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Preliminary integrated magnetostratigraphic and biostratigraphic correlation in the Miocene Lorca basin, (Murcia, SE Spain)

Correlación magnetoestratigráfica y bioestratigráfica en la cuenca Miocena de Lorca (Murcia, SE de España)

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ABSTRACT

The Lorca basin is one of the Neogene basins of South Eastern Spain. The infilling Tortonian-Messinian deposits are mainly composed of marls and reach up to 1,200 m in thickness. A biostratigraphic survey of these deposits, assisted by the determination of the magnetic polarity reversal pattern for most of these deposits (900 m), has enabled the Tortonian-Messinian chronostratigraphy to be precised. The close sampling space for biostratigraphic determination has enabled the accurate location of four main biostratigraphic events than can be correlated with characteristic events of the Mediterranean biostratigraphic Zones. In addition, the location of the Tortonian/Messinian boundary has been accurately placed at some 150 m below the main gypsum unit outcropping in the basin. The integrated bio-magnetostratigraphic data from the studied section allows a tentative interpretation of the identified magnetozones. Thus, a correlation to the Geomagnetic Polarity Time Scale is presented for more than 900 m of pre-evaporite Miocene stratigraphic succession from the Lorca basin. Moreover, about 15° of anticlockwise rotation has been detected. Its significance is evaluated in the basin geodynamic framework.

Keywords: Magnetostratigraphy. Biostratigraphy. Messinian. Lorca basin. Betic Cordillera.

RESUMEN

La cuenca de Lorca es una de las cuencas neógenas del sureste de España. Los depósitos de edad Tortoniense-Messiniense son mayoritariamente margosos y llegan a alcanzar hasta 1.200 m de espesor en el depocentro. Se ha refinado la estratigrafía para los sedimentos de esta edad, a partir de los resultados de un estudio bioestratigráfico de toda la sucesión, y de la determinación del modelo de inversión de polaridad magnética para la mayor parte de los depósitos (900 m). La alta resolución en el espaciado del muestreo biostratigráfico ha permitido detectar cuatro eventos biostratigráficos principales que pueden ser correlacionados con eventos característicos de las Zonas Biostratigráficas del Mediterráneo. Además, se ha precisado la posición del límite Tortoniense/Messiniense a unos 150 m por debajo de la unidad evaporítica (yesos de la Serrata) aflorante en la cuenca. La integración de los resultados bio- y magnetostratigráficos ha permitido una interpretación tentativa de las magnetozonas identificadas. Así pues, se presenta la correlación de más de 900 m de la sucesión estratigráfica del Mioceno preevaporítico aflorante en la cuenca de Lorca con la Escala Temporal de Polaridad Magnética. Además, se han detectado unos 15° de rotación antihoraria, el significado de la cual se evalúa en el marco geodinámico de la cuenca.

Palabras clave: Magnetoestratigrafía. Bioestratigrafía. Messiniense. Cuenca de Lorca. Cordilleras Béticas.

INTRODUCTION

The study of the Tortonian/Messinian deposits from the Neogene Mediterranean Basins and their relation with the so-called "Messinian salinity crisis" has been addressed by many authors since the 1970's. Some major problems still unresolved are the age and correlation of reef events between different basins and the precise timing and contemporary deposition of evaporites for the whole Mediterranean region (Rouchy and Saint Martin. 1990). Timing, significance and relationships of restricted (anoxic/hypersaline) facies associations with the Tortonian/Messinian reefs and evaporites are also still major goals in the study of the Mediterranean Neogene basins. Although much work has been done in these basins, good age constraints are still lacking in some of them. However, recent work and work under progress carried out by several teams (Gautier et al., 1994; McClelland et al., 1996; Krijgsman et al., 1996; Franseen y Goldstein, 1996, and the hereby presented results) on the biostratigraphy, magnetostratigraphy and absolute dating in these basins, will enlarge the data set of the existing framework for correlation of the main sedimentary events in the Mediterranean during the Upper Neogene.

The Tortonian/Messinian sedimentary succession of the Lorca basin (SE Spain) together with equivalent Sicilian counterpart sections in the Caltanissetta basin have been targeted in an integrated multidisciplinary project (NATENMAR / EU-funded project), combining sedimentology, micropaleontology, isotope geochemistry, organic and inorganic geochemistry and magnetostratigraphy. This research has enabled the characterization of the environmental changes during deposition and early diagenesis in these Mediterranean successions that record an increase in restriction from open-marine to hypersaline depositional conditions (Russell et al., 1997; NATENMAR network and Rouchy, 1997, Sprovieri et al., 1996). In this report we shall discuss the first results on the temporal framework in the Lorca basin, constrained by an integrated biostratigraphic and magnetostratigraphic survey. The paper shall also address the main changes in the sedimentary environment recorded during the restriction of the basin and represented by the main units distinguished in the studied section. In addition, the potential of the paleomagnetic techniques (derived structural block rotations and anisotropy of magnetic susceptibility, AMS) for evaluating some tectonic and sedimentary aspects will be addressed.

GEOLOGICAL SETTING

The Lorca basin is a 200 km^2 basin lying on the boundary of the Internal Zones (Betic) and the External Zones (Subbetic) of the Betic Cordillera in SE Spain (Fig. 1). The origin of the basin has been considered as a result of strike-slip faulting or a combination of strike-slip and normal conditions (e. g. Montenat et al., 1987; Sanz de Galdeano, 1990; Guillén Mondéjar et al., 1995), who consider the basin as an hybrid case between a pull-apart and a graben basin. In addition, the formation of the basin has been related to extensional-collapse (e. g. Platt and Vissers, (1989).

Since the early work of Geel (1976), many other authors have studied the tectonosedimentary record of the Lorca basin and have defined different stratigraphic units within the basin infill sediments. In the southwestern part of the basin, in the area northwest of the town of Lorca, and along a conspicuous ridge known as La Serrata, Geel (1976) defines two main formations. The Hondo formation overlies shallow marine sediments that interfinger with deltaic conglomerates and sandstones. This formation consists of marine marls containing planktonic foraminifera which interfinger with coastal alluvial fan deposits to the south of the Sierra de la Tercia. Above the Hondo formation, Geel (1976) informally defines the Serrata formation, which includes Messinian gypsiferous deposits. This author subdivides the Serrata formation into three members: a lower Varied member (pelites, sandstones, diatomites, carbonates and gypsum beds), a mid-

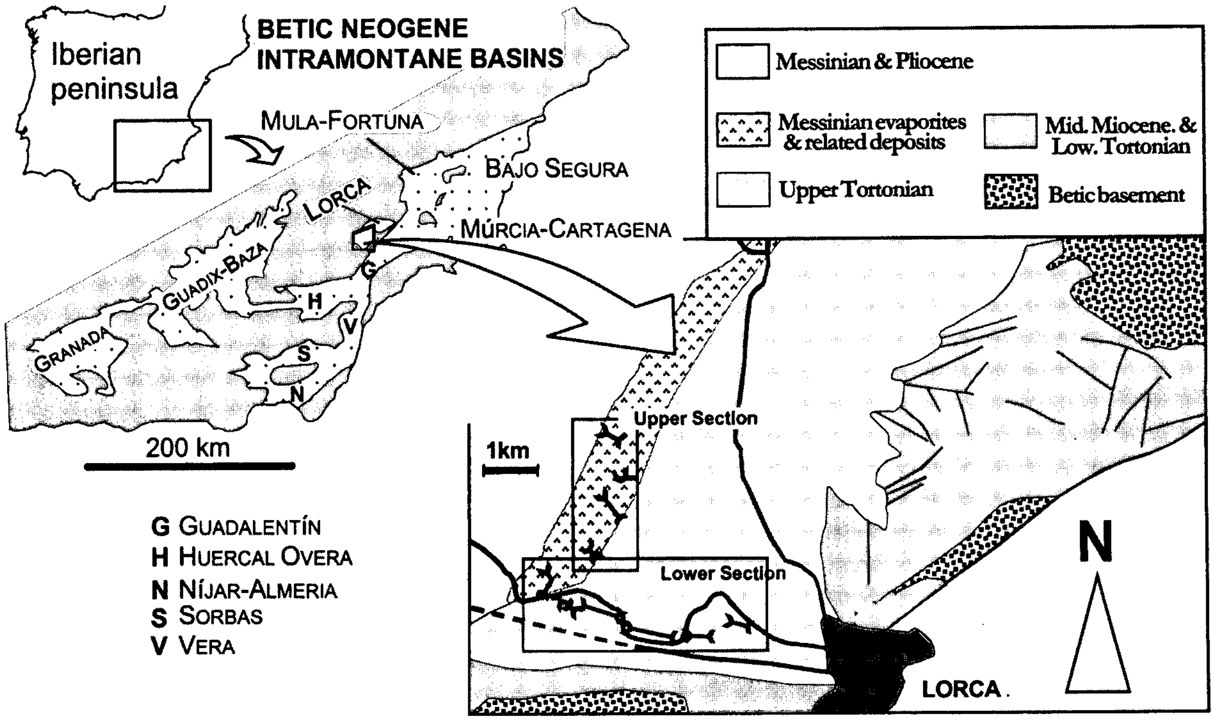

Figure 1. Geological sketch with location of the sampled sections. The boxes indicate the composite parts of the lower and upper sections as in Fig. 2.

Figura 1. Esquema geológico con la situación de las sucesiones estudiadas. Los recuadros indican las sucesiones compuestas tal como se presentan en la Fig. 2.

dle Gypsum member (the main gypsum body), and an upper Laminated pelite member (laminated pelites, sandy calcarenites and gypsum beds). The thickness and lateral continuity of these units change both towards the southwest, where the Serrata formation interfingers with the top of deltaic deposits, and also towards the northeast, where, in particular, the lower Varied member thins out and the gypsiferous deposits merge laterally into shallow marine conglomerates, calcarenites and coral limestones. More recently Guillén Mondéjar et al. (1995, 1996) have distinguished five tectonosedimentary units from the upper Burdigalian to the Pliocene infill sediments, which in turn include a total of twelve formations.

THE TORTONIAN/MESSINIAN DEPOSITS OF THE LORCA BASIN

The studied composite section (about 1.200 m) starts in the Tortonian marls west of Lorca (Fig. 1) and comprises three main lithological units, forming a sequence which begins with marine marls -the Hondo Fm. of Geel (1976) or the Carivete Fm of Guillén Mondéjar et al. (1995)-, grades upward to laminated diatomite-bearing deposits -the Varied member of Geel (1976) or Tripoli Fm. in the central Mediterranean- and ends in an evaporitic formation -La Serrata Gypsum Fm. or the Gypsum member of Geel (1976). The karstified surface of the gypsum is covered by undifferentiated Late Messinian to Quaternary continental deposits. The lithology and mineralogy of these three major units represent different environmental conditions.

The *lower unit* (990 m) is mainly composed of homogeneous marlstones, with local syndepositional slides. The upper 60 m of the unit exhibit intercalations of several dm-thick sandstone and dolomite beds. This unit finishes in a thin sandstone bed, immediately below the first diatomite deposits of the next unit.

The *middle unit* (130 m) is subdivided into two major terms:

1) The lower term (90 m thick) is composed of thick levels of finely laminated diatomites. These are occasionally silicified and are found interbedded with silty claystones or

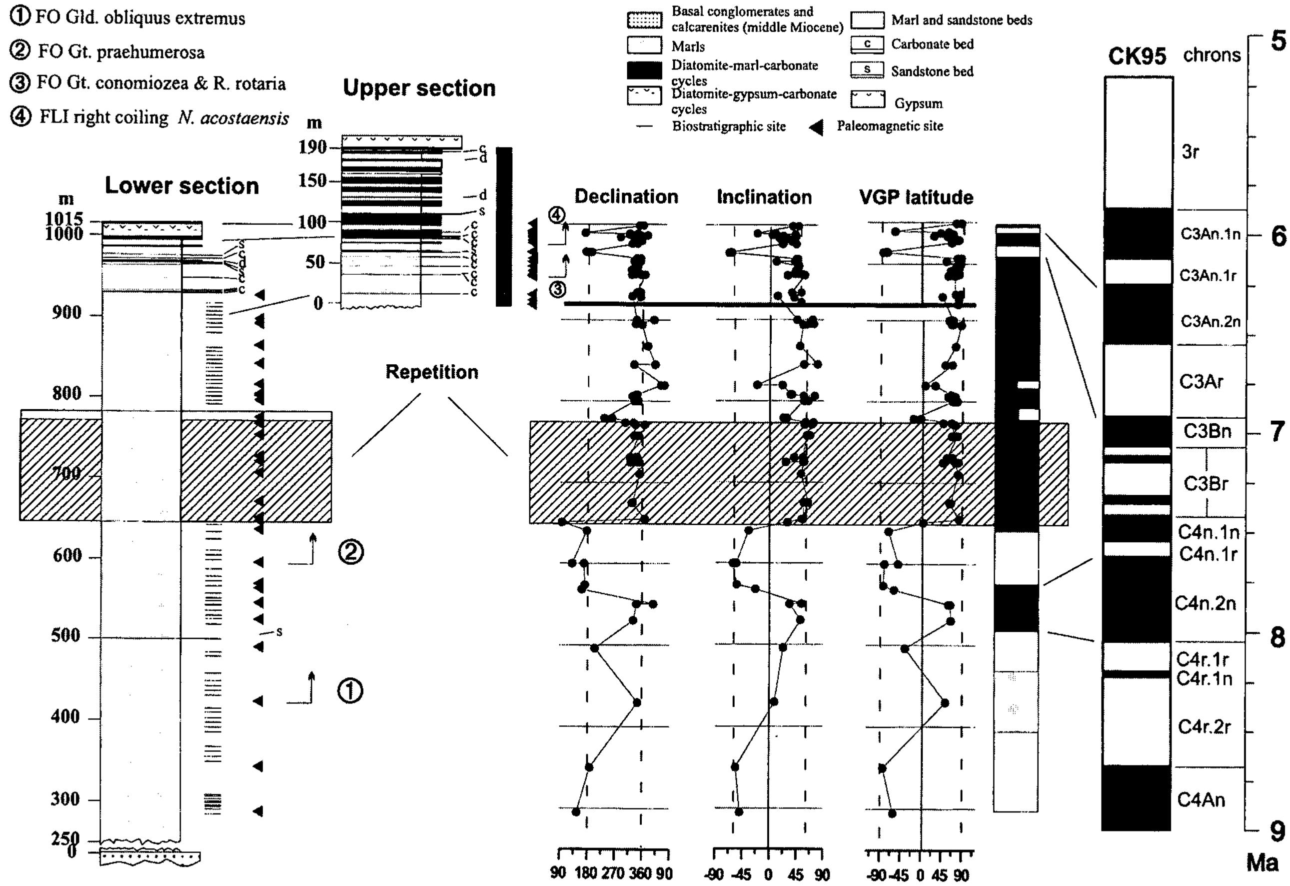

Figure 2. Lithologic, biostratigraphic and magnetostratigraphic data for the Lorca composite section.

Figura 2. Datos litológicos, bioestratigráficos y magnetoestratigráficos de la sucesión compuesta de Lorca.

marlstones and dolomite beds. The significant biosiliceous fraction and the presence of layers with high organic contents indicate that deposition occurred in a marine environment with both high productivity and restricted bottom conditions (Geel, 1976; Rouchy, 1982; Permanyer et al., 1994; Benali et al., 1995; Russell et al., 1997).

At least five main levels of sulphur-bearing dolomitic limestones, less than 1 m thick, are interbedded within the diatomitic intervals and are associated with aragonite layers. The relics of unaltered gypsum, as well as the carbonate pseudomorphs after gypsum crystals, indicate that these deposits were formed during periods of hypersaline conditions. At the eastern margin of the basin, these hypersaline episodes are recorded by thicker intercalations of primary gypsum and anhydrite (Geel, 1979; Rouchy, 1982).

2) The upper term (40 m) is mostly composed of silty claystones, containing mm-thick intercalations of diatomites in the lower part, and some thin dolomitic beds. Towards the top there are intercalations of dm to m-thick beds of reddish sandstones. The topmost part of this term, just below the massive gypsum unit, corresponds to about 2 m of dolomitic mudstones. The higher content of terrigenous components and the reddish color of the sediments suggest an increasing continental influence in the upper part of the series.

The *upper unit* (40 m of maximum thickness) is composed of gypsum displaying detrital, laminated and nodular features. Syndepositional deformations are observed in the lower part. Thick intercalations of silty claystones and brecciated deposits are locally associated with the gypsum, indicating that periods of erosion and karstification occurred either syndepositionally or later during the Pliocene. A salt formation of up to 200 m-thick is known from two boreholes. The evaporites were precipitated from marine brines, as indicated by the isotope composition of the sulfates and by the geochemistry of the halite fluid inclusions (Rouchy and Pierre, 1979;

Ortí et al., 1993; Ayora et al., 1994), except for the upper part of the salt where recycling occurred (Ayora et al., 1994).

CALCAREOUS PLANKTON BIOSTRATIGRAPHY

Foraminiferal assemblages are generally badly preserved along the section and planktonic foraminifera are only a minor component of the assemblage. Nevertheless, the investigation of many samples, about every 5 meters up to 900 meters and about every meter in the following upper part, allows the identification of 4 biostratigraphic events, namely the first occurrence (FO) of *Glogiberinoides obliquus* extremus at 420 m (lower section; Fig. 2), the FO of *Globorotalia praehumerosa* at 597 m (which just follows the last occurrence of *Globorotalia continuosa*), the FO of *Globorotalia conomiozea* (very rare) at 35 m (upper section; Fig. 2), and the first local increase (FLI) in abundance of right coiling specimens of *Neogloboquadrina acostaensis*, at 71.50 m (upper section; Fig. 2). In terms of Mediterranean biostratigraphic Zones (Iaccarino, 1985), the first event coincides with the base of the *Globigerinoides obliquus extremus / Globigerinoides bulloides Zone*. The FO of *Gt. praehumerosa* just predates (Sprovieri et al., 1996) the appearance level of *Globorotalia suterae*, a biostratigraphic marker which was not found in the Lorca section, therefore, the *Gt. praehumerosa* FO allows the approximation of the base of the *Gt. suterae* Zone. In coincidence with the first appearance of *Gt. conomiozea* the base of the *Gt. conomiozea* Zone (and the Tortonian / Messinian boundary) was identified. Finally, the first occurrence of dominant right coiling specimens of *N. acostaensis* identifies the "non distinctive" Zone. In the segment between 640 and 775 m of the lithological log reported in Fig.2 (lower section), *Gt. praehumerosa* was not found, but *Gld. obliquus extremus* and *Gt. continuosa* are present. Consequently, we conclude that this segment represents a repetition of the segment included between 420 and 590 m (lower section; Fig. 2). In the upper part of the section, about 20 meters thick, between about 180 m and the base of the gypsum layer, the foraminiferal assemblage is composed only of species reworked from Cretaceous and Eocene sediments.

Concerning the calcareous nannofossil biostratigraphy, only one event was detected, since the assemblage is always very poor and badly preserved, with a high degree of dissolution and/or overgrowth. Placoliths of *Reticulofenestridae* are the dominant group. Late Miocene stratigraphic markers belonging to Asteroliths and Ceratoliths are absent or extremely rare. On the contrary, very abundant taxa reworked from Cretaceous to Middle Miocene sediments occur. The *Reticulofenestra rotaria* FO was identified at 35 m, allowing the recognition of the *R. rotaria* Zone, which is virtually coincident with the base of the *Gt. conomiozea* biozone (Sprovieri et al., 1996).

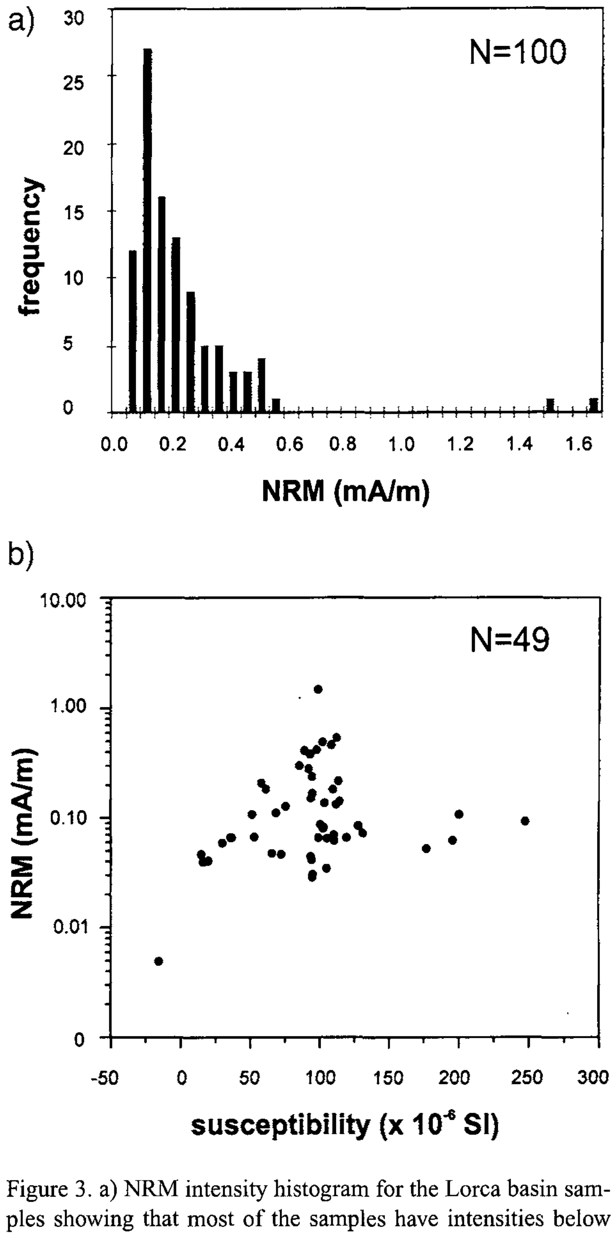

Figure 3. a) NRM intensity histogram for the Lorca basin samples showing that most of the samples have intensities below 0.3 mA/m. b) plot of the NRM intensity versus susceptibility.

Figura 3. a) El histograma de la intensidad de la magnetización remanente natural de las muestras de Lorca indica que la mayoría de muestras presentan magnetización inferior a 0.3 mA/m. b) diagrama de relación entre magnetización remanente natural y susceptibilidad magnética.

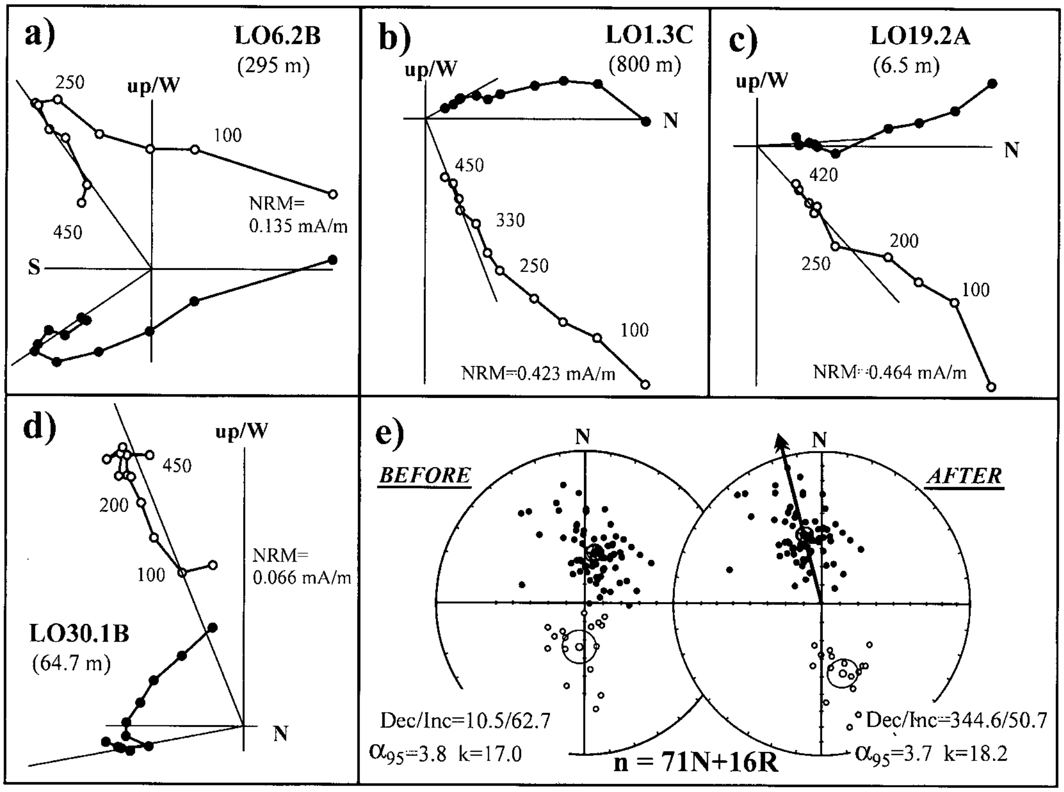

Figure 4. a) to d) Typical orthogonal plots of thermal demagnetization of the Lorca basin samples. Solid (open symbols) represent projections on the horizontal (vertical) plane. a) and b) from the lower section, and c) and d) from the upper section. e) Equal area projections of the ChRM directions before and after bedding correction. The 95% confidence ellipse for the normal and reverse mean direction is indicated.

Figura 4. de a) a d) Diagramas ortogonales de desmagnetización térmica de muestras representativas. Círculos negros (blancos) representan la proyección sobre el plano horizontal (vertical). a) y b) muestras de la sucesión inferior de Lorca; c) y d) de la sucesión superior. e) Proyección estereográfica equiareal de las direcciones paleomagnéticas características antes y después de la corrección tectónica. Se indica también la elipse de confianza (α_{95}) de las direcciones medias normal e inversa.

PALEOMAGNETIC SAMPLING AND RESULTS

A total of 62 sites are distributed along the Lorca composite section (Fig. 2). In the lower 250 m of the studied section, sampling was confined to a series of adjacent outcrops with often no suitable material for paleomagnetic purposes, thus providing a loose sampling interval in this part. A minimum of two standard paleomagnetic samples were drilled and oriented in-situ at each site, although in some instances an oriented hand sample was collected instead. Stepwise thermal demagnetization was used to unravel the natural remanent magnetization (NRM) components. NRM intensity ranges between 0.05 to 0.5 mA/m, although few samples have intensities of around 1.5 mA/m (Fig. 3a). The magnetic susceptibility in the studied rocks is around 100 x 10^{-6} SI (Fig. 3b). Only one sample, from a dolomite bed located at about 100 m from the base of the upper Lorca section has negative susceptibilities, due to its major diamagnetic contribution. Typical orthogonal demagnetization plots are illustrated in Fig. 4a-d. At low temperatures, and up to approx. 300 °C, a northerly downward oriented component is demagnetized, in addition to a randomly oriented component of viscous origin removed below 100 °C. Usually above 300 °C and up to approx. 450 °C a characteristic remanent component (ChRM) of either normal (Fig. 4b, 4c) or reverse polarity (Fig. 4a, 4d) is successfully recovered. Acquisition of spurious magnetization above that temperature due to breakdown of mineral phases and creation of new magnetite prevents the full demagnetization of the NRM. ChRM directions were computed by principal component analysis from the demagnetization data. Only in five sites did the acquisition of spurious magnetization due to heating, coupled with its original low NRM intensity, prevent the computation of the ChRM directions. Those sites were not used for the magnetostratigraphy. The declination and inclination of the ChRM component are used to compute the latitude of the virtual geomagnetic pole (VGP), which defines the normal (positive VGP latitude) or negative polarities (negative VGP latitude).

Although no significant fold test is available due to the similar bedding along the section (dip direction/dip angle=300/20), the presence of both normal and reverse components, in addition to a low-temperature recent overprint, suggests a primary nature for such components. Moreover, the normal mean direction before bedding correction (dec/inc=11.2/61.9, α_{95}=4.2) is significantly different from the present geomagnetic field.

A total of 9 magnetozones have been identified (Fig. 2). The lower half of the studied section is predominantly reverse although sampling resolution is very loose (around 70 m) in the first 250 m, as mentioned above, In this part, two consecutive normal then reverse magnetozones are supported by only one sampling site. The upper half of the studied section is predominantly normal. This includes a normal magnetozone, approx. 350 m long, which includes two poorly defined reverse intervals. The uppermost part of the section consists of a r-n-r-n succession of narrow zones.

Vertical-axis block rotations and anisotropy of magnetic susceptibility (AMS)

The mean direction of the characteristic remanence (ChRM) after bedding correction (Fig. 3e) implies about 15° anticlockwise rotation for this area (see discussion below).

The anisotropy of magnetic susceptibility (AMS) was measured in at least one specimen from most of the sites in order to determine the magnetic fabric and to determine whether it reflected a sedimentary fabric or a tectonic imprint that would induce any deflection of the paleomagnetic components (Dinarès-Turell et al., 1991, Parés and Dinarès-Turell, 1993). The AMS is a second order tensor that can be represented by an ellipsoid determined by the three orthogonal principal susceptibility axes (K_{max}, K_{int} and K_{min}). All mineral phases present in the rock (ferromagnetic, paramagnetic and diamagnetic phases) contribute to some extent to the magnetic susceptibility. Conversely, the magnetic remanence is only carried by the ferromagnetic phases. In Figure 3a it can be seen that there is no direct correlation of NRM intensity to magnetic susceptibility and therefore we may conclude that magnetic susceptibility and AMS is likely to be dominated by the paramagnetic phases (clays in this type of sediments), although NRM alone may not represent the best estimate for the ferromagnetic content. In Fig. 5 the shape anisotropy parameter (T) (T<1 for prolate or cigar ellipsoid and T>1 for oblate or disc-shaped ellipsoids) is plotted against the anisotropy degree P' (Jelinek, 1991). The anisotropy degree is usually low (P'<1.05), with the exception of a single sample. It can also be seen that both oblate and prolate forms exists. There seems not to be a clear correlation between lithology or stratigraphic position with the shape of the AMS ellipsoid. For the oblate ellipsoids (Fig 5b), the mean K_{min} axis conforms to the bedding pole and K_{max} is grouped in a W-SW subhorizontal direction. This could be interpreted as a typical sedimentary fabric, where K_{max} would represent the depositional paleocurrent direction. The majority of the prolate ellipsoids have a similar orientation as the oblate ellipsoid, but with K_{max} and K_{min} interchanged. In this case Kmax is aligned with the bedding pole and K_{min} conforms to the subhorizontal W-SW direction. One explanation that could account for the observations is that the ellipsoids with subvertical K_{max} represent an inverse fabric. Inverse fabrics are those which do not conform to the petrofabric (either sedimentary or tectonic) and are known to occur in nature related to several mineralogical controls (e. g. Rochette, 1988; Ihmle et al., 1989). The fact that the K_{max} direction is consistently grouped all along the section and that this direction is parallel to the elongated direction of the basin and perpendicular to the dip direction makes us suspect that the actual observed fabric could also represent a weakly tectonic fabric. Further constraints on the origin and nature of the AMS in the Lorca basin should be obtained after a more extensive sampling, targeting the different lithological units throughout the basin.

INTEGRATED BIOSTRATIGRAPHIC AND PALEOMAGNETIC CORRELATION

The integrated bio-magnetostratigraphic data of the section allows an interpretation of the identified magnetozones. The *Gld. obliquus extremus* FO was detected in a reversed interval with the age of this bioevent being estimated at 8.28 Ma (Sprovieri et al., 1996). Therefore this event can be correlated with the reversed subchron C4r.1r (Cande and Kent, 1995; Krijgsman et al., 1995) and the normal event above can be interpreted as C4n.2n. The reversed interval recording the FO of *Gt.*

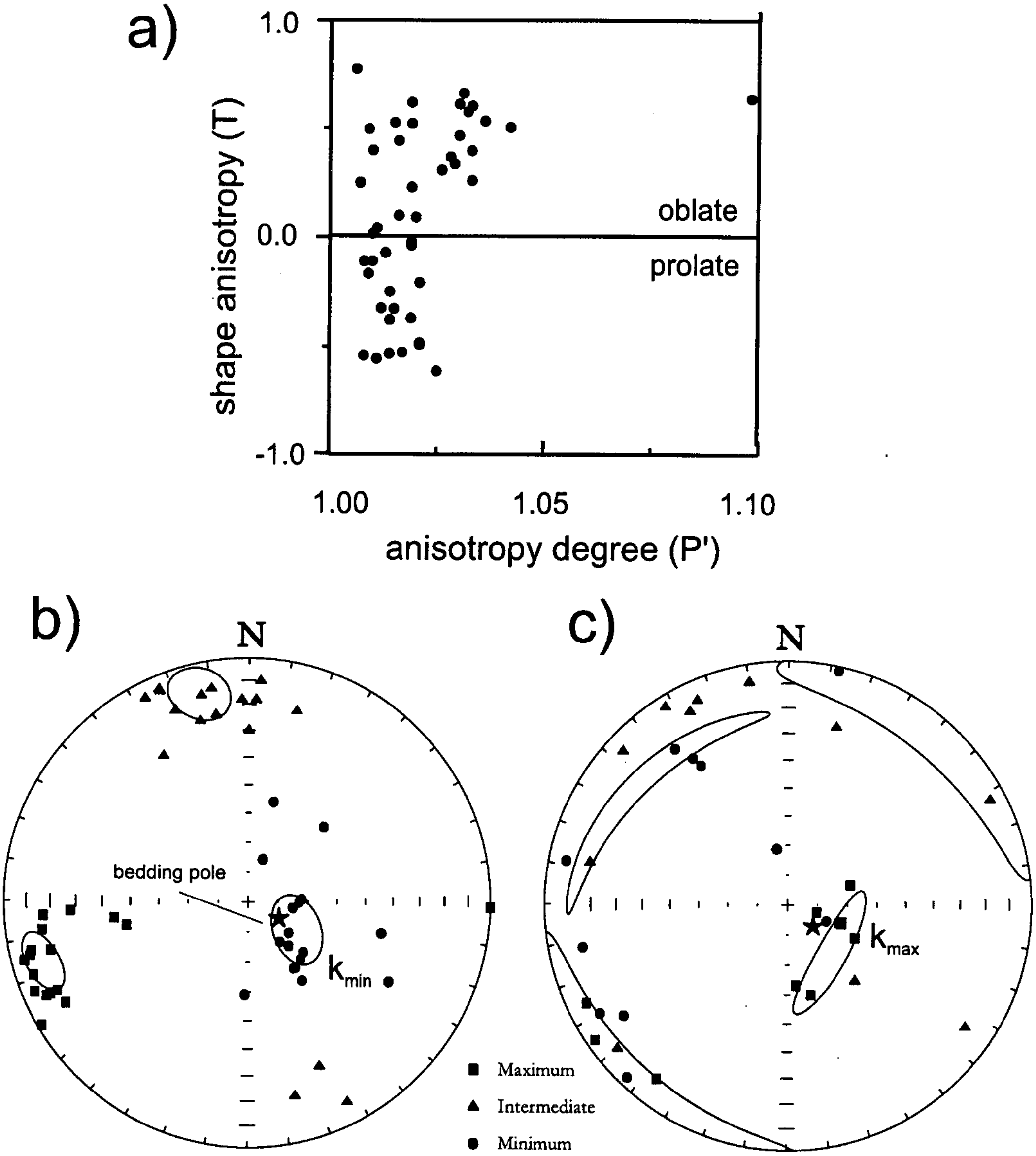

Figure 5. a) Hrouda-Jelinek diagram showing the presence of both oblate and prolate ellipsoids. b) and c) equal area projections of the principal susceptibility axis for the oblate and prollate ellipsoids respectively.

Figura 5. a) Diagrama de Hrouda-Jelinek mostrando la presencia de fábricas magnéticas lenticulares y en forma de huso. b) y c) proyección estereográfica de los ejes principales de susceptibilidad de las muestras de fábrica lenticular y en huso respectivamente.

praehumerosa can be correlated with C4n.1r, and then the normal interval above is ascribed to C4n.1n. The available paleomagnetic data indicates normal polarities between 650 and 900 m, with only two not well documented, narrow, potentially reversed zones at around 779 m and 819 m (lower section; fig. 2) and we tentatively correlate this interval to include the reversed subchrons C3Br.3r and C3Br.2r and also the normal subchrons C3Br.2n and C3Br.1n. The postulated repeated interval between 640 and 775 m only records normal polarity and therefore is in conflict with the biostratigraphic determinations which implied that this interval should be a repetition of a lower part of the section that includes reversed polarities. Consequently, it may be argued that some of the observed normal polarities may actually represent overprinted samples. The normal polarity interval between 13 and 62 meters from the upper Lorca section, in which the FO of *Gt. conomiozea* was detected, is ascribed to C3Bn. Above the *Gt. conomiozea* FO, the beginning of dominance of right coiling *N. acostaensis* is a world-wide biostratigraphic event, which occurs in the normal C3An.2n magnetozone (Sprovieri et al., 1996).

In conjunction, the actual biostratigraphic and magnetostratigraphic determinations in the Lorca basin enable: 1) the unambiguous placing of the Tortonian/Messinian boundary at about 150 m below the main gypsum unit and 2) the detection and location of four biostratigraphic events that occur in magnetozones of either normal or reverse polarity, as is found elsewhere in the Mediterranean.

CONCLUSIONS

The Miocene sedimentary succession of the Lorca basin has been classically interpreted as the result of progressive restriction of the open marine environment which prevailed during the Tortonian/early Messinian. This restriction ended with the continental conditions of the Pliocene, through a period of restricted marine environments recorded by the diatomite-bearing deposits and a thick evaporitic unit. The results of this multidisciplinary study reveal a more complex evolution of the basin infill. The close sampling for biostratigraphical determinations, coupled to magnetostratigraphy, has allowed the dating of the sediments infilling the Lorca basin and also of the onset of evaporitic conditions. The detection of a significant anticlockwise structural block rotation of the Tortonian deep water deposits and the Lower Messinian shallow water sediments emphasizes the importance of the tectonic control in this basin, which is also reflected in the sedimentation of the infilling sediments.

Shallow water conditions prevailed during the deposition of the Tripoli and evaporitic formations up to the top of the section, where continental influence increases progressively. Following the restriction of the basin, the combined effects of the sea-level fluctuations and of the climate changes may explain the episodic phases of high productivity-bottom stagnation and hypersaline conditions responsible for gypsum deposition. The episodic deposition of primary gypsum/anhydrite under either subaqueous or desiccated conditions during the deposition of the Tripoli Fm demonstrates that, in the Lorca basin, the onset of episodic evaporitic conditions occurred long before the deposition of the main evaporitic unit. Continental influences in the basin are recorded soon after the deposition of the Messinian Tripoli Fm, although the main evaporite unit was deposited mainly under the influence of marine waters

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REFERENCES

Ayora, C., García-Veigas, J., Pueyo, J.J., 1994. X-ray microanalysis of fluid inclusions and its application to the geochemical modeling of evaporite basins. Geochim. Cosmochim. Acta, 58, 43-55.

Benali, S., Schreiber, B.C., Helman, M.L., Philip, R.P., 1995. Characterization of organic matter from a restricted evaporative sedimentary environments: late Miocene of Lorca Basin, southeastern Spain AAPG Bull., 79(6), 816-830.

Cande, S.C., Kent, D.V., 1995. Revised calibration of the Geomagnetic Polarity Time Scale for the Late Cretaceous and Cenozoic. J. Geophys Res., 100, 6093-6095.

Dinarès Turell, J., McClelland, E., Santanach, P. 1991. Contrasting Rotations within Thrust Sheets and Kinematics of Thrust-Tectonics as derived from Palaeomagnetic data: an excample from the southern Pyrenees. In K.R. McClay (ed.), Thrust Tectonics, Chapman and Hall, London, 255-265.

Franseen, E.K., Goldstein, R.H., 1996. Paleoslope, sea-level and climate controls on Upper Miocene platform evolution, Las Negras area, Southeastern Spain. In E.K. Franseen, M. Esteban, W.C. Ward, J.M. Rouchy (eds.). Models for carbonate stratigraphy from Miocene reef complexes of Mediterranean regions, SEPM Concepts in Sedimentology and Paleontology, 5, 159-176.

Gautier, F., Clauzon, G., Suc, J.P., Cravatte, J., Violanti, D., 1994. Age et durée de la crise de salinité messinienne. C. R. Acad. Sci. Paris, 318, sér. II, 1103-1109.

Geel, T., 1976. Messinian gypsiferous deposits of the Lorca basin (province of Murcia, SE Spain). Mem. Soc. Geol. It., 16, 369-385.

Guillén-Mondéjar, F., Rodríguez-Estrella, T., Arana, R., López-Aguayo, F., 1995. Unidades tectonosedimentarias y rupturas en la Cuenca de Lorca (Murcia). Geogaceta, 17, 39-42.

Guillén-Mondéjar, F., Arana, R., M.T. Fernández, López-Aguayo, F., Mancheño, M.A., Pérez Lorente F., Rodríguez-Estrella, T., Serrano, F., 1996. Las formaciones del mapa geológico a escala 1:25.000 de la Cuenca de Lorca (Murcia). Geogaceta, 20(5), 1196-1199.

Iaccarino, S., 1985. Mediterranean Miocene and Pliocene plnaktic foraminifera. In H.M. Bolli et al. (eds.). Plankton Stratigraphy, Cambridge University Press, 283-314.

Ihmlé, P. F., Hirt, A. M., Lowrie, W., Dietrich, D., 1989. Inverse magnetic fabric in deformed limestones of the Morcles nappe, Switzerland. Geophys Res. Lett. 16, 12, 1383-1386.

I.G.M.E., 1974. Mapa Geológico de España, Plan Magna, E 1/50.000, Hoja 953 Lorca.

Jelinek, V., 1981. Characterization of the magnetic fabric in rocks. Tectonophysics, 79, 63-67.

Krijgsman, W., Hilgen, F.J., Langereis, C.G., Santarelli, A., Zachariasse, W.J., 1996. Late Miocene magnetostratigraphy, biostratigraphy and cyclostratigraphy from the Mediterranean. Earth Planet. Sci. Lett., 136, 475-494.

McClelland, E., Finegan, B., Butler, R. W. H. A., 1996. A magnetostratigraphic study of the onset of the Mediterranean Messinian Salinity Crisis, Caltanissetta Basin, Sicily. In A. Morris, D. H. Tarling (eds.). Palaeomagnetism and Tectonics of the Mediterranean Region, Geological Society Special Publication nº 105, 53-57.

Montenat, C., Ott d'Estevou, P., Masse, P., 1987. Tectonic sedimentary characters of the Betic Neogene basins evolving a crustal transcurrent shear zone (SE Spain). Bull. Centr. Rech. Expl.-Prod. Elf Aquitaine, 11, 1-22.

NATENMAR network, Rouchy, J.M. 1997. Natural markers in Messinian restricted environments. Terrra Nova, 9, Abstract Supplement No 1.EUG 9 General Assembly, Strasbourg (France), 399.

Ortí, F., García-Veigas, J., Rosell, L., Rouchy, J.M., Inglès, M., Gimeno, D., Kasprzyk, A., Playà, E., 1993. Correlación litostratigráfica de las evaporitas messinienses en las cuencas de Lorca y Fortuna (Murcia). Geogaceta, 14, 98-101.

Parés, J. M., Dinarès-Turell, J., 1993. Magnetic fabric in two sedimentary rock-types from the southern Pyrenees, J. Geomag. Geoelectr., 45, 2, 193-205.

Permanyer, A., Baranger, R., Lugardon, B., 1994. Oil shale characterization in Messinian pre-evaporitic sediments from the Lorca bassin (south-east Spain). Bull. Centr. Rech. Expl.-Prod. Elf Aquitaine, 18, 135-149.

Platt, J.P., Vissers, R.L.M., 1989. Extensional collapse of thickened continental lithosphere: a working hypothesis for the Alboran Sea and the Gibraltar arc. Geology, 17, 540-543.

Rochette, P., 1988. Inverse magnetic fabric in carbonate-bearing rocks. Earth Planet. Sci. Lett. 90, 229-237.

Rouchy, J.M., 1982. La crise evaporitique messinienne de Mediterranee; nouvelles propositions pour une interpretation genetique. Mémoire du Muséum National d'Histoire Naturelle, Nou. Sér., C.T.L., 267 p.

Rouchy, J.M., Pierre, C., 1979. Donnees sedimentologiques et isotopiques sur les gypses des series evaporitiques messiniennes d'Espagne meridionale et de Chypre. Rev. Géogr. Phys. et Géol. Dynam., 21(4), 267-280.

Rouchy, J.M., Saint-Martin, J.P., 1990. Late Miocene events in the Mediterranean as recorded by carbonate-evaporite relations. Geology, 20, 629-632.

Russell, M., Taberner, C., Rouchy, J.M., Grimalt, J.O., 1997. Evidence from biomarkers for variations in the depositional environments of the Messinian sediments of the Lorca basin (SE Spain). Terrra Nova, 9, Abstract Supplement No 1 EUG 9 General Assembly, Strasbourg (France), 269.

Sanz de Galdeano, C., 1990. Geologic evolution of the Betic Cordilleras in the western Mediterranean, Miocene to present. Tectonophysics, 172, 107-119.

Sprovieri, R., Di Stefano, E., Sprovieri, M., 1996. High resolution chronology for Late Miocene Mediterranean stratigraphic events. Riv. Ital. Paleont. 102(1), 77-104.