The Middle-Upper Jurasscic disconformity in the Lusitanian Basin, Portugal: preliminary facies analysis and evidence for palaeoclimatic fluctuation

La disconformidad Jurásico Medio-Superior en la Cuenca Lusitánica, Portugal: análisis de facies preliminar e indicios de fluctuación paleoclimática

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ABSTRACT

The Middle to Upper Jurassic boundary in the Lusitanian Basin is uneven, in similarity to other peri-atlantic basins, being associated to a stratigraphical gap spanning at least the interval late Callovian-Lower Oxfordian.

In the E of the basin, Middle Jurassic inner ramp carbonates are truncated by erosional surfaces (palaeokarsts), associated with a strong stratigraphical gap. The disconformity is draped and overlain by ferruginous deposits, coals, pedogenic carbonates. These grade upwards into lacustrine carbonates and restricted marine, lagoonal carbonates (probably Middle Oxfordian). In the West, Middle Jurassic outer ramp carbonates grade without marked sedimentary discontinuity (or a very subtle one), but with stratigraphical gap, into Malm (probably Middle Oxfordian) sediments. These show much less pronounced subaerial exposure features than in the East of the Basin; they mostly consist of marginal-marine carbonates, with clear freshwater influence, associated with shallow-marine carbonates with intermittent exposure.

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This article stresses some specific features related to this Middle-Upper Jurassic transition, which are interesting to contrast with coeval events in other basins, in particular, in the Iberian basins. Special attention is paid to the asymmetry of facies successions recognized between the eastern and western areas of the Lusitanian Basin and to the varied and contrasting palaeoclimatic markers occurring within these sequences. A possible climatic fluctuation during Oxfordian times is suggested.

Key-words: Middle-Upper Jurassic; disconformity; palaeoclimatic markers; facies.

RESUMEN

El límite entre el Jurásico Medio y Superior en la Cuenca Lusitánica es desigual, a semejanza de lo que ocurre en otras cuencas peri-atlánticas, y está asociado a lagunas estratigráficas que se prolongan por lo menos durante el intervalo Calloviense superior-Oxfordiense inferior.

En la parte oriental de la cuenca, las zonas internas de las rampas carbonatadas se encuentran truncadas por superficies de erosión (paleocarst), asociadas a una fuerte laguna estratigráfica. La disconformidad está formada y cubierta por depósitos ferruginosos, carbones y carbonatos pedogénicos. Estos sedimentos pasan gradualmente y hacia techo a carbonatos lacustres y a carbonatos de lagoon confinado (probablemente del Oxfordiense medio). Hacia occidente, los carbonatos de la rampa externa del Jurásico Medio pasan sin discontinuidad sedimentaria evidente, pero con laguna estratigráfica, a los sedimentos del Malm (probablemente Oxfordiense medio). Estos presentan características de exposición subaérea mucho menos pronunciada que en la parte E de la cuenca; consisten principalmente de carbonatos marinos-marginales, con clara influencia de agua dulce, asociados a carbonatos marinos someros con emersión intermitente.

Este artículo realza algunas características específicas relacionadas con la transición Jurásico Medio-Superior, que merecen ser comparadas con otros acontecimientos contemporáneos en otras cuencas, en particular en las cuencas Ibéricas. Merecen especial atención la asimetría de las sucesiones de facies detectada entre las zonas oriental y occidental de la Cuenca Lusitánica y los marcadores paleoclimáticos variados y contrastantes que aparecen entre estas secuencias. Se sugiere una posible fluctuación climática durante el Oxfordiense.

Palabras clave: Jurásico Medio-Superior; disconformidad; marcadores paleoclimáticos; facies.

INTRODUCTION

The Middle to Upper Jurassic boundary in the Lusitanian Basin (West-Central Portugal, Fig.1) is uneven, in similarity to other peri-atlantic basins, being associated to a stratigraphical gap spanning at least the interval late Callovian-lower Oxfordian (three ammonite biozones), although at places the missing record is much longer (Ruget-Perrot, 1961; Ramalho, 1971, 1981; Mouterde *et al.*,1979; Azerêdo, 1993). At a broader scale, it is generally accepted that a major tectono-eustatic event has controlled this widespread uneven boundary, in many places including emersion and/or condensed levels. These features are recorded, for instance, in the: Iberian and Catalan basins, NE Spain (Aurell & Meléndez, 1990; Aurell, 1991; Aurell, Fernández-López & Meléndez, 1994; Fernández-López *et al.*, 1996); Asturian region, NW Spain (Valenzuela, García-Ramos & Suárez de Centi, 1986); Paris Basin, France (Vail *et al.*, 1987; Rioult *et al.*,1991); Bourgogne, France (Floquet *et al.*,1989); Swiss Jura Basin, Switzerland (Gygi and Persoz, 1986); Neuquen Basin, Argentina (Legarreta, 1991).

In the Lusitanian Basin, this Middle-Upper Jurassic uneven transition has been recognized for a long time, as referred above, but it was never the focus of a specific multidisciplinary study. This is the approach of a broader, detailed research project that is being undertaken on a basinwide scale. It aims to improve current knowledge on sedimentological, palaeoclimatic and stratigraphical aspects of this phase of the basin's history. At the present stage of this project, only preliminary data are available; consequently, this article is only intended to stress some specific features related to this Dogger-Malm boundary which may be interesting to contrast with coeval events in other peri-atlantic basins, in particular, with the Iberian basins. We will basically focus on the following features:

— the existence of a clear asymmetrical distribution of facies types on the eastern (landward) and western (seaward) margins of the onshore area of the basin, which raises some interesting palaeoenvironmental questions;
— the reconnaissance of varied and contrasting palaeoclimatic markers, some of which had not been previously recognized and none of which was deeply investigated before.

GEOLOGICAL SETTING

The Lusitanian Basin of West-Central Portugal (Fig.1) is one of the marginal basins associated with the opening of the North-Atlantic Ocean and, consequently, displays a gross lithostratigraphical succession which is broadly similar to those from several other basins (see, for instance, Jansa, 1986;
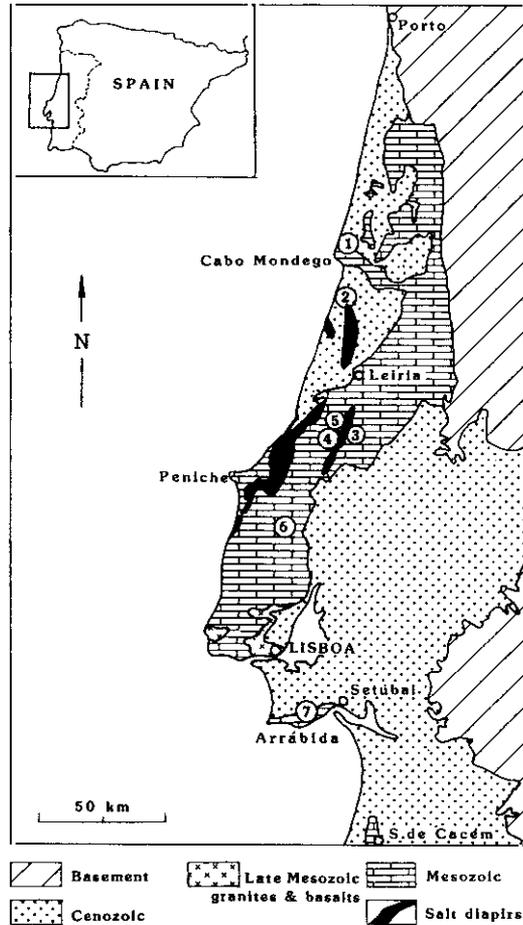
FIG. 1.—Simplified geological map of the Lusitanian Basin,West-Central Portugal and location of exposures mentioned in the text.1: Cabo Mondego; 2: Pedrógão; 3-5: Serra dos Candeeiros (Valverde, Vale de Ventos, Memória/Cabeço Gordo); 6: Serra de Montejunto, 7: Serra da Arrábida.

FIG. 1.—Mapa geológico simplificado de la cuenca Lusitánica, Portugal centro-occidental, y localización de los afloramientos mencionados en el texto. 1: Cabo Mondego; 2: Pedrógão; 3-5: Sierra dos Candeeiros (Valverde, Vale de Ventos, Memória/Cabeço Gordo); 6: Sierra de Montejunto; 7: Sierra da Arrábida.

Wilson, 1988; Gradstein *et al.*, 1990). The basin is bounded to the east by uplifted Hercynian basement, but to the west (offshore) by only small basement horsts. Two main episodes of extension and rifting are recorded in the Lusitanian Basin: the first one, in the Upper Triassic, was later followed by one which gave rise to ocean opening, began in the Upper Jurassic and developed through to the Lower Cretaceous (Mougenot *et al.*, 1979; Ribeiro *et al.*,1979; Wilson, 1988).

Whereas most of the basin fill is Jurassic in age, sediments from the Upper Triassic to the Upper Cretaceous occur, with a Tertiary cover (Fig. 1). The basin underwent tectonic inversion in the Cenozoic (probably during the Miocene), related to the Betic compressional movements (Ribeiro *et al.*, 1979) and, consequently, a great part of its pre-, syn- and post-rift sequences became exposed, after erosion of the cover. This is particularly illustrated by the ranges of Jurassic limestone hills that form a major area of the Lusitanian Basin, namely those that will be referred to in this note (Serra da Arrábida, Serra de Montejunto, Serra dos Candeeiros; see Fig.1).

The Middle Jurassic is mainly composed of limestones in the East of the basin, and of marls and limestones in the West (Ruget-Perrot, 1961; Mouterde *et al.*, 1971, 1979). These successions have been more recently interpreted as inner and mid ramp facies (eastern part of the basin) and mid to outer ramp facies towards the centre (present shoreline) and West (offshore) (Azerêdo, 1988, 1993; Watkinson, 1989).

The Middle Jurassic is separated from the Upper Jurassic by a basinwide hiatus (disconformity and/or stratigraphical gap), which has been mentioned at different locations on the basin (Ruget-Perrot, 1961; Ramalho, 1971, 1981; Mouterde *et al.*, 1979; Ruget *et al.*, 1988; Azerêdo, 1993). This stratigraphical gap spans at least from the latest Callovian to the Lower Oxfordian, because the Lamberti, Mariae and Cordatum Zones have not been recorded over the whole of the basin, where the next documented ammonite fauna (from Serra de Montejunto) belongs to the Plicatilis Zone (Middle Oxfordian), according to Mouterde *et al.* (1979). However, at places (for instance, at Serra dos Candeeiros) the missing interval is much longer, as the Malm deposits directly overlie upper Bathonian limestones (see below).

A summary description of the studied basal Upper Jurassic deposits above the discontinuity is presented below. These sediments belong to the Cabaços Formation (usually attributed to the middle Oxfordian: see, for instance, Mouterde *et al.* 1979) which basically corresponds to the Cabaços Beds and the Vale Verde Beds (*sensu* Choffat, followed in Ruget-Perrot, 1961, Ramalho 1971). This Formation is mostly composed of lacustrine/brackish carbonates and lignitic clays and of marginal marine/restricted lagoonal marls and marly limestones. Previous descriptions of the Cabaços Formation or differently named equivalent deposits may be found, for instance, in: Ruget-Perrot (1961), Ramalho (1971, 1981), Mouterde *et al.* (1971, 1979), Wilson (1979), Wright (1985).

SELECTED OUTCROPS AND STUDY METHODS

In the present note we will compare preliminary data from some of the eastern and western exposures of the Dogger-Malm transition (location in Fig.1), respectively from three field sections at Serra dos Candeeiros and from Pe-

drógão section, though Cabo Mondego and Serra da Arrábida outcrops will be sporadically mentioned.

At Serra dos Candeeiros, besides reconnaissance of a few incomplete outcrops, three locations that show the best field sections of the Dogger-Malm succession have been selected for detailed study: Valverde, Vale de Ventos and Memória/Cabeço Gordo (Fig.1). This study, currently being undertaken, includes field bed-by-bed observation, carbonate petrography, mineralogy of clay and iron deposits (X-Ray diffraction and fluorescence), micropalaeontology (foraminifera, ostracods, charophytes). Here we present a synthesis of outcrop features from those three sections, coupled with some analytical data, because a detailed description of each section is beyond the aim of this report. The Dogger-Malm disconformity at Serra dos Candeeiros has been referenced before (Ruget-Perrot,1961; Ruget *et al.*,1988; Azerêdo, 1993), but without any thorough characterization of boundary surfaces and facies above the discontinuity.

The Pedrógão section has been previously referred to basically because of its biostratigraphical interest concerning Callovian macrofauna (Ruget-Perrot, 1961; Mouterde *et al.*1979), but scarcely from the points of view of facies interpretations and micropalaeontology, although a short description of two charophyte species has been published by Grambast-Fessard & Ramalho (1985). The present description of the Pedrógão section bears mostly on field data, developed from previous unpublished work made by one of us (M. Ramalho). The degree of occurrence of palaeoclimatic sediments and/or key-beds, as well as the nature of the boundaries between facies transitions are now being especially investigated, both from continuing field observations and petrographical study. Micropalaeontolgical studies (ostracods, charophytes) by other colleagues are also in progress.

Symbols used in the lithological columns presented below are explained in Fig. 2.

FACIES SUCCESSIONS IN THE STUDIED SEQUENCES

SERRA DOS CANDEEIROS

The three selected sections in this region show Middle Jurassic shallow-marine, lagoonal carbonates truncated by highly irregular erosional surfaces, probably palaeokarstic surfaces (Fig.3), locally (Vale de Ventos) coupled with an angular discordance between the Dogger and the Malm beds above. The palaeokarst is most developed, that is, has a much higher relief, at Memória/Cabeço Gordo and Valverde.

The Middle Jurassic below the discontinuity (referred to by *number 1* in Fig. 3) is mainly composed of wackestones and floatstones with abundant algal/cyanobacteria nodules, oncoids, porostromata, benthic foraminifera, os-

- Limestones
- Bioclastic limestones
- Oncoidal limestones
- Black-pebble limestones
- Marly limestones
- Microbial laminites
- Marls/clay marls
- Marls w/ ferruginous crusts/oncoids
- Lignitic marls and clays
- Pedogenic conglomerates (calcretes)
- Ferruginous breccias
- Dessication cracks
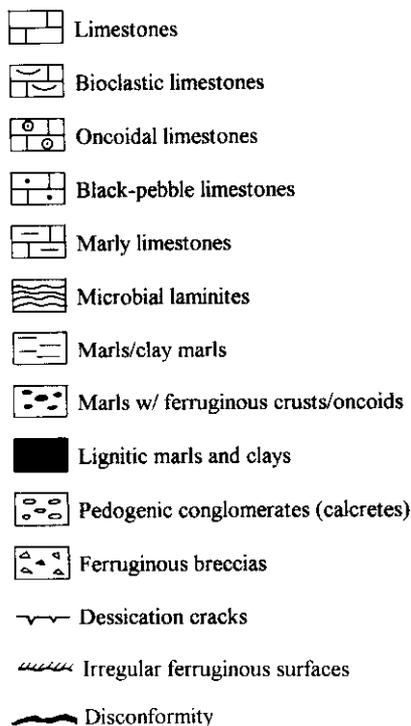- Irregular ferruginous surfaces
- Disconformity

FIG. 2.—Legend of symbols used in Figs. 3 and 9.
FIG. 2.—Simbología utilizada en las Figs. 3 y 9.

tracods, gastropods and, less frequently, bivalves, dasyclads, charophyte gyrogonites, associated with fenestral micrites; iron stained grains are typical in these carbonates (further description can be found in Azerêdo, 1993). The foraminifera assemblage includes *Meyendorffina bathonica* AUROUZE & BIZON 1958, in all three sections, a species that enables us to date these deposits as upper Bathonian.

The uneven surface is draped and overlain by ferruginous deposits (*number 2* in Fig. 3), comprising reddish and yellowish clays and marls, with fragments of iron crusts, loose iron «oncoids» and ferruginized carbonate nodules; and a red ferruginous breccia (Fig. 4), formed by heterometric limestone clasts in a red mudstone cement; it was only recognized at Valverde, where it corresponds to an irregularly bounded deposit (up to 5 m thick) and it looks very similar to a probably time-equivalent breccia from Serra da Arrábida, well-known as an ornamental stone, which occurs in similar sequences to those described here (see, for instance, Wright & Wilson, 1987). This Valverde breccia does not exhibit any clear evidence of a tectonic origin, so it could be a

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MARINE LAGOONAL FACIES

Bioclastic and marly limestones w/ Dasyclads (*Heteroporella lusitanica*), benthic Foraminifera, Ostracods, Charophytes, Gastropods, Bivalves, bioturbation; some fenestral limestones.

LACUSTRINE FACIES

Argillaceous/marly limestones w/ black-pebbles, Charophytes, non-marine Ostracods, Gastropods, Bivalves, plant remains, pyrite; some desiccation cracks, fenestrae and/or other exposure features; ferruginous surfaces, marls, crusts and "oncoids".

SUBAERIAL EXPOSURE

Palaeokarsts, local angular unconformities, ferruginous breccias and/or clays/marls w/ iron crusts and "oncoids", pedogenic conglomerates, lignitic clays and marls.

LAGOONAL/MARGINAL MARINE (INNER RAMP) FACIES

Fenestral and oncoidal, Cyannobacteria-rich limestones, w/ benthic Foraminifera.
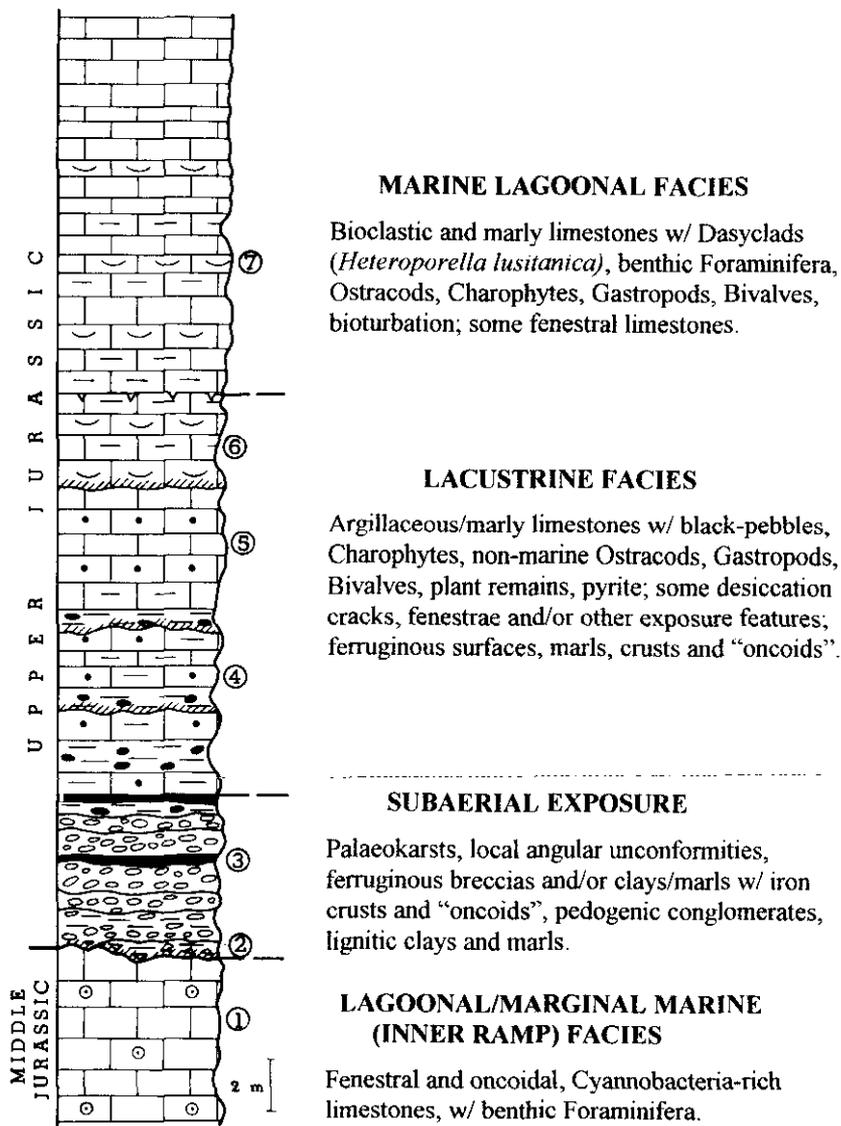
FIG. 3.—Synthetic facies succession, based on three outcrops from Serra dos Candeeiros, representing the Middle-Upper Jurassic transition in the E of the Lusitanian Basin. Numbers 1 to 7 refer to groups of beds used for clearer description in the main text.
FIG. 3.—Secuencia sintética de facies, basada en tres afloramientos de Sierra dos Candeeiros, que representan la transición Jurásico Medio-Superior en la parte oriental de la Cuenca Lusitánica. Los números 1 a 7 se refieren a grupos de estratos utilizados para hacer más clara la descripción en el texto principal.

collapse-breccia related to the palaeokarst, but this hypothesis requires further investigation (see also below).

The first analytical data obtained for these ferruginous deposits refer only to the Valverde section, where the ferruginous clays/marls contain (whole-rock analyses) hematite, goethite and kaolinite, but also magnetite (which is unexpected) and a K-feldspath, probably sanidine; the less than 2 micron clay fraction indicates the presence of chlorite and illite-smectite. Ferruginous crusts and «oncoids» are *now* hematite and goethite but show many preserved crystal faces (pyrite or marcassyte pseudomorphs?); the ferruginous breccia also contains many pyrite crystals and magnetite in the matrix. Hence, it is obvious that a simple «lateritization-model» for these ferruginous deposits is not enough to explain what seems to be the record of a much more complex depositional and diagenetic history, which we will try to unravel in the future. Both weathering and pedogenic processes seem to have operated and probably interacted, during(?) and after the erosional/karstification event.

Immediately over the basal ferruginous deposits, several conglomeratic beds occur in the three outcrops, ranging from 0,05 to 1 m thick (Fig. 3, *number*

FIG. 4.—Close view of the reddish, ferruginous breccia occurring at the disconformity at some places of the eastern part of the basin (here at Valverde) associated with red marls, ferruginous «oncoids» and crusts, as indicated in Fig. 3. Scale bar is 20 mm.

FIG. 4.—Detalle de la brecha ferruginosa, rojiza, que aparece en la disconformidad en algunos lugares de la parte oriental de la cuenca asociada a margas rojas, costras y «oncoides» ferruginosos, como se indica en la Fig. 3 (Valverde). La escala gráfica es 20 mm.

FIG. 5.—Field view of one of the «conglomeratic» calcrete beds occurring above the Middle-Upper Jurassic disconformity, as indicated in Fig. 3; it includes reworked black pebbles and an argillaceous cement (Vale de Ventos). Scale bar is 60 mm.
FIG. 5.—Aspecto de una de las capas de calcretas «conglomeráticas» existente sobre la disconformidad Jurásico Medio-Superior, como se indica en la Fig. 3; incluye cantos negros resedimentados y cemento arcilloso (Vale de Ventos). La escala es 60 mm.

3 and Fig. 5). These are irregularly bounded layers of conglomeratic limestones and conglomerates with heterometric black pebbles, limestone clasts and calcareous nodules, in a grey argillaceous cement; these beds may grade into, or from, grey marls with loose black pebbles and may be intercalated by lignitic clays. Both coarsening- and fining-up gradations are observed in individual layers, but no other macroscopic structures. In thin-section, these «conglomerates» exhibit unequivocal pedogenic features (Figs. 6 to 8), namely: rhizocretions, alveolar texture, orthic and disorthic nodules, circumgranular cracking and other displacive growth brecciation fabrics, rare possible degraded calcite needles. Associated features include irregular fenestrae, micritic bridge-cement, peloidal and laminated crusts and coatings, iron staining, ferroan dolomite/dedolomite.

Further up in the sequences (referred to by *number 4* in Fig. 3), ferruginous clays and marls with iron crusts, as well as ferruginized irregular surfaces, alternate with yellowish argillaceous/marly limestones with black pebbles, gradually passing into more massive black-pebble limestones with scarcer iron stains (Fig. 3, *number 5* and Fig. 8). All these lithotypes contain abundant

FIG. 6.—Pedogenic microfeatures in the basal Upper Jurassic «conglomerate» represented in Fig. 3: note alveolar septa texture and longitudinal sections of rhizocretions (Memória/Cabeço Gordo). Scale bar is 0,5 mm.
FIG. 6.—Micro-características pedogénicas en el «conglomerado» basal del Jurásico Superior representado en la Fig. 3; notar la textura alveolar con septos y secciones longitudinales de rizocreciones (Memória/Cabeço Gordo). La escala es 0,5 mm.
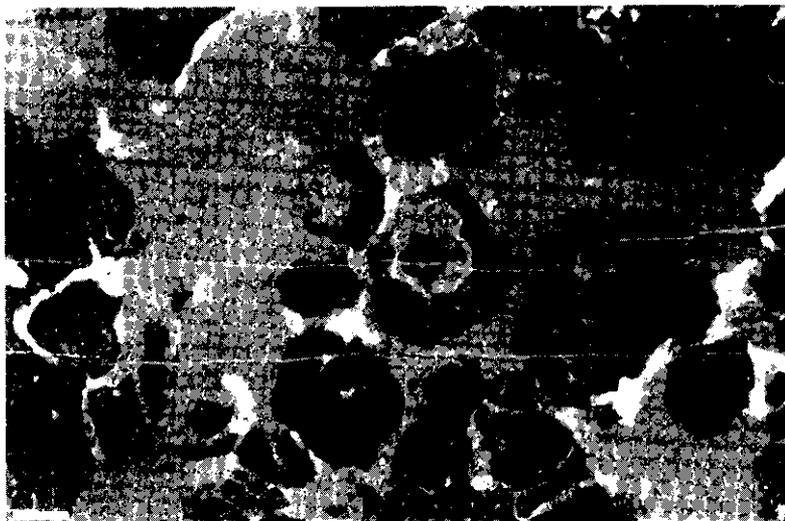

FIG. 7.—Other microscopical aspects of the pedogenic conglomerates: orthic and disorthic nodules, internal brecciation (Memória/Cabeço Gordo). Scale bar is 0,6 mm.
FIG. 7.—Otros aspectos microscópicos de los conglomerados pedogénicos: nódulos «orthic» y «disorthic», brechificación interna (Memória/Cabeço Gordo). La escala es 0,6 mm.
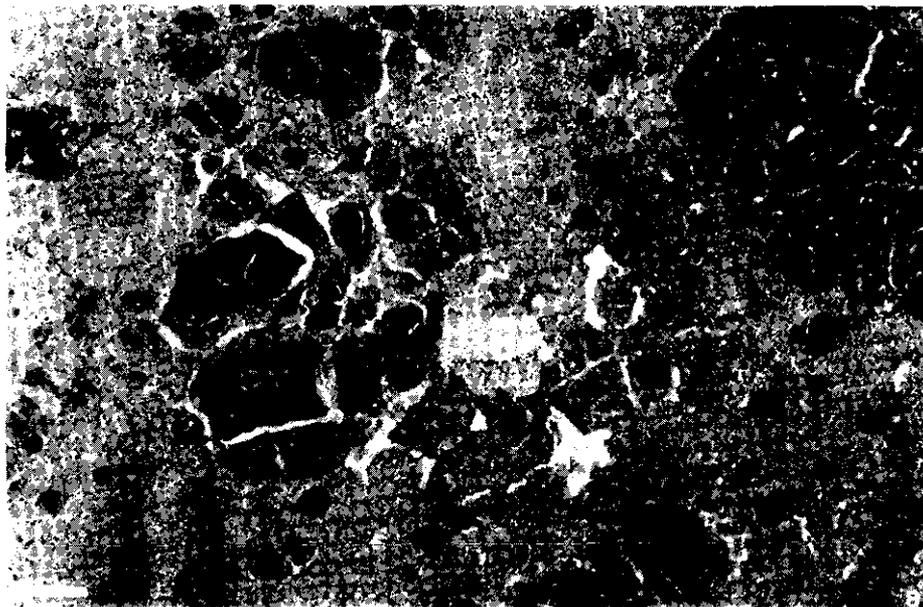
Fig. 8.—Microscopical view of the black-pebble lacustrine limestones (Vale de Ventos). Scale bar is 1 mm.
Fig. 8.—Aspecto microscópico de las calizas lacustres de cantos negros (Vale de Ventos). La escala es 1 mm.

charophytes, non-marine ostracods, plant remains, gastropods, bivalves, pyrite; locally, burrows, fenestrae and desiccation cracks occur. The iron-rich horizons look like ferruginous paleosols, as they show soil textures developed on a charophyte/ostracod limestone, though more detailed characterization of these paleosol fabrics is still required. This part of the sequences is usually followed (Fig. 3, *number 6*) by bioclastic, locally marly limestones with some intermitent-exposure features (internal brecciation, fenestrae and desiccation cracks), grading upwards into bioclastic or massive limestones with a «more marine» fossil content (Fig. 3, *number 7*): dasyclads, namely, *Heteroporella lusitanica* (RAMALHO) 1970 and benthic foraminifera become common, even abundant at certain levels, together with the previously referred organisms. Towards the top, fenestral micrites and rare «algal-mat» layers occur.

The described succession above the disconformity, as far as it is currently possible to say, only provides an indication of age at the *Heteroporella lusitanica* beds, as this dasyclad is usually taken to indicate a middle Oxfordian age in Portugal (Ramalho, 1970, 1971, 1981). This Serra dos Candeeiros succession, which is here presented as broadly representative of the basal Upper Jurassic eastern successions in the Lusitanian Basin, is interpreted as an evidence of the following suite of depositional/diagenetic conditions, from the base

to the top (Fig. 3): lengthy subaerial exposure facies, involving different events and processes, in order to produce the palaeokarst and the contrasting palaeo-climatic markers that were mentioned above (see also discussion); lacustrine facies; restricted marine lagoonal facies. The lacustrine and lagoonal facies are transitional between each other.
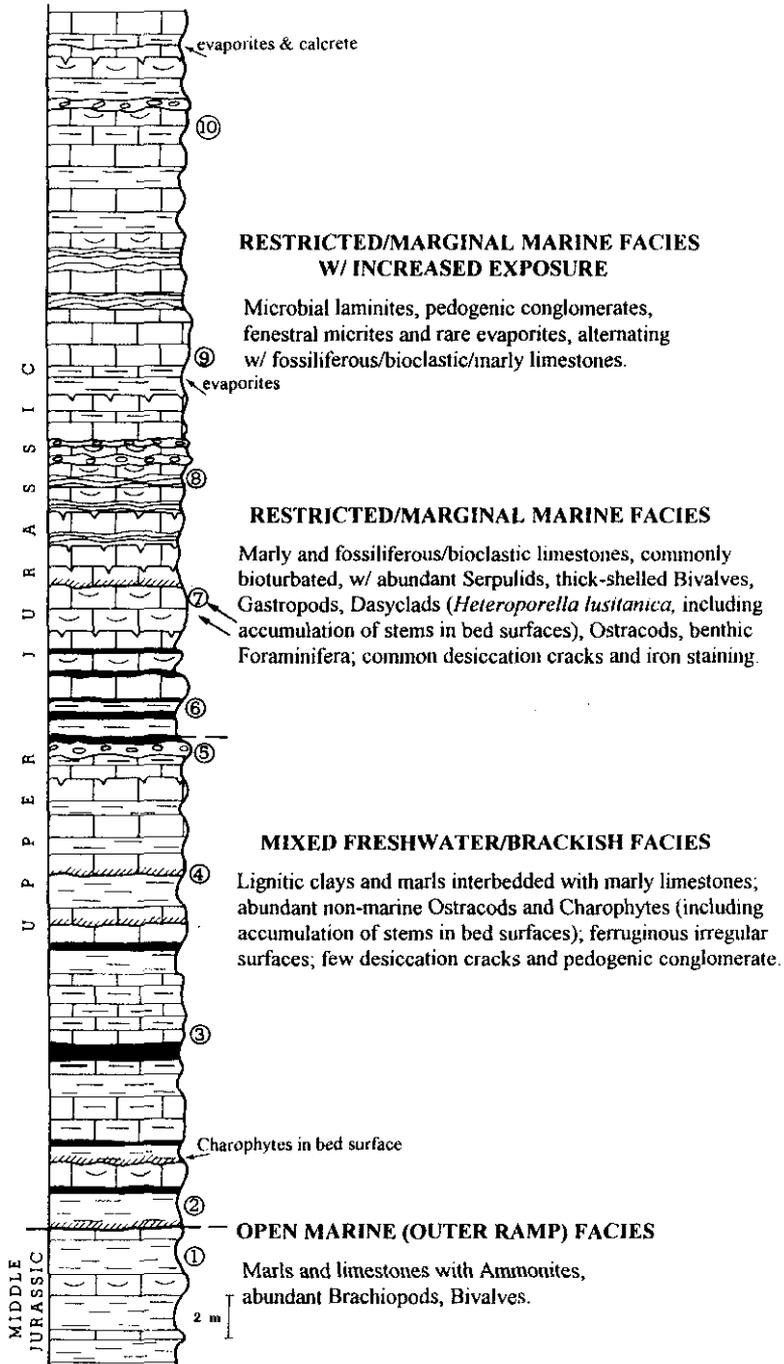
PEDRÓGÃO

Here, the Middle Jurassic corresponds to open marine, outer (or mid to outer) ramp facies, represented by marls and limestones with ammonites, abundant brachiopods, bivalves (including oysters and «filaments»), solitary corals (*number 1* in Fig. 9). According to studies of the ammonite fauna (Ruget-Perrot, 1961), the upper Callovian is represented (which is not common in the basin) except for its latest part (Lamberti Zone), which is missing across the whole of the basin.

The Callovian beds seem to grade without marked sedimentary discontinuity into the completely different facies attributed to the Upper Jurassic (Fig. 9), but we have recognized, at this boundary, an irregular ferruginous surface, draping a thin limestone bed with very abundant brachiopods and bivalves; taphonomic studies have not been made, but if the nature of this fossil concentration (ecological, sedimentary or stratigraphical condensation?) come to be established, this, coupled with the probable non-deposition ferruginous surface, would serve as a marker-bed for this transition. Previous mentions to the Pedrógão and/or Cabo Mondego sections considered Dogger-Malm transition as apparently conformable (Ruget-Perrot, 1961; Wilson, 1979; Wright, 1985).

The fossiliferous carbonates of Callovian age are overlain by brown to yellowish marls with lignitic fragments (*number 2* in Fig. 9), followed by interbedded marly limestones, lignitic clays and marls (Fig. 9, *number 3*); irregular iron stains are common. These beds may be bioturbated and contain very abundant non-marine ostracods and charophytes (gyrogonites and stems); there is one particular ferruginous limestone bed whose top surface is totally formed by accumulation/encrustation of charophyte stems (Fig. 9). A few more ferruginous irregular surfaces are recognized upwards (Fig. 9, *number 4*), as well as desiccation cracks at bedding planes. This part of the sequence is capped by a «conglomeratic-like» calcareous bed (*number 5*, Fig. 9), possibly pedogenic (in similarity to those found at Candeeiros), though unequivocal evidence can not be provided at the moment.

Further upwards (*number 6*, Fig. 9), an alternation of lignitic marls and marly limestones grades into fossiliferous and bioclastic limestones, commonly bounded by ferruginous surfaces and/or desiccation cracks. Immediately before the *Heteroporella* beds next described (*number 7*, Fig. 9), an isolated occurrence of thin bioclastic layers forming plane and very low-angle cross-la-

**RESTRICTED/MARGINAL MARINE FACIES
W/ INCREASED EXPOSURE**

Microbial laminites, pedogenic conglomerates,
fenestral micrites and rare evaporites, alternating
w/ fossiliferous/bioclastic/marly limestones.

RESTRICTED/MARGINAL MARINE FACIES

Marly and fossiliferous/bioclastic limestones, commonly
bioturbated, w/ abundant Serpulids, thick-shelled Bivalves,
Gastropods, Dasyclads (*Heteroporella lusitanica,* including
accumulation of stems in bed surfaces), Ostracods, benthic
Foraminifera; common desiccation cracks and iron staining.

MIXED FRESHWATER/BRACKISH FACIES

Lignitic clays and marls interbedded with marly limestones;
abundant non-marine Ostracods and Charophytes (including
accumulation of stems in bed surfaces); ferruginous irregular
surfaces; few desiccation cracks and pedogenic conglomerate.

OPEN MARINE (OUTER RAMP) FACIES

Marls and limestones with Ammonites,
abundant Brachiopods, Bivalves.

mination is found, being interpreted as a storm event deposit. The limestones grouped in number 7 of Fig. 9 are often bioturbated and iron stained, and are rich in dasyclads, namely *Heteroporella lusitanica* (RAMALHO) (Fig.10), including stems accumulated in bed surfaces, together with serpulids, large, thick-shelled and often brown coloured bivalves, small and large gastropods; diverse benthic foraminifera and ostracods are also present. As before, *H. lusitanica* is the only biostratigraphical marker available, though with some uncertainty (middle Oxfordian).

The above described succession gradually passes into fossiliferous/bioclastic limestones (including an ostracodite layer), interbedded by sediments with increasingly frequent evidence of subaerial exposure, such as: microbial laminites (Fig. 9, *number 8* and Fig. 11), desiccation cracks, pedogenic conglomerates (*number 9*, Fig. 9, these with unequivocal microscopic evidence, such as nodules, laminar coatings, circumgranular brecciation, etc), fenestral micrites, rarer calcite replaced evaporites. Some limestone beds (*number 10*, Fig. 9) also show *Thalassinoides* and *Rhizocorallium* ichnotypes. The upper part of the section (which is not completely described here) is probably equivalent to the *Pholadomya protei* Beds (*sensu* Choffat: see Ruget-Perrot, 1961; Mouterde *et al.*, 1971; Ramalho, 1971), attributed to the upper Oxfordian, which are recognized at Cabo Mondego (Ruget-Perrot, 1961; Wilson, 1979; Wright, 1985).

The Pedrógão Upper Jurassic sequence displays an interesting association of depositional facies, which call for a deeper approach than the one intended in this preliminary paper (see also Wright, Ramalho & Azerêdo, 1997). However, in broad terms, the succession may be regarded as representative of, from the base to the top (Fig. 9): mixed freshwater/brackish facies (distal deltaic/paralic environment?); restricted, marine lagoonal/marginal marine facies; restricted to marginal marine with increasingly frequent subaerial exposure.

At Cabo Mondego, which is geographically very close to Pedrógão (Fig.1), the Callovian to Upper Jurassic is well exposed and some interesting differences also exist between the two sections, but this issue will not be addressed here. There are previous studies of the Cabo Mondego section (Ruget-Perrot, 1961; Wilson, 1979; Wright, 1985), but we are aiming to explore a different detailed facies model approach.

FIG. 9.—Synthetic facies succession, based on Pedrógão section, representing the Middle-Upper Jurassic transition in the W of the Lusitanian Basin. Numbers 1 to 10 refer to groups of beds used for clearer description in the main text.

FIG. 9.—Secuencia sintética de facies, basada en el corte de Pedrógão, que representa la transición Jurásico Medio-Superior en la parte occidental de la Cuenca Lusitánica. Los números 1 a 10 se refieren a los grupos de estratos utilizados para hacer más clara la descripción en el texto.

FIG. 10.—Typical restricted marine microfacies from the Oxfordian sequence at Pedrógão, showing *Heteroporella lusitanica* (RAMALHO) 1970 (arrowed), ostracods, bivalve fragments. Scale bar is 0.5 mm.
FIG. 10.—Microfacies típicamente marina restringida de la secuencia del Oxfordiense de Pedrógão, con *Heteroporella lusitanica* (RAMALHO) 1970 (señalada), ostrácodos y fragmentos de bivalvos. La escala es 0,5 mm.

DISCUSSION

The calcretes (pedogenic conglomerates), identified in all the studied outcrops, had never been recognized as such in these Lusitanian Basin Upper Jurassic formations and, to our knowledge, are not a common feature to coeval
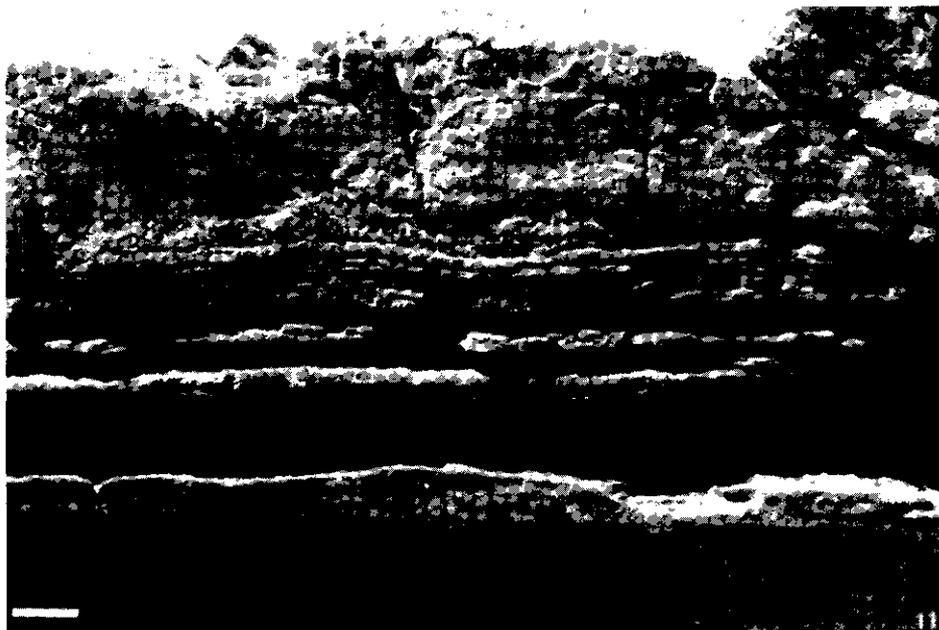
FIG. 11.—Field view of the microbial laminites from the Pedrógão section. Scale bar is 35 mm.
FIG. 11.—Aspecto de laminaciones microbianas del corte de Pedrógão. La escala es 35 mm.

deposits in other peri-atlantic basins (for instance, those referenced in the introduction). To the south of the Lusitanian Basin, at one location in Serra da Arrábida, Wright & Wilson (1987) have described a very restricted occurrence related to the Dogger-Malm unconformity, where red mudstones above a ferruginous breccia (similar to the Valverde breccia of this paper) were interpreted as a «terra-rossa-like» paleosol complex which has associated laminar calcrete crusts.

On the other hand, ferruginous deposits (iron oolites, ferruginous marls and crusts) are a typical feature of the Dogger-Malm transition in other basins, although some differences exist (see below). They have been previously mentioned in the Lusitanian Basin as «laterites» or «lateritic crusts», but have never been the subject of analytical or petrographical investigation. This preliminary study shows that these diverse iron-rich deposits seem to record a much more complex depositional and diagenetic history, instead of a simple process of lateritization after emersion. Only careful definition of the chronological and spatial relationships between different events and processes will enable a better model to be proposed.

An interesting comparison can be made between the «iron horizon» at the Dogger-Malm uneven boundary in the Lusitanian Basin and in the Iberian

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Basin (Spain). In the latter, this deposit usually corresponds to a ferruginized oolitic limestone, with original carbonate components perfectly identifiable, though locally it grades into iron crusts (Aurell & Meléndez, 1990; Aurell, 1991; Aurell *et al.*, 1994; and personal observation). This ferruginous oolite key-bed has no equivalent in Portugal and, furthermore, it encloses an abundant pelagic and benthic fauna, including ammonites of Middle and Upper Jurassic age. Complex taphonomic studies of these mixed assemblages (see, for instance, Aurell & Meléndez, 1990; Aurell et *al.,* 1994) enabled a basinwide biostratigraphical constrain, that does not compare well with the Portuguese case, too. However, the maximal and minimal ranges of the Dogger-Malm stratigraphic gap in the Iberian Basin are almost identical to those documented in the Lusitanian Basin: the maximal range is from middle Bathonian to middle Oxfordian, the minimal from upper Callovian to lower Oxfordian (Aurell, 1990; Aurell *et al.*, 1994). In the Catalan Basin, the unconformity is marked by ferruginous crusts and corresponds to a lacune from the middle Callovian to the middle Oxfordian (Fernández-López *et al.,* 1996).

The origin and depositional conditions of these ferruginous deposits at the Dogger-Malm boundary, always related to an unconformity and/or strong stratigraphical hiatus, in so many basins, has been the subject of debate for many years (see, for instance, Aurell *et al.*, 1994; Legarreta, 1991). Some authors interpret this level as a condensed section, formed in relatively deep marine environment in relation to a transgressive event, under a eustatic control (Vail *et al.,* 1987; Legarreta, 1991). Other authors as, for instance, Floquet *et al.* (1989) and, in particular, authors working in the Spanish basins (Aurell, 1991; Aurell *et al.*, 1994), on the contrary, interpret it as a stratigraphically condensed level, deposited under very shallow marine depositional conditions, with intermittent exposure, on low-angle carbonate platforms/ramps, and favour more regional dependent, tectonic or tectono-eustatic controls. This is clearly the closest situation to the one reported in the Lusitanian Basin.

Although all this requires further research, our preliminary idea is that this Middle-Upper Jurassic uneven transition reflects a forced regression, probably controlled by an E to W tilted half-graben tectonics, causing significant exposure in the E and much less so in the W, coupled with subtle palaeoclimatic evolution. This would have been from «more humid» (paleokarsts, ferruginous sediments, lignites) to «more arid» (calcretes, evaporite moulds) or, perhaps more probably, to conditions of increased seasonality and, consequently, to frequent fluctuations in the depth of water table. This has favoured the development of paleosols in «more continental» settings and increased the chances of preservation of exposure features in the marginal/shallow marine settings. The idea of a climatic fluctuation during the Oxfordian, from humid to more arid, has been tentatively suggested by Wright & Wilson (1987) in the already cited work from one location at Serra da Arrábida.

In the perspective of sequence stratigraphy, the Dogger-Malm discontinuous transition (disconformity, probably passing basinward to a sedimentary

conformity, always with a stratigraphical gap) would represent a sequence boundary; the overlying subaerial (E) and deltaic or paralic/to marginal marine (W) deposits would be the low-stand systems tract; and the lacustrine to restricted lagoon (E) and marginal to shallow marine (W) sediments the transgressive systems tract. However, we will not develop this approach for the time being, without having a more detailed characterization of facies, regionally correlatable surfaces and, most important, a better biostratigraphical control.

CONCLUSIONS

The Middle to Upper Jurassic boundary in the Lusitanian Basin is uneven, in similarity to other peri-atlantic basins, being associated to a stratigraphical gap spanning at least the late Callovian-Lower Oxfordian interval (three Ammonite biozones).

In the E of the basin, Middle Jurassic (either upper Bathonian or Callovian) inner ramp, shallow-water carbonates are truncated by erosional surfaces (palaeokarsts), associated with a strong stratigraphical gap. The disconformity is draped and overlain by ferruginous deposits, coals, pedogenic carbonates. Upwards, this sequence (probably middle Oxfordian) are mostly composed of lacustrine carbonates, gradually passing into restricted marine, lagoonal carbonates.

In the W of the onshore area of the basin, Middle Jurassic (upper Callovian) outer ramp carbonates grade without marked sedimentary discontinuity (or a very subtle one), but with stratigraphical gap, into Malm (probable middle Oxfordian) sediments. These show much less pronounced subaerial exposure features than in the E of the basin; they mostly consist of marginal-marine carbonates, with clear freshwater influence, associated with shallow-marine carbonates with intermittent exposure.

Our preliminary idea is that this Middle-Upper Jurassic uneven transition reflects a forced regression, probably controlled by an E to W tilted half-graben tectonics, causing significant exposure in the E and much less so in the W, coupled with subtle palaeoclimatic evolution. This would have been from «more humid» to «more arid» or, more probably, to conditions of increased seasonality.

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