 89 %). The second major component of the assemblage is Punctula sulcata (4 to 16 %). T1b is marked by a continuous and rapid decrease in diatom abun-

Figure 1: Studied area. Position of the studied core in this paper as well as the site cores TG-5 and K6238. Location of the prevalently oceanographic features of the Alboran Sea, the western anticyclonic gyre (WAG) and the Almeria-Oran Front. Shadow zones represent today's high fertility areas.

Figure 1a: Area de estudio. Localización del testigo estudiado en este trabajo así como la posición de los testigos TG-5 y K6238. Localización de los patrones oceanográficos mas importantes del Mar de Alborán, el giro anticyclónico occidental (WAG) y el frente Almería-Orán. Las zonas sombreadas representan las zonas actuales de alta fertilidad.
dance with a final disappearance of diatoms in the early Holocene, very few samples contained entire diatom valves, mostly only fragments could be found. At the surface, diatoms reappear, but in contents lower than the values found downstream for MIS2 and the Termination (Fig. 2).

Freshwater diatoms together with phytoliths were counted along core MD95-2043 (Fig. 2). The main fresh-water diatom in the Alboran Sea is *Anacocera* sp., a planktonic and lacustrine diatom, together with other limnobiontic forms (*Cyclotella ocellata* and *Stemphidium aster*). Abundance pattern of this group is parallel to the total diatom assemblage. Maximum abundance of both groups occurs during the LGM and the YD. The group disappears after 8.5 ky BP, reappearing in the surface samples. Fresh-water diatoms and phytoliths, show clear differences. During the MIS2 until T1a, fresh-water diatoms have a relatively high abundance with a decreasing tendency towards T1a. During the B-A period, the group has a very low abundance. For the YD period the fresh-water group presents a peak of higher abundance and afterwards follows a decreasing tendency. The phytoliths pattern is the opposite of the previously observed fresh-water diatoms, they reach their highest value during the deglaciation, after the YD event, moreover in the MIS2 the appearance of the group is constant trough time (Fig. 2).

Discussion and conclusions

Current hydrography reveals the existence of two high productivity systems in the Alboran Sea, the WAG and the Almeria-Oran Front (Fig. 1). Previous studies by Abrantes (1988), Bárzona and Abrantes (1998) and Bárcena et al. (submitted) have already related diatom presence in Alboran Sea sediments to upwelling conditions in the overlying waters. Therefore, the high abundance of diatoms in the sediment are related to the productivity of the surface waters, and the variations in downcore diatom abundance is the result of changes in paleoproduction.

The persistence of the double gyre of the Alboran Sea is variable and its permanence depends of several factors (thermohaline circulation, meteorological factors, etc.) (Paullira and Kinder, 1987). The present-day Mediterranean climate type is due to the position of the ITZC in the upper atmosphere, its seasonal migration, and the influence that the ITZC has upon more localised pressure systems. During glacial period the ITZC migrates to the south favouring the localisation of a low-pressure system over the Mediterranean and prevailing westerlies (COHMAP Members, 1988), its dominance induces maximum stream flux, the stream enter directly till the centre of the basin, and the WAG is displaced to the east (Parrilla, 1984), Vernaud-Grazzini and Pierre (1991) suggested that before 16 ky, prevailing westerlies and low pressures over the Mediterranean favoured the eastward displacement of the WAG of the Alboran Basin.

Recent studies by Bárcena et al. (submitted) on two cores located at the continental shelf (Fig. 1), core KS8230 (36°27′N/3°53′W, and 795 m water depth), and core TG-5 (36°23′N/4°15′W, and 626 m water depth) show a clear evidence of reduced surface paleoproducitivity for the time period studied in this work by comparing with surface paleoproducitivity recorded in core MD95-2043 (Fig. 3). Both cores are located under the influence of today's upwelling system at the northern limb of the WAG. In overview, one can assess that for the all time interval considered in this study, highest productivity was displaced towards the East; core MD95-2043 record maxima diatom abundance, while TG-5 and KS8230 record the lowest values in paleoproducitivity. Therefore, we infer that during MIS2 meteorological conditions would induce an intensified eastward flow which would displaced the WAG to the East, and the North Alboran upwelling system would be moved, therefore maxima fertility in surficial waters could occur in the eastern area.

Based on the diatom record paleoceanographic conditions favours increases in paleoproducitivity from 22.5 ky to 16 ky during the LGM with a maximum at ca. T1a. During the B-A event a significant reduction in paleoproducitivity was observed, but a new increase in paleoproducitivity occurs during the YD (Fig. 2). Several other paleoproducitivity indicators point to changes in paleoproducitivity during the last 25 ky in the Alboran Sea that have been attributed to variations in the oceanographic conditions by several authors (Abrantes, 1988; Weaver and Pujol, 1988; Turon and Londeix, 1988; Taragona et al., 1997; Vernaud-Grazzini and Pierre, 1991). During the Holocene inferred paleoproducitivity decreased to the lowest values of the last 23 ky; paleoproducitivity was slightly reestablished recently (Fig. 2).

Recent SST studies on core MD95-2043 (Cacho et al., in press) show evidence of a clear connection between the Greenland 810O record in GISP2 (Meese et al., 1997) and its D-O events and Alboran's SST, as well as a good coherence among the temperature minima in both records. Cacho's study also recognise the influence of the Heinrich events in the Alboran Sea, and assess that important invasions of polar waters occurred in base to the presence of *N. pachyderma* (s) (Cacho et al., in press). In this sense, diatom assemblages respond to these cool water invasions. The increase in paleoproducitivity during the YD
The Spanish coast has been widely described. This "red rain" is related to south-westerlies generated by low pressures on the Gulf of Cadiz (Parrilla and Kinder, 1987). African climate is clearly linked to that of high-latitude ice sheets, with glacial aridity and interglacial humidity (Sarnthein et al., 1982; Stuiver, 1986). Besides, during glacial periods the ITZ migrates to the south favouring the localisation of a low-pressure system over the Mediterranean and prevailing westerlies, and therefore favouring "red rain" over the Mediterranean. The abundance of fresh-water diatom was used as an aridity indicator, while opal phytoplankton were linked to relatively wet conditions on land. Also, fresh-water diatoms would indicate arid conditions in North Africa with lake desiccation during the MIS2 until 15 cal ky BP, the progressive phytoplankton decline would also indicate a gradual climatic deterioration and a gradual belt-grass loosing with a wetter episode from 19 to 17 cal ky BP (Fig. 2). LGM would be characterised by an intensification of the winds while the B-A would correspond to the re-establishment of vegetation belts and replenish of lakes which continues throughout the rest of the deglaciation and prevails until ca. 8 cal ky BP (Fig. 2). Therefore, climatic conditions would be warmer and moister. Nevertheless, during the YD climatic conditions could have been relatively dryer, as indicated by the presence of fresh-water diatoms and the reduction in opal phytoplankton. However, the total windblown particles was high during this interval which could indicate a wind intensification. Besides an aridity index has been calculated as the result of the following equation: phytoplankton/phytoplankton + fresh-water diatoms. The index indicates the same dry and wet episodes that those described before (Fig. 2).

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