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Facies associations, sequence stratigraphy and timing of the earliest Jurassic peak transgression in central Spain (Iberian Range): Correlation with other Lower Jurassic sections

Asociaciones de facies, estratigrafía secuencial y edad del primer máximo transgresivo del Jurásico en España central (Cordillera Ibérica): Correlación con otras secciones del Jurásico Inferior

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Abstract

Facies associations and sequence stratigraphy of the Lower Jurassic shallow platform to peritidal carbonates of the Cuevas Labradas Formation (Sinemurian to Pliensbachian) have been studied in the Barranco de la Hoz section, located in the central−southern part of the Iberian Range.

Four stratigraphical units (A to D) have been differentiated. Unit A, deposited in a restricted platform, is organized in aggradational thickening- and shallowing-upward sequences. Unit B, deposited in external restricted platform environments, is composed of shallowing- and deepening-upward sequences. This unit contains *Polymorphites* sp., *Uptonia* cf. *jamesoni* (SOW.) and *Uptonia* cf. *angusta* (QUENST.) that characterize the upper part of the Jamesoni Zone of the Lower Pliensbachian. The transgressive peak of 3rd order Cycle LJ2−2 is located in the marly facies of unit B. Unit C is composed of shallowing-upward sequences of "muddy" type in the lower part, deposited in the proximal part of the shallow restricted external platform and "grainy" type in the upper part, representing wave-dominated bioclastic shoals. Unit D is constituted by peritidal shallowing-upward sequences deposited in shallow restricted subtidal environment of the internal platform to the intertidal and supratidal environments.

The 5th order cycles constituting the 3rd order facies Cycle LJ2−2, have been grouped into 4th order cycles. The duration of the 3rd order Cycle LJ2−2 is estimated as 2.6 Myr, and the possible average duration of the 4th order cycles as 0.4 Myr. This figure is close to the most frequent duration of the long-term Milankovitch orbital eccentricity cycles.

Comparison of the obtained results with other Lower Jurassic sections in Spain, Europe and with the global cycles shows that the boundary between cycles LJ−1 and LJ−2, which represents the onset of the first Jurassic transgression and the peak transgression identified in this work at the Lower Pliensbachian Jamesoni Zone as well as the boundary between cycles LJ−2 and LJ−3 seem to represent good criteria for correlation between the different palaeogeographical domains.

Keywords: Lower Jurassic, sequence stratigraphy, facies cycles, ammonoids, Iberian Range, Spain

Resumen

Se han estudiado las asociaciones de facies y la estratigrafía secuencial de los carbonatos del Jurásico Inferior, depositados en plataformas someras a ambientes perimareales de la Formación Cuevas Labradas (Sinemuriense-Pliensbachiense), en la sección del Barranco de la Hoz, situada en la parte centro-meridional de la Cordillera Ibérica.

En ella se han diferenciado cuatro unidades (A a D). La unidad A, depositada en una plataforma restringida, se organiza en secuencias agradacionales estratocrecientes de somerización. La unidad B, depositada en ambientes de plataforma externa restringida, está compuesta por secuencias de somerización y de profundización que contienen *Polymorphites* sp., *Uptonia* cf. *jamesoni* (SOW.) y *Uptonia* cf. *angusta* (QUENST.), los cuales caracterizan a la parte superior de la Zona Jamesoni del Plienbachiense Inferior. El pico transgresivo del Ciclo de facies de 3er orden LJ2−2 se sitúa en las facies margosas de la unidad B. La unidad C está compuesta por secuencias "fangosas" de somerización en la parte inferior, depositadas en la parte proximal de la plataforma externa restringida, y secuencias "granudas" en la parte superior representando barras bioclásticas dominadas por el oleaje. La unidad D está constituida por secuencias de somerización depositadas en ambientes submareales de rampa interna a ambientes inter- y supramareales.

Los ciclos de 5º orden incluidos en el Ciclo LJ2−2 se han agrupado en ciclos de 4º orden. La duración del Ciclo LJ2−2 se estima en 2,6 Ma y la posible duración media de los ciclos de 4º orden en 0,4 Ma. Esta cifra está próxima a la duración más frecuente de los ciclos orbitales de excentricidad de larga duración de Milankovitch.

La comparación de los resultados obtenidos con otras secciones españolas, europeas y con los ciclos globales muestra que el límite entre los ciclos LJ−1 y LJ−2, que representan el comienzo de la primera transgresión jurásica, el pico transgresivo identificado en este trabajo, de edad Pliensbachiense Inferior, Zona Jamesoni, y el límite entre los ciclos LJ−2 y LJ−3 parecen representar excelentes elementos de correlación entre los diferentes dominios paleogeográficos.

Palabras clave: Jurásico Inferior, estratigrafía secuencial, ciclos de facies, ammonoideos, Cordillera Ibérica, España.

1. Introduction

The precise timing and definition of the facies associations of the transgressive-regressive (TR) cycles is of primary importance to perform high-resolution correlations based on sequence stratigraphy among the different subbasins. Occurrence of ammonoids in the Jurassic deposits represents a conventional tool for bio(chrono)stratigraphical dating and allows excellent basis for correlation with other areas.

In the Iberian Range, which is a northwest trending folded and thrusted belt located in central and eastern Spain (Fig. 1), the Triassic−Jurassic transition occurs within a mainly evaporitic thick succession (the Lecera Formation) or its dissolved equivalent unit (the Cortes de Tajuña Formation) (Gómez *et al.*, 2007). This represents the regressive portion of the TR Upper Triassic−Lower Jurassic Cycle 1 (LJ-1) defined by Gómez and Goy (2005) (Fig. 2). The first Early Jurassic transgression resulted in the installation of a very shallow extensive carbonate platform, on which subtidal to intertidal and supratidal environments have been recognized. The initial extensive carbonate platform was breaked-up into several blocks due to extensional syndepositional tectonics around the Sinemurian−Pliensbachian transition. In the northeastern part of the area, movements along the Montalban Fault (Fig. 3) caused subsidence of hanging wall blocks located to the northeast of the fault, and the generation of enough accommodation space as to allow better development of the Sinemurian−Pliensbachian TR facies Cycle LJ−2. Ammonoids-bearing external platform facies, represented by the Rio Palomar and the Almonacid de la Cuba Fms were deposited northeast of the Montalban Fault, whereas peritidal carbonate deposition continued southwest of the fault (Figs. 2, 3). The transgressive peak of the Cycle LJ−2 (Gómez and Goy, 2005) has been dated northeast of the Montalban Fault as Lower Pliensbachian Jamesoni Zone on the basis of the ammonoids and brachiopods found in the deposits of the Almonacid de la Cuba Fm (Sequeiros *et al.*, 1978; Comas-Rengifo, 1985; Comas-Rengifo *et al.*, 1997, 1999). However, in the peritidal facies of the Cuevas Labradas Fm, deposited southwest of the Montalban Fault, the known record of the Sinemurian−Lower Pliensbachian ammonoids and brachiopods remains very poor (Goy *et al.*, 1976) and in the southern part of the Iberian Range no ammonoids allowing dating of the Cuevas Labradas Fm were previously found.

The aim of this work is to report the results of the work performed in the sequence and cycle stratigraphy of the Early Jurassic shallow platform to peritidal carbonates of the Cuevas Labradas Fm, which includes the analysis of the facies associations and the finding of ammonoids that allowed dating of the peak transgression of Cycle LJ−2 in this part of the Iberian platform system. The synchronism of some of these key stratigraphical intervals is also analyzed through the correlations with other sections located in Spain as well as in Western Europe and in the Tethys domains.

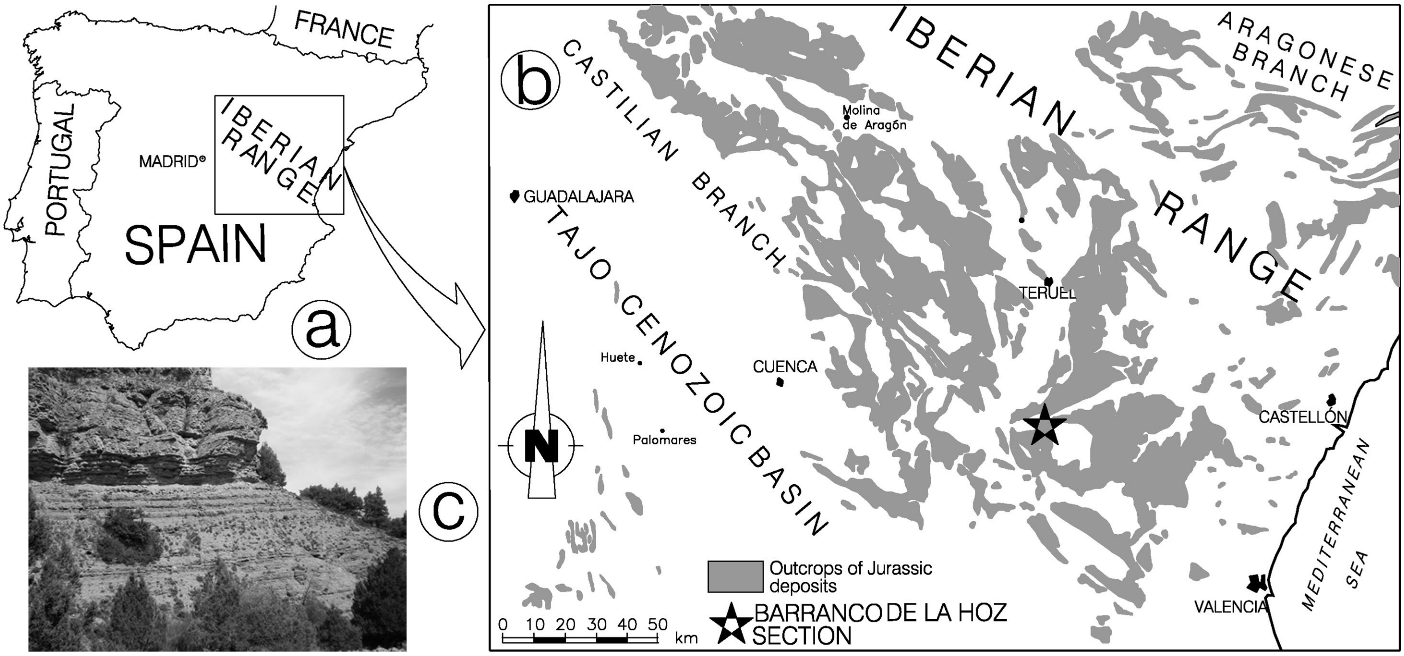


Fig. 1.- Location maps of the studied section. (a) Map of the Iberian Peninsula showing the location of the Iberian Range. (b) Distribution of the outcrops of the Jurassic deposits in the Iberian Range and the location of the Barranco de la Hoz section. The geographical coordinates of the base of the section are: 40º05' 56" N, 0º 56' 24"W. (c) Outcrop of the middle part of the section (unit B). The change in the slope corresponds to the transition from the shallowing- and deepening-upward sequences (present in the lower part) to the exclusively shallowing-upward sequences of the upper part.

Fig. 1.- Mapas de situación de la sección estudiada. (a) Mapa de la Península Ibérica mostrando la situación de la Cordillera Ibérica. (b) Distribución de los afloramientos de los materiales del Jurásico en la Cordillera Ibérica y la situación de la sección del Barranco de la Hoz. Las coordenadas geográficas de la base de la sección son: 40º05' 56" N, 0º 56' 24"W. (c) Afloramiento de la parte media de la sección (unidad B). El cambio de pendiente corresponde a la transición entre las secuencias de profundización y de somerización (presentes en la parte inferior) a las secuencias exclusivamente de somerización en la parte superior.

2. Stratigraphical succession

The studied section is located in the Barranco de la Hoz creek, situated near the town of Sarrión, south of Teruel (Fig. 1b). The stratigraphical succession (Fig. 4) represents the upper part of the Cuevas Labradas Fm and the base of the Barahona Fm. The succession, which is mainly constituted by carbonates with interbedded marls, is representative of the LJ2−2 facies Cycle (Fig. 2). On the basis of the facies associations, which have been based on field observations, four units (A to D) have been distinguished. These units constitute well differentiated facies belts which can be mapped along most of the southtern part of the Iberian Range.

2.1. Unit A

Unit A is formed by mudstone to wackestone limestones which are organized in aggradational muddy thickening- and shallowing-upward sequences. The unit can contain layers of bioclastic packstone limestones showing a sharp erosional base, internal hummocky cross-lamination and bioclastic rills (Figs. 4, 5A). This unit was deposited in a restricted shallow platform affected by the storms.

2.2. Unit B

Unit B is composed of shallowing- (B1) and deepening-upward (B2) sequences. The shallowing-upward sequences (B1 in Fig. 5) are composed of thickening- and coarsening-upward sequences showing a marly unit at the base, which grades upward to nodular mudstone and bioclastic wackestone limestones. The upper part of the sequence is constituted by intraclastic packstone to grainstone limestones showing internal hummocky cross-lamination. Geometries are tabular to lenticular and the base is frequently marked by an erosive surface.

The deepening-upward sequences (B2 in Fig. 5) are composed of thinning- and fining-upward sequences showing at the base amalgamated packstone to grainstone limestones with hummocky cross-lamination. The middle part is constituted by wackestone−packstone limestones which can contain layers of packstone−grainstone limestones and interbedded marls that predominate in the up-

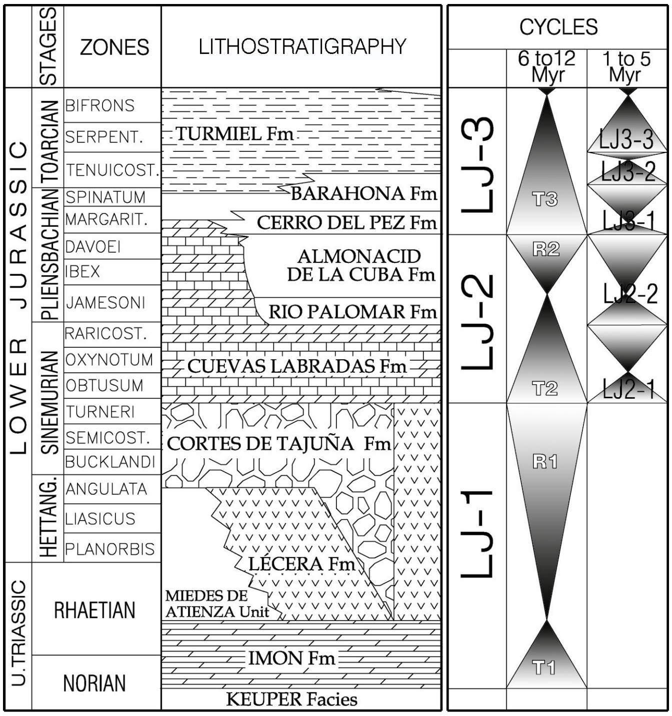


Fig. 2.- Lithostratigraphical units and cycles defined in the Upper Triassic and Lower Jurassic deposits of the Iberian Range (after Gómez and Goy 2005, modified), referred to the standard stratigraphical units.

Fig. 2.- Unidades litoestratigráficas y ciclos definidos en los materiales del Triásico Superior y del Jurásico Inferior de la Cordillera Ibérica (modificado de Gómez y Goy, 2005), referidos a las unidades estratigráficas estándar.

per part of the sequence.

This unit B contains *Polymorphites* sp., *Uptonia* cf. *jamesoni* (SOW.) and *Uptonia* cf. *angusta* (QUENST.) that characterize the upper part of the Jamesoni Zone of the lowermost Pliensbachian. The exclusive presence of adults, with the absence of juvenile forms, suggests that these parts of the platform were not colonized by ammonoids and that the found shells arrived to the studied area by drift, derived from more external parts of the platform, coinciding with the overall deepening conditions.

2.3. Unit C

Unit C is composed of shallowing-upward sequences of "muddy" type in the lower part of the unit and "grainy" type in the upper part. Marls are very scarce even at the base of the sequences. The "muddy" thickening- and shallowing-upward type of sequences, are frequently constituted by lime mudstones to wackestones, occasionally bioturbated, which can contain rills of bioclastic wackestone to packstone limestones with internal hummocky cross-lamination and lime mudstones at the top (C1 in Fig. 5). These bioclastic layers, which can contain a bioclastic lag at their base (Aigner, 1982) can be amalgamated and are interpreted as tempestitic deposits. The lower part of unit C was deposited in a shallow external restricted platform frequently affected by the storms.

The sequences of "grainy" type, corresponding to the upper part of unit C (C2 in Fig. 5), are composed of bioclastic and intraclastic packstone to grainstone limestones showing planar and through-type cross-bedding. These deposits mainly represent wave-dominated shoals located at the shallow portions of the platform, on which beach environments including the shoreface and foreshore sub-environments, can be recognized. These "grainy" type of deposits represent the progradation of the high energy belt of the shallow platform over the lower energy restricted platform located at the front of the bioclastic shoals, during the regressive part of the cycle.

2.4. Unit D

Unit D is constituted by the classical peritidal shallowing-upward sequences (D in Fig. 5). The lower part is constituted by thin marls and nodular lime mudstones which can contain thin and lenticular layers of carbonate breccias. These breccias contain clasts of limestones representatives of the different peritidal sub-environments, such as lime-mudstones, bioclastic wackestones and mudstones with algal laminations. The marls are commonly absent, and the base of the sequences is constituted by thick-bedded bioclastic wackestone to packstone limestones containing mainly unfragmented gastropods and bivalves. The middle part of the sequence is composed of lime mudstones with algal laminations and the upper part of algal laminations occasionally with fenestral porosity and mud-cracks. The top of the sequence is sometimes constituted by a pebble breccia of similar composition to the one included in the marls, containing fragments of the described lithologies.

The depositional environments represented in this unit are ranging from the shallow restricted subtidal environments of the internal platform (lagoon) to the intertidal and supratidal environments. The breccia located at the top of the sequences is interpreted as tempestitic deposits accumulated in the supratidal portion of the ramp, which was reworked into the basal lag of the overlying sequence at the onset of the following stratigraphic cycle.

3. Discussion of the results

The superposition of sequences shown in figure 5 illustrates the transgressive−regressive parts of Cycle LJ2−2.

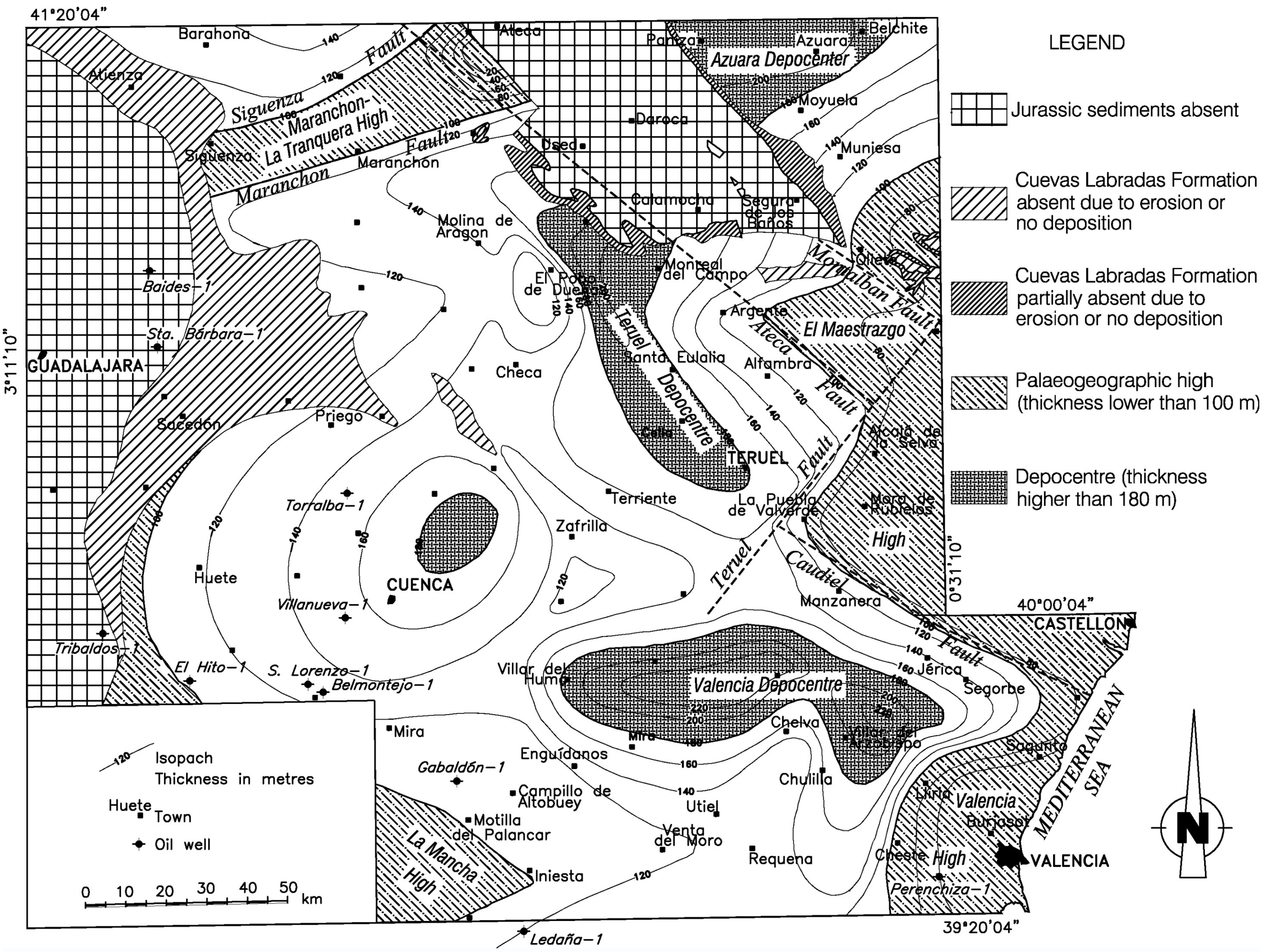


Fig. 3.- Palaeogeographical map of the Cuevas Labradas Fm (Sinemurian–Pliensbachian) at the Iberian Range after Gómez and Goy, 2005 (modified). The Montalban Fault, located in the northeastern part of the area covered by the map, separates the downthrown block, located to the northeast side of the fault, where the Rio Palomar and the Almonacid de la Cuba Fms have been deposited. South of this fault, the Pliensbachian sections are mainly represented by the peritidal carbonate facies of the Cuevas Labradas Fm, represented in the Barranco de la Hoz section.

Fig. 3.- Mapa paleogeográfico de la Fm Cuevas Labradas (Sinemuriense-Pliensbachiense) de la Cordillera Ibérica modificado de Gómez y Goy (2005). La Falla de Montalban, situada en la parte noreste del área cubierta por el mapa, separa el labio hundido, situado al lado noreste de la falla, donde se depositaron las formaciones Rio Palomar y Almonacid de la Cuba. Al sur de esta falla, las secciones pliensbachienses están principalmente representadas por las facies de carbonatos perimareales de la Fm Cuevas Labradas, representadas en la sección del Barranco de la Hoz..

The transgressive phase is represented by unit A and sequences of type B1, which culminates in the peak transgression represented by the sequences of type B2. The base of the transgressive deposits does not outcrop in the section, but the regressive part of the cycle is well represented by units C and D.

The succession of shallowing- and deepening-upward sequences plotted against the recognized depositional environments is shown in figure 6. The definition of parasequences of Van Wagoner *et al*. (1990) only included shallowing-upward sequences. However several authors recognized the presence of transgressive deposits, suggesting the possibility of redefinition of the parasequence concept to include those deposits (Arnott, 1995). On the other hand, Myers and Milton (1996) pointed out that shallow marine sediments are commonly arranged into regular upward-coarsening units with an upward-shoaling facies succession, separated by much thinner units representing a deepening-upward facies succession. These shallowing- and deepening-upward sequences have also been described in many areas of the Jurassic deposits of Spain (e.g.; Gómez, 1991; Gómez and Fernández-López, 1994, 2006; Gómez and Goy, 2000, 2005).

For some authors (Guillocheau, 1995), the high frequency sequences can be modified by the superposition of several signals that record the different variations of sea-level. This effect, which is named "sequence or stratigraphic distortion", implies that in a long period of time of relative sea-level fall, a more asymmetrical pattern of the high frequency sequences can be preserved and the record can be restricted to the progradational units. On the contrary, a high frequency sequence formed during a long period of time of sea-level rise, tends to generate a symmetrical cyclical pattern. In our case, a part of unit B at the Barranco de la Hoz section shows an arrangement consisting of some alternating deepening-upward and shallowing-upward sequences (cf. Guillocheau, 1995). Unit B corresponds to a maximum in the relative sea-level rise representing a maximum in the generation of accommodation space and consequently to the low frequency retrogradational phase. Units A, C, D and sequences B1 have a shallowing-upward trend corresponding to the low frequency aggradational and progradational phases.

There is a lack of general agreement on the hierarchical order of the sequences, genetic units or shallowing/deepening sequences. For some authors (e.g. Myers and Milton, 1996; Haq *et al.*, 1988) the parasequences are cycles of 4th order, but other authors do not assign a hierarchical order to the high frequency sequences (Guillocheau, 1995) or to the genetic units (Homewood *et al*., 1992). Goldhammer *et al*. (1990, 1993) distinguished high frequency cycles of 4th and 5th order within the 3rd order sequences. Fernández-López (1997, 2004) assigns a 5th order to the sequences and recognizes that they can be grouped into sets of sequences of a higher order, which correspond to the 4th order stratigraphical cycles. If the shallowing- and deepening-upward sequences are considered as 5th order sequences or cycles, and the 1 to 5 Ma Cycles (like Cycle LJ2−2) are considered 3rd order cycles, it looks clear that the intermediate cycles should be considered as 4th order cycles.

This 4th order cyclicity has been recognized in the studied section, as shown in figure 6. As the lowermost part of the 3rd order Cycle LJ2−2 does not outcrop in this area, the 4th order cycles have been provisionally named from the lower to the upper part of the studied section as LJ2−2a to LJ2−2g. These cycles also show the transgressive−regressive trend at a lower scale than the 3rd order cycles. The transgressive peak or deepening maximum is located in the ammonite-bearing marly facies of unit B and the shallowest facies correspond to the peritidal deposits of unit D.

The transgressive maximum of the 4th order cycles coincide with major accumulations of marly facies while in the regressive phases calcareous facies are predominant. In unit D, where marly facies are virtually absent and following the criteria established by Goldhammer *et al*. (1993), the transgressive peaks of the 4th order cycles coincide with the bases of the thickest shallowing-upward sequences (highest accommodation space) and the deepest facies, while the regressive maximums are located at the tops of the shallowing-upward sequences with the thinner (less accommodation space) and the shallowest facies.

3.1. Cyclostratigraphy

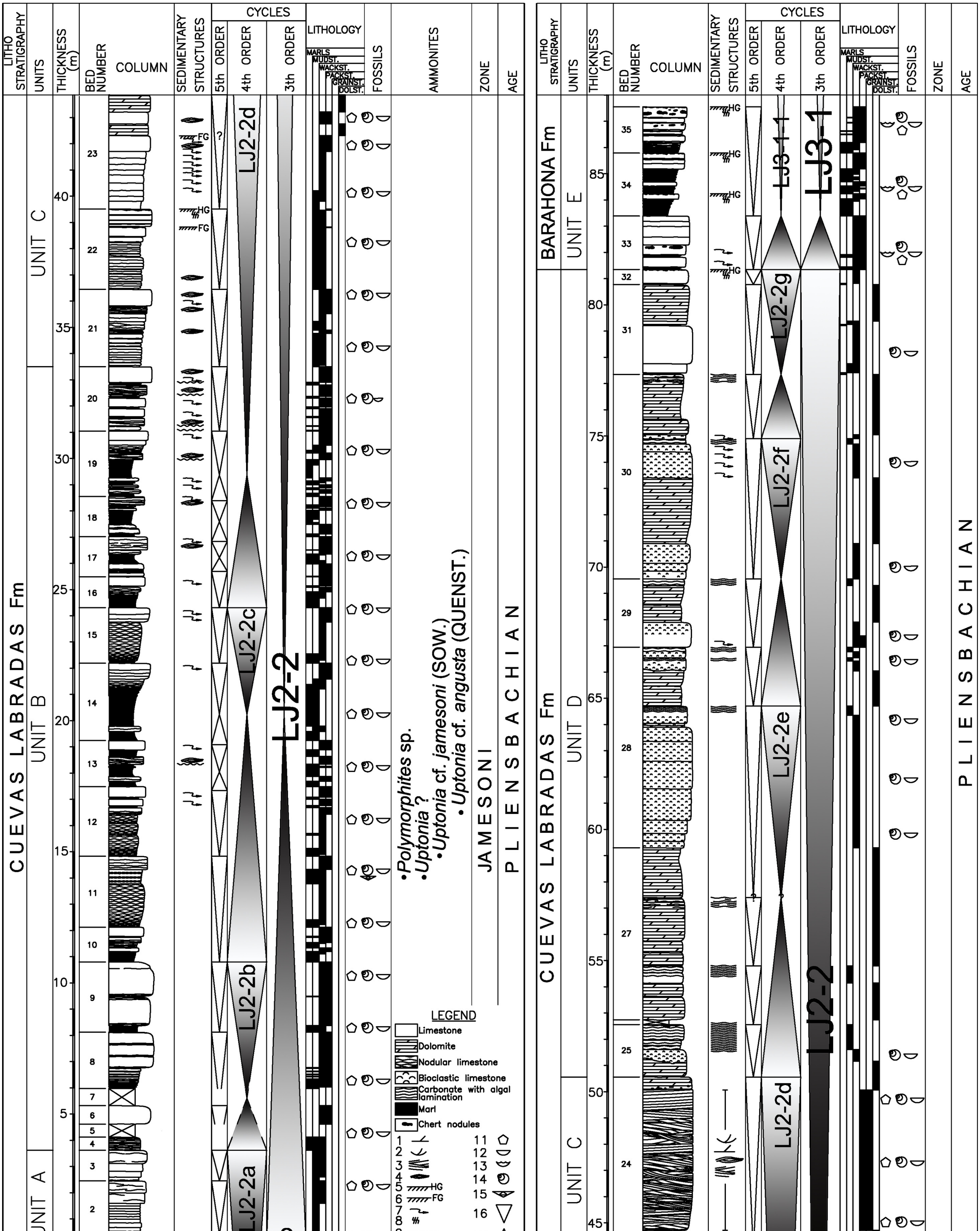
Following the Ogg (2004) Jurassic time scale, a duration of about 2.6 Myr is estimated for the 3rd order Cycle LJ2−2 (from the base of the Pliensbachian at 189.6Ma to the top of the Davoei Zone at 187.0Ma). The duration of the 4th order cycles cannot be established here due to the lack of a high resolution stratigraphy, but if it is supposed that Cycle LJ2−2 is constituted by 7 cycles of 4th order and considering that the sedimentary control in the basin is mostly allocyclic, a possible time span of about 0.4Myr for these cycles can tentatively be estimated. This figure is nearly coincident with one of the principal modes of the Milankovitch orbital eccentricity cycles (404 kyr) which seem to have remained relatively stable over much of the Phanerozoic (Hinnov, 2004).

3.2. Comparison with other Lower Jurassic sections

Comparison of the obtained results with other Lower Jurassic sections in Iberia, other areas of Europe and

Fig. 4.- (opposite page) Stratigraphical column of the Cuevas Labradas Fm and the base of the Barahona Fm at the Barranco de la Hoz section. Legend of symbols: (1) Planar cross-bedding. (2) Through cross-bedding. (3) Cross lamination. (4) Hummocky cross-lamination. (5) Hardground. (6) Firmground. (7) Bioclastic rill. (8) Bioturbation. (9) Erosive base. (10) Algal lamination. (11) Echinoderm. (12) Bivalve. (13) Oyster. (14) Gastropod. (15) Brachiopod. (16) Shallowing-upward sequence. (17) Deepening-upward sequence.

Fig. 4.- (página opuesta) Columna estratigráfica de la Fm Cuevas Labradas y la base de la Fm Barahona en la sección del Barranco de la Hoz. Leyenda de los símbolos: (1) Estratificación cruzada planar. (2) Estratificación cruzada de surco. (3) Laminación cruzada. (4) Laminación cruzada "hummocky". (5) Hardground. (6) Firmground. (7) "Rill" bioclástico. (8) Bioturbación. (9) Base erosiva. (10) Laminación de algas. (11) Equinodermo. (12) Bivalvo. (13) Ostréido. (14) Gasterópodo. (15) Braquiópodo. (16) Secuencia de somerización. (17) Secuencia de profundización.


LITHO STRATIGRAPHY
UNITS
THICKNESS (m)
BED NUMBER
COLUMN
SEDIMENTARY STRUCTURES
CYCLES
5th ORDER
4th ORDER
3th ORDER
LITHOLOGY
MARLS
MUDST.
WACKST.
PACKST.
GRAINST.
DOLST.
FOSSILS
AMMONITES
ZONE
AGE
CUEVAS LABRADAS Fm
UNIT A
UNIT B
UNIT C
UNIT D
UNIT E
BARAHONA Fm
LJ2-2a
LJ2-2b
LJ2-2c
LJ2-2d
LJ2-2e
LJ2-2f
LJ2-2g
LJ2-2
LJ3-1
LJ3-1-1
•Polymorphites sp.
•Uptonia ?
•Uptonia cf. jamesoni (SOW.)
•Uptonia cf. angusta (QUENST.)
JAMESONI
PLIENSBACHIAN
LEGEND
Limestone
Dolomite
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Bioclastic limestone
Carbonate with algal lamination
Marl
Chert nodules
HG
FG

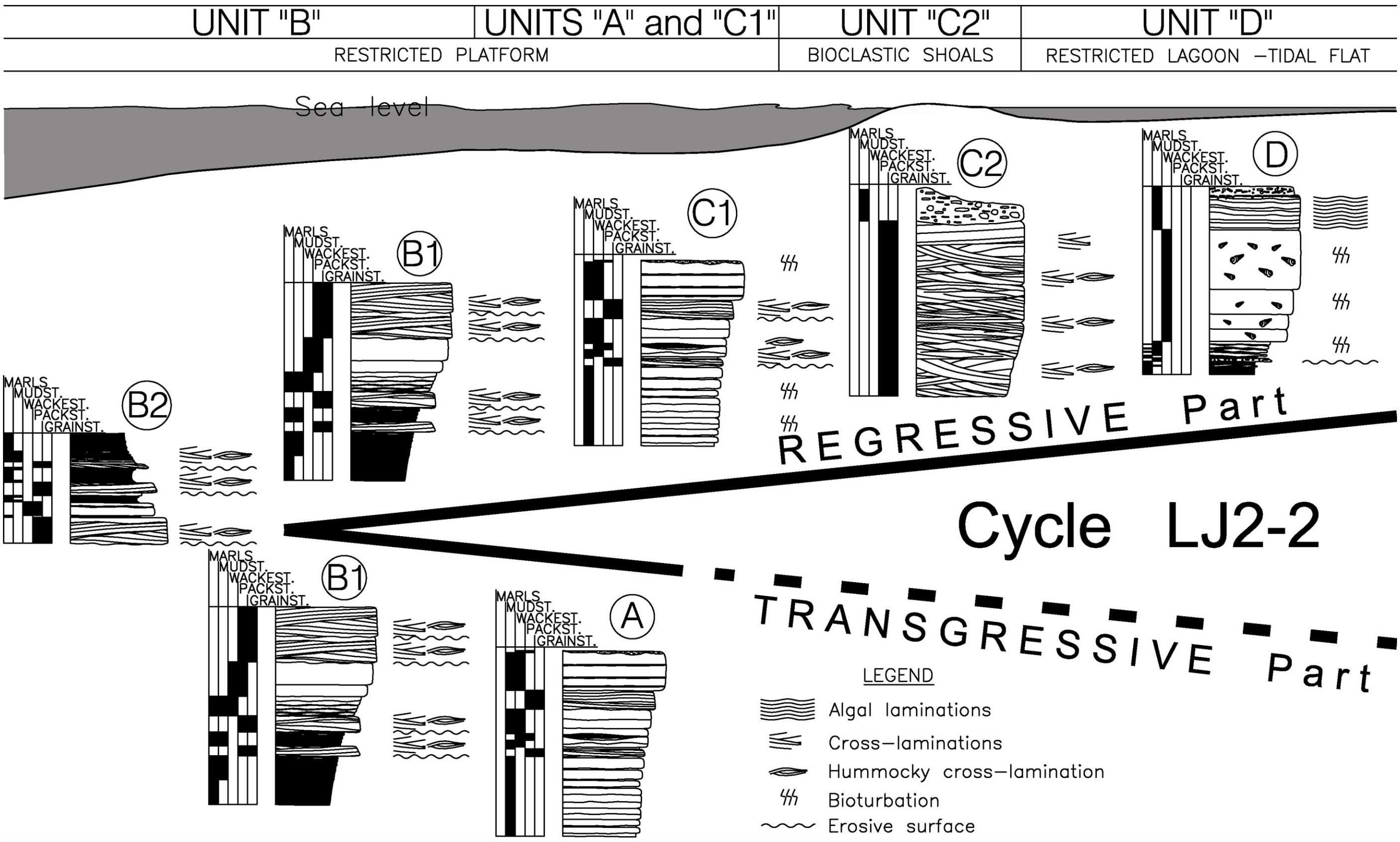


Fig. 5.- Shallowing- and deepening-upward sequences representative of units A to D and their location in the transgressive−regressive Cycle LJ2−2, referred to their depositional environments.

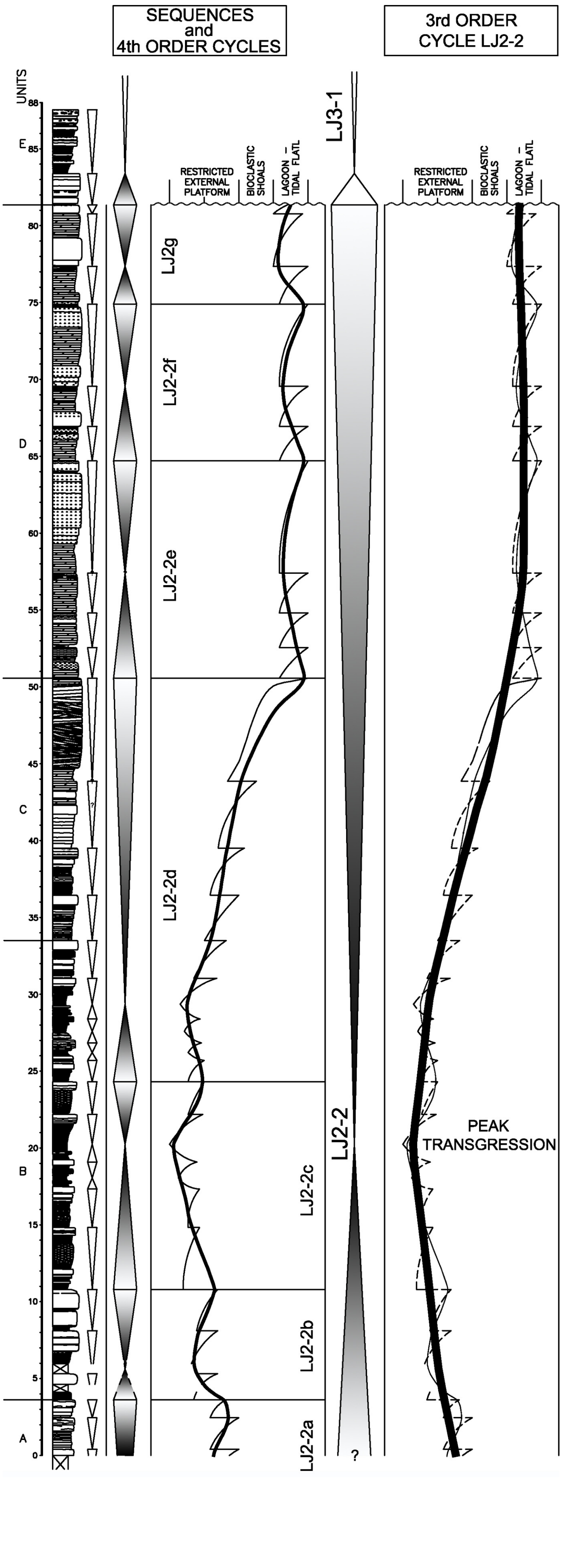
Fig. 5.- Secuencias de somerización y de profundización representativas de las unidades A a D y su localización en el Ciclo transgresivo-regresivo LJ2-2, referidas a su ambiente sedimentario.

the global cycles proposed by Haq *et al.* (1988) (Fig. 7) reveals some interesting similarities that can be used as correlation criteria between the different basins. Referring the 2nd order cycles, the boundary between cycles LJ−1 and LJ−2, which represents the onset of the first Jurassic transgression, looks to be nearly synchronous, within a reasonable margin of error, in the Iberian Range (Gómez and Goy, 2005), in the Basque−Cantabrian Basin of Northern Spain (Quesada *et al.*,2005; Rosales *et al.*, 2006), in the Boreal province (Graciansky, de *et al.*, 1998; Jacquin and de Graciansky, 1998), in the UK (Hesselbo and Jenkyns, 1993) and looks to coincide with the boundaries between cycles 3.1 and 3.2 of Haq *et al.* (1988).

The boundary between 3rd order cycle LJ2−1 and cycle LJ2−2 looks to be another good correlation criterion in Iberia. This boundary coincides with the limit between sequences 2 and 3 of the Basque−Cantabrian Basin in Northern Spain (Quesada *et al.*, 2005; Rosales *et al.*, 2006) and with the onset of the sequence SP in the Lusitanian Basin of Portugal (Duarte *et al.*, 2004; Duarte, 2006) and the boundary between cycles 4 and 5 in the UK (Hesselbo and Jenkyns, 1993).

Another good correlation criterion seems to be the peak transgression corresponding to cycles LJ−2 and LJ2−2 identified in this work at the Lower Pliensbachian Jamesoni Zone. Peak transgressions of this age have been reported in the Boreal province (Graciansky, de *et al.*, 1998) and in the UK (Hesselbo and Jenkyns, 1993), but this age do not coincide with the timing reported in the Basque−Cantabrian Basin, in the Lusitanian Basin, in the Tethyan domain and in the Haq *et al.* (1988) cycles.

The boundary between LJ−2 and LJ−3 also looks to be a good element for correlation between the different basins. Ages around the Early and Late Pliensbachian boundary are reported in most of the considered areas, including the Haq *et al.* (1988) cycles. The only exception is the Tethyan domain on which the onset of this transgressive interval seems to be older. The LJ3−1 transgressive peak seems to have an age corresponding to the Upper Pliensbachian Margaritatus Biochron in the Basque−Cantabrian Basin, in the Lusitanian Basin and in the Tethyan domain, representing another key interval for correlation purposes.



4. Conclusions

Facies analysis and sequence stratigraphy of the Early Jurassic shallow platform to peritidal carbonates of the Cuevas Labradas Fm studied in the Barranco de la Hoz section allowed the differentiation of 4 units (A to D) which constitute well differentiated facies belts along the southtern part of the Iberian Range.

Unit A, deposited in a restricted platform, is organized in aggradational muddy thickening- and shallowing-upward sequences. Unit B is composed of shallowing- and deepening-upward sequences deposited in an external restricted platform environment. This unit contains *Polymorphites* sp., *Uptonia* cf. *jamesoni* (SOW.) and *Uptonia* cf. *angusta* (QUENST.) that characterize the upper part of the Jamesoni Zone of the Lower Pliensbachian. Shells of ammonoids arrived to the studied area by drift from more open-marine parts of the platform, coinciding with the overall deepening conditions. Unit C is composed of shallowing-upward sequences of "muddy" type in the lower part, deposited in the proximal part of the shallow restricted external platform, frequently affected by the storms and "grainy" type in the upper portion, representing wave-dominated bioclastic shoals, located at the shallow portions of the platform. Unit D is constituted by peritidal shallowing-upward sequences representing depositional environments ranging from shallow restricted subtidal environments of internal platform (lagoon) to intertidal and supratidal environments.

The 5th order cycles have been recognized and grouped into seven 4th order cycles, which constitute the 3rd order Cycle LJ2−2. The transgressive peak or maximum deepening is located in the ammonite-bearing marly facies of unit B. The duration of the 3rd order Cycle LJ2−2 is estimated as 2.6 Myr, and the possible average duration of the 4th order cycles as 0.4Myr.

Comparison of the obtained results with other Lower Jurassic sections in Iberia, Europe and the global cycles shows that the boundary between cycles LJ−1 and LJ−2, which represents the onset of the first Jurassic transgres-

Fig. 6.- Plotting of the 5th order cycles recognized in the Barranco de la Hoz section against their depositional environments. From this curve the 4th order sets of cycles LJ2−2a to LJ2-2g have been delineated. The curve on the right represents the 3rd order Cycle LJ2−2, which has the peak transgression in the middle part of unit B.

Fig. 6.- Sección del Barranco de la Hoz mostrando la distribución de los ciclos de 5º orden respecto a los ambientes sedimentarios. A partir de la curva así obtenida, se ha trazado la curva de conjuntos de ciclos de 4º orden LJ2-2a a LJ2-2g. La curva de la derecha representa al ciclo de 3er orden LJ2-2, que tiene su pico transgresivo en la parte media de la unidad B.

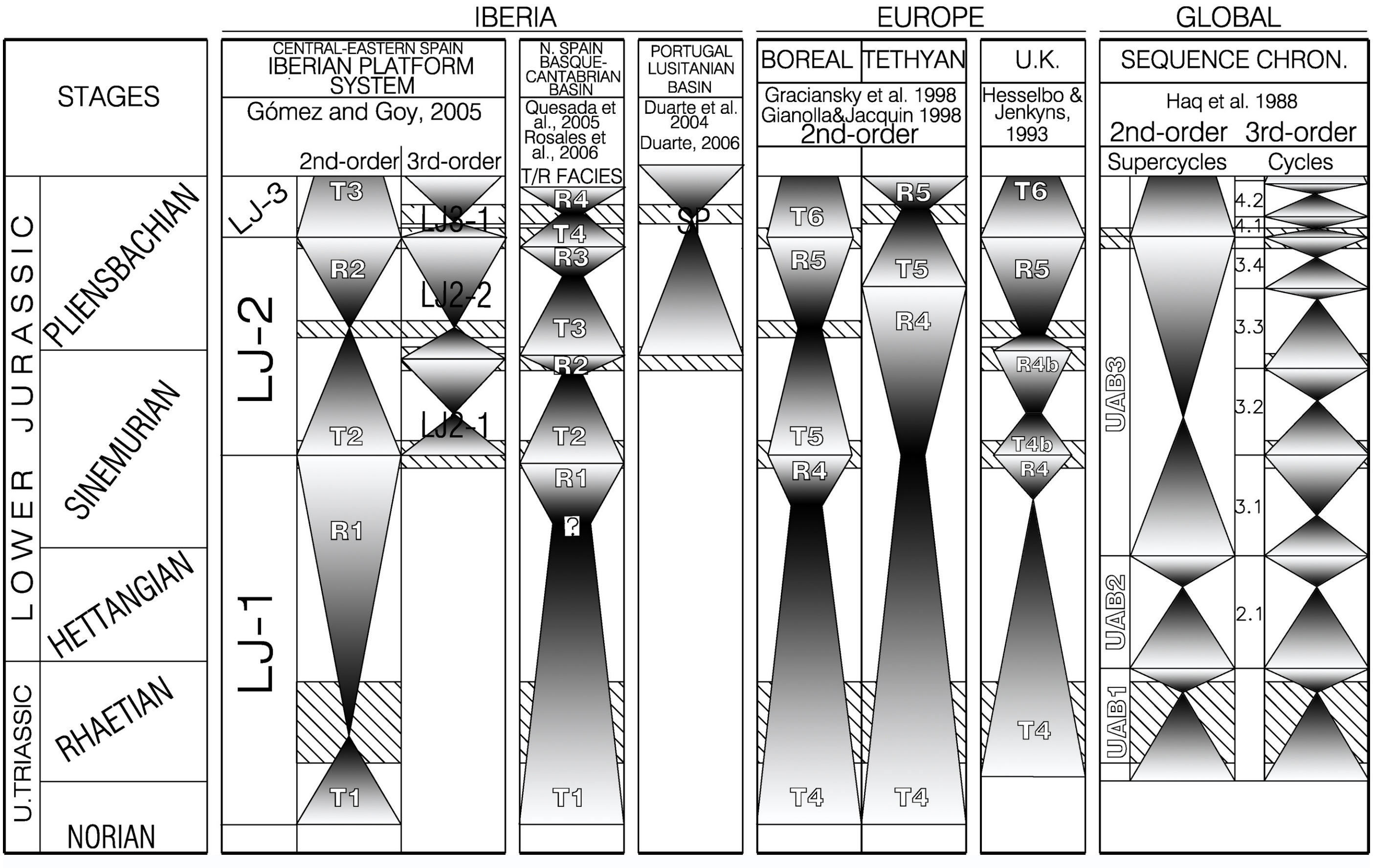


Fig. 7.- Correlation between the transgressive–regressive facies cycles found in the uppermost Triassic and Lower Jurassic deposits of the Iberian platform system and the transgressive–regressive facies cycles reported in the Basque-Cantabrian Basin (Northern Spain), in the Lusitanian Basin of Portugal, in Europe (Boreal and Tethyan provinces and the UK) and the global curve of Haq *et al* (1988).

Fig. 7.- Correlación de los ciclos de facies transgresivo-regresivos encontrados en los materiales del Triásico "terminal" y del Jurásico Inferior en el sistema de plataformas ibéricas y en la Cuenca Vasco-Cantábrica (Norte de España), en la cuenca Lusitánica de Portugal, en Europa (provincias Boreal y Tethysiana, y en el Reino Unido), así como la curva global de Haq *et al.* (1988).

sion seems to be nearly synchronous, as recorded in Northern Spain, in the Boreal realm, in the UK and in the global cycles. The boundary between cycles LJ2−1 and LJ2−2 looks to be nearly synchronous in Northern Spain, in western Portugal and in the UK.

The peak transgression identified in this work at the Lower Pliensbachian Jamesoni Zone has been recorded at a similar age at the Boreal domain and at the UK. The boundary between cycles LJ−2 and LJ−3 seems to be good criterion for correlation between the different palaeogeographycal domains, as similar ages have been assigned in Central and Northern Spain, in the Boreal Domain and in the global cycles. The uppermost correlation level here considered is the peak transgression of Cycle LJ3−1, which has been observed with a similar age in Central and Northern Spain, in western Portugal and in the Tethyan domain.

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References

Aigner, T. (1982): Calcareous tempestites: storm-dominated stratification in Upper Muschelkalk limestones (Middle Trias, SW-Germany). In: G. Einsele, A. Seilacher, (eds), *Cyclic and event stratification*. 180-198. Springer-Verlag, Berlin.

Arnott, R.W.C. (1995): The parasequence definition –are transgressive deposits inadequately addressed? *Journal of Sedimentary Research,* B65(1): 1-6.

Comas-Rengifo, M.J. (1985): El Pliensbachiense de la Cordillera Ibérica. *Colección Tesis Doctorales 19/85, Universidad Complutense de Madrid*, 591 p.

Comas-Rengifo, M.J., Gómez, J.J., Goy, A., Herrero, C., Perilli, N., Rodrigo, A. (1997): El Jurásico inferior en la sección de Almonacid de la Cuba (Sector central de la Cordillera Ibérica, Zaragoza, España). *Publicaciones del Seminario de Paleontología de Zaragoza*, 3: 31-63.

Comas-Rengifo, M.J., Gómez, J.J., Goy, A., Herrero, C., Perilli, N., Rodrigo, A. (1999): El Jurásico Inferior en la sección de Almonacid de la Cuba (Sector central de la Cordillera Ibérica, Zaragoza, España). *Cuadernos de Geología Ibérica,* 25: 27-57.

Duarte, L.V. (2006): Sequence stratigraphy and depositional setting of the Pliensbachian and Toarcian marly limestones in the Lusitanian Basin, Portugal. Volumina Jurassica 4. 157-158.

Duarte, L.V., Wright, V.P., Fernández-López, S., Elmi, S., Krautter, M., Azerêdo, A.C., Henriques, M.H., Rodrigues, R., Perilli, N. (2004): Early Jurassic carbonate evolution in the Lusitanian Basin (Portugal): facies, sequence stratigraphy and cyclicity. In: L. V. Duarte, M. H. Henriques (eds.), *Carboniferous and Jurassic Carbonate Platforms of Iberia*. 23rd IAS Meeting of Sedimentology, Coimbra 2004, Field Trip Guide Book, 1: 45-71.

Fernández-López, S. (1997): Ammonites, clinos tafonómicos y ciclos estratigráficos en plataformas epicontinentales carbonáticas. *Revista Española de Paleontología*, 12 (2): 151-174.

Fernández-López, S.R. (2004): Diagnóstico paleontológico de ciclos paleoambientales en plataformas continentales carbonáticas. Ejemplos del Jurásico Medio de la Cordillera Ibérica. In: E. Baquedano, S. Rubio, (eds.) Miscelánea en homenaje a Emiliano Aguirre. Vol II Paleontología, *Zona Arqueológica,* 4*:* 180-201.

Gianolla P., Jacquin, T., 1998. Triassic sequences stratigraphic framework of western European basins. In: P.C. de Graciansky, J. Hardenbol, T. Jacquin and P. Vail, Editors, *Mesozoic and Cenozoic Sequence Stratigraphy of European Basins*, Spec. Publ.-Soc. Sediment. Geol. vol. 60, SEPM, Tulsa, OK (1998), pp. 643–650.

Goldhammer, R.K., Dunn, P.A., Hardie, L.A. (1990): Depositional cycles, composite sea level changes, cycle stacking patterns, and the hierarchy of stratigraphic forcing -Examples from platform carbonates of the Alpine Triassic. *Geological Society of America Bulletin*, 102: 535-562.

Goldhammer, R.K., Lehmann, P.J., Dunn, P.A. (1993): The origin of high-frequency platform carbonate cycles and third-order sequences (Lower Ordovician El Paso Gp., west Texas): Constraints from outcrop data and stratigraphic modelling. *Journal of Sedimentary Petrology*, 63: 318-359.

Gómez, J.J. (1991): Sedimentología y paleogeografía del Jurásico en la hoja geológica nº 40 (7-5) de Daroca del Mapa Geológico de España a escala de 1:200.000. *Instituto Tecnológico- Geominero de España*, 31-82.

Gómez, J.J., Fernández-López, S. (1994): Condensation processes in shallow platforms. *Sedimentary Geology*, 92: 147-159.

Gómez, J.J., Fernández-López, S.R., (2006): The Iberian Middle Jurassic carbonate-platform system: Synthesis of the palaeogeographic elements of its eastern margin (Spain). *Palaeogeography, Palaeoclimatology, Palaeoecology,* 236: 190-205.

Gómez, J.J., Goy, A. (2000): Sequential analysis of the Toarcian in the northern and central-eastern part of the Iberian subplate. Spain. *GeoResearchForum,* 6: 301-309.

Gómez, J.J., Goy A. (2005): Late Triassic and Early Jurassic palaeogeographic evolution and depositional cycles of the Western Tethys Iberian platform system (Eastern Spain). *Palaeogeography, Palaeoclimatology, Palaeoecology*, 222: 77-94.

Gómez, J.J., Goy, A., Barrón, E. (2007): Events around the Triassic-Jurassic boundary in northern and eastern Spain: A review. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 244: 89-110.

Goy, A., Gómez, J.J., Yébenes, A. (1976): El Jurásico de la Rama Castellana de la Cordillera Ibérica (Mitad Norte). I. Unidades litoestratigráficas. *Estudios Geológicos*, 32: 391-423.

Graciansky, P.C. de, Jacquin, T., Hesselbo, S.P. (1998): The Ligurian Cycle: an overview of Lower jurassic 2nd-order transgressive-regressive facies cycles in western Europe. In: P.C. de Graciansky, J. Hardenbol, P.R. Vail, (eds.), *Mesozoic and Cenozoic Sequence Stratigraphy of European Basins. SEMP Spec. Publication,* 60: 468-479.

Guillocheau, F. (1995): Nature, rank and origin of Phanerozoic sedimentary cycles. *Comptes Rendus. Académie des Sciences, Paris,* 320(IIa): 1141-1157.

Haq, B.L., Hardenbol, J., Vail, P. (1988): Mesozoic and Cenozoic Chronostratigraphy and Eustatic Cycles. In: C. K. Wilgus, B.S. Hastings, C. G. St. C. Kendall, H. W. Posamentier, C. A. Ross, J. C. Van Wagoner (eds.), *Sea−level Changes: an integrated approach*, *Society of Economic Paleontologists and Mineralogists. Special Publication* 42: 71-108.

Hesselbo, S.P., Jenkyns, H.C. (1993): A comparison of the Hettangian to Bajocian successions of Dorset and Yorkshire. In: P. D. Taylor (ed.), *Field Geology of the British Jurassic.* pp. 105-150. *London Geological Society*.

Hinnov, L.A. (2004): 4. Earth's orbital parameters and cycle stratigraphy. In: F. Gradstein, J.G. Ogg, A. Smith (eds.), *A geologic Time Scale 2004*. pp. 55-62. Cambridge University Press, UK.

Homewood, P., Guillocheau, F., Eschard, R., Cross, T.A. (1992): Corrélations haute résolution et stratigraphie génétique: une démarche integrée. *Bulletin Centres de Recherches Exploration- Production Elf-Aquitaine,* 16(2): 357-381.

Jacquin, T., Graciansky, P.C. de (1998): Major transgressive-regressive cycles: the stratigraphic signature of European Basin development. In: P. C. de Graciansky, J. Hardenbol, P. R. Vail, (eds.), *Mesozoic and Cenozoic Sequence Stratig-*

raphy of European Basins. Society of Economic Paleontologists and Mineralogists. Special Publication, 60: 15-29.

Myers, K.J., Milton, N.J. (1996): Concepts and principles of Sequence stratigraphy. In: D. Emery, K. J. Myers (eds.), *Sequence Stratigraphy*: 11-41. Blackwell Science, London.

Ogg, J.G. (2004): The Jurassic Period. In: F. Gradstein, J.G. Ogg, A. Smith (eds.), *A geologic Time Scale 2004*: 307-343. Cambridge University Press, UK.

Quesada, S., Robles, S., Rosales, I. (2005): Depositional architecture and transgressive–regressive cycles within Liassic backstepping carbonate ramps in the Basque–Cantabrian basin, northern Spain. *Journal of the Geological Society, London*, 162: 531-548.

Rosales, I., Quesada, S., Robles, S. (2006): Geochemical arguments for identifying second-order sea-level changes in hemipelagic carbonate ramp. *Terra Nova*, 18: 233-240.

Sequeiros, L., Cólera, I., Valenzuela, R., Sánchez, I. (1978): Bioestratigrafía del Jurásico (Lias y Dogger) en el sector Belchite-Almonacid de la Cuba (prov. de Zaragoza, Cordillera Ibérica). *Estudios geológicos,* 34: 293-298.

Van Wagoner, J.C., Mitchum, R.M. Jr., Campion, K.M., Rahmanian, V.D. (1990): Siliciclastic sequence stratigraphy in well logs, cores and outcrops: concepts for high resolution correlation of time and facies. *American Association for Petroleum Geologists. Methods in Exploration Series*, 7, 55p.