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FACTORS CONTROLLING THE SEDIMENTARY EVOLUTION OF THE KIMMERIDGIAN RAMP IN THE NORTH IBERIAN BASIN (NE SPAIN)

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ABSTRACT

The aim of this paper is to summarize the present knowledge reached by the authors on the carbonate ramp which developed in the iberian basin during Kimmeridgian times. Our results were obtained from a combined field analysis and computer modelling carried out in the north Iberian Chain (NE Spain). Extensive field analysis in the Ricla area (Zaragoza, NE Spain), resulted in a detailed mapping of the transition from inner to outer-ramp facies on this carbonate ramp. Three facies belts may be distinguished in this ramp. The outer ramp facies consists of marls and mudstones rhythmic facies. The inner ramp facies, located above fair-weather wave base, are dominated by coral patch reef growing. The middle ramp facies are represented by marls and micrites bearing skeletal and oolitic tempestite levels which sharply grade into high-amplitude oolitic sandwave.

Factors such as resedimentation by storms, carbonate production and relative variation of sea level acting in the Kimmeridgian ramp are also quantiphied and discussed. Most of the mud accumulated in outer-ramp areas was produced in the coral «carbonate factory» located in inner areas. Off-shore resedimentation by storm was the main agent of basinward transport of this mud. The deduced accommodation curve consists of three elements: a linear rise which satisfactorily matches the normal subsidence figures observed in intracratonic basins; a third-order cycle, that may have a regional cause and higher order cycles in the Milanckovich band, that may be eustatic in origin.

Key words: *Kimmeridgian, carbonate ramps, modelling.*

RESUMEN

La sedimentación en la cuenca ibérica septentrional durante el Kimmeridgiense tuvo lugar en una extensa rampa carbonatada de bajo ángulo. Las facies de rampa externa, acumuladas por debajo del nivel de base del oleaje debido a tormentas (i.e., c. 50 to 80 m de profundidad), están formadas por una ritmita de margas y calizas (i.e., Fm Loriguilla). Las facies de rampa interna, localizadas por encima del nivel de base del oleaje de buen tiempo (i.e., hasta 10 m de profundidad), están dominadas por bioconstrucciones de corales (i.e., Fm Torrecilla). Las facies de rampa media están representadas por margas y micritas con niveles de tempestitas bioclásticas y oolíticas que pasan lateral y verticalmente a sandwaves oolíticos de gran amplitud (i.e., Mb. Ricla).

La modelización por ordenador ha permitido cuantificar algunos aspectos de esta rampa. Así, la distancia de resedimentación mar adentro del sedimento de grano fino producido en las zonas internas de la rampa, por el efecto de tormentas, puede ser de hasta 40 Km. La producción de carbonato oscilaría entre 8 y 2 cm/1.000 años, en función de la profundidad. Por otra parte, la curva de la variación de la acomodación deducida para el Kimmeridgiense está compuesta por tres elementos: un ascenso lineal de 4 cm/1.000 años, un ciclo de tercer orden de baja amplitud y ciclos de mayor orden, de 20.000 y 100.000 años respectivamente. Tanto el ascenso lineal como el ciclo de tercer orden se han relacionado con causas regionales, mientras que los ciclos de mayor orden se encuentran en la banda de Milanckovich y pueden ser por tanto de origen eustático.

Palabras clave: *Kimmeridgiense, rampas carbonatadas, modelización.*

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Introduction

Shallow epeiric seas covered most of the central and south european intracratonic basins during late Jurassic times. Sedimentation in low-angle carbonate ramps dominated on these basins. The Iberian basin (NE Spain) was an intracratonic basin covered by a shallow epeiric sea. A very extensive carbonate ramp developed during Kimmeridgian times in the Iberian basin. The analysis of this ramp is constrained by two important features: excellent exposition, allowing accurate reconstruction of proximal to distal ramp sections, and time framework for correlation, provided by a well-defined ammonite biostratigraphy (Aurell, 1991).

Recent computer and outcrop modelling carried out in the Kimmeridgian of the north Iberian Chain provided some quantitative data on this carbonate ramp. A cross-section 200 Km wide, extending from inner to distal outer of the ramp, has been recently modelled by Aurell *et al.* (1994) with the aid of the computer program CARBONATE introduced by Bosence and Waltham (1990). On the other hand, extensive field analysis in the Ricla area (Zaragoza, NE Spain) resulted in a detailed mapping on the transition from rhythmic outer-ramp facies to oolitic and coral-reef inner ramp facies (Bádenas *et al.*, 1993).

The aim of this paper is to summarize the present knowledge reached by the authors on the carbonate ramp which developed in the Iberian basin during Kimmeridgian times. Extensive facies analysis and computer modelling resulted in the quantiphycation of a set of parameters as production rates, off-shore resedimentation or accommodation curve. This quantiphication, combined with the data provided from the sedimentological analysis of the Ricla outcrops, gives some information which allow to further discuss on the factors which controlled the sedimentary evolution of the Kimmeridgian ramp in the north Iberian basin.

Geological setting and palaeogeographical remarks

The Iberian basin, located NE of Spain (fig. 1A), was an intracratonic basin which was filled-up by shallow marine and continental sedimentary units during Mesozoic times. The evolution and amount of accommodation in the basin was mainly controlled by discontinuous tectonic activity, which involved the reactivation of some basement faults. Tectonicaly stable episodes are also detected alternating with theses episodes of tectonic activity and resulted in deposition of shallow-marine units in extensive, low-angle ramp setting.

Sedimentation in the Iberian basin took place in shallow and extensive ramp settings (several hundreds of kilometers) during late Jurassic times. Phases of local activity of some basement faults occurred only at the Oxfordian-Kimmeridgian boundary and at the latest Jurassic. These tectonic phases involved the uplift of the marginal areas and a correlative basinwards shift of coastal facies.

The late-Jurassic ramps opened towards the East, into the Tethys sea. However, during major flooding episodes (i.e., middle Oxfordian and early Kimmeridgian) connection with boreal realms was possible across the so-called Soria seaway (fig. 1A). At the onset of the late Jurassic a series of palaeogeographic highs are detected, such as the so-called Ejulve high (Bulard, 1972; Salas, 1989; Aurell, 1990; Alonso and Mas, 1990; Aurell and Meléndez, 1993).

Sequence stratigraphy

The late Jurassic depositional sequences

The late Jurassic of the Iberian basin consists of three depositional sequences (*sensu* Haq *et al.*, 1987), i.e., Oxfordian, Kimmeridgian and Tithonian-Berriasian sequences. These depositional sequences were studied in the central part of the Iberian basin, by the measurement of 65 stratigraphic sections (Aurell, 1990). Further research on these sequences was carried out by Alonso and Mas (1990) in the northwest part of the basin, with additional measurement of 20 sections. Each depositional sequence developed different ramps which were successively dominated, in their middle and distal areas, by sponge and ammonite wackestone facies (Oxfordian sequence), thick rhythmic mudstones and marl alternation (Kimmeridgian sequence) and grain-supported oncolitic and skeletal facies (Tithonia-Berriasian sequence).

This report deals with the Kimmeridgian sequence. Some selected stratigraphic sections on figure 2 display the main lithological features of the Kimmeridgian sequence across the more complete transverse section, which is located at the north part of the basin (see fig. 1 for location). Systems tracts and facies distribution in this sequence have been described in detail by Aurell (1991) and Aurell and Meléndez (1993). Below we outline the facies distribution observed in the Kimmeridgian sequence.

Facies and systems tracts distribution in the Kimmeridgian sequence

The lower boundary of the sequence is represented by a subaereal exposure surface in western inner areas of the ramp, which were located in the shallo-

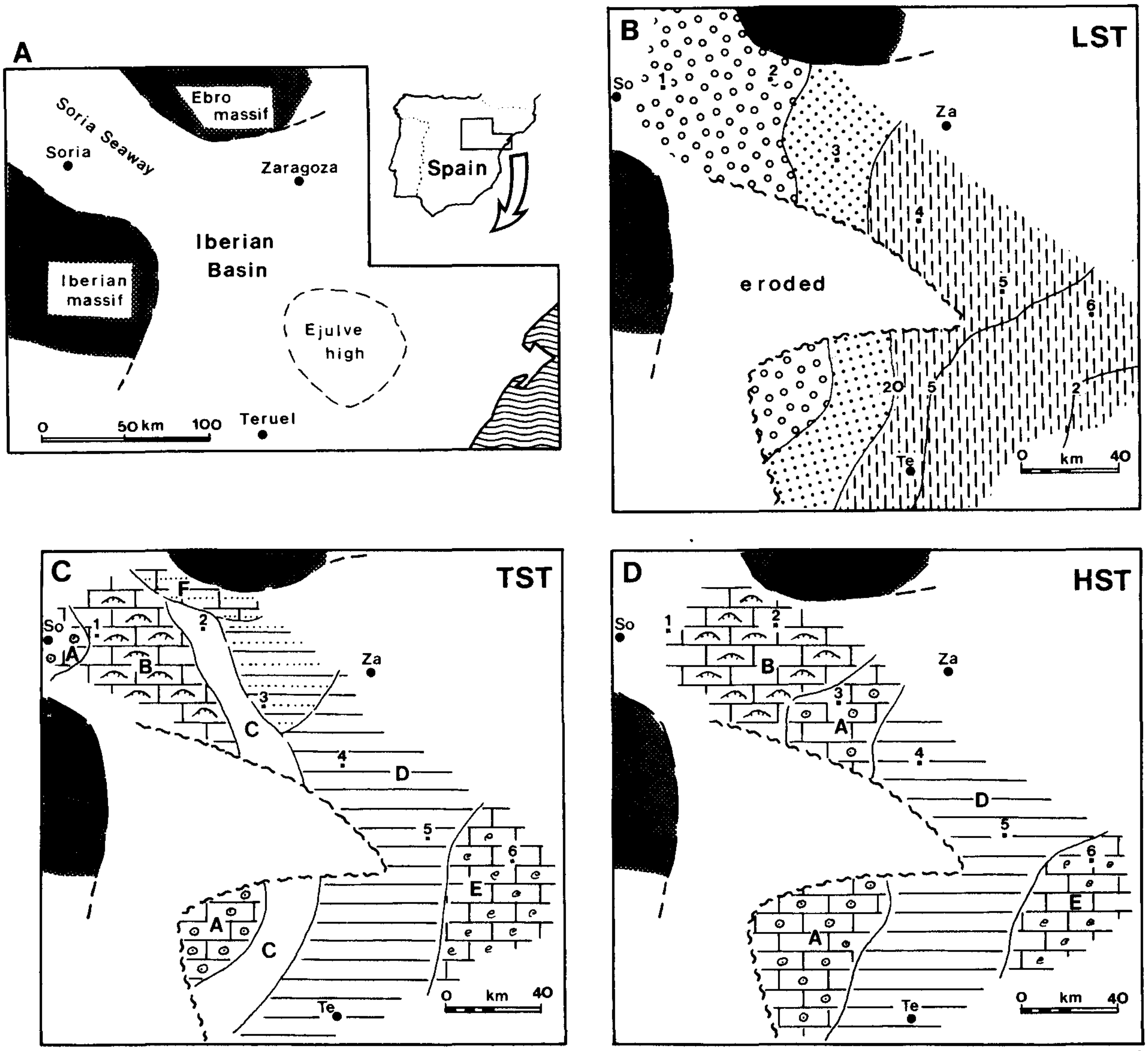

Fig. 1.—A) Locality map showing the palaeogeography of the Iberian basin during late Jurassic. B-D) Facies distribution during the successive systems tracts of the Kimmeridgian sequence. In B), open circles to the west indicates areas of no deposition (i.e., subareal exposure), the middle belt consists of marls and interbedded sandstones and the eastern belt is formed by marls (thickness variation is also indicated). Facies legend for C) and D): (A) oolitic grainstones; (B) coral boundstones; (C) marls bearing tempestite levels; (D) mudstones and marls (rhythmic series); (E) ammonite wackestones; (F) sandstones and sandy mudstones to packstones. Compiled from Aurell and Meléndez (1993) and Alonso and Mas (1990).

west realms of the Soria Seaway. In these areas (see fig. 1B) the sequence boundary is an uneven ferruginous surface overlaying the shallowest siliciclastic and carbonate banks of the Oxfordian sequence. These contain numerous evidences for subaereal exposure, such as karstic surfaces or partly reworked edaphic layers (Alonso and Mas, 1990). In middle and outer areas of the ramp, a horizon rich in ferruginous particles with an associated hiatus affecting the upper part of the last Oxfordian biozone (i.e., Planula zone, Planula subzone) separates the Oxfordian and Kimmeridgian sequences. No evidences for subaereal exposition associated to this surface have been found so far.

The lower part of the Kimmeridgian sequence or lowstand systems tract is formed by a sandy marly unit (i.e., Sot de Chera Fm p.p.) which reach its maximum thickness in the middle areas of the ramp, where it can be up to 50 m thick (fig. 1B). Based on both the thickness and facies distribution of the marls

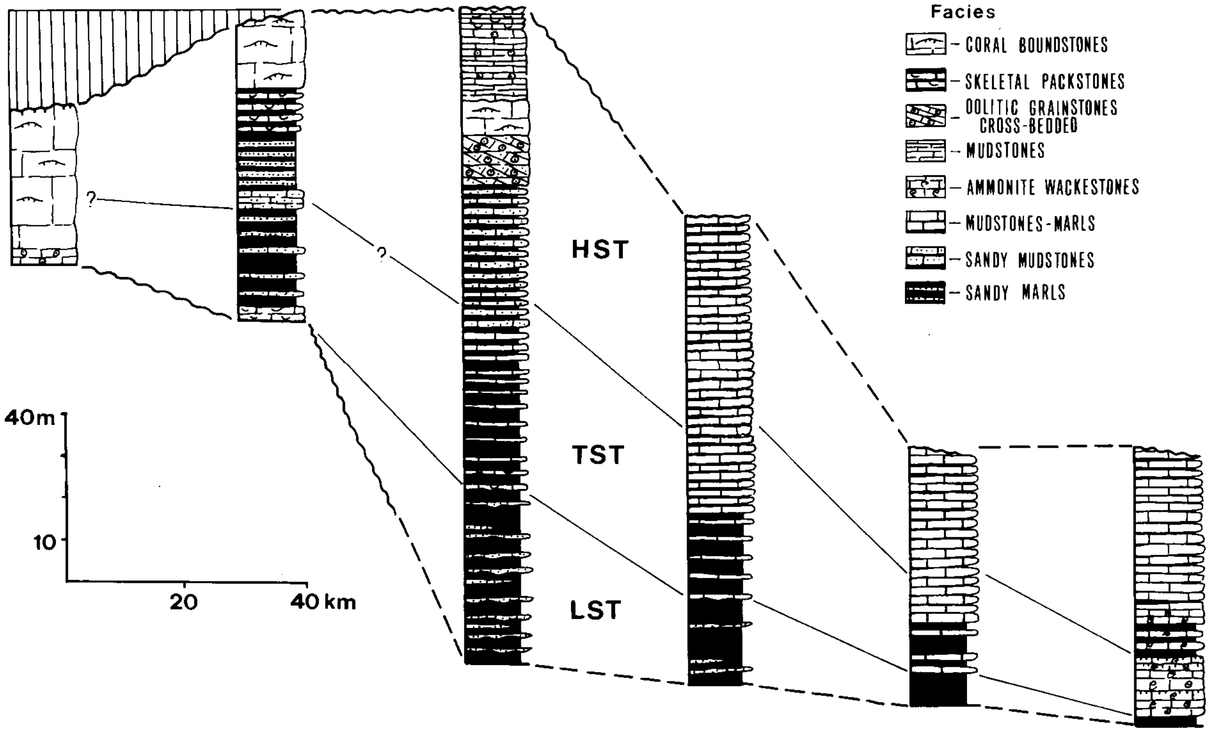

Fig. 2.—Selected sections located in the north part of the basin (see fig. 1), indicating also the distribution of systems tracts and sequence boundaries.

and sandstones at the bottom of the Kimmeridgian sequence, a tectonic origin for the Oxfordian-Kimmeridgian sequences boundary, and for the new accommodation created during deposition of this lowstand marls, was proposed in Aurell and Meléndez (1992). Tectonic quiet conditions were restored at the onset of the Kimmeridgian.

The first marine flooding surface across the Kimmeridgian ramp or transgressive surface is earliest Kimmeridgian in age (Platynota zone, Desmoides subzone) and is clearly represented in the distal part of the ramp, where the lowstand marls are overlain by a series of ammonite wackestones via sharp, planar surface. The overlaying ammonite facies or transgressive systems tract are early Kimmeridgian in age and are generally reduced in thickness. The areal extent of these condensed ammonitic facies in the outer part of the ramp is shown in figure 1C, facies E.

In the middle part of the ramp a rhythmic alternation of marls and mudstones containing scattered benthic fossils (brachiopods, bivalvs, crionids) was deposited (fig. 1C, facies D). These rhythmic series grades landward into marls containing evidences for deposition above storm wave base, as graded beds bearing sedimentary particles resedimented from proximal environments (fig. 1C, facies C). Besides oolitic facies, in the more inner areas located to the north, coral rich facies are also observed (fig. 1C, facies A and B).

The relative sea-level rise during the early Kimmeridgian produced a retrogradational facies geometry. Change to aggradational and progradational facies architecture at the early-late Kimmeridgian boundary implies a change from transgressive to highstand systems tract. A prominent hard-ground surface capping the early Kimmeridgian ammonitic facies in the distal part of the ramp is interpreted as the maximum flooding surface of the Kimmeridgian sequence. In outer areas of the ramp, this highstand unit contains ammonites ranging in age from late Kimmeridgian to earliest Tithonian (i.e., Hybonotum biozone, Atrops and Meléndez, 1985). The lateral component of the progradation during this highstand systems tract ranges between 25 to 40 Km (compare lateral extension of facies A and B in figs. 1C and 1D). In western, proximal areas of the basin, the upper boundary of the sequence is an angular unconformity (Aurell, 1991).

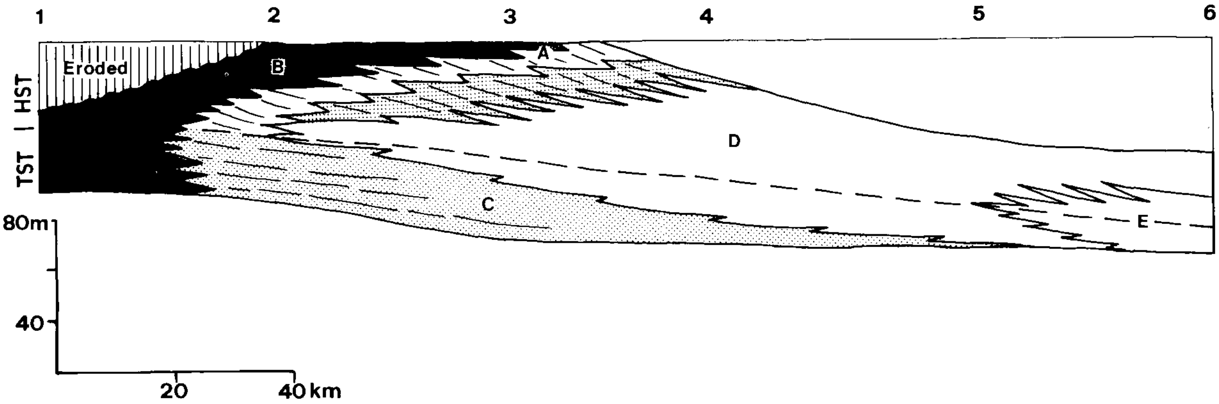

Fig. 3.—Facies and thickness distribution (decompacted) for the transgressive and highstand systems tracts of the Kimmeridgian sequence in a section located and the north part of the basin. See figure 1 for location and legend of facies (modified from Aurell *et al.*, 1994).

Computer Modelling

Conventional sedimentological and stratigraphic analysis arrives at an understanding of facies, facies models and sequence stratigraphy. Computer modelling is probably the best technique by which the different controlling rates may be quantified, as it allows the quantitative analysis of the different controlling parameters. Also the complex interaction of these effects can be studied in a logical way. It is important to remember that modeling only gives a rang of solutions, and that the results are not unique and therefore cannot be correct or prove any one solution (Aurell *et al.*, 1994).

A cross-section reconstructed from the Kimmeridgian sequence of the northern part of the basin was modelled with the computer program CARBONATE introduced in Bosence and Waltham (1990). This section is 200 Km in length and expose facies from proximal to distal areas of the ramp (figs. 1 and 2). Facies, geometries and the decompacted thickness of this section is shown in figure 3. Because lowstand systems tract of the Kimmeridgian sequence is partly related to tectonic activity (see above), only transgressive and highstand systems tract were modelled. Bellow we summarize the results presented in Aurell *et al.* (1994).

Input data and results

In order to carry out the computer modelling and to generate the synthetic stratigraphies various data concerning the initial surface of ramp growth, the geometric and the temporal scaling of the ramp and the rates of sedimentological processes acting on the ramp are required. The thicknesses were corrected for decompaction prior to the modelling, because the current version of the computer model does not take into account compaction. Observed thicknesses were decompacted taking into account both the original textures and the burial depth of the sediments, according to the tables presented in Bond and Kominz (1984). On the other hand, the initial topographic surface at the bottom of the transgressive systems tract of the Kimmeridgian sequence is assumed to be a very low-angle slope surface, slightly dipping to the East, into the more open-marine realms.

The time scale for the deposition of these sedimentary units is based on a well-established ammonite biozonation (Atrops and Meléndez, 1985). To transform this biostratigraphic scale into geological time, we first assumed that the geological time covered for each Kimmeridgian ammonite biozone is equal. According to that, and assuming the time scale proposed in Harland *et al.* (1990), the length of the transgressive and highstand systems tracts of the Kimmeridgian sequence is 1.1 and 1.7 My respectively.

A local, relative sea-level curve for the variation of accommodation was constructed for Kimmeridgian sequence (fig. 4A). This curve includes, both a linear rise of 4 cm/Ky and a low-amplitude third order cycle (i.e., 15 m), and results in faster creation of accommodation during deposition of transgressive systems tract. To this accommodation curve a set of higher order cycles were introduced. The closests matches between synthetic and actual geometries from our modelling were obtained when cycles of 100 and 20 Ky with amplitudes of between 4-5 and 1-2 m respectively were input. These cycles were deduced from Crevello (1991) from the study of early Jurassic platforms of Morrocco.

A curve of variation of carbonate production rates with depth was also deduced by model matching the

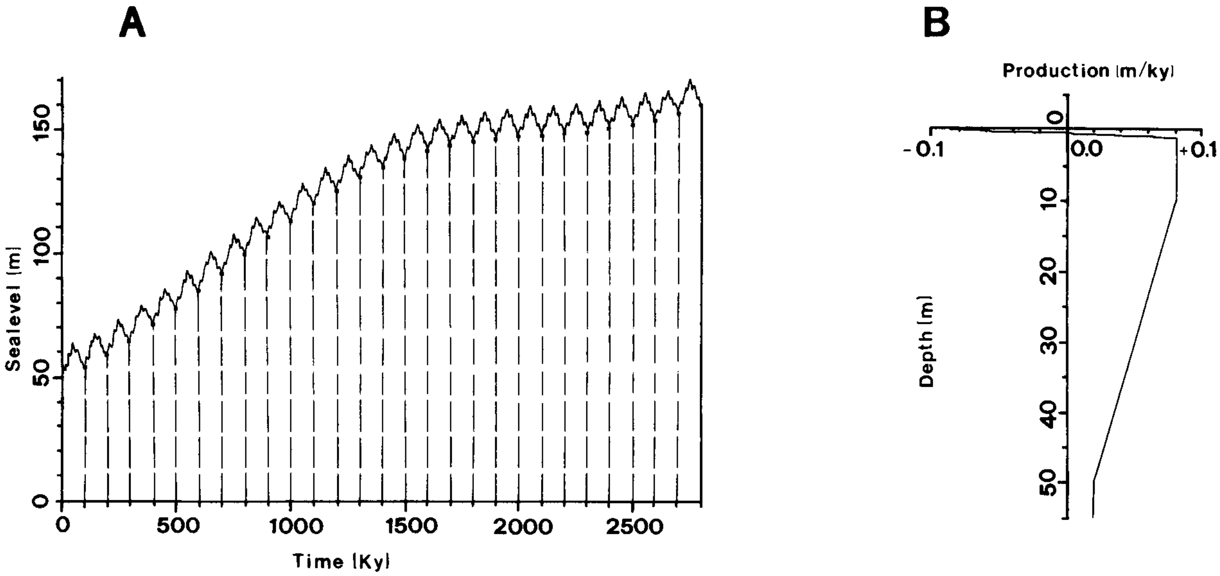

Fig. 4.—Curve of relative sea level variation (A) and curve of variation of production rates with depth (B) deduced from computer modelling of the section represented in figure 3 (modified from Aurell *et al.*, 1994).

synthetic and the actual stratigraphies (fig. 4B). For our modelling we increase production from a negative value in the intertidal to a maximum figure of 8 cm/Ky which is held 1 to 10 m depth and then reduced to a straight line to a value of 2 cm/Ky at the depth of storm wave base, assumed to be located around 50 m. These values, which are 1 to 2 orders of magnitude lower than the production rates observed in the recent shallow-water open marine carbonate environments, are in coherence however with the figures observed in some recent restricted environments (minimum figures in the Florida Bay are 1 cm/Ky, Enos, 1991) or in open ramp (e.g., West Florida carbonate ramp-slope, around 5 cm/Ky; Roof *et al.,* 1991). It should be also noted that these figures are comparable to values obtained from ancient carbonate platforms. Sedimentary rates in the four Jurassic platforms compiled by Enos (1991) range between 1.5 and 9.5 cm/Ky. Similar figures of carbonate production were obtained from computer modelling of carbonate ramps developed in ancient epeiric platforms (Aigner *et al.*, 1990; Elrick and Read, 1991).

Finally, erosion and redeposition was carried out in two ways in the program. First, muddy sediments are eroded at definable rates (average value of 10 cm/Ky) down to zero at a definable wave base (average value of 10 m). Second, mud produced in the shallow-proximal ramp was transported basinwards at a distance of 40 Km. This figure is based on both matching of the synthetic and the actual stratigraphies, and the observed facies distribution. In coherence with that, the belt defined by the facies containing mud transported from proximal domains of the ramp (i.e., rhythmic alternation of marls and mudstones, see discussion below) is 30 to 50 Km wide (facies D in figs. 1C and 1D).

Facies analysis in the Ricla area

Field evidences and computer modelling indicate that erosion and redeposition by storms were important processes acting on this Kimmeridgian ramp. This supports evidence from other ramps described from ancient epeiric seas as storm dominated systems (e.g., Aigner, 1985). Storms and marine circulation produce significant erosion, transport and resedimentation to outer areas of the ramps. Basinward transport is favoured by the flat topography, with no physical barriers.

This general approach has some relevance in order to better understanding the origin of the rhythmic alternation of marls and mudstones covering wide areas of theKimmeridgian ramp in the Iberian basin. One point that should be addressed is the relationship between these micritic, outer-ramp facies and the coraline and oolitic facies which were originated and deposited in the shallow to inner realms of the ramp. To answer this question, we carried out a detailed facies analysis in the outcrops near Ricla, west to Zaragoza (see section 3 in fig. 1 for location). These

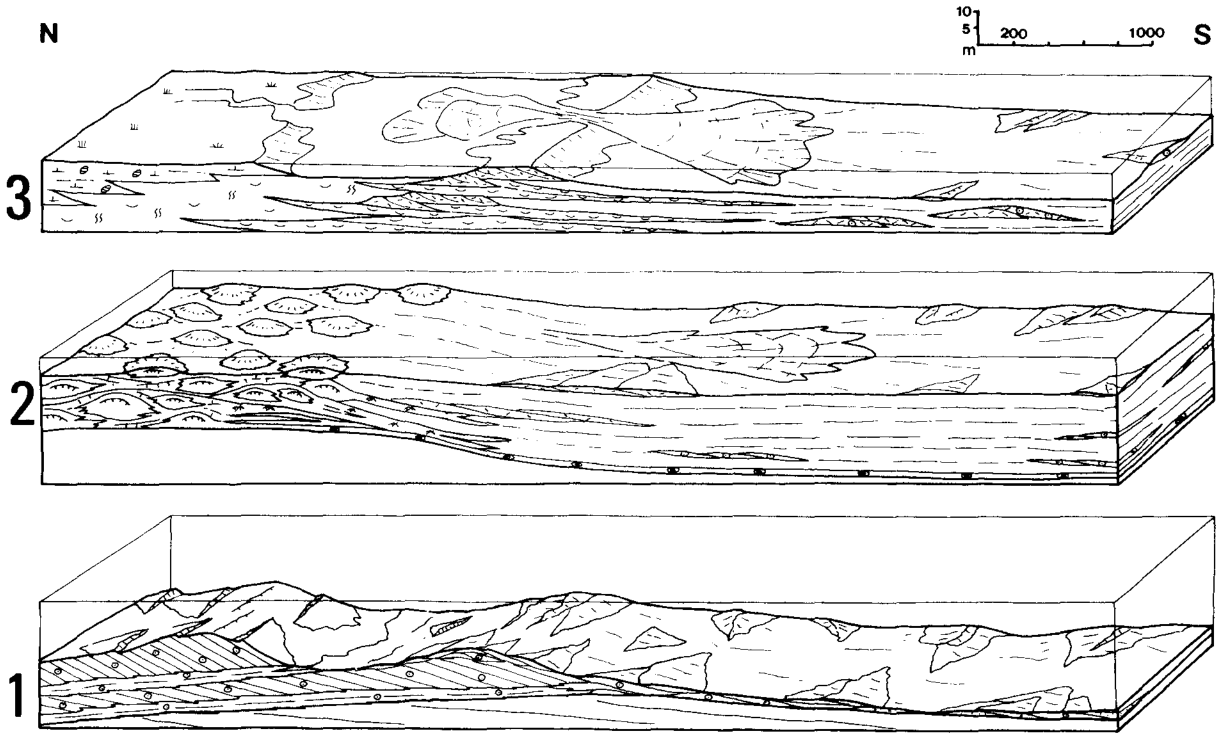

Fig. 5.—Sedimentary model for the three successive episodes distinguished in the Kimmeridgian ramp in the Ricla area (from Bádenas *et al.*, 1993).

outcrops allow to examine the Kimmeridgian ramp in a key point. From them, a 6.5 Km long section nearly transversed to the ramp, showing the transition from outer ramp facies (i.e., Loriguilla Fm) to inner ramp facies (i.e., Torrecilla Fm, Ricla Mb) may be examined in detail.

The Kimmeridgian sequence consists of three sedimentary units in the Ricla outcrops: Sot de Chera Fm, Loriguilla Fm and Torrecilla Fm (see fig. 2, section 3). In Ricla, the Torrecilla Fm consists of a wide spectrum of facies, including cross-bedded oolitic grainstones, well cemented sandstones and microconglomerates, coraline boundstones, skeletal wackestones to packstones and mudstones, and was defined as a Ricla Mb by Aurell *et al.* (1989). According to these authors, the Ricla Mb is late Kimmeridgian in age and corresponds to the upper part of the highstand systems tract of the Kimmeridgian sequence. A detailed facies analysis has been presented in Bádenas *et al.* (1993). Bellow, we summarize the main results of this work.

Facies distribution on the Ricla Member

Three facies associations were distinguished in the Ricla Mb:

1. Association I: The facies of this association can be grouped in two members; the lower member is mainly siliclastic, whereas the upper one mainly consists of oolitic facies. In the transition between Loriguilla Fm and Ricla Mb, a set of shallowing-upwar sequences (ca. 1 m thick) of bioclastic sandstones and trough cross-laminated microconglomerates is present. Sharply overlaying this siliciclastic facies, an up to 20 m thick wedge-shaped-unid of oolitic facies is found. To the north the oolitic unit consistis of two stacked units, each one of them having a lower well-bedded burrowed marls, sandstones and oolitic grainstone facies, and an upper oolitic grainstones showing high-scale planar-cross bedding. The oolitic unit pinches out to outer areas of the ramp located to the south, and laterally grades into low-amplitud oolitic bars which are interbedded between the lower siliciclastic facies.

2. Association II: At the bottom of this association of facies a very continuous oncolitic level (i.e., wackestones to packstones) is found. Oncoids are irregularly coated and have bioclastic cores (mainly corals). In northern areas, a set of patch-reef (c. 1-3 m thick) rich in corals, chaetetids and red algae, overlies this oncolitic level. This coral facies grades to the south into well-bedded mudstones bearing in-

tercalations of both rippled sandy levels, oolitic to bioclastic grainstones-packstones arranged in low-amplitude bars, and intraclastic grainstones composed of well-rounded clasts which generally display primary rim-cements.

3. Association III: This association is formed by both skeletal packstones to wackestones facies (i.e., bivalvs, gasteropods and lituolids), arranged in low-amplitude prograding bars and displaying graded beds, and burrowed mudstones facies and marls bearing charophites and ostracods.

Sedimentary evolution

The three above described facies associations correspond to three episodes of the sedimentary evolution of the Kimmeridgian ramp in the Ricla area.

1. Episode 1 (Association I): Fast progradation of a set of oolitic sandwaves over the subtidal facies of the Loriguilla Fm (fig. 5.1). The onset of this episode is represented by the progressive shallowing of the facies of the Loriguilla Fm, resulting in both an increase of the siliciclastic input, and in the first nucleation of the oolitic bedforms. In an intermediate stage, development and growing of a set of megaripples and oolitic sandwaves took place. These bedforms prograded up to 3-4 Km over the low-angle ramp as a consequence of storm-generated waves. The last stage of this episode is represented by the stabilization of the sandwaves, which are covered by lower-amplitude oolitic bedforms.

2. Episode 2 (Association II): Setting of the reef complex (fig. 5.2). This second episode represents a sharp transition from the above described first episode and is characterized by the development of a reef complex in the inner ramp areas. The transition between the first and the second episode is marked by the presence of a widely distributed oncolitic bed, which was deposited under low sedimentary rates. This oncolitic bed laterally grades into the coral facies to the northern inner areas. These inner ramp areas, extensively colonized by coral and other benthyc fauna, are considered to be the main source of the mud accumulated in outer realms of the ramp, via storm resedimentation. Tempestite levels as graded beds, oolitic rippled levels, or skeletal and oolitic bars are commonly found in outer areas of the ramp, interlayered with well-bedded mudstones. Some resedimented grains on these tempestite levels have features developed under litoral environments (i.e., rounded grains, beachrock cements) and evidence the presence of beach environments, which would be located landward to the belt defined by the coral facies.

3. Episode 3 (Association III): Setting of the restricted lagoonar and palustrine environments (fig. 5.3). The high carbonate productivity combined with the effectivity of the off-shore mud resedimentation, involved the progressive infilling of the accommodation in inner ramp areas and the increased restriction of the marine-circulation across the ramp. Lagoonar and palustrine facies were deposited behind litoral environments. The main feature of this third episode is the fast progradation of these restricted environments over the above described coral and micritic facies which are successively overlain by litoral intraclastic facies, skeletal lagoonar facies and mudstones and plaustrine marls.

Discussion

The role of storms

Both the field analysis and the computer modelling results presented here rackets a set of parameters which model the sedimentological evolution of the Kimmeridgian ramp developed in the north Iberian basin. These data can be used to discuss the relative importance of the different factors controlling the development and facies distribution on the Kimmeridgian ramp. A first process that can be evaluated is the off-shore resedimentation by storms.

Facies analysis of the Ricla outcrops clearly shows that storms were the main agent of off-shore transport and resedimentation. Evidences for fair weather wave or tidal reworking is scarce. This supports the general view of epeiric seas (Tucker and Wright, 1990), with the tides and waves being damped out by frictional effects over the very extensive shallow sea floor. The dominant processes affecting epeiric platform sedimentation would have been storms.

Based on recent environments (e.g., Hine, 1977), progradation of the oolitic sandwaves of Ricla was interpreted to be activated by storms (Bádenas *et al.*, 1993). The seaward progradation of these sandwaves was very fast. Distances of progradation of nearly 4 Km during what it must be a short period of time can be measured in the Ricla outcrops. The rapid progradation rates of the Kimmeridgian ramp is a function not only of the erosion and resedimentation activated by storms but also of the shallow depth and low-angle depositional geometry. Storms are also dominant during the second and third sedimentary episode deduced from the Ricla outcrops. During deposition of the second distinguished episode, it is specially remarkable the relationship between the shallower coral-facies and the outer mudstones. And intermediate spectrum of micritc facies with tempestite levels interlayered can be observed. These tem-

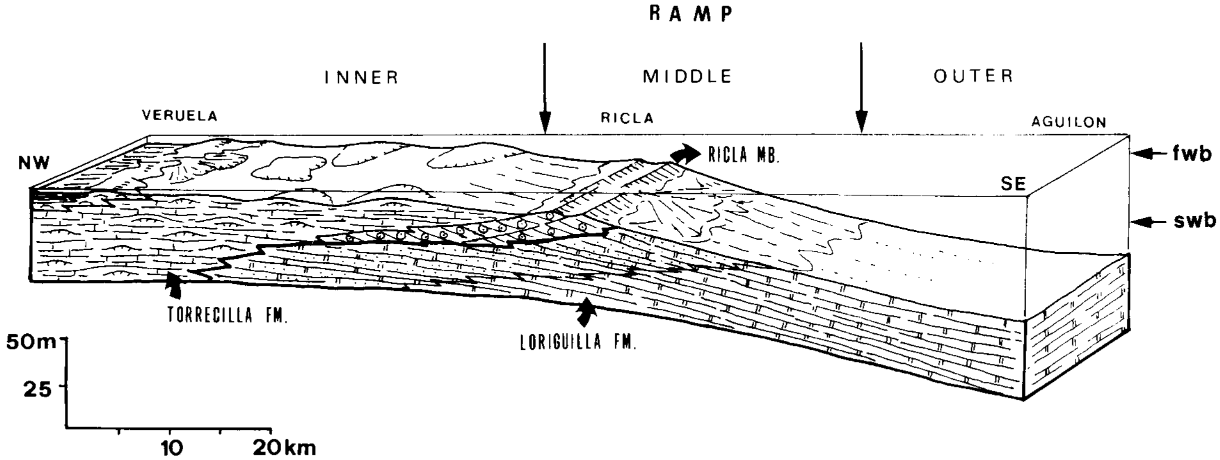

Fig. 6.—Sedimentary model during deposition of the highstand systems tract of Kimmeridgian sequence (i.e., late Kimmeridgian). Veruela, Ricla and Aguilón correspond to sections 2, 3 and 4 respectively (see fig. 1 for location). Legend: fwv: fair-weather wave base; swv: storm wave base (modified from Bádenas *et al.*, 1993).

pestite levels pinch out basinward and they grade into the mudstone facies.

In the Kimmeridgian ramp, basinward sediment transport distances of 40 Km are indicated from the distribution of storm beds, the occurrence of shallow-water allochems, and the model-matching known geometries. Storm wave-base depth considered in our computer modelling is 50 m. This figure, which is consistent with the observed in recent partly enclosed basins such as the Persian Gulf, has also been deduced from computer modelling of Mississippian carbonate ramps (Elrick and Read, 1991).

Relationship between coraline and rhythmic mudstones facies

The presented data yield new information about the overall relationship between the inner, coraline facies of the Torrecilla Fm, and the outer, rhythmic mudstones of the Loriguilla Fm. The Ricla outcrops only allow a partial view of the Kimmeridgian ramp. However, taking into account the general distribution of the facies at the northern part of the basin (i.e., fig. 1D), it clearly appears that the oolitic sandwaves of the Ricla Mg are spread in an intermediated facies belt located between shallow ramp areas, dominated by coral growing, and relatively deep ramp areas, were deposition of carbonate-mud took place. These sandwaves would be placed in an intermediate depth, below fair weather wave-base, but above storm wave-base level. According to the classification for carbonate ramps recently proposed in Burchette and Wirght (1992), these sandwaves would be located in the middle ramp. The inner ramp areas, developed above fair weather wave-base, are represented by coraline, litoral and lagoonar facies. The outer ramp domains of the ramp, placed below storm wave-base, consists of a rhythmic alternation of mudstones and marls (fig. 6).

Both the facies distribution and the above discussed role of the off-shore transport by storms, allow to state that most of the mud accumulated in outer-ramp areas was produced in the coral «carbonate factory» located in inner areas. Taking into account that storm episodes would be the main agent of basinward transport, it remains unanswered the question of how episodic storms and a single marl-mudstone couple are related. Observations in the Ricla outcrops show that each single micritic bed (which grades landward intoc oral facies) may contain, in fact, more than one tempestite level. This observation probes that a single marl-mudstone couple records a complex depositional history, involving more than one storm episode.

The origin of systems tracts and accommodation

The distribution of facies within systems tracts is considered to be the result of the interplay between the accommodation and sedimentary rates. The accommodation depends on eustacy and subsidence rates (Aurell, 1991). We have modeled a depositional sequence which correspond to a third-order cycle. Sequence boundary and lowstand systems tract of the Kimmeridgian sequence were related to a relative sea-level fall produced by tectonic uplift (Aurell and

Meléndez, 1993). Transgressive and highstand systems tracts were developed with smaller rates of accommodation. Transition from retrogradational transgressive systems tract to fast progradational highstand systems tract was satisfactory modeled by slightly decreasing the rates of accommodation, thus increasing the capacity of filling the accommodation with sediment.

Computer modeling offers an elegant way to discuss about the interplay of eustacy and subsidence creating the accommodation. As exposed above, the more satisfactory modelling comes from the superposition of 20 and 100 Ky cycles onto a both a linear rise of 4 cm/Ky and a low-amplitude third order cycle. The higher-order cycles are in the Milanckovich band and may be eustatic in origin. The magnitude of the linear rise satisfactorily matches the normal subsidence figures observed in intracratonic basins. The origin of third-order cycles remains uncertain as their timespan and amplitude do not match the eustatic curves proposed by Haq *et al.* (1987) and Hallam (1988).

Conclusions

1. This work offers a sedimentary model for the Kimmeridgian ramp in the north Iberian basin, showing its bathimetry and the distribution of its facies belts. The outer ramp facies, accumulated below storm wave base (i.e., ca. 50 to 80 m depth), consists of marls and mudstones rhythmic facies (i.e., Loriguilla Fm). The inner ramp facies, located above fairweather wave base (i.e., up to 10 m depth), are dominated by coral patch reefs (i.e., Torrecilla Fm). The middle ramp facies are represented by marls and micrites bearing skeletal and oolitic tempestite levels (i.e., upper part of the sandy, Loriguilla Fm) which sharply grade into high-amplitude oolitic sandwaves (i.e., Ricla Mb).

2. Resedimentation by storms was an important sedimentary process in the Kimmeridgian ramp and helped to maintain the low-angle ramp profile through time. Down-ramp transport distances were measured to be of around 40 Km. Fine-grained sediment produced in inner ramp areas accumulated in outer areas, below storm-wave base level, where micritic rhythmic series are recorded.

3. The deduced accommodation curve for Kimmeridgian sequence consists of three elements: a linear rise of 4 cm/Ky, a low-amplitude third order cycle and both a 20 and 100 Ky sea-level cycles. The magnitude of the linear rise satisfactorily matches the normal subsidence figures observed in intracratonic basins. The third-order cycle may have a regional cause as the timespan and amplitude of this cycle do not match the ones proposed in the published eustatic curves. The higher order cycles are in the Milanckovich band and may be eustatic in origin.

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