Marine sediments: an accurate tool for reconstructing climatic variability in equatorial Africa during the Late Pleistocene

Sedimentos marinos: una herramienta precisa para la reconstrucción de la variabilidad climática en Africa Ecuatorial durante el Pleistoceno superior

M.A. Bárcena (*), J.F. Sierro (*), G. Francés (**), J. Baraza (***), G. Ercilla (***), and J.A. Flores (*)

(*) Dpto. Geología. Fac. Ciencias. Universidad de Salamanca. 37008- Salamanca. Spain.
(**) Facultad de Ciencias del Mar. Universidad de Vigo, 36200-Vigo, Pontevedra. Spain.
(***) Instituto de Ciencias del Mar. Paseo Juan de Borbón s/n. 08001-Barcelona. Spain.

RESUMEN

El análisis micropaleontológico de los últimos 140 000 años registrados en testigo de gravedad CAMEL-1 (5·6'25S/21·2'36W), sugirió valores bajos en la paleoproductividad de las aguas superficiales circundantes. Por otro lado, el registro de diatomeas de agua dulce y fitolitos en sedimentos marinos reflejaron incrementos en la aridez en el Continente africano durante los estadios glaciales, indicando desecación de lagos y desplazamientos del cinturón herbáceo. La combinación de los registros marinos y continentales permitió estimar la intensidad de los vientos.

Palabras clave: Atlántico ecuatorial, sedimentos marinos, microfósiles transportados por el viento, microfósiles planctónicos marinos, paleoproductividad, episodios glacial/interglacial, Pleistoceno superior.

Introduction

The purpose of this work is to explore the variability of African climatic changes using eolian material (freshwater diatoms and opal phytoliths) found in deep-sea sediments, together with autochthonous marine microfossils, calcareous nanno-plankton, planktic foraminifera and marine diatoms, for the last 140 000 years. Freshwater diatoms in eolian sediments come from the deflation of diatomaceous deposits in dry lake beds. Thus, they are an indirect indicator of lake levels and therefore aridity. Opal phytoliths are silica bodies growing in the leaves of vascular plants (Baker, 1960) that are injected into the atmosphere by bush fires and wind storms during dry seasons. Their presence in deep-sea sediments off Africa reflects the position of the tall-grass savannahs and could be used to estimate wind directions and intensities. *Florisphaera profunda* is a coccolithophorid that lives in the lower euphotic zone linked to the nutricline. In the fossil record, high abundances of this taxon are related too nutrient-poor surface waters, where most of the cocco-lithophores live, and a deep nutricline; a

situation that occurs in stratified waters (Molfino and McIntyre, 1990a,.b).

In recent years, several attempts have been made to reconstruct atmospheric circulation and climate on the African Continent by using the freshwater diatoms found in Atlantic cores (e.g. Pokras and Mix,1985; Stabell, 1986; Pokras, 1991). Such research assumes that these freshwater diatoms are all windblown from Africa. The atmospheric circulation in the area is considered to be responsible for the dust supply to the Atlantic. Dust flow is linked to the Easterly Waves, a system of tropical disturbances connected to the Inter-Tropical Convergence Zone (ITCZ). During glacial times, the ITCZ did not migrate very far outside its present seasonal boundaries (Gardner and Hays, 1976). Rainfall seasonality results in two seasonal dust plumes. During the northern hemisphere summer, the plume occurs off northwest Africa at about 10°N to 25°N. Dust in the summer plume comes mainly from the western and central Sahara and its borders. In the northern winter, the plume originates mainly along the southeast edge of the Sahara (Fig. 1) and the focus of activity is

situated between 5·N and 15·N along the coast of Africa. These easterly trade-winds became more vigorous during periods of ice growth and ceased shortly during interglacial times (Sarnthein *et al*, 1982). Pokras and Mix (1985), Stabell (1986), and Pokras (1991) have related variations in the freshwater diatoms and opal phytoliths recorded in marine sediments to glacial/interglacial episodes. Cold periods were characterized by higher levels of intertropical aridity, drying larger humid areas, and by southwards displacement of the ITCZ. Windblown freshwater diatoms and phytoliths in the Atlantic may thus be used as an index of enhanced wind activity and intertropical aridity.

Materials and methods

The CAMEL-1 gravity core was recovered during the CAMEL-93 BIO Hesperides Cruise (Cañón Medioceánico Ecuatorial-1993) (Baraza and Ercilla, 1993) in the Sierra Leone Rise (Equatorial Atlantic) at 5°6'25S/ 21°2'36W. Water depth at the core location is 2685 m. The total length of CAMEL-1 is 446 cm. It contains alter-
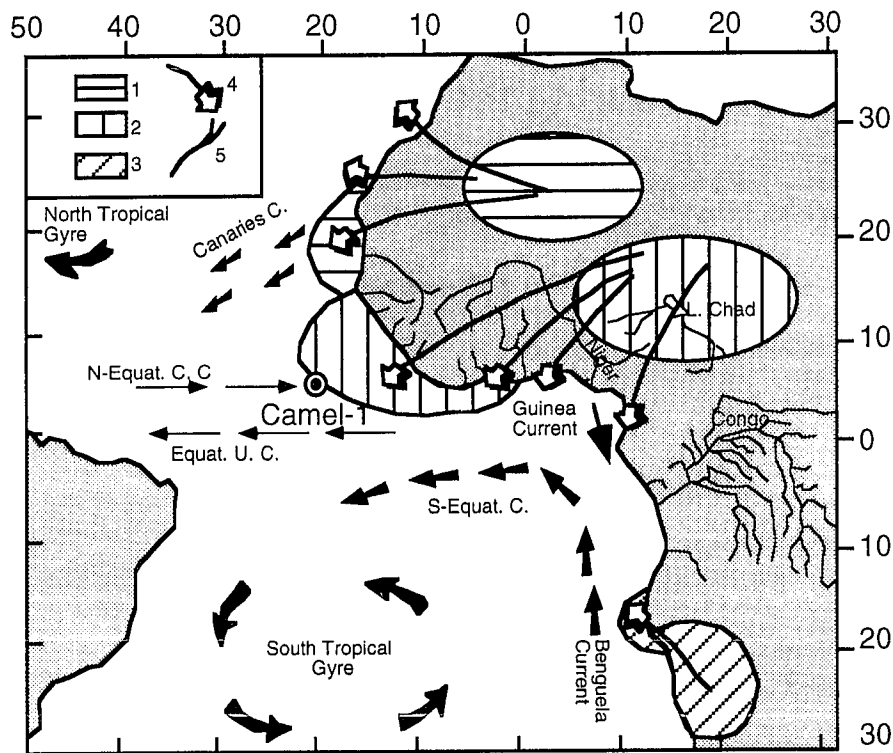
Fig. 1- CAMEL-1 location. Approximate present-day sources of freshwater diatoms and opal phytholiths in the Atlantic Ocean and their approximate source areas with dust trajectories. 1- northern summer plume. 2- northern winter plume. 3- southern spring plume. 4- dust trajectories. 5- rivers. (after Gasse et al., 1989). Canaries C.: Canaries Current; N-Equat. C.C.: North-Equatorial Counter Current; Equat. U.C.: Equatorial Under Current; S-Uquat. C.: South-Equatorial Current.

Fig. 1.- Localización del testigo CAMEL-1. Representación esquemática de las áreas en las que se registran diatomeas de agua dulce y fitolitos en el Oceano Atlántico, áreas fuentes y trayectorias de las plumas de polvo. 1- Pluma de verano del norte. 2- Pluma de invierno del norte. 3- Pluma de primavera del sur. 4- Trayectorias del polvo. 5- Rios. (after Gasse et al., 1989). Canaries C.: Corriente de Canarias; N-Equat. C.C.: Corriente norequatorial; Equat. U.C.: Equatorial Under Current; S-Uquat. C.: Corriente surequatorial.

nations of gray muddy sands, brown sandy muds, and ochre sandy muds. At the top of CAMEL-1 (0-8 cm) an organic matter-rich level has been observed. Since our interest lay in studying the last 140 000 years, only the upper 160 cm part of the core was examined.

Micropaleontological samples for calcareous nannoplankton, planktic foraminifera, and siliceous microfossils were taken at the same core depths (every 3 cm). To estimate absolute numbers of diatoms, phytoliths and coccoliths, microscopical slides with randomly distributed microfossils were prepared. For foraminiferal studies, samples were wetsieved at 150 and 63 μm.

Results and discussion

Biostratigraphic control is based on the distribution of the planktic fora-

minifer *Globorotalia*. Biozones X, Y, and Z are recognised (Ericson and Wollin, 1968). Isotopic stages were infered from the foraminifera data.

Variations in the abundance of planktic foraminifera greater than 63 μm are linked to climatic changes. Higher values are recorded during interglacial episodes, while for glacial periods lower values are observed. Three factors could be responsible for these variations: productivity, dilution or/and dissolution. The latter factor does not seem to be related to these variations because there is no evidence of dissolution on the samples. The abundance patterns of both planktic foraminifera and coccolith curves are parallel, but opposite that observed for wind-transported particles (freshwater diatoms and opal phytoliths) (Fig. 2). Therefore, changes in the accumulation rates of terrigenous

sediments, especially eolic components from the African Continent, could be responsible for the variations in abundance of the calcareous plankton in the area studied. At the location of CAMEL-1, surface waters are meso-trophic, and coccolithophorids are currently, as well as during the Pleistocene, the most important primary producers. Their variations in abundance could therefore be interpreted as changes in paleoproductivity (Flores, et al., 1995). The abundance pattern of this group at CAMEL-1 seems to be relatively uniform throughout the core interval studied (Fig. 2.a). The dominant taxa is *F. profunda* (75 to 95 % of the total assemblage) (Fig. 2.b) and, as already mentioned, high values of this taxon in the fossil record are related to a deep nutricline and high surface water stratification. A deep nutricline means that the upper euphotic zone is nutrient-depleted and hence the production of *F. profunda* is enhanced relative to other coccolithophorids. The high abundance values of *F. profunda* throughout the entire time interval studied at CAMEL-1 are in agreement with a deep nutricline and therefore with low nutrient concentrations at the surface. Additionally, maximum values of *F. profunda* are recognised at the base of stage 4, together with a minimum in foraminifers and wind-transported particles. According to these data, sea-surface productivity was relatively low during the time interval studied, the lowest values being found during the base of stage 4 and during the interstage 5.3.

Marine diatoms are regularly present at low frequencies in the upper section of the core (40 cm) but are almost absent in the rest of the core. The deposition of marine diatoms depends on high diatom productivity, which requires nutrient-rich waters and, in particular, a large supply of silica, such as that provided by deep waters in upwelling areas (Abrantes, 1988; Van Bennekom et al., 1988). As discussed above, large amounts of the coccolith *F. profunda* indicate unmixed waters, and poor nutrient contents in the upper photic layer, characterizing an area unaffected by equatorial upwelling.

The numbers of freshwater diatoms per gram of dry sediment as well as the numbers of phytoliths are relatively high: from 0.2 to 3 $x10^6$ and from 0.15 to 1.5 $x10^6$, respectively (Fig. 2.c). The diversity of freshwater diatoms is low. All records are dominated by *Melosira*, a widely distributed taxon adapted to shallow, turbid lakes and the littoral zones

of larger lakes (Gasse *et al.* 1983). Other taxa identified are, *Cyclotella ocellata*, *Stephanodiscus astraea*, and *Synedra ulna*. The freshwater diatom assemblages recognised and their origin are in agreement with the observations of other authors (Schrader, 1977; Stabell, 1986; Gasse *et al.*, 1989; Lange *et al.*, 1994). All these authors have concluded that the primary source of land-derived micro-fossils in the central Atlantic is eolian transport from Africa north of the equator, and particularly from the winter-plume dust (Fig. 1). CAMEL-1 is located under the influence of the dust trajectory of the northern winter-plume. Maxima in wind-transported particles occur during isotopic stages 2, 4 and interstage 5.3 (Fig. 2.c). Separately, both particle types, *Melosira* and phytoliths, have different patterns. While phytoliths are more common in stage 6, the uppermost part of stage 4, the lower and middle stage 3 and in stage 2, their abundance is only moderate in stage 5 and even lower in stage 4. *Melosira* does not show especially high values in stage 3; instead its maximum value occurs during stage 4 just before the maximum in phytoliths. These data are consistent with other cores from the middle Atlantic (Pokras and Mix, 1985; Stabell, 1986). This signal must therefore have a climatic explanation.

In marine surface sediments phytoliths are less abundant than *Melosira* and decrease rapidly seawards (Melia, 1984). According to Pokras and Mix (1985) and Melia (1984), the capacity of the wind to transport land particles would be more efficient for *Melosira* than for phytoliths, and the maximum concentrations of phytholiths would occur off the tall-grass savannah belt. Changes in rainfall would control the position of the grass belt, which would move towards the Sahara during relatively wet interglacial times, and southwards during relatively arid glacial times. Pokras and Mix (1985) found higher values of phytoliths for the Last Glacial Maximum (LGM) than for present times, and suggested that both margins of the grass belt would have probably moved southwards during the glacial time. A different explanation is given for *Melosira*. This species is also transported by wind but over longer distances. The increased abundance of *Melosira* during glacial times reflects aridity and the desiccation of lakes bordering the western Sahara. Pokras (1991) has indicated that freshwater diatom transport has always been via the
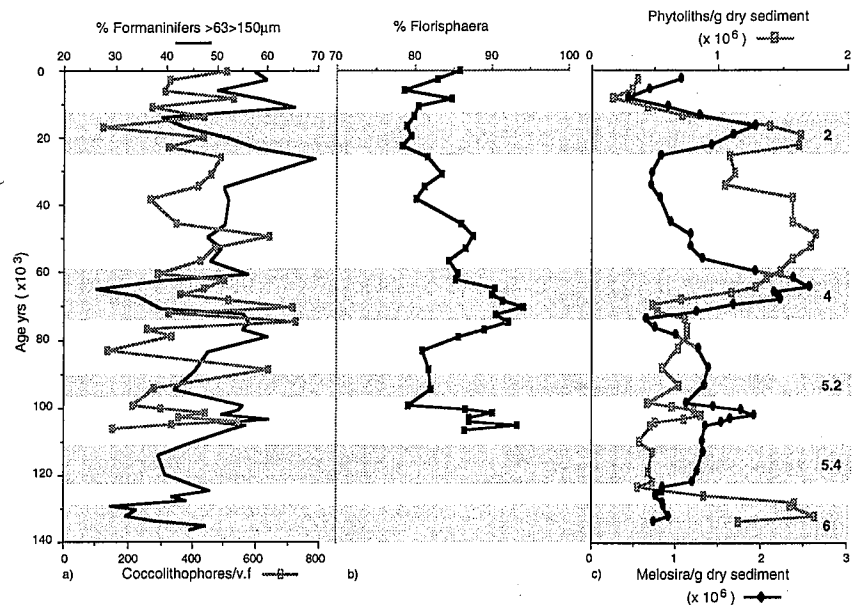

Fig. 2- Age interpretation of CAMEL-1 is based on biostratigraphic distribution of the planktic foraminifer *Globorotalia* according to Ericson and Wollin (1968). Isotopic stages were inferred from the foraminifera data. Gray transversal bars indicate isotopic stages 2, 4, 5.2, 5.4 and 6. a) Variations in relative abundance of foraminifers and absolute variations of coccoliths per visual field. b) Relative abundance of *F. profunda*. c) Absolute values of wind-tranported particles, freshwater diatoms and opal phytoliths.

Fig. 2.- La interpretación de la edad está basada a partir del control bioestratigráfico del foraminífero plactónico Globorotalia según Ericson y Wollin (1968). Los estadios isotópicos se infirieron a partir de los datos de foraminíferos. Las barras grises trasversales indican los estadios isotópicos (2, 4, 5.2, 5.4, y 6.) a) Variaciones relativas de la abundancia de foraminíferos planctónicos y variaciones absolutas de cocolitos por campo visual. b) Abundancia relativa de·F. profunda. c) Valores absolutos de partículas transportadas por el viento, diatomeas de agua dulce y fitolitos silíceos.

winter dust plume and that the source area has remained north of the equator. Also, diatom supply would depend not only on the intensity of the arid phase, but also on how humid conditions were prior to aridification.

According to our data, it is possible to interpret glacial times as more arid periods, but with a different response for the lakes as compared to the savannah. Maxima in aridity occurred during glacial periods, as indicated by higher con-centrations in marine sediments of *Melosira* as well as of phytoliths. However, while isotopic stage 3 can be interpreted as a humid interglacial period with well developed lakes in central Afri-ca, the phytoliths seem to indicate an unstable grass belt with larger areas exposed to wind transport during this episode. Thus, according to our data it is possible to interpret a large southward expansion of the desert during the colder stages 2, 4 and 6, as well as during stage 3.

Returning to the *F. profunda* abun-dance curve, owing to the stability of the water column, it can be interpreted as a wind intensity curve. Average abundance values around 80% of the total calcarous

nannoplankton assemblage during the last 140 000 years are representative of high stratification in the water column. The highest abundances observed for *F. profunda* determine periods with maximum stability in the water column. However, also during the isotopic stages 4 and 2, with theoretically more vigorous easterly trade-winds, abundance does not drop significantly. Thus, these intensified trade-winds that occurred during glacial times were insufficient to break the water column stability.

Conclusions

The CAMEL-1 gravity core recove-red in the Sierra Leona Rise (Equatorial Atlantic) has been dated using the distribution of the planktic foraminifer *Globorotalia*. Biozones X, Y, and Z are recognised. The base of the upper 160 cm of the core has been dated at 140 000 years B.P. Isotopic stages from 6 to 1 were inferred from the foraminifer data.

Micropaleontological analyses show the presence of autochthonous marine microfossils, calcareous nannoplankton, planktic foraminifera and marine diatoms,

37

as well as freshwater diatoms and opal phytoliths.

High numbers of the coccolithophore *F. profunda* as well as the almost complet absence of marine diatoms suggest low paleoproductivity in the area studied during the last 140 000 years, the lowest values being recorded during the base of stage 4 and during interstage 5.3.

High amounts of freshwater diatoms and opal phytoliths are recorded in CAMEL-1. The primary source of these land-derived microfossils in the central Atlantic is eolian transport from Africa, north of the equator, and particularly from the winter-plume dust.

Increased *Melosira* abundance in glacial times reflects aridity and the desiccation of lakes bordering the western Sahara.

Maximum episodes of phytoliths seem to indicate an unstable grass belt, with larger areas exposed to wind transport during this time.

The intensified trade-winds that occurred during glacial times were not strong enough to break the water column stability.

References

Abrantes, F. (1988): *Marine Geology*, 85: 15-39.

Baker, G. (1960): *Micropaleontology*, 6: 79-85.

Baraza, J. and Ercilla, G. (1993): *Informe de Campaña*, proyecto ANT93-1008-C02-02.

Ericson, D.B. and Wollin, G. (1968): *Science*, 162: 1227-1234.

Flores, J.A., Sierro, F.J. and Raffi, I. (1995): *Procc. of the O.D.P.*, 138: 163-176.

Gardner, J.Y. and Hays, J.D. (1976): *Geol. Soc. Am. Menm.*, 145: 221-246.

Gasse, F., Stabell, B., Fourtanier, E. and van Iperen, Y. (1989): *Quaternary Research*, 32: 229-243.

Gasse, F., Talling, J.F. and Kilham, P. (1983): *Revue d'hydrobiology Tropicale* 16: 3-4.

Lange, C.B., Treppke, U.F. and Fischer, G. (1994): *Deep-Sea Research*, 41: 859-878.

Melia, M. B. (1984): *Marine Geologie*, 58: 345-371.

Molfino, B. and McIntyre, A. (1990a): *Science*, 249: 766-769.

Molfino, B. and McIntyre, A. (1990b): *Paleoceanography*, 5 (6): 997-1008.

Pokras, E.M. (1991): *Quaternary Research*, 35: 144-156.

Pokras, M. and Mix, A.C. (1985): *Quaternary Research*, 24: 137-149.

Sarnthein, M., Erlenkeuser, H. and Zahn, R. (1982): *Bull. Inst. Geol. Bassin d'Aquitanie*, 31: 393-407.

Stabell, B. (1986): *Marine Geology*, 72: 305-323.

Schrader, H.J. (1977): *Init. Repts. D.S.D.P.*, 41: 791-812.

Van Bennekom, J., Berger, G.W., Gaas, S.J. van der and Vries, R.T.P. (1988): *Palaeogeog., Palaeoclimatol., Palaeo-ecol.*, 67: 19-31.