Astronomical cyclicity and sapropels in the pre-evaporitic Messinian of the Sorbas basin (Western Mediterranean)

Ciclicidad astronómica y sapropeles en el Messiniense pre-evaporítico de la cuenca de Sorbas (Mediterraneo occidental)

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ABSTRACT

A high resolution study of the Messinian pre-evaporitic marls of the Sorbas basin was carried out with the main object of analysing the high frequency cyclicity identified in this basin. In the lower part of the succession, sedimentary cycles are characterised by an alternation of indurated, opal-rich layers and homogeneous marls. In the upper part, sapropels have been identified in the middle part of the cycles. These cycles have an average duration of 23,500 years and therefore a relation to precession variations in the Earth's orbit may be inferred. Quantitative analyses of the planktic Foraminifera and Nannofossil assemblages suggest the occurrence of strong environmental fluctuations in the basin before the Messinian Salinity Crisis.

RESUMEN

El principal objetivo de este trabajo ha sido el estudio de alta resolución de las margas messinienses pre-evaporíticas de la cuenca de Sorbas con la finalidad de analizar la ciclicidad de alta frecuencia identificada en esta cuenca. Se ha reconocido la existencia de una serie de secuencias sedimentarias de corta duración, definidas por la presencia de capas duras, ricas en ópalo, intercaladas en una sucesión de margas homogéneas. En la parte superior de la serie, se ha identificado tambien la existencia de sapropeles intercalados en la parte central de los ciclos. De acuerdo con el modelo de edad utilizado, estos ciclos tienen una duración media de 23.500 años lo que nos lleva a inferir que están claramente relacionados con variaciones en la precesión del eje de la Tierra. Los análisis cuantitativos de Foraminíferos planctónicos y Nanoplancton calcáreo nos permiten deducir que la cuenca se vio afectada por fuertes fluctuaciones ambientales antes de la Crisis de Salinidad Messiniense.

Key Words: *Astronomic cycles, sapropels, planktic foraminifera, nannofossils, Messinian, Spain, Western Mediterranean.*

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Introduction

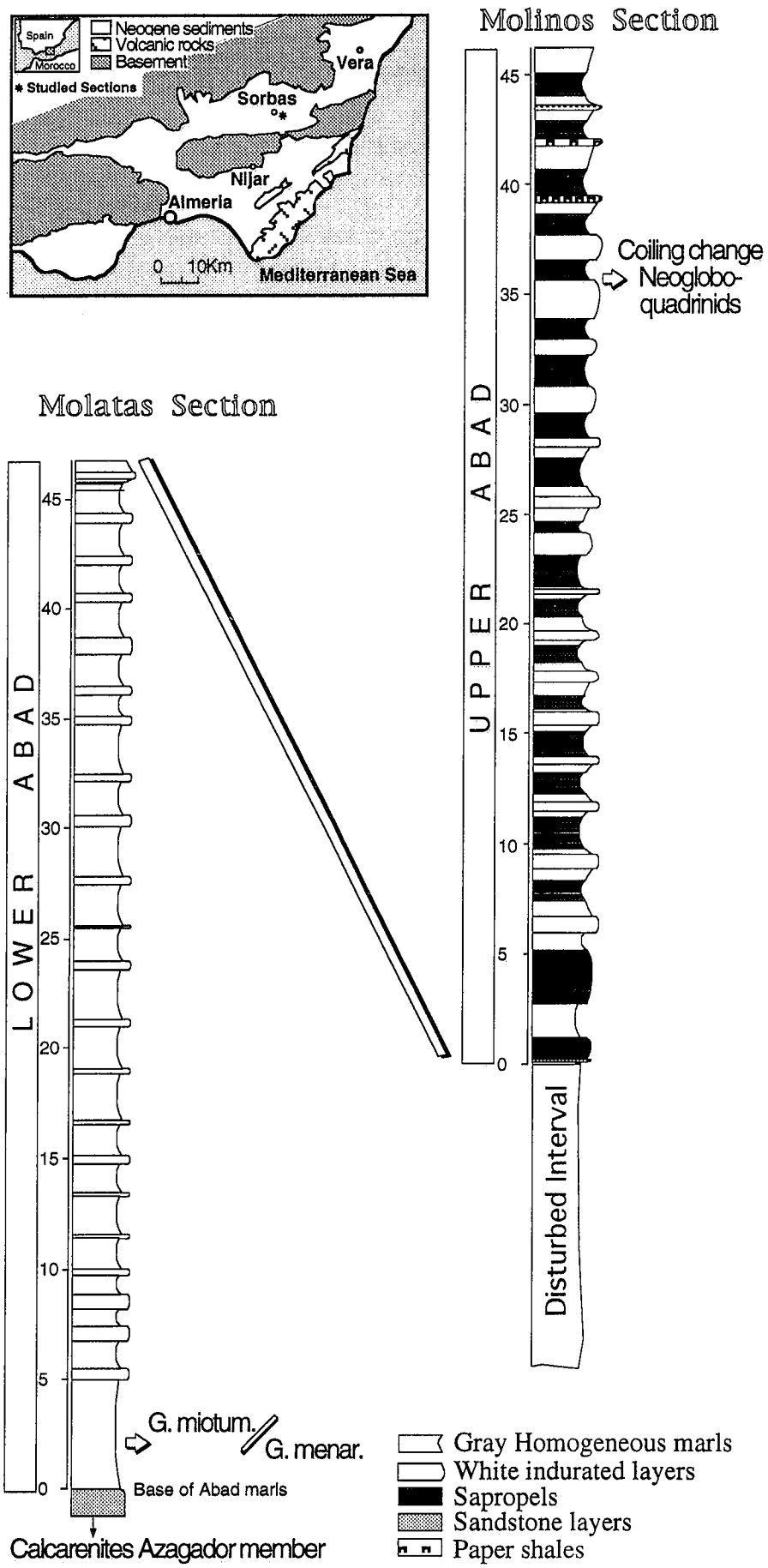
Over the last few decades, the Sorbas basin has been the subject of numerous studies that have mainly focused on aspects of the shallow sediments of the margins, such as reef evolution or siliciclastic or evaporitic deposition. Recently, several investigations have provided evidence of high frequency cyclicity in this kind of deposits (Braga & Martín, 1992; Martín & Braga 1994; Dabrio & Polo, 1995; Martín & Braga, 1996; Martín *et al.*, 1996).

In this paper, we report the preliminary results of a high resolution study of the sedimentation of the Abad marls in the central part of the basin that may provide a more precise record of the cyclicity, and the controlling climatic and paleoceanographic parameters.

To accomplish this goal, two sections were sampled in detail, following the recognition of a precession induced sedimentary cyclicity in these marls. Average sampling resolution was around 9 samples per cycle, representing one sample every 2.5 ky. These samples are currently being used for micropaleontologic (Foraminifera, Nannofossils), paleomagnetic, and geochemical and sedimentologic analyses (low-magnesium calcite, dolomite, Corg, terrigenous components, isotopes, etc).

Sedimentation and cyclicity of the pre-evaporitic marls

The Abad member forms part of a Late Miocene series that begins in the latest Tortonian with the deposition of the Azagador member. The Azagador member lies unconformably over turbiditic deposits of the Lower Tortonian and consists of very shallow calcarenitic sediments that rapidly pass upwards into a thick series of marls known in the literature as the Abad member. In the central part of the basin, the Abad marls are



overlain by gypsum deposits that, according to Rouchy and Saint-Martin (1992), form part of the Mediterranean Upper Evaporites.

The above is only a very brief description of the basin's stratigraphy; for more detailed studies of the basin, the reader is referred to other publications (Völk, 1966; Ott d'Estevou, 1980; Riding *et al.*, 1991; Braga & Martín, 1992; Martín & Braga, 1994).

The «Molinos del Rio Aguas» section is located in the central part of the basin (Fig. 1), along the old road between Sorbas and Nijar (see Montenat, 1975 or Ott d'Estevou,1980 for a general description of the section). The total thickness of the Abad marls varies considerably from one region to another; in the neighbourhood of the Molinos del Rio Aguas, the unit reaches a considerable thickness due to the intercalation of slumps and olistholiths in its middle part.

Our section is a composite of two sections. The Molatas section (Fig. 1) contains the lower part of the Abad member (Lower Abad), which consists of grey homogeneous marls, while the Molinos section (Fig. 1) contains the upper part of the Abad unit (Upper Abad). The marls of the upper Abad are brownish due to the intercalation of organic-rich, laminated beds, that we shall refer to as sapropels, following the terminology of Hilgen (1991b).

The transition from the Lower to the Upper Abad is marked by a hiatus or a series of slumps which consist of Lower Abad marls that slid into the basin before deposition of the Upper Abad. This slumped interval and the hiatus in other areas undoubtedly correspond to the unconformity separating the Abad marls from the overlying Messinian reefs of the Cantera formation along the basin margins (Martín & Braga, 1990; Riding *et al.*, 1991; Martín & Braga 1996). Currently, we are not entirely certain whether the tectonic instability might have produced some break in our sedimentary record. However, if this discontinuity does exist, the missing time interval should be very short.

Fig. 1.- Location map of the area studied in the Sorbas basin (SE Spain). Location of the biostratigraphic events in the Molatas section (Lower Abad) and Molinos section (Upper Abad). G. men./G. miot.= Replacement of the *G. menardii* group by de *G. miotumida* group.

Fig. 1.- Mapa de localización del área estudiada en la cuenca de Sorbas (SE de España). Localización de los eventos bioestratigráficos en la sección Molatas (Abad inferior) y sección Molinos (Abad superior). G. men./G.miot. = Reemplazamiento del grupo the G. menardii por el grupo de G. miotumida.

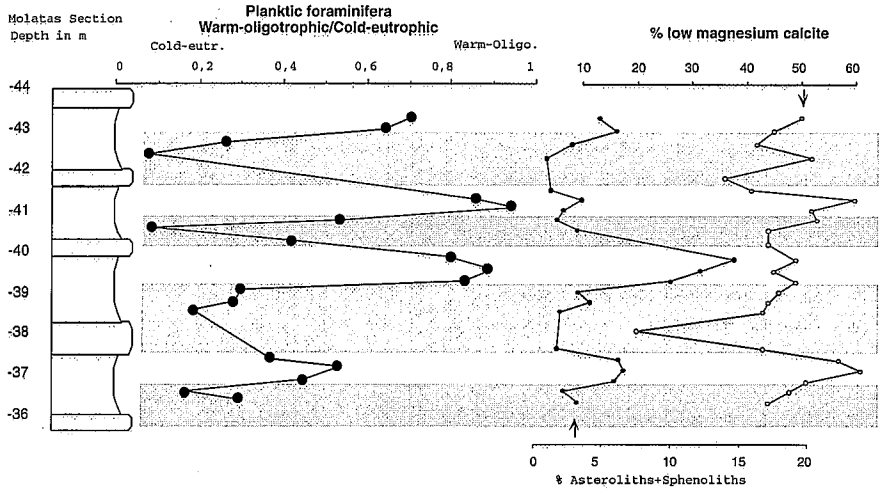


Fig. 2.- Quantitative variations in planktic Foraminifera and Calcareous Nannofossil assemblages along with the low magnesium calcite content. The Warm-oligotrophic/Cold-eutrophic parameter is the ratio between warm oligotrophic Foraminifera (i.e. *Globigerinoides obliquus*, *Globigerinoides sacculifer*, *Globigerina apertura*) and cold eutrophic forms (i.e. *Globigerina bulloides*, Neogloboquadrinids, *Globigerina quinqueloba*). This ratio varies between 0 and 1. Shade areas indicate the cold-eutrophic intervals.

Fig. 2.- Variaciones cuantitativas en las asociaciones de Foraminíferos planctónicos y Nanofósiles calcáreos junto con el contenido en calcita baja en magnesio. El parámetro «Cálido-oligotrófico/Frío-eutrófico» es la relación entre los Foraminíferos cálidos-oligotróficos (por ej. Globigerinoides obliquus, Globigerinoides sacculifer, Globigerina apertura) y las formas frías-eutróficas (por ej., Globigerina bulloides, Neogloboquadrinidos, Globigerina quinqueloba). Esta relación varia entre 0 y 1. Las áreas sombreadas indican los intervalos fríos-eutróficos.

In the Lower Abad (Molatas section), the cycles are defined by the regular alternation of white indurated layers and homogeneous marls, every 2 to 4 m. The indurated layers are generally rich in opal CT, and occasionally consist of chert. As can be seen in Fig.1, 22 cycles of this type have been recognized in this section. In the Upper Abad (Molinos section), the cycles are slightly more complex. Although indurated layers define the upper and lower limit of the cycles, as in the Lower Abad, brownish laminated layers occur in addition in the middle part of the cycles. Another difference is that the indurated layers are more like paper shales and that the biogenic opal is better preserved. In the Molinos section, we have identified 21 sedimentary cycles (Fig. 1), although a few more cycles remain until the evaporite unit is reached.

Average periodicity and astronomic origin of the cycles

For a first estimation of the periodicity, our calculations were simply based on two well calibrated biostratigraphic events because so far we have been unable to obtain any reliable magnetostratigraphic results in the two sections.

We have identified the replacement of the *Globorotalia menardii* group by the *Globorotalia miotumida* group about 2 m above the base of the Molatas section (Fig. 1). This event occurs 2 biogenic cycles below the lowermost sedimentary cycle, as can be deduced from the micropaleontological analyses currently in progress. This event has been widely recognized in the Northeast Atlantic (Sierro, 1984, 1985; Sierro *et al.*, 1993; Benson *et al.*,1991, 1995; Hodell *et al.*, 1994) and the Mediterranean (D'Onofrio *et al.*, 1975; Zachariasse, 1975; Langereis *et al.*, 1984; Glaçon *et al.*, 1990; Krijgsman *et al.*, 1994, 1995; Hilgen *et al.*, 1995). Correlation of magnetostratigraphic records to the Geomagnetic Polarity Time Scale (Cande and Kent, 1995) unambiguously shows that this event falls within subchron C3Br.1r, resulting in an age of 7.12 Ma (Krijgsman *et al.*, 1994, 1995). The age of the same event arrived at 7.240 Ma, according to the astronomical time scale of Hilgen *et al.* (1995).

The second biostratigraphic event used for the estimation is the coiling change from preferentially sinistral to preferentially dextral of the Neogloboquadrinids recorded in the upper part of the Molinos section (see Fig. 1). This event has been also recognized in the North Atlantic and Mediterranean (Stainforth *et al.*, 1975; Zachariasse 1975; González Donoso & Serrano, 1977; Cita y Ryan, 1978; Civis *et al.* 1979; Sierro 1984, 1985; Sierro *et al.* 1993; Benson *et al* 1991, 1995; Gautier *et al* 1994, etc.), although the magnetostratigraphic calibration is less accurate. However, this event always seems to be located within subchron C3An.1r (Hooper and Weaver, 1987; Benson *et al.*, 1991, 1995; Gautier, *et al.*, 1994) and, therefore, the approximate age of this event is 6.180 Ma, according to the Cande and Kent time scale.

Assuming that no cycle is missing in the disturbed interval, we have identified 40 cycles between both bio-events. Therefore, we assume that the average duration of the cycles is around 23.5 kyr. This average periodicity clearly suggests that we are dealing with a precession-induced cyclicity, as is usual in other Neogene and Quaternary marine basins of the Mediterranean.

Micropaleontological records of the cyclicity

During the Upper Miocene, the Sorbas basin formed part of a mosaic of small interconnected basins that were also connected with the open Mediterranean through narrow, shallow passages. This configuration often led to the appearance of marginal environments subject to very restricted and fluctuating oceanographic conditions. Such basins are very sensitive to global climatic and oceanographic changes and are therefore very useful to obtain good and strongly-amplified records of the global signal. This is evidently the case in the Sorbas basin, where, parallel to the sedimentary cycles, we have identified a distinct cyclicity in other variables of our micropaleontological and geochemical records. As seen in Fig. 2 significant quantitative changes can be identified in the assemblages of planktic foraminifera in 4 cycles of the upper part of the Molatas section. Within the lower part of the cycles, species typical of cold and nutrient-rich waters are dominant (*Globigerina bulloides*, Neogloboquadrinids, *Globigerina quinqueloba*, etc.) whereas in the upper part of each cycle such species become rare and are replaced by other group of species, such as *Globigerinoides obliquus*, *Globigerinoides sacculifer*, *Globigerina apertura*, which are living, or are equivalent to forms currently proliferating in warm oligotrophic waters (Fig.2). In the Upper Abad, this group of species becomes dominant in the upper part of the sapropels.

The calcareous nannofossils follow very similar patterns (Fig. 2). Small placoliths, usually the most abundant component of the assemblages, are replaced by other forms, such as Discoasterids and Sphenoliths, in the upper part of the cycles.

Regarding the calcite content, the low magnesium calcite content also shows some

cyclicity, reaching minimal values within the indurated layers, which define the bottom and top of the cycles. By contrast, the highest values tend to be reached in the upper part of the cycles (see Fig. 2) which coincides with the dominance of the warm oligotrophic fauna and flora.

Sorbas basin cyclicity and the astronomical time scale

Over the last decade, cyclostratigraphic, magnetostratigraphic and biostratigraphic studies of cyclically bedded sections in the Eastern Mediterranean have led to the construction of an astronomical time scale for the Pleistocene and Pliocene (Hilgen, 1991a, b). This astronomical time scale was constructed by tuning the sapropel pattern to the astronomical solutions for the variations in the Earth-Sun geometry. The tuning procedure was based on the hypothesis that, in the Eastern Mediterranean, sapropels were only formed at times of prominent peaks of summer insolation in the northern hemisphere (Hilgen, 1991a, b).

In recent years, the MIOMAR European Program (Miocene Marine Archives Reading) has mainly aimed at extending the Astronomical Time Scale into the Upper and Middle Miocene (Hilgen *et al.*, 1995; Krijgsman *et al.*, 1995), although the occurrence of the Evaporite unit during the upper Messinian has not permitted the construction of a continuous cyclostratigraphic record. Despite this problem, Hilgen *et al.* (1995) were able to extend the astronomical time scale into the Miocene using sedimentary cycle patterns, especially the sapropel pattern, and their calibration to astronomical target curves.

However, a significant gap, including the Mediterranean Evaporites and the underlying pre-evaporitic sediments of the Upper Messinian, still exists. The Sorbas basin could be an appropriate area for closing this «Messinian gap» in the astronomical time scale.

Conclusions

A series of sedimentary cycles have been recognized in the pre-evaporitic Messinian of the Sorbas basin. According to age estimates based on biostratigraphic events calibrated to the magnetostratigraphic scale in other areas (Northeast Atlantic and eastern Mediterranean), the average periodicity of these cycles is around 23.5 kyr. This suggests that they are related to variations in the precession of the Earth's orbit.

The present study confirms the existence of sapropels in the western Mediterranean; these sapropels may be used for calibration to astronomical target curves in the same way as eastern Mediterranean sapropels.

A high resolution study of the micropaleontological and geochemical variables leads us to conclude that the variations in the astronomical parameters were strongly amplified owing to the restricted conditions existing in the basin. Repeated and cyclic fluctuations in the structure of the water column strongly limited the mixing process within the basin, leading to the repeated appearance of stagnant conditions in bottom waters.

Intervals with warm-oligotrophic fauna and flora in the upper part of sapropels probably correlate with periods of maximum summer insolation in the northern Hemisphere due to a reduction in the hydrologic deficit of the Mediterranean.

The cyclicity identified in this work may well be compared to that recognized in the margins of the Sorbas basin by Dabrio and Polo (1995) and Martín *et al.* (1996).

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