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Callovian and the Callovian - Oxfordian transition sedimentary record in NE Iberian Chain: Taphonomic analysis and palaeogeography

El Calloviense y el registro sedimentario del tránsito Calloviense-Oxfordiense en la Cordillera Ibérica nororiental: Análisis tafonómico y paleogeografía

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Abstract

A comparative study is made on Callovian to middle Oxfordian sequences along the Northeastern Iberian Chain (E. Spain). In the NW areas, from Veruela-Ricla to Tosos (SW-S of Zaragoza), Callovian deposits are represented by expanded carbonate sequences (mudstone and marls with a variable content in clastics) ranging from early Bullatus to Athleta Biozone. Farther East in the near area of Moneva-Ariño (Sierra de Arcos) and in the area of Calanda (SE of Zaragoza), this stratigraphic interval is represented by a strongly condensed, 2-4 m thick, highly incomplete sequence. Bullatus to early Anceps biozones are partly represented under bioclastic or oolitic packstone facies. The Callovian-Oxfordian transition interval deposits are represented by a decimeter-thick iron-ooid fossiliferous limestone condensed sequence (low values of sedimentation rate) formed by expanded sediments (high values of instant rate of sediment accumulation). Ammonite recorded associations frequently show traces of reelaboration and clear evidence of taphonomic condensation. The palaeogeographic evolution of the platform is reconstructed on the basis of extensive sedimentologic studies and on the analysis of taphonomic gradients shown by ammonite associations. Such taphonomic gradients clearly show a shallowing trend of the platform during the Callovian, which would take place earlier in the SE areas (Sierra de Arcos-Calanda) from Gracilis Biozone onwards, and later, from Coronatum Biozone onwards, in the NW areas (Veruela-Ricla to Tosos), the SE area acting as a shallow to temporarily emerged palaeogeographic threshold. The shallowing process would lead to the widespread emersion of the platform from latest Callovian (Lamberti Biozone) to earliest Oxfordian (Mariae and Cordatum biozone, p.p.)

Keywords: Middle Jurassic, Late Jurassic, ammonites, sedimentary environments, taphonomic analysis, palaeogeography

Resumen

Se realiza un estudio comparativo de las sucesiones del Calloviense al Oxfordiense medio en la Cordillera Ibérica nororiental (Rama Aragonesa). En la parte noroccidental, en el sector de Veruela-Ricla a Tosos, del SW al S de Zaragoza, los materiales del Calloviense están representados por sucesiones carbonatadas expandidas (calizas mudstone y margas con un contenido variable en siliciclásticos) que abarcan desde la parte inferior de la Biozona Bullatus hasta la Biozona Athleta. Más al E, en la región de Moneva-Ariño (Sierra de Arcos) y en el sector de Calanda, este intervalo, entre las biozonas Bullatus y Anceps está representado sólo parcialmente, por una sucesión condensada, muy incompleta, en facies de packstone bioclástico o en ocasiones oolítico. Los materiales del intervalo correspondiente a la transición Calloviense-Oxfordiense constituyen una sucesión condensada (= baja tasa de sedimentación) de espesor decimétrico formada por calizas fosilíferas con ooides ferruginosos que constituyen sedimentos expandidos (= altos valores de tasa instantánea de acumulación de sedimento). Las asociaciones registradas de ammonites muestran con frecuencia claras señales de reelaboración tafonómica y evidencias de condensación tafonómica (= asociaciones condensadas). La evolución paleogeográfica de la plataforma se ha reconstruido sobre la base de análisis sedimentológicos extensivos y del análisis de los gradientes tafonómicos mostrados por las asociaciones de ammonites. Estos gradientes muestran claramente la progresiva somerización de la plataforma durante el Calloviense. Esta somerización es más temprana (a partir de la Biozona Gracilis) en el sector de Sierra de Arcos-Calanda, que actuaría como un alto paleogeográfico temporalmente emergido, y más tardía (biozonas Coronatum-Athleta) en el sector noroccidental, entre Veruela-Ricla y Tosos. Dicha somerización culmina al final del Calloviense (Biozona Lamberti) y comienzos del Oxfordiense (biozonas Mariae y Cordatum p.p.) con la probable emersión generalizada de la plataforma.

Palabras clave: Jurásico Medio, Jurásico Superior, ammonites, ambientes sedimentarios, análisis tafonómico, paleogeografía

1. Introduction

The Callovian-Oxfordian sequence in Northeastern Iberian Range at the southern margin of Ebro valley (the so-called “Aragonese Branch”) has been the subject of numerous stratigraphic and palaeontological studies in the last thirty years. Bulard (1972) first presented a general description of the stratigraphic succession and ammonite dating of successive units. The study area expands at the South of Zaragoza between, from NW to SE, the areas of Moncayo (sections of Veruela and Ricla), Tosos (in the region of Cariñena-Belchite), Moneva-Ariño (Sierra de Arcos area) and Calanda-Ráfales, farther East (Fig. 1a). A detailed correlation of Callovian to middle Oxfordian deposits has been carried out in some selected sections along the Jurassic outcrops (Fig. 1b). Callovian sequences in both regions show remarkable differences in the development of facies and thickness, as well as in the content and taphonomic features displayed by ammonite recorded associations. Among the most relevant detailed biostratigraphic studies it is worth noting those of Sequeiros and Meléndez (1979) and Sequeiros (1982a,b; 1984). Sequeiros *et al.* (1984) described the ammonite associations in the Callovian-Oxfordian iron-ooid transition level in Aguilón, near Tosos. Lardiés (1988, 1990) and Lardiés *et al.* (1988) carried out a detailed biostratigraphic and palaeogeographic study of the Callovian in NE Iberian Chain. Aurell *et al.*, 1997 supplied an updated stratigraphic description of the Callovian-Kimmeridgian interval in the area of Moneva. More recently, Page *et al.* (2004) have presented a detailed biostratigraphic revision of Bathonian to middle Oxfordian deposits throughout the northeastern Iberian Cordillera, and a correlation with European provinces. Ramajo (2006) has provided an updated monographic revision of the Callovian and Oxfordian depositional sequences in the central and northeastern Iberian range.

Litho and biostratigraphic data for the Oxfordian sequence in the Iberian Range come from previous works of the present authors and from the classical monographs of Meléndez (1989), Fontana (1990) and Bello (2005).

The Callovian-Oxfordian transition interval, known as the oolitic ironstone boundary bed, or “Arroyofrío Bed”, has also been the subject of numerous sedimentologic and taphonomic studies. Aurell *et al.* (1994), Fernández-López and Meléndez (1994, 1995) and Ramajo and Meléndez (1996) carried out detailed analyses of the lithofacies and the palaeogeographic distribution of this boundary interval, and of the taphonomic features displayed by the ammonite associations in the bed. A more recent re-interpretation of this interval in Moneva has been presented by Meléndez and Ramajo (2001) and by Meléndez *et al.* (2002), which presented a first analysis of taphonomic gradients of ammonite recorded associations of this interval in the Tosos-Moneva area. Overlying the iron-ooid interval in the whole study area, are the middle Oxfordian (Transversarium Biozone) sponge limestone deposits of the Yátova Fm.

The purpose of this paper is to present an updated correlation of Callovian deposits throughout the northeastern branch (the Aragonese Branch) of the Iberian Range and to show the relevance of taphonomic analysis of ammonite recorded associations in reconstructing and interpreting the sedimentation and palaeogeographic evolution of this platform (Fig. 1b).

2. Material and methods

The basic database for the litho and biostratigraphic study comes from the numerous studies carried out by different authors on the Callovian sequence of NE Iberian Range (see references above). More recent direct references are the works of Page *et al.* (2004) and Bel-

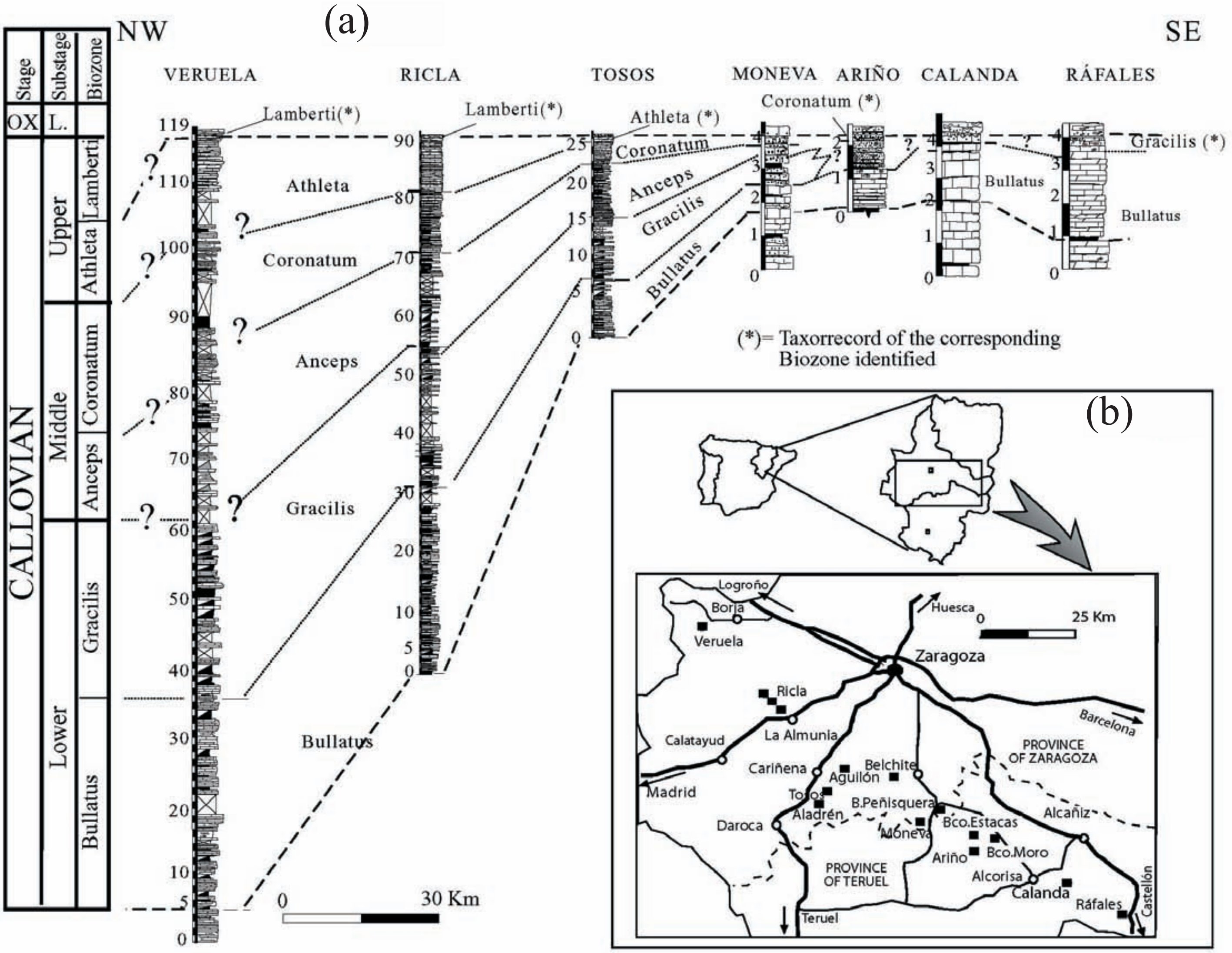

Fig. 1.- (a) Geographical location of the studied sections in NE Iberia (Aragón), South of Zaragoza. (b) Biostratigraphic correlation of the Callovian deposits in the Moncayo (Veruela-Ricla) and Tosos area (left), and the Sierra de Arcos (Moneva-Ariño) and Calanda-Ráfales area (right) showing the strong thickness reduction from West to East, in the Sierra de Arcos area. Numbers in the log indicate scale in metres. Logs generally represent a composite sequence of different outcrops in every locality.

Fig. 1.- (a) Situación geográfica de las secciones estudiadas en la Cordillera Ibérica nororiental (Aragón), al S de Zaragoza. (b) Correlación bioestratigráfica de los materiales del Calloviense en los sectores del Moncayo (Veruela-Ricla) a Tosos (izquierda) y Sierra de Arcos (Moneva-Ariño) y Calanda-Ráfales (derecha), mostrando la fuerte reducción de espesor de las sucesiones de Oeste a Este, en el sector de Sierra de Arcos. Los números en las columnas indican la escala en metros. Las secciones generalmente representan una columna sintética de distintos afloramientos en cada localidad.

lo (2005), which present a detailed biostratigraphic review of Bathonian to Oxfordian deposits in this area and Ramajo (2006), who presents an extensive sedimentological analysis and palaeogeographic interpretation of this interval in the same area (Fig 1b). Recent works by Meléndez *et al.* (2002, 2005) have presented a detailed account on the taphonomic aspects of the Callovian-Oxfordian iron-ooid boundary level. Reference sections in the different studied sectors of the Aragonese Branch of Iberian Range include: Veruela; Talamantes, and the numerous outcrops in Ricla (Ri-1 to Ri-7). Southeast from the River Jalón, between Ricla and Aguilón, the sections of Río Grío (Morata), Aladrén, Tosos Aguilón and Ventolano Massif. At the SE of Aguilón, between Belchite and Sierra de Arcos, the sections of Belchite, Moneva, Peñisquera, and the numerous sections around Ariño (AR.1-2; Barranco de las Estacas –BE, and Andorra, outcrops: And. 1-4). In the Calanda Area (River Guadalope), the numerous sections around Calanda-Mas de las Matas (outcrops Ca.1-3) and Ráfales. From all these areas, seven selected sections have been described and illustrated (Fig. 1.b).

2.1. Ammonite taxa

Palaeontological data for the Callovian come from the different ammonite collections by Sequeiros, Lardiés (*loc. cit.*) and the present authors. Oxfordian ammonites come from collections by Meléndez; Fontana; Bello (*loc. cit.*), and also from recent collections by the present authors. Detailed taxonomic data, at a species-level, constitute the base for the biostratigraphic analysis. In order to present these data in a more simplified way, they have been quantified at a genus or subfamily level (besides suborder Phylloceratina), in the following way: Oppeliids, including Callovian genera: "*Hecticoceras*", *Oxycerites*, *Paralcidia*, *Paroecotraustes*, and Oxfordian *Neocampylites*, *Trimarginites*, *Glochiceras*, *Taramelliceras* (including *Proscaphites*), and *Ochetoceras*. Tulitidae (genus: *Bullatimorphites*), Macrocephalitidae; Reineckeiidae; Perisphinctidae, including Callovian genera *Homoeoplanulites* and *Grossouvria*, and Oxfordian *Perisphinctes*, *Prososphinctes,* and *Larcheria* (Perisphinctinae) and *Passendorferia* and *Sequeirosia* (Passendorferiinae); Aspidoceratidae (genus *Euaspidoceras*).

2.2. Taphonomic features

Taphonomic analysis of ammonite recorded associations has been carried out following the model established by Fernández-López and Suárez Vega (1981) and Fernández-López (1985a, b, 1995, 1997).

Taphonomic features displayed by ammonites are categorised following a succession which would, in fact, correspond with an increasing turbulence and shallowing gradient, from complete, peristomed shells (Ps) to fragmented internal moulds (Fm) or mould fragments (Mf) (see Figs. 4-7). Complete or fragmented shells are, normally, resedimented elements (i.e. displaced on the sea bottom and/or fragmented before burial). Fragmented, disarticulated or faceted internal moulds are generally reelaborated fossils, undergoing taphonomic reworking (reelaboration), i.e. a process of exhumation and displacement on the substrate, after the initial burial. Disarticulation surfaces and abrasion facets, such as, roll facets; truncation facets, ellipsoidal facets or annular furrows are particular reelaboration features typically revealing reelaboration (see Fernández-López, 1985a; Fernández-López and Meléndez, 1994). The key to the plotted taphonomic features is as follows:

S: Resedimented elements.

W: Reelaborated elements

Conc: Concentration of ammonites. The increasing degree of concentration of fossils (resedimented shells or reelaborated moulds) may be connected with decreasing values of rate of sedimentation.

Ps: Complete, peristomed shells

Fs: Fragmented shells. Generally indicate resedimented elements, with a certain degree of energy and displacement on the sea bottom before burial.

Sf: Shell fragments. Resedimented elements; indicate a higher degree of turbulence and/or longer duration of necrocinetic processes before burial, and hence, more intense fragmentation of shells.

Fm: Fragmented moulds. Early cemented internal moulds of ammonites, showing a clear discontinuity between the infill and the sedimentary matrix around. Reelaborated; displaced on the sea bottom and fragmented before final burial.

Mf: Mould fragments: Reelaborated internal moulds suffering a more intense and lasting process of displacement (and fragmentation) on the sea boom, before final burial.

Dm: Disarticulated Mould. Reelaborated element, early cemented internal mould of ammonites, exhumed and fragmented or disarticulated along a septum. The sedimentary matrix around appears directly in contact with the septum surface. Indicates early cementation of the mould; exhumation and taphonomic reelaboration; early dissolution of the shell and fragmentation along the less-cohesive lines of the mould, i.e. the early septa, which once dissolved become weaker lines of the mould.

Tm: Truncated mould: Internal moulds of ammonites may display one or more truncation surfaces, acquired during partial or complete exhumation as an effect of directional currents. This feature only indicates taphonomic reelaboration (= complete exhumation and displacement on the sea bottom) if the truncation surface is inconsistent (non-concordant) with the bedding plane.

Rm: Rolling mould (or Roll facet): a particular case of truncation facet produced on a reelaborated internal mould as a result of a turbulent or oscillatory current and displacement of the mould on the sea bottom by rolling. Roll facets tend o increase the roundness and spherecity of the reelaborated element.

Pm: Phosphatic moulds: Concentrations of phosphatic internal moulds of ammonites, most generally as fragmented moulds (Fm), disarticulated moulds (Dm) or small mould fragments (Mf) indicate a sudden remobilisation process and early cementation of a shell infilling rich in organic matter during initial phase of diagenesis (Fernández-López, 1997). Phosphatic mould fragments show a clear lithologic and structural discontinuity with the surrounding matrix, and constitute reelaborated elements. They are particularly abundant in the Callovian-Oxfordian boundary interval ("Arroyofrío Bed") at Ricla (Ramajo and Meléndez, 1996) and, less frequently, associated to other minor stratigraphic discontinuities.

Ef: Ellipsoidal facet: A particular case of abrasion surfaces developed on one flank, on the last, external portion of the last preserved whorl. Its precise location and shape indicate that it was formed by the action of a directional, non-oscillatory current, under extremely shallow conditions; most probably a centimetre-thick layer of water. On the other hand, the internal mould, once free of matrix should be able to re-orientate with the most external part of the outer whorl directed upstream this portion being hence the most exposed to abrasion by the current. Besides a clear reelaboration criterion, ellipsoidal facets are important palaeobathymetric, environmental and palaeogeographic criteria (Fernández-López, 1985a; Fernández-López and Meléndez, 1994).

Af: Annular furrow: A particular case of abrasion facets, when the abrasion surface is developed only in the external, ventral region of the ammonite mould to form a real external "channel", not even affecting the ornamentation of the whorl flanks. This is interpreted as an evidence that the thickness of the water layer should be minimum, not enough to even cover completely the ammonite mould.

Quantitative analysis has been made on a whole of the specimens referred by different authors: Sequeiros (1984) including over 1400 specimens from the whole Aragonese Branch of Iberian Range, including most of the sections studied here. Lardiés (1988) including over 500 specimens from the sections of Ricla, Tosos, Moneva and Peñisquera, and Meléndez *et al.* (2002): c. 438 ammonite specimens from lower Callovian to middle Oxfordian (Transversarium Biozone) of Tosos and Moneva.

3. Callovian Biostratigraphy (Figs. 2 and 3)

Biostratigraphic results are here discussed, largely based on previous data from authors quoted above, and the recent tentative reference chronostratigraphic proposal by Page *et al.* (2004).

3.1. Lower Callovian

The Lower Callovian of NE Iberian Range (Aragonese branch) is well developed, although local ammonite incompleteness, means that a full ammonite sequence has yet to be established. In the NW areas, between Veruela and Ricla, where relatively expanded sequences are present, ammonite associations are often less well preserved or less abundant (Cariou *et al.*, 1988). Farther Southeast, however, for instance near Moneva, Ariño (Sierra de Arcos) and Calanda areas, extremely rich assemblages are present in thin, condensed successions, with many non-sequences (see Fig. 3). The following is therefore a review of the current state of knowledge, key published sources including: Sequeiros (1982a, b, 1984), Sequeiros and Cariou (1984), Cariou *et al.* (1988), Lardiés, (1988, 1990), Meléndez and Ramajo (1996, 2001), Ramajo (2006). The zonal framework reviewed by Thierry *et al.* (1997) for the Submediterranean Province lower Callovian of France is applicable, although rich ammonite associations from the Bullatus Biozone in these localities suggest that some refinement at the level of biohorizon, will ultimately be possible. Detailed data on successive ammonite associations come mainly from Page *et al.* (2004) (see Figs. 2 and 3).

Bullatus Biozone. It is well developed in the NW sector (Veruela-Ricla to Tosos) under black to grey marl and mudstone facies, showing a higher content in siliciclastics in the Northwest (30 to 35 m thickness) and becoming slightly bioclastic in the Tosos-Aguilón area (5 m thickness). In the Sierra de Arcos (Moneva-Ariño) and Calanda area it reaches minimum values of thickness (less than 1 m in Moneva-Ariño). Ammonite association: *Macrocephalites* aff. *verus* Buckman (= *M. verus* Beta in Page 1995), *Homeoplanulites* aff. *furculus* (Neumayr), *Bullatimorphites* (*Kheraiceras*) ex gr. *bullatus* (d'Orbigny), *Paralcidia subcostarius* (Oppel), *Hecticoceras* (*Jeanneticeras)* ex gr. *prahecquense* (Petitclerc) (cf. *verus* Beta Biohorizon at Aguilón). *Macrocephalites* sp., *Oxycerites* spp., *Paralcidia* cf. *subdiscus* (d'Orbigny), *Homeoplanulites* spp., including *H.* aff. *petitclerci* (Spath), *H.* aff. *pseudaurigerus* (Siemiradzki), *H. furculus* (Neumayr), *H.* aff. *demariae* (Parona & Bonarelli) *Bullatomorphites bullatus* (d'Orbigny) (Ricla).

Records include: Ricla (e.g. section Ricla (III), beds 23-? 64: Cariou *et al.*, 1988); Aguilón (Ag3A, Bed 104 (= cf. *verus* Beta Biohorizon; Page and Meléndez 1998, 2000), Belchite (Beds 343-344 of Sequeiros 1982b), Moneva (beds 6a-7a of Aurell *et al.*, 1999).

The absence of associations with basal Callovian *M. jacquoti* (Douvillé) below *M.* ex gr. *verus* Buckman, suggests the presence of a small widespread non-sequence of the Callovian basal horizon in the study area (Fig 3). Elsewhere in the Aragonese Branch and especially to the South-east, the aff. *verus* Buckman association is also missing and the Callovian typically begins somewhere in a succeeding higher biohorizon.

Gracilis Biozone: It is well developed in the NW sector (Veruela-Ricla to Tosos) under black to grey marl and mudstone facies, showing a higher content in siliciclastics in the Northwest where terrigenous input was higher (c. 20 m thickness) and becoming slightly bioclastic in the Tosos-Aguilón area (5 m thickness). In the Sierra de Arcos (Moneva-Ariño) and Calanda area, the ammonite assemblage corresponding to this biozone is represented by a reelaborated association (see particularly the discussion on the biostratigraphy of the rich section of Moneva, in Aurell *et al.*, 1997, Fig. 2). This may indicate a stratigraphic gap of this biozone, suggesting the possibility that the bed containing such association could in fact be more recent (? middle Callovian or perhaps, locally, even early Oxfordian see below, the discussion on Calanda area).

Prahecquense Subbiozone, Prahecquense Biohorizon. Ammonite association: *Bullatimorphites* (*Bomburites*) ex gr. *prahecquense* (Petitclerc), *Homeoplanulites* spp. (abundant), *Hecticoceras* sp., *Paralcidia* sp., *Macrocephalites* sp. Records include: Ricla (e.g. Ricla (III), beds 63/64; Cariou *et al.*, 1988), Aguilón (e.g. Ag.1), Moneva (?Bed 12 of Sequeiros 1982a), Ariño (e.g. Ar.1, Bed 107, upper part).

Grossouvrei Subbiozone, Grossouvrei Biohorizon. Ammonite association: *Reineckeia* (*Rehmannia*) cf. *grossouvrei* (Petitclerc), *R.* (*Rh.*) *rehmanni* (Oppel), *Bomburites globuliforme* (Gemmellaro), *Macrocephalites* spp. (including *M.* aff. *gracilis* Spath and possibly *Macrocephalites macrocephalus* (Schlotheim)), *Hecticoceras* sp., *Parapatoceras* sp. Records include: Ricla (e.g. Ricla (III), beds 71-87; Cariou *et al.*, 1988), Aguilón (e.g. Ag.3A, Beds 106-?110).

Pictava, Laugieri and Michalskii subbiozones. Ammonite association: *Macrocephalites* ex gr. *gracilis* Spath (locally abundant), also *Reineckeia* sp. (including *R.* (*Tyrannites*) spp.), *Paralcidia* sp., Hecticoceratidae (including *Chanasia* spp.). Pseudoperisphinctinae records include: Ricla (e.g. Ricla (III), Bed 96 to Ricla (II), Bed 10; Cariou *et al.*, 1988), Aguilón (e.g. Ag.1, beds 41-?80 of Sequeiros and Meléndez, 1981), Aladrén, Ventolano massif, Belchite (beds 346-353 of Sequeiros 1982b), Moneva (beds 7b-8a of Aurell *et al.*, 1999), Ariño (e.g. Ar.1, 108A-B of Meléndez 1978, 1989). Comment: Above the Grossouvrei Subbiozone, assemblages with common *M*. ex gr. *gracilis* Spath are typical and span the Pictava to Michalskii subbiozone interval (teste Thierry *et al.,* 1997). At least three different assemblages of *M.* ex gr. *gracilis* Spath can be recognised in the Aragonese branch of the Iberian Cordillera, although due to local correlation problems they cannot yet be placed in sequence and even subbiozonal assignment is currently uncertain.

Patina Subbiozone. Ammonite associations:

(a) Boginense Biohorizon: *Macrocephalites* sp., *Reineckeia* spp, including *R.* (*Collotia*) *oxyptycha* (Neumayr), "*Indosphictes*" *petaini* (Lemoine), *Grossouvria* sp. (possibly including *Grossouvria meridionalis* Parona & Bonarelli), *Hecticoceras* spp., including *H.* (*H.*) *boginense* Petitclerc, *H.* (*Zieteniceras*) *pseudolunula* Elmi, *H.* (*Z.*) *zieteni* (Tsytovitch) *H.* (*Jeanneticeras*) *perlatum* Zeiss, *H.* (*J.*). *girodi* (Bonnarelli).

(b) Pamprouxensis Biohorizon: "*Indosphinctes*" *patina* (Neumayr), *R.* (*C.*) *oxyptycha* (Neumayr), *H.*(*Z.*) *pseudolunula* Elmi.

(c) The terminal Lower Callovian, Posterius Biohorizon of Thierry *et al.* (1997) is not recognisable at Ricla based on the records of Cariou *et al.* (1988).

Records include: Boginense Biohorizon -Ricla (e.g. Ricla (III), beds 27- ?30 and Ricla (IV), beds 72-?76; Cariou *et al.*, 1988); Pamprouxensis Biohorizon - Ricla (IV), Bed 77-?; Cariou *et al.,* 1988). Patina Subbiozone (undifferentiated) –Aguilón (e.g. Ag.1, Bed 81-? of Sequeiros and Meléndez 1981), Belchite (Bed 354? of Sequeiros 1982b), ?Moneva (beds 14-?15 of Sequeiros 1982a).

3.2. Middle and upper Callovian

Above the lower Callovian sequence, development of the middle and upper Callovian is mainly limited to the relatively expanded sequences of the Ricla-Aguilón area as described by Sequeiros and Meléndez (1981), Cariou

STAGE		BIOZONE	SUBBIOZONE		BIOHORIZONS
CALLOVIAN	UPPER	LAMBERTI	Lamberti		Paucicostatum
					Lamberti
					Praelamberti
			Poculum		Athletoides
					Subtense
					Nodulosum
		ATHLETA	Collotiformis		Collotiformis
					Piveteaui
			Trezeense		Trezeense/ Athleta
					Leckenbyi
	MIDDLE	CORONATUM	Rota		"Pseudopeltoceras"
					Rota/ Regulare
			Leuthardti		Waageni
					Leuthardti
			Baylei		Baylei
					Villanyensis
		ANCEPS	Tyranniformis		Richei
					Blyensis
			Stuebeli		Turgidum
					Bannense
	LOWER	GRACILIS	Patina		Posterius
					Pamprouxensis
					Boginensi
			Michalskii		Michalskii
			Voultensis	Laugieri	Laugieri
				Pictava	Tyranna/ Pictava
			Grossouvrei		Grossouvrei
			Prahecquense		Prahecquense
		BULLATUS	Bullatus		

Fig. 2.- Biostratigraphic standard biozonation of the Callovian for the Submediterranean Province, according to Thierry *et al.* (1997).

Fig. 2.- Biozonación Standard del Calloviense en la Provincia Submediterránea, según Thierry *et al.* (1997).

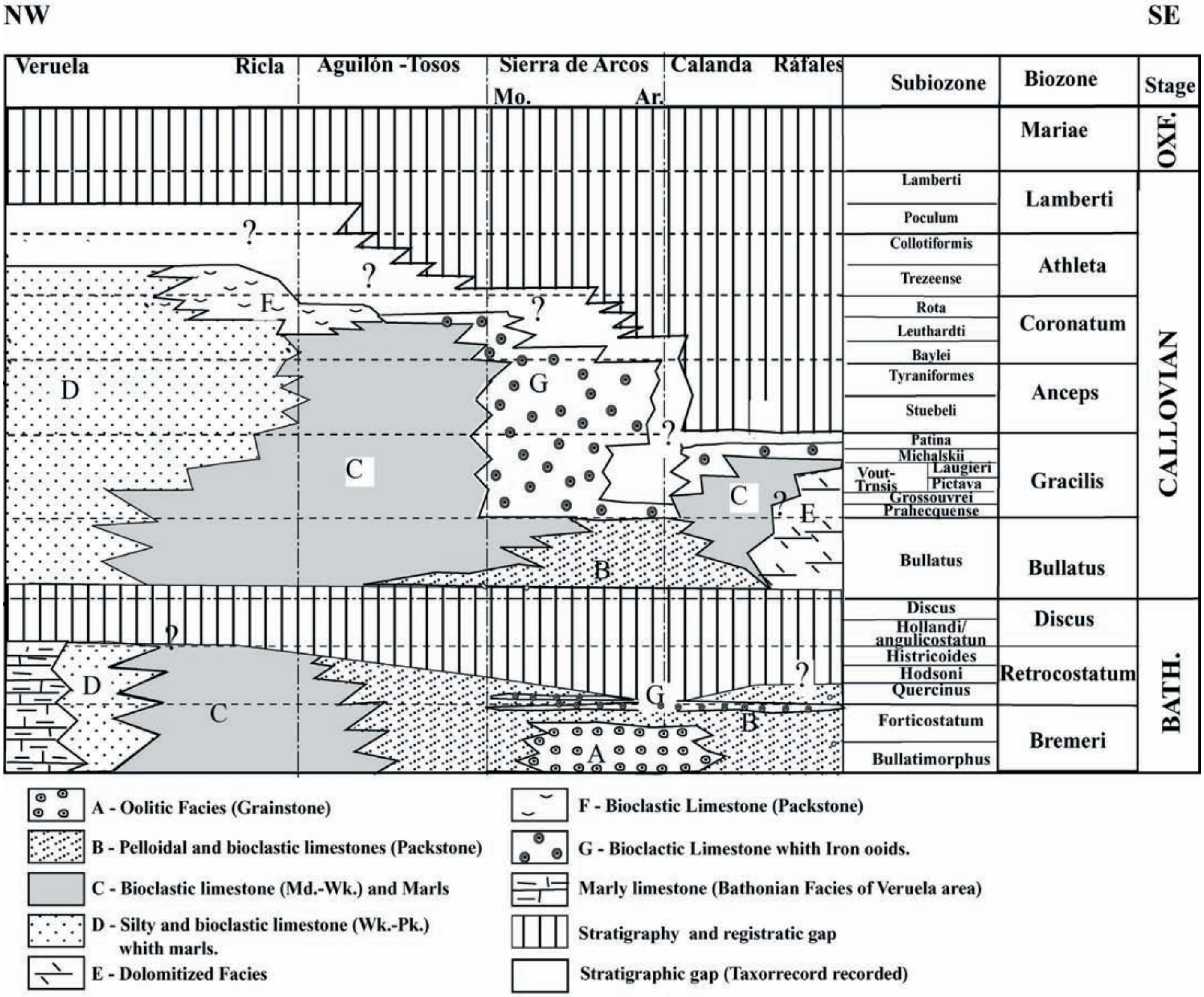

Fig. 3.- Stratigraphic and facies development of the Callovian sequence in the NE Iberian Range, from the Veruela-Ricla area (NW) to the Calanda-Ráfales region (SE). Mainly based on Page *et al.* (2004) and Ramajo (2006).

Fig. 3.- Desarrollo estratigráfico y facies de la sucesión del Calloviense en la Cordillera Ibérica nororiental, desde el area de Verurela-Ricla (NO) a la de Calanda-Ráfaless (SE). Basado fundamentalmente en datos de Page *et al.* (2004) y Ramajo (2006).

et al. (1984, 1988) with the exception, perhaps, of Moneva, where a lower iron-ooid limestone interval is recorded, ranging in age from Anceps to lower Coronatum Biozone, Villanyensis Biohorizon (Aurell *et al.*, 1994, Meléndez *et al.*, 2002). To the Southeast, the interval is missing in a non-sequence, which also includes the lower and early middle Oxfordian. The Submediterranean zonal scheme utilised in France for the middle and upper Callovian (as most recently reviewed by Thierry *et al.*, 1997) is applicable in the Iberian Range and many of its component biohorizons are recognisable. Hecticoceratidae are often abundant, with a variety of Pseudoperisphinctinae, Reineckeiidae and Peltoceratidae at appropriate levels. Currently the most completely known sequence is at Ricla, although ammonite associations from other sites in the Northwest part of the study area are likely to yield additional important material.

Anceps Biozone, Stuebeli Subbiozone. Ammonite association:

(a) Bannense Biohorizon: *Reineckeia stuebeli* (Steinmann), *Hecticoceras* (*Zieteniceras*) *pseudolunula* Elmi, *H.* (*Z.*) cf. *balinense* Bonarelli, *H.* (*Chanasia*) spp., including *Ch. hartmanni* Zeiss, *Ch.* aff *turgidum* (Loczy)*, Ch. bannense* Elmi; "*Choffatia*" sp., *Grossouvria steinmanni* (Parona & Bonarelli), "*Indosphinctes*" spp. (including "*I.*" aff. *petaini* (Lemoine), "*I.*" aff. *choffati* (Parona & Bonarelli)), *Parapatoceras* sp., *Macrocephalites* sp.

(b) Turgidum Biohorizon: *Reineckeia anceps* (Reinecke), *R.* (*Loczyceras*) *greppini* (Oppel), "*Choffatia*" sp., "*Indosphinctes*"sp., *H.* (*Rossiensiceras*) spp., including *R. metomphalum* Bonnarelli, *R. loczyi* Zeiss, *H.* (*Lemoineiceras*) sp., *H.* (*Lunuloceras*) aff. *lunula* (Reinecke), *H.* (*Zieteniceras*) spp., including *H (Z.)* aff. *kiliani* Petitclerc, *H (Z.) karpinskyi* Tsytovitch, *H (Z.) sarasini* Tsytovitch, *H (Z.) evolutum* Lee; *H.* (*Putealiceras*) spp., including *H (P.) krakoviense* Neumayr, *H (P.) rectangulare* Tsytovitch., *H (P.) virile* Zeiss; *H.* (*Sublunuloceras*) *didieri* Petititclerc, *H.*(*S.*) *crassicostatum* (Chikhachev), *H.* (*Chanasia*) *turgidum* (Loczy), *H.* (*Orbignyceras*) *pseudopunctatum* Lahusen, *Phlycticeras poygonium* Zieten. Records include: Bannense Horizon - Ricla (e.g. Ricla (III), beds 32-51; Cariou *et al.*, 1988); Turgidum Biohorizon - Ricla (e.g. Ricla (III), beds 52-53 and Ricla (IV), beds 83-87; Cariou *et al.*, 1988), Moneva (beds 8b-9a of Aurell *et al.*, 1994, Meléndez *et al.*, 2002; = Bed 16 of Sequeiros 1982a?).

Tyranniformis Subbiozone. Ammonite association may include: *Hecticoceras*. (*Rossieniceras*) *tsytovitchi* Zeiss, *H.* (*R.*) aff. *multicostatum* Tsytovitch, and *H.* (*Brightia*) *submatheyi* Lee, *H.*(*B.*) *difforme* Tsytovitch. Records include: Ricla (e.g. Ricla (IV), Bed 92+; Cariou *et al.*, 1988), ?Belchite (?Bed 353 of Sequeiros 1983).

The ammonite association recorded at Ricla by Cariou *et al.* (1988) is not definitive and neither component biohorizons -Blyensis and Richei of Thierry *et al.* (1997)- are currently recognisable.

Coronatum Biozone, Baylei Subbiozone. Ammonite association: *Flabellisphinctes* spp., including *F. villanyensis* Till., *F. tsytovitchae* Mangold; *Hecticoceras* (*Rossieniceras.*) spp., including *H.*(*S.*) *metomphalum* Bonarelli, *H.*(*S.*) *multicostatum* Tsytovitch., *H.*(*S.*) *savoiense* Zeiss; *H.* (*Orbignyceras*) *bronni* Zeiss, *H.* (*Orb.*) *schloenbachi* Tsytovitch, *H.* (*Brightia.*) spp., including *H.*(*B.*) *difforme* Tsytovitch, *H.*(*B.*) *tenuinodosum* Zeiss, *H.*(*B.*) *scaphitoides* Tsytovitch; *Collotia gigantea* (Bourquin), "*Choffatia*"sp. (Villanyensis Horizon); *Erymnoceras* spp. (including *E. baylei* Jeannet), *Reineckeia fehlmanni* Jeannet, *Grossouvria* sp., *Lytoceras* sp. (Baylei Horizon). Records include: Villanyensis Horizon - Ricla (e.g. Ricla (II), 70-?76; Cariou *et al.*, 1988), ?Moneva (?Bed 9b of Aurell *et al.*, 1994; Meléndez *et al.*, 2002). Baylei Horizon - Ricla (e.g. Ricla (II), 77-?79; Cariou *et al.*, 1988).

Leuthardti and Rota subbiozones. Ammonite association: Including *Hecticoceras* (*Rossieniceras*) *regulare* Till. (Leuthardi Subbiozone). No component biohorizons are currently recognisable.

Record: the Leuthardti-Rota interval probably corresponds to beds 75-85 at Ricla (I) and 80-84 at Ricla (II), which have not yielded diagnostic ammonite associations (Cariou *et al.*, 1988). Aguilón: Reelaborated assemblage of Leuthardti Subbiozone age in beds 106-107 (Sequeiros *et al.*, 1984). This means that instability in sedimentation, which had started probably at the Bullatus-Gracilis biozone boundary at the Calanda-Sierra de Arcos region, was the general rule farther NW in the platform, in the Aguilón-Tosos area from Baylei Subbiozone onwards. From this subbiozone upwards until the middle Oxfordian long periods of reworking and taphonomic reelaboration were only punctuated by ephemeral sedimentary episodes. The actual age of beds 106-107 in Aguilón might be in fact early middle Oxfordian, as demonstrated recently by Meléndez *et al.* (2005), since resedimented (non-reelaborated) elements from these levels correspond in fact to *Perisphinctes* (*Otosphinctes*).

No component biohorizons are currently recognisable. The Leuthardti-Rota interval probably corresponds to beds 75-85 at Ricla (I) and 80-84 at Ricla (II), which have not yielded diagnostic ammonite associations (Cariou *et al.*, 1988). The reelaborated assemblage recorded in beds 106-107 at Aguilón includes the Taxorrecords (= ammonite associations preserved as reelaborated elements characteristic of subbiozones, as defined by Fernández-López, 1986) Leuthardi, Trezeense, Collotiformis, Poculum and Claromontanus (= Bukowskii). The Claromontanus Taxorrecord is defined by the record of *Prososphinctes claromontanus* (Bukowski), *Passendorferia czenstochowiensis* (Siemiradzki) and *Neocampylites delmontanus* (Oppel) (Sequeiros *et al.*, 1984). On the other hand, the record of scarce fragmentary ?resedimented representatives of *Perisphinctes* (*Otosphinctes* and *Kranaosphinctes*) might characterise the Paturattensis (= Vertebrale) Subchronozone of the Plicatilis Chronozone, which could presumably be the actual age of the bed (Meléndez *et al.*, 2005).

Athleta Biozone, Trezeense Subbiozone. The only sections in which this subbiozone can be recognised and characterised by a non-reelaborated (= resedimented) assemblage are those of the Northwest, i.e. those of Ricla and Veruela, by the presence of non-reelaborated elements of *H. (Orbignyceras) trezeense* (Gerard & Contaut) and *Peltoceras trifidum* (Quenstedt) in the upper Callovian beds of Ricla below the "Arroyofrío Bed" (Sequeiros and Cariou, 1984; Cariou *et al*, 1988). The ammonite association includes: *Hecticoceras* (*Orbygniceras*) *trezeense* (Gérard & Contaut), *Hecticoceras* (*Sublunuloceras*) sp., *H.* (*Putealiceras*) *lugeoni* Tsytovitch, *Pseudopeltoceras* sp., *Peltoceras* (*Rursiceras*) cf. *stolleyi* (Priest), *Collotia thiebauti* (Gérard & Contaut), *Orionoides* sp., *Pseudopeltoceras* sp., *Distichoceras pasdejeuensis* (Gérard & Contaut). Records include: Ricla (e.g. Ricla (I), beds 87-89; Cariou *et al.*, 1988). In Aguilón-Tosos, the reelaborated assemblage recorded in beds 106-107 includes elements characteristic of this subbiozone (Sequeiros *et al.*, 1984; Lardiés, 1988, Meléndez *et al.*, 2002, 2005). Therefore, a stratigraphic gap of the Athleta Biozone is evidenced, although not an ammonite gap (= registratic gap, as defined by Fernández-López, 1986). Although the Athleta Biozone cannot be evidenced, the characteristic ammonite assemblage, preserved as a reelaborated association, constitutes the so-called: *Athleta Taxorrecord*, as defined by Fernández-López (*loc. cit*).

Collotiformis Taxorrecord. The ammonite association including *Collotia fraasi* (Oppel) is included in Aguilón (reelaborated assemblage in beds 106-107; Sequeiros *et al.*, 1984; Meléndez *et al.*, 2002, 2005). Component horizons are not recognisable. In the eastern areas, in the Sierra de Arcos-Calanda sections, both a stratigraphic and a registratic gap of this interval (i.e. lack of this stratigraphic interval and of the corresponding ammonite associations) is detected.

Lamberti Biozone. Ammonites characteristic of this biozone are recorded in Ricla and Aguilón within the Callovian-Oxfordian transition level (= Arroyofrío Bed) preserved as reelaborated elements, hence characterising the Poculum Taxorrecord. Therefore, a stratigraphic gap of the lower Subbiozone of Lamberti Biozone is evidenced, although not an ammonite (= registratic) gap (see above). Ammonite association includes *Hecticoceras* (*Sublunuloceras*) *lairense* Spath, *H.* (*S.*) *nodosulcatum* (Lahusen) (Poculum Taxorrecord). Records include: Ricla-1 and 2 (reelaborated assemblage within the Arroyofrío Bed). Aguilón: reelaborated assemblage characterising the Poculum Taxorrecord in the iron-ooid beds 106-107 (Sequeiros *et al.*, 1984; Meléndez *et al.*, 2002, 2005). In the Sierra de Arcos-Calanda sections, a stratigraphic and registratic gap of this interval is detected.

The highest Callovian Lamberti Biozone (Lamberti Subbiozone) and lowest Oxfordian Mariae Biozone, and their corresponding taxorrecords (= characteristic ammonite associations) are absent throughout the whole studied area (= stratigraphic and registratic gap).

4. Taphonomic-biostratigraphic remarks (Figs. 4 to 7)

4.1. Ricla

In Ricla, the Callovian sequence is formed by a monotonous, c. 100 m thick alternation of black mudstone to scarcely bioclastic wackestone beds with variable content in siliciclastics, interbedded with marly intervals. The succession becomes progressively more carbonate and ends in an uneven erosional surface, which marks the Callovian-Oxfordian boundary. The last limestone beds (10,6 m; levels 185-197 of Sequeiros and Cariou, 1984) include a non-reelaborated (resedimented) ammonite association including *Peltoceras trifidum* (Quenstedt), *Collotia thiebauti* (Gerard & Contaut) and *Hecticoceras (Orbignyceras) trezeense* (Gerard & Contaut), which characterizes the lower athleta Biozone, Trezeense Subbiozone. The upper bed is sharply cut by an irregular ?bioturbation surface deepening more than 30 cm in the underlying bed and delineating irregular “cavities” filled with a bioclastic carbonate matrix including a “conglomerate” of intraclasts, bioclasts and fossil fragments. Three generations of infillig are recognized in these cavities, separated by discontinuities, hard-grounds and/or stromatolitic crusts (Meléndez *et al.*, 1983a; Ramajo and Meléndez, 1996; Ramajo, 2006). Ammonites, belemnites, brachiopods and crinoid remains are the most frequent components.

Discussion

Ammonite content inside this level is a condensed association including several reelaborated, topologically-successive ammonite associations, which characterize successively the Collotiformis, Poculum, lower Bukowskii (= Claromontanus: Meléndez *et al.*, 1983b) and Paturattensis taxorrecords (*cfr*. Fernández-López, 1986; Meléndez and Ramajo, 1996). Taphonomic gradients displayed by the ammonite fossils (Fig. 4) show a sharp decrease in resedimented elements and a correlative increase in reelaborated elements, meaning a rapid fall of rate of sedimentation progressive shallowing process, probably from moderately deep subtidal to shallow subtidal environment conditions. Among them, fragmented moulds and mould fragments show a progressive increase. Phosphatic moulds show a sudden increase in the interior of cavities, together with rounded, truncated and disarticulated moulds (Fig. 8, a; c). The particular case of annular furrows (Fig. 8 b) indicates the existence of extremely shallow, to intertidal and even emerged conditions in this area during a long interval of time, probably at the latest Callovian (Lamberti Chronozone)-earliest Oxfordian (Mariae Chronozone), coinciding with the generalized registratic gap. The infilling deposits are integrated by successive episodes of concentrations of clasts filling the cavities and ammonite mould fragments and other fossils showing grain-size selection and bounded by hard-ground discontinuities and/or stromatolitic crusts (Meléndez and Ramajo, *loc. cit.*; Ramajo, 2006). These features indicate quick event sedimentation episodes, most probably storm deposits (= high values of instant rate of sediment accumulation; *cfr*. Gómez and Fernández-López, 1994), and long intervals of non-deposition (= low values of rate of sedimentation). This conforms a condensed sequence integrated by expanded deposits.

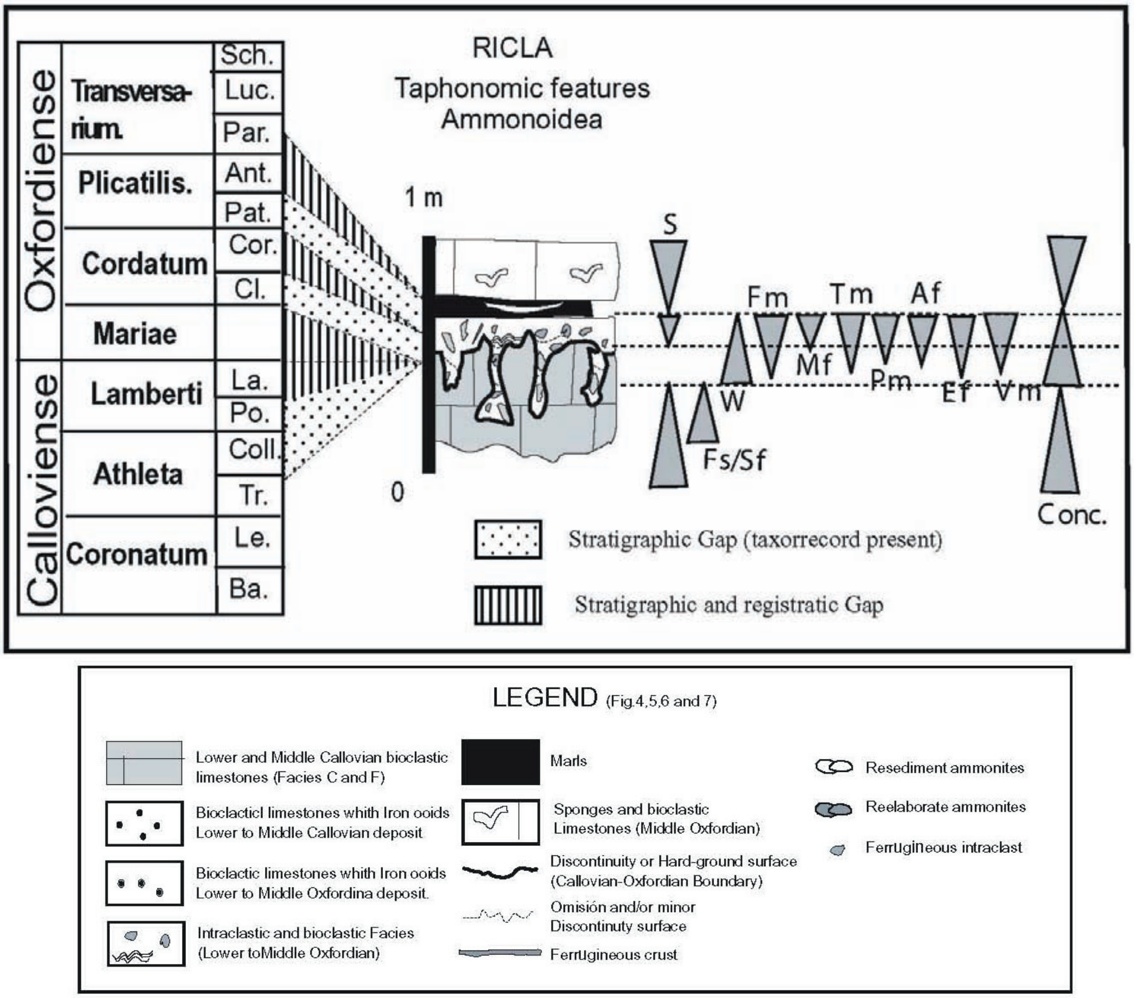

Fig. 4.- The Callovian-Oxfordian transition interval at Ricla. Taphonomic features and gradients shown by ammonites correlate with variations of the environmental energy and bathymetry: Ps Peristomed shells; Fs: fragmented shells, Sf: shell fragments, Fm: fragmented internal moulds, Dm: Disarticulated internal moulds Mf: Mould fragments, Tm: Truncated moulds, Ef: Ellipsoidal facets, Af: Annular furrows.

Fig. 4.- Transición Calloviense-Oxfordiense en Ricla. Los caracteres y gradientes tafonómicos presentados por los ammonites se correlacionan con las variaciones en la energía del medio sedimentario y la batimetría: Ps Conchas peristomadas; Fs: Conchas fragmentadas, Sf: Fragmentos de conchas, Fm: Moldes internos fragmentados, Dm: Moldes internos desarticulados Mf: Fragmentos de moldes, Tm: Moldes truncados, Ef: Facetas elipsoidales, Af: Surcos anulares.

4.2. Aguilón-Tosos

In the Aguilón-Tosos area, lower to early middle Callovian sediments are represented by an expanded sequence formed by a 25 m thick alternation of micritic limestones (mudstone to bioclastic wackestone) and marls (Lardiés, 1988). Late middle Callovian, Coronatum Biozone, deposits are formed by a 3 m thick succession of hard, cemented bioclastic limestones (packstone of filaments and fossils). Attention should be paid to the fossil content in the iron-ooid interval (level 81 of Tosos; levels 106-107 of Aguilón) at the top of the Callovian succession in this locality (the so-called *Arroyofrío Bed*). In Aguilón, the detailed studies carried out by Sequeiros and Meléndez (1981) Cariou *et al.* (1984), Meléndez *et al.* (1983a, b), Meléndez (1989) have allowed a more recent interpretation of this interval taking into account the taphonomic features displayed by ammonite recorded associations (Meléndez *et al.*, 2002, 2005; Page *et al.*, 2004; see above). The iron-ooid interval in Aguilón includes several limestone bands with abundant, small-size, well-sorted ooliths. These layers show a marked lenticular shape and are separated by clear discontinuities (Aurell *et al.*, 1994). The irregular shape of the surfaces was first interpreted as a result of intense bioturbation and an explanation for the mixing of diachronic ammonite fossils in these beds (Sequeiros *et al.*, 1984). However, the local development of iron crusts on the oolitic beds, the erosional shape of stratification surfaces and the presence of truncated fossils, as well as the biochronological analysis of successive ammonite associations indicate the development of hard-grounds and the presence of important stratigraphic gaps associated. On the other hand, the lenticular shape of the beds and the clastic (oolitic) well-sorted content

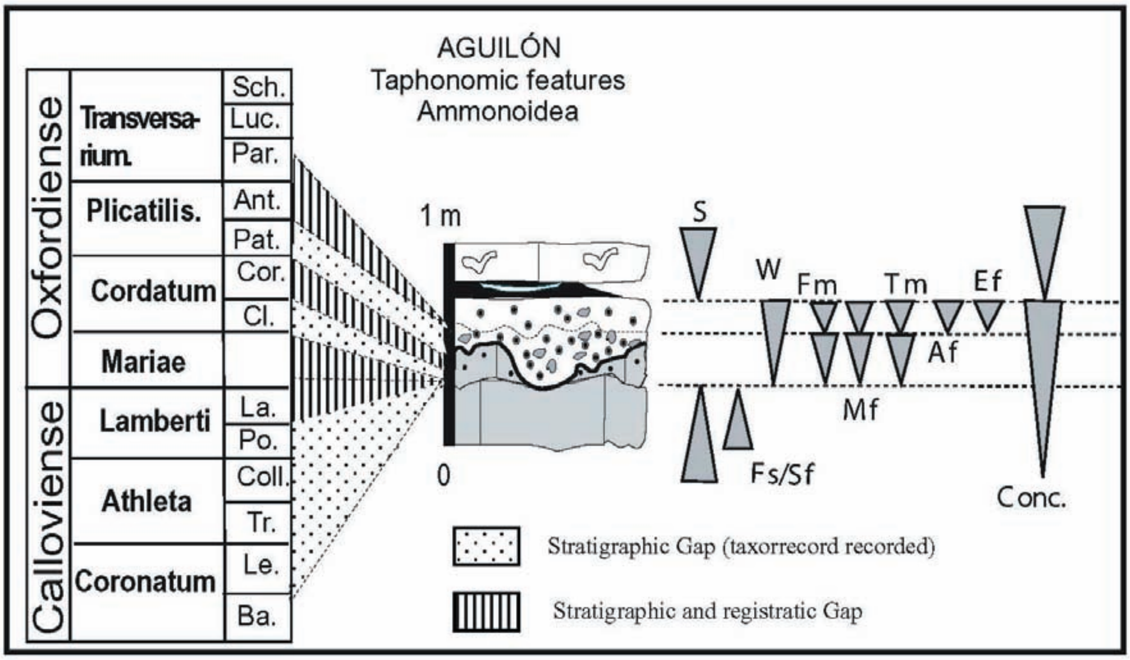

Fig. 5.- The Callovian-Oxfordian transition interval at Aguilón. Legend, as for Fig. 4. The Callovian-Oxfordian transition interval corresponds to the iron-ooid transition level (*i.e.* Arroyofrío Bed: upper Callovian, or most probably, middle Oxfordian Paturattensis to (?) Parandieri Subbiozone.

Fig. 5.- La transición Calloviense-Oxfordiense en Aguilón. Leyenda igual que para la Fig. 4. El intervalo que marca la transición Calloviense-Oxfordiense corresponde al nivel de oolitos ferruginosos (i.e. la Capa de oolitos ferruginosos de Arroyofrío) probablemente Oxfordiense medio, quizás correspondiente a las Subbiozonas Paturattensis o Parandieri (*cfr.* Meléndez *et al.*, 2005).

indicate, again, rapid event sedimentary episodes, i.e. the oolitic interval at Aguilón (and similarly Tosos, although at this locality the iron-ooid level shows a much lesser development) also constitutes a condensed stratigraphic sequence integrated by expanded deposits.

Discussion

Analysis of taphonomic gradients shows a clear decrease of ammonites (resedimented shells) in the last levels of the Callovian sequence just below the oolitic boundary level. In the iron-ooid interval, concentration of ammonite fossils (reelaborated moulds) increases sharply. Elements are preserved as Fragmented moulds (Fm); Mould fragments (Mf) (sometimes showing a rolling facet or an iron crust coating), Truncated moulds (Tm), and disarticulated moulds (Dm) (Fig. 8 d) indicating a clear decrease of values of sedimentation rate and a shallowing process, from deeper to shallow subtidal conditions. The presence of common elements wearing Ellipsoidal facets (Ef) and Annular furrows (Af) associated to the upper discontinuity surface suggests shallower, intertidal to even supratidal conditions, i.e. the probable subaerial exposure of the platform during a long interval at the Callovian-Oxfordian boundary (upper Lamberti to Mariae Chronozone). On the other hand, the constant presence of specimens of middle Oxfordian Perishinctes in all oolitic levels seems to indicate an early middle Oxfordian age (?Paturattensis Subchronozone) for this interval (Meléndez *et al.*, 2005).

The lowermost bed of the overlying sponge limestone unit (the so-called *Yátova Fm*) contains resedimented (non-reelaborated) specimens of *Perisphinctes* close to the *P. parandieri* Loriol group, which could still characterize the middle Oxfordian Parandieri Subbiozone of the Transversarium Biozone. Above these lower beds, the common occurrence of *P. (Dichotomosphinctes*) cf. *luciaeformis* Enay and *P. (Otosphinctes) nectobrigensis* Meléndez, clearly characterises the Transversarium Biozone, Luciaeformis Subbiozone.

4.3. Moneva

Ammonite biostratigraphy of the Callovian of Moneva has been discussed in detail by different authors in the last 20 years, and more recently by Aurell *et al.* (1999), Meléndez and Ramajo (2001; see also references therein) and Meléndez *et al.* (2002). Among the most remarkable points of this section are:

(1) The scarce stratigraphic development of the Callovian sequence, which forms a condensed sequence less than 2 m thick as a whole.

(2) In contrast, the important development of the iron-ooid transition level (*Arroyofrío Bed*) reaching over 1 m thickness in this locality. Despite the lenticular shape of the

beds and their scarce lateral continuity, two main sets of beds can be distinguished within this sequence (Fig. 6):

- A lower interval (levels 7-9) formed by red-coloured fossiliferous micritic, bioclastic wackestone, containing sparse small iron ooids and Callovian ammonites characterising the Gracilis Biozone (levels 7-8) and perhaps, lower Anceps Biozone (level 9). Callovian ammonites are preserved mostly as fragmented or disarticulated internal moulds (Fm, Dm) showing common evidence of reelaboration such as lithological, textural or structural discontinuity between the sedimentary infill and the surrounding matrix. Non-reelaborated (= resedimented) specimens preserved as shell fragments (Sf) are generally difficult to determine due to their incomplete state. Therefore, some reservation should be made on precise dating of this first oolitic interval (see Aurell *et al.*, 1999, Fig. 2)

This lower interval is separated from the overlying one (level 10) by a thin (3 to 5 cm thick) micritic, somewhat oolitic layer (9c), wedging out laterally or reduced to few mm thick limonitic crusts. It is capped by an erosional, truncation surface.

Discussion

This thin layer contains common ammonite fossils from lower and middle Callovian showing clear evidence of reelaboration. They are preserved as internal moulds showing truncation facets (Tm) or disarticulation facets (Dm) as well as a clear discontinuity between the micritic, non-oolitic (or sparsely oolitic) infill and the dense oolitic sedimentary matrix. Some specimens may develop ellipsoidal facets (Ef) and/or annular furrows (Af) (see Fig. 6) indicating again a transition during the lower to middle Callovian from subtidal to shallower bathymetric, subtidal to intertidal conditions. The age of this upper oolitic layer (9c) is difficult to assess, since non-reelaborated specimens are not common in this association, attention should be paid to one specimen of *Flabellisphinctes (Flabellia)* apparently showing an oolitic infill in structural and textural continuity with the surrounding matrix (hence, a resedimented shell), which would characterise the lower Coronatum Biozone (Baylei Subbiozone, see Meléndez *et al.*, 2002; Page *et al.*, 2004). The flat truncational surface separating the bed 9c from the overlying bed (10), might represent the Callovian-Oxfordian boundary involving a stratigraphic and registratic gap which would span the upper Coronatum, Athleta, Lamberti and Mariae biozones and their corresponding taxorrecords. Therefore, Callovian deposits in this area (Moneva-Peñisquera) constitute a condensed sequence (resulting from low values of sedimentation rate), mainly integrated by thin, lenticular-shaped oolitic and clastic beds, including abundant, heterometric iron-ooids, and separated by sharp sedimentary discontinuities. Discontinuity surfaces include local development of iron crusts and truncated fossils and represent hard-grounds. In contrast, the scarce lateral continuity of the beds and their oolith and clast content (fragments of fossils, such as reelaborated Mould fragments) showing positive gradation indicate episodic, rapid deposition events (event sedimentation) corresponding probably to storm deposits, and high values of instant rate of sediment accumulation (Gómez and Fernández-López, 1994).

- An upper interval formed by a 30 cm thick, somewhat compact limestone band (level 10 a-b): grey-yellowish bioclastic packstone including abundant and larger (over 2 mm diameter) iron ooids. Fossil content in bed 10a is less abundant than in the lower interval. It includes scarce resedimented specimens of *Prososphinctes*, preserved as fragmented, incomplete shells (Fs) or shell fragments (Sf). These specimens allow assigning this level to the early Oxfordian, perhaps Claromontanus Biozone (Aurell *et al.*, 1999). Reelaborated internal moulds (*Homoeoplanulites*; *Hecticoceras*) are also recorded. They are preserved as fragmented or disarticulated moulds (Fm, Dm). The upper bed of this interval (bed 10b), separated from the underlying bed 10a by a clear limonitic crust, has yielded scarce specimens of Perisphinctinae, such as *Per.* (*Otosphinctes*) showing clear evidence of reelaboration, such as truncation facets (Tm) and even ellipsoidal facets (Ef; see fig 8-f) Therefore, the age of this level is, again, difficult to assess, until further finding of resedimented, non-reelaborated specimens may add more precision. Tentative assignment of this bed to lower Plicatilis, Paturattensis Subbiozone should be taken with reservation. It is not excluded that the real age of this bed may be higher in the middle Oxfordian.

Levels 11 to 16 form a thick, well-bedded, pink-coloured sponge limestone interval above the erosive, truncation surface capping the bed 10b. They correspond to the lower part of *Yátova Fm,* formed by micritic, somewhat bioclastic fossiliferous wackestone (see Fontana, 1990). Ammonites are mostly preserved as fragmented shells (Fs, resedimented elements) or else smaller shell fragments (Sf) indicating slightly energetic conditions in a moderately deep subtidal environment, under wave action and also long duration of biostratinomic, pre-burial phase. However, attention should be paid to some specimens of *Perisphinctes (Otosphinctes)* from the basal levels of this interval, preserved as Fragmented or Truncated moulds (Fm; Tm) or even showing ellipsoidal facets (Ef: see Fig 8-e). This would mean that extremely shallow subtidal to intertidal conditions might persist in this area until late in the middle Oxfordian and support the idea of the Sierra de Arcos area as a persistent uplifted palaeogeographic

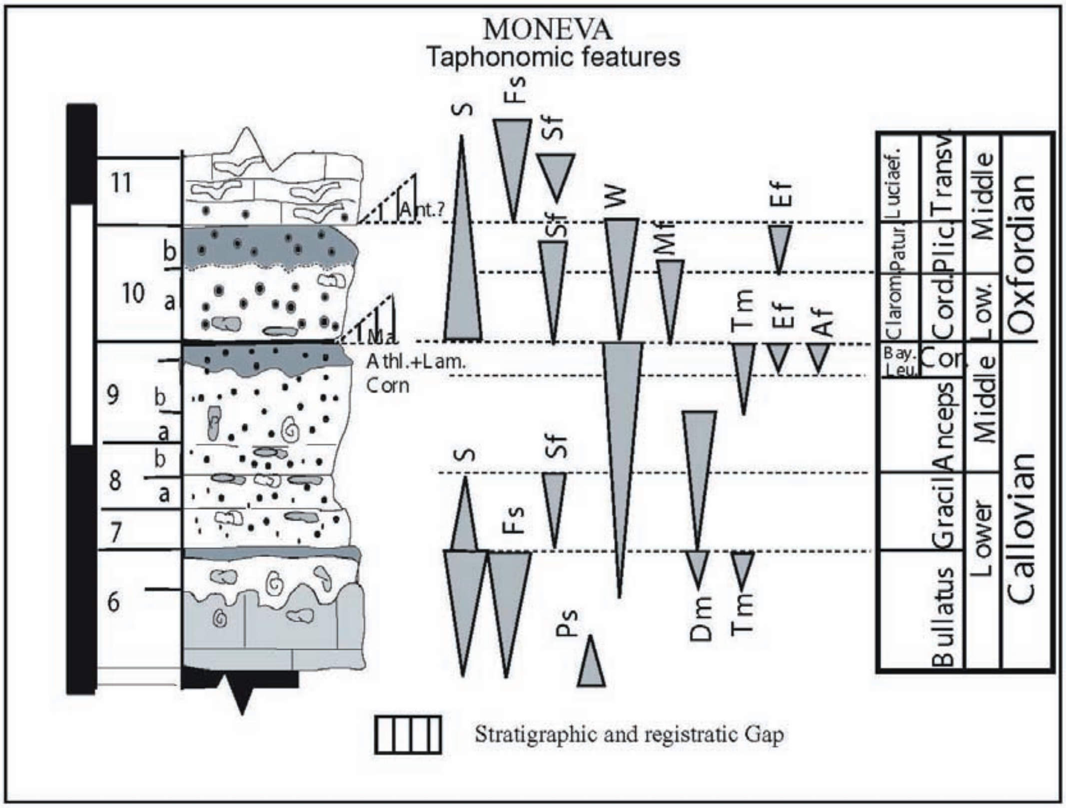

Fig. 6.- The Callovian-Oxfordian transition interval at Moneva. Legend, as for Fig. 4. The Callovian-Oxfordian transition interval corresponds to the iron-ooid transition level (*i.e.* Arroyofrío Bed) ranging in this locality from lower Callovian, Gracilis Biozone to middle Oxfordian Transversarium Biozone (?) Luciaeformis Subbiozone.

Fig. 6.- La transición Calloviense-Oxfordiense en Moneva. Leyenda igual que para la Fig. 4. El intervalo que marca la transición Calloviense-Oxfordiense corresponde al nivel de oolitos ferruginosos (i.e. la Capa de oolitos ferruginosos de Arroyofrío), que en esta localidad abarcaría probablemente desde el Calloviense inferior (? Biozona Gracilis) al Oxfordiense medio, Biozona Transversatium (?) Subbiozona Luciaeformis.

threshold during Callovian and Oxfordian times.

The record of some specimens of *Perisphinctes nectobrigensis* Meléndez; *Perisphinctes. luciaeformis* Enay, *Ochetoceras cf. canaliculatum* (von Buch) and *Trimarginites stenorhynchus* (Oppel) from the lower levels of the overlying sponge limestone interval (the Yátova Fm.) allows assigning this interval to the Transversarium Biozone, Luciaeformis Subbiozone.

4.4. Ariño

Classical references of Callovian biostratigraphy of Ariño (the area around the river Martín, including the outcrops between the localities of Ariño and Oliete) are: Marin and Toulouse (1972), Meléndez (1978), Sequeiros (1984, see also references therein), Lardiés *et al.* (1988) and Meléndez (1989). In all these studies, it was generally assumed that the lower Callovian was represented by the Macrocephalus (= Bullatus) and Gracilis biozones in a condensed sequence, partly included in the iron-ooid interval (the *Arroyofrío Bed*). However, the different authors called the attention on the fact that the successive oolitic beds contained a mixed ammonite assemblage including forms from lower Callovian Gracilis Biozone to early Oxfordian (*Prososphinctes*) and even, in the upper oolitic band, early middle Oxfordian, such as *P. (Otosphinctes)* and *P. (Kranaosphinctes)*.

Subsequent studies slowly incorporated the progress achieved by taphonomic analysis to biostratigraphic interpretations. Meléndez *et al.* (1997) revised the Callovian biostratigraphy of the sections of Ariño (outcrops AR.1, AR.2; Barranco de las Estacas) and showed the relevance of taking into account the taphonomic features displayed by ammonites. The authors (*loc. cit*., pp 288, 289; Fig. 5) were able to demonstrate that the “Gracilis association”, recorded in the lower oolitic interval (levels 108 a-c) was in fact a reelaborated entity constituted by fragmented or disarticulated moulds (Fm; Dm), non deformed; maintaining their original shape and volume, and formed by a micritic, non-oolitic (or with few sparse ooliths) infill. They were included in an oolitic, somewhat marly limestone bed (108 a-c), 25-30 cm thick, which locally showed evidence of secondary lamination due to late diagenetic compaction. Ammonite moulds showed a clear lithologic, textural and structural discontinuity with the surrounding matrix, hence fulfilling at least three of the main eight groups of empirical diagnostic criteria of taphonomic reelaboration as defined by Fernández-López (1985; 1990). The authors concluded that the bed 108 would in fact correspond, most probably, to a higher interval (? Anceps Biozone) and indicated the existence of a stratigraphic gap of Praecquense and Gracilis biozones between level 107 and 108. Similarly, the boundary surface between beds 108 and 109 would, most probably, represent a stratigraphic and registratic gap involving the biozones and corresponding taxorrecords (?) Coronatum to Mariae.

The bed 108 is capped by a truncation erosional surface, which cuts the fossils and the sedimentary structures showing local development of a ferruginous crust, and represents a hard-ground. Above this surface, the second oolitic interval (levels 109 a-c) still contains common reelaborated Callovian ammonites (from Gracilis to Anceps taxorrecords) with scarce resedimented (= non reelaborated) specimens of perisphinctids, which allow assigning the successive levels to the biozones Claromontanus (109 a; lower Oxfordian), Plicatilis (? Paturattensis; and Antecedens subbiozones: bed 109 b) and Transversarium (? Parandieri Subbiozone: bed 109 c). Successive beds within this interval are generally separated by irregular, erosion surfaces showing local development of iron crusts and reelaborated fossils, frequently truncated moulds (Tm) and representing hard-grounds.

The Callovian succession, would, therefore, be reduced to Bullatus Biozone in the 1.2 m thick sequence underlying the oolitic interval and a thin 25-30 cm thick oolitic bed, which might represent the Anceps Biozone, and it is clearly more incomplete than in Moneva. The oolitic interval (the "Arroyofrío Bed") until the middle Oxfordian also represents a reduced, condensed sequence, i.e. a wide stratigraphic interval represented by very thin deposits, and important stratigraphic gaps, hence implying very low values of sedimentation rate. However, as in the former cases in Moneva and other sections, the sedimentary record is formed by clastic (oolitic) lenticular beds, which enclose fragmented, reelaborated fossils, showing dominant orientation and positive gradation. Such deposits typically represent successive episodes of event sedimentation, (storm deposits) which indicate high values of Instant rate of sediment accumulation (= expanded deposits, *cfr.* Gómez and Fernández-López, 1994).

Discussion

Taphonomic gradients in this locality are represented in Figure 7 for the near outcrop of Barranco de las Estacas (section B.E.1). At this point the Callovian stratigraphic succession is very similar to that of River Martín described above (section Ar.2) but the lower (? Callovian) oolitic interval shows a wider development (beds 13 to 17; roughly equivalent to bed 108 a-c in outcrop Ar.1). As shown in the diagram, four main lithologic intervals can be distinguished:

(1) Levels 6-12: a 1,2 m thick thickening-coarsening upwards sequence formed by regular limestone (fossiliferous bioclastic wackestone) with thin marl interbeddings. The last bank (bed 12) presents a high fossil content: ammonites, belemnites, brachiopods, bivalves, and scarce gastropods and echinoderms. Ammonites show a progressive increase in both resedimented and reelaborated elements. Resedimented elements are peristomed shells or, more frequently, Fragmented shells (Fs) or Shell fragments (Sf). They are usually preserved as non-deformed internal moulds, maintaining their shape and volume and clearly display lithological and structural continuity between the infilling and the surrounding matrix. However, they quite frequently are not filled with sediment in the phragmocone, i.e. they are conceptually *Hollow ammonites*; Ha (Fernández-López, 1997; Figs. 1, 4), which means rapid process of burial, leaving not sufficient time for the sediment to enter the innermost chambers of the phragmocone. According to the author, hollow ammonites are usually associated to event sedimentation, high turbulence processes and storm deposits, involving high values of Instant rate of sediment accumulation, "within sedimentary environments of low Rate of sedimentation" (*loc. cit*., p. 106), and rapid burial of shells. This bed is capped on top by an uneven truncation surface showing a high concentration of fossils (reelaborated ammonites) mainly preserved as encrusted, truncated, fragmented or disaticulated internal moulds and mould fragments. Above the surface, at the base of the lower oolitic interval, few specimens of *Macrocephalites* close to gr. *verus* Buckman showing micritic, non-oolitic infill and clear lithologic, textural and structural discontinuity with the surrounding oolitic marly sedimentary matrix, are found. Some specimens display such features as Ellipsoidal facets (Ef) or Annular furrows (Af). All these taphonomic and sedimentologic features indicate a progressive transiton during Bullatus Chronozone from subtidal to shallow subtidal bathymetric conditions and, at the boundary between the lower, micritic interval and the oolitic sequence, to intertidal or even supratidal (temporarily emerged) conditions.

(2) Levels 13-18: 0,8 m, yellow limestone (bioclastic to oolitic wackestone to packstone) with thin oolitic marl intercalations. This lower oolitic interval is roughly equivalent to level 108 a-c in the section Ar.2 Iron-ooids are small in size and slightly heterometric; less abundant than in the upper interval. Ammonites are relatively common, increasing progressively upwards. They are preserved as reelaborated elements: fragmented or dis-

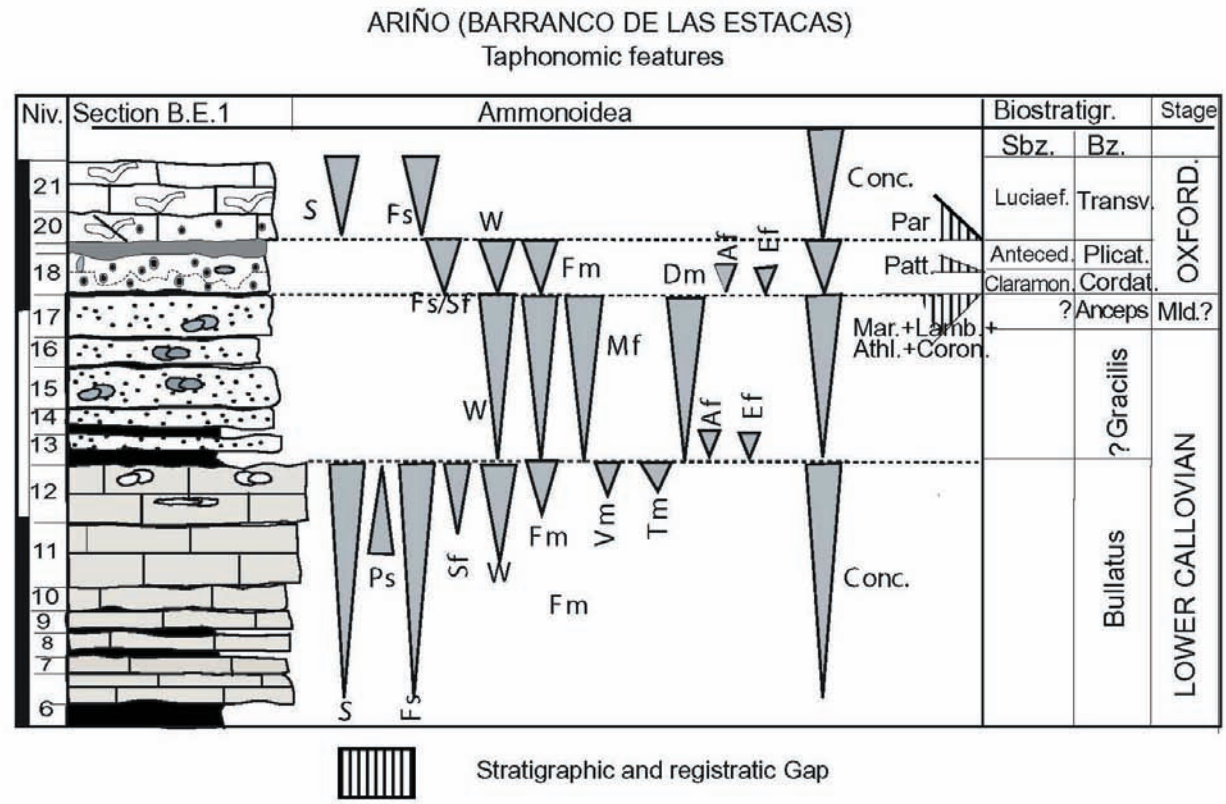

Fig. 7: The Callovian-Oxfordian transition interval at Barranco de las Estacas (Section B.E.1; Ariño area). Legend, as for Fig. 4. The Callovian-Oxfordian transition interval corresponds to the iron-ooid transition level (*i.e.* Arroyofrío Bed) spanning in this locality most probably in several brief sedimentary episodes from middle Callovian, (?) Anceps Biozone to middle Oxfordian Transversarium Biozone.

Fig. 7: La transición Calloviense-Oxfordiense en Barranco de las Estacas (Sección BE.1, en la región de Ariño). Leyenda igual que para la Fig. 4. El intervalo que marca la transición Calloviense-Oxfordiense corresponde al nivel de oolitos ferruginosos (i.e. la Capa de oolitos ferruginosos de Arroyofrío), que en esta localidad se extendería probablemente en forma de varios y breves episodios sedimentarios sucesivos, entre el Calloviense medio (? Biozona Anceps) y el Oxfordiense medio, Biozona Transversarium.

articulated internal moulds, and mould fragments. No resedimented elements have been recorded so far. Although such typical form as *Macrocephalites gracilis* Spath is quite common, the actual age of this lower oolitic interval could be higher in the Callovian (?Anceps Chronozone. See Meléndez *et al.*, 1997 and comments above). However, more information is still needed to precise the age of this interval.

(3) Levels 18-19: This upper oolitic interval, 30-40 cm thick is roughly equivalent to level 109 (a-c) in section Ar.2. formed by yellow-reddish iron ooid wackestone to packstone, including abundant, thick highly heterometric ferruginous ooliths. Beds show irregular, lenticular bedding underlined by the presence of frequent ferruginous surfaces with local development of hard-ground. Fossil, specially ammonites, show an increase upwards. Ammonite record is complex and difficult to analyze. In the lower band (18a) resedimented specimens of *Prososphinctes sp*., characterize the lower Oxfordian Claromontanus Subbiozone whilst resedimented specimens of *Kranaospinctes*, *Arisphinctes*, and early *Dichotomosphinctes* in the upper band (18 b) in this outcrop and in the near section Ar.1 (Meléndez, 1989) allow characterizing the Plicatilis Biozone, Antecedens Subbiozone. In contrast, some specimens of *Otosphinctes* of the *paturattensis-montfalconensis* Loriol groups showing clear evidence of taphonomic reelaboration, would indicate the probable stratigraphic gap of the lower Plicatilis Biozone, Paturattensis Subbiozone. As a consequence, the biostratigraphic and taphonomic data indicate that in the section of Barranco de las Estacas, the Callovian-Oxfordian boundary most probably coincides with the boundary between beds 17 and 18, between the two different iron-ooid intervals, involving a stratigraphic and registratic gap, at least of Coronatum to Mariae biozones (Fig. 7). This conclusion is also supported by the sedimentologic data, wich show a greater content of filaments (more typical in Callovian deposits) in the lower interval, and a greater content in sponge spicules and crinoid bioclasts in the upper interval (*cfr.* Ramajo, 1986). In this same interval, the frequent record of specimens showing ellipsoidal facets of even annular furrows evidences the predominance of extremely shallow bathymetric conditions; from intertidal to even supratidal, dominated by centimetre-thick directional,

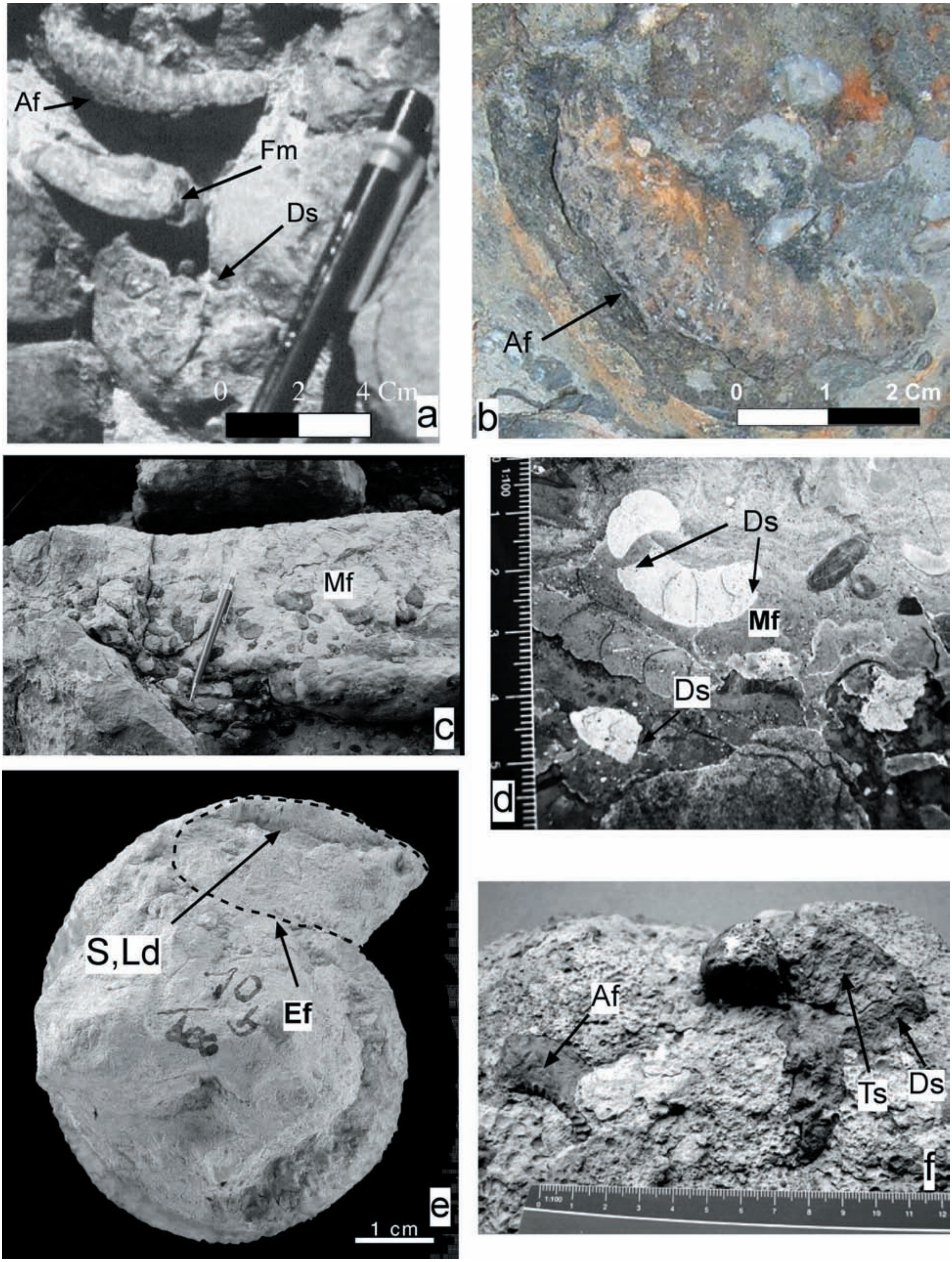

Fig. 8: Illustrations of some taphonomic features shown by ammonites from the Callovian- Oxfordian transition interval (i.e. the Arroyofrío Bed) in NE Iberian Range.

(a) Reelaborated elements from Ricla; Callovian-Oxfordian transition level. A disarticulated mould showing a Disarticulation surface along a septum (Ds), a fragmented mould (Fm) and an ammonite mould (Grossouvriine? ind.) showing an annular furrow (Af).

(b) Detail of the ammonite mould (Grossouvriine? ind.) showing an annular furrow (Af).

(c) Phosphatic ammonite moulds preserved as Mould fragments (Mf). Ricla. Same level as (a-b).

non-oscillatory currents, during this long interval, from early middle Callovian to late lower Oxfordian.

(4) Levels 20-21 and overlying sequence (over 2m thick). Grey-yellowish limestone (fossiliferous bioclastic wackestone) with abundant sponges and other microfossil groups (*cfr.* Meléndez *et al.*, 1997). Ammonites indicate middle Oxfordian Transversarium Biozone, Luciaeformis to Schilli Subbiozone (Meléndez *et al.*, *loc. cit.*, Bello, 2005). The progressive increase in open marine fossil groups, preserved as resedimented elements, indicate the recovery of moderately deep subtidal conditions in the platform.

4.5. Calanda

In the region of Calanda, between the localities of Calanda and Mas de las Matas, and farther East down to Ráfales, the situation is more accentuated, and the stratigraphic and registratic gap at the Callovian-Oxfordian boundary is wider than in the region of Sierra de Arcos, ranging probably from lower Callovian Bullatus Biozone to middle Oxfordian Transversarium Biozone, Luciaeformis Subbiozone. The iron-ooid interval (Arroyofrío Bed) forms a very irregular single band, from few to 15-20 cm thick (Aurell *et al.*, 1999) integrated by one or several lenticular layers. It is separated from the lower, Bullatus Biozone sequence by an erosional, encrusted truncation surface showing local development of an iron crust and which constitutes a Hard-ground. The lower Callovian, Bullatus Biozone sequence forms a thickening upwards, up to 2 m thick alternation of grey limestones (fossiliferous bioclastic wackestone) which may be partly dolomitized, and shaley marls. Resedimented (non-reelaborated ammonites in this sequence include scarce specimens of *Macrocephalites cf. verus* Buckman, *Bullatimorphites bullatus* Spath and some fragmentary remains of Pseudoperisphinctinae ind. No ammonite characteristic of the Gracilis Biozone (i.e. the *Gracilis Taxorrecord*) has been evidenced in this interval.

Above the hard-ground ferruginous surface, which cuts the lower sequence, the iron-ooid Arroyofrío Bed forms a very irregular interval, integrated by lenticular layers and changing rapidly from one outcrop to another. However, no evidence of Callovian resedimented (= non-reelaborated) elements has been found inside. In outcrop Ca1-b, between Calanda and Mas de las Matas, the iron-ooid bed forms a 20 cm thick interval of a grey-reddish wackestone to packstone of iron ooliths and bioclasts. Callovian ammonites in this bed are common. They are normally preserved as micritic, non-oolitic, fragmented internal moulds showing clear disarticulation surfaces along a septum or truncation facets encrusted and non-consistent with the bedding plane. Specimens showing ellipsoidal facets or annular furrows are also common, the abrasion

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(continuation of Fig. 8)

(d) Mould fragments of ammonites (Mf) with infilling partly phosphatic, showing disarticulation surfaces along septa (Ds). Aladrén; Tosos-Aguilón area.

(e) Reelaborated specimen of *Perisphinctes (Otosphinctes)* sp., showing an ellipsoidal (or perhaps truncation) facet on the left flank, at the final part of the last preserved whorl, and a clear structural and lithological discontinuity with the surrounding matrix (S,Ld). The facet is also encrusted by a microbian crust (Mc). Early middle Oxfordian, Moneva, level 10b.

(f) Block of the iron-ooid boundary bed in Calanda (outcrop Ca.1b) including a reelaborated specimen of an ammonites (*Macrocephalites sp.*) preserved as a Truncated mould (Tm) showing a disarticulation surface (Ds) and Truncation surface (Ts) encrusted by an iron crust. A second specimen (?*Macrocephalites* ind.) showing an annular furrow (Af.). In both specimens, the surrounding oolitic sedimentary matrix shows a clear lithologic and structural discontinuity with the micritic infilling. Both fossils are inclined within the bed and the abrasion surfaces are incongruent with the bedding plane.

Fig. 8: Ilustración de algunos caracteres tafonómicos presentados por los ammonites del intervalo de transición Calloviense-Oxfordiense (la Capa de Arroyofrío) en la Cordillera Ibérica nororiental.

(a) Elementos reelaborados en el nivel de transición Calloviense-Oxfordiense en Ricla. Molde desarticulado mostrando una superficie de desarticulación (Ds) a favor de un septo. Molde fragmentado (Fm) y molde de ammonites (Grossouvriinae? ind.) mostrando un surco anular (Af) en la region ventral.

(b) Detalle del molde de ammonites (Grossouvriinae? ind.) mostrando un surco anular (Af) en la región ventral.

(c) Moldes internos fosfáticos de ammonites (Pm) conservados como fragmentos de moldes (Mf). Ricla. Relleno de las cavidades. Mismo nivel que en las figuras (a) y (b). Relleno de las cavidades de dicho nivel.

(d) Fragmentos de moldes de mmonites (Mf) con relleno en parte fosfático, mostrando una superficie de desarticulación a favor de un septo (Ds). Aladrén (area de Tosos-Aguilón)

(e) Ejemplar reelaborado de *Perisphinctes (Otosphinctes)* sp., mostrando una faceta ellipsoidal (Ef) o quizás faceta de truncamiento (Ts?) en el flanco izquierdo, sobre la parte final de la última vuelta conservada, y una clara discontinuidad litológica y estructural con la matriz sedimentaria alrededor. La faceta aparece asimismo encostrada por un crecimiento microbiano (Mc). Oxfordiense medio; Moneva. Nivel 10b.

(f) Bloque de la capa de Caliza de oolitos ferruginosos en Calanda (afloramiento Ca.1b) que incluye un ejemplar reelaborado de un ammonites (*Macrocephalites sp.*) conservado como Molde truncado (Tm) mostrando una superficie de desarticulación (Ds) y una faceta de truncamiento (Ts). Un segundo ejemplar (?*Macrocephalites* ind.) mostrando un surco anular (Af). En ambos casos, la matriz sedimentaria oolítica se encuentra en clara discontinuidad litológica, textural y estructural con el relleno micrítico de los ejemplares. Ambos ejemplares se encuentran inclinados en la capa y las superficies de abrasión se encuentran incongruentes con la superficie de estratificación.

facet showing a clear lithological, textural and structural discontinuity with the surrounding sedimentary matrix (Fig. 8-f). Among the identifiable specimens, *Macrocephalites ex gr. verus* Buckman; *Bullatimorphites*, and *Homoeoplanulites* spp. They all characterize as a whole the Bullatus Taxorrecord. No characteristic elements of the Gracilis Taxorrecord have been found so far. Similarly, no clear resedimented (= non-reelaborated) elements have been collected, although certain scarce shell fragments found, could represent middle Oxfordian Perisphinctinae. This would

Gracilis to middle Oxfordian, (?) late Plicatilis or even Transversarium Biozone (Aurell *et al.*, 1999).

Discussion

Analysis of taphonomic gradients and biostratigraphic data indicate that sedimentation in this eastern area was interrupted very early, probably at the Bullatus-Gracilis Chronozone boundary or even during the Bullatus Biochron. Sedimentary and bathymetric conditions were gradually changing from subtidal to shallow intertidal or even supratidal leading to a long period of probable subaerial exposure of the platform in this area, perhaps punctuated by brief periods of very shallow directional currents that would generate the abrasion facets on the ammonite internal moulds. However, the wide registratic gap detected in this area suggests that, unlike the areas of Sierra de Arcos or Moneva, farther West, where remains of a first Callovian iron-oolite interval is detected, and several brief episodes of flooding are recognised, the Calanda-Ráfales area might have been, in fact, almost completely emerged (implying subaerial exposure of the platform) from lower Callovian to middle Oxfordian.

5. Palaeogeography and discussion.

As it is shown in Fig. 1b, differences in facies and thickness development between Callovian succession in both localities allow inferring a more important terrigenous input in the NW Veruela-Ricla and Tosos Area (Fig.9). On the other hand, taphonomic features displayed by ammonite recorded associations also indicate lower turbulence and deeper sedimentary conditions in this area. The region of Moneva-Sierra de Arcos and Calanda should have occupied a shallower, elevated area, acting as a palaeogeographic threshold in the middle to distal part of the outer platform between lower Callovian and early middle Oxfordian times.

Shallower areas in the distal outer platform would receive slight terrigenous influence (iron-rich clays) from presumably emerged areas farther East, in the Calanda-Ejulve-Montalbán area (the so-called Ejulve-Maestrazgo High). Iron supply clays could come, either from emerged areas by extensive development lateritic environments (Aurell *et al.*, 1994; Meléndez and Ramajo, 2001, Ramajo *et al.*, 2002) or else from alternative sources, such as submarine volcanic emissions in southern Iberian platform during Middle Jurassic (see, e.g. García-Frank *et al.*, 2006). Although both hypotheses are currently under consideration, none of them has so far reached definitive or solid support by clear unequivocal evidence. This iron supply would constitute the basic material for the production of iron-ooids under shallow subtidal to intertidal environment conditions around the margins of such emerged areas as the "Ejulve-Montalbán palaeogeographic High" (Ramajo *et al.*, 2002), during episodes of very low rate of sedimentation (see fig 9). Arrival of iron ooids to the area of Moneva (Sierra de Arcos) in early Callovian, Gracilis Chronozone, indicates an early block breakup of the platform, in subsident and somewhat elevated, shallow blocks in lower Callovian, which would persist until middle Oxfordian, Transversarium Chronozone.

According to Fernández-López (1995) and Fernández-López and Meléndez (1995) taphonomic gradients recognised in ammonites, as exposed in Figs 4 to 7, would allow recognising a palaeoenvironmental transition from moderately deep conditions (peristomed shells, fragmented shells or shell fragments) to shallow subtidal conditions (reelaborated specimens including fragmented and disarticulated internal moulds; to truncated moulds and roll facets) to intertidal or even supratidal conditions (ellipsoidal facets; annular furrows, see fig. 8a-f). These last features developed in ammonite internal moulds would indicate an interval of extremely shallow to emerged conditions in the platform (Fernández-López, 1985a,b; Fernández-López and Meléndez, 1994). In such intervals, shallow directional water currents acting during ephemeral episodes of flooding, would have been able to carve such facets and annular furrows on preserved internal moulds. As demonstrated by Fernández-López and Meléndez (1995) ammonite recorded associations within the iron-ooid level form a so-called: "Abrasion taphonomic cline" (*loc. cit.*, fig. 6) in which fragmented shells are gradually replaced by reelaborated moulds showing diverse abrasion surfaces, from disarticulation surfaces along septa (indicative of turbulent oscillatory currents under subtidal conditions) to truncation surfaces (directional currents in subtidal environment) to ellipsoidal facets and eventually annular furrows, indicative of directional currents under extremely shallow, intertidal to supratidal conditions. This *taphonomic cline* is supported by the common occurrence in this interval, in the area of Sierra de Arcos, of reelaborated internal moulds of ammonites showing two or more phases of infill with early cementation, and internal whorls only partly filled with sediment and dissolution of septa. These particular moulds constitute *concretionary internal moulds without septa* (Fernández-López, 1997, p. 113, Fig. 11) and are interpreted as developed during a phase of subaerial exposure.

These conditions were probably reached earlier, at the lower-middle Callovian boundary in the elevated block of Sierra de Arcos, as it can be inferred by (1) the greater development of the iron-ooid level; (2) the wider extent of the stratigraphic and registratic gap and (3) the taphonomic features shown by ammonites. However, these shallow to emerged conditions should have spread to the deeper and more subsident area of Tosos-Aguilón and Ricla-Veruela at the end of Athleta Chronozone, and during the lower Lamberti Chronozone, Poculum Subchronozone, and would be widespread throughout the whole Iberian Basin during latest Callovian to earliest Oxfordian times (Lamberti-Mariae chronozones). This period would correspond to the interval of maximum extent of the Middle-Upper Jurassic discontinuity in the basin.

During the lower to early middle Oxfordian, the platform remained mostly exposed or temporarily covered by a thin layer of water in which directional currents would predominate over oscillatory or turbulent currents. Two short-lived flooding episodes are detected during this interval, probably related with the beginning of the Middle Oxfordian widespread transgression (Ramajo *et al.*, 1999; Aurell *et al.*, 2003 and Ramajo, 2006). These events, ephemeral and clearly discontinuous, took place, first during the early Cordatum Chronozone, Bukowskii Subchronozone, and second, at the base of Plicatilis Chronozone, Paturattensis Subchronozone, and are represented by two thin condensed levels of iron-oolith limestones (bioclastic wackestone-packstone with iron ooids) or bioclastic and intraclastic limestones (wackestone to packstone). Both levels are bounded on top by discontinuity surfaces, which mark widespread stratigraphic gaps. Shallow bathymetric to temporarily emerged conditions are inferred by the taphonomic features of ammonite moulds preserved in these levels (see above). A progressive deepening during the Middle Oxfordian led to the general development of sponge facies, characterized by microbiolite build-ups interbedded with biostromes. Relatively open marine conditions in the platform were restored at early Transversarium Chronozone (Parandieri to Luciaeformis subchronozones). Such process started first in the NW part of the Platform (Veruela-Ricla area) and were progressively spreading towards the SE in farther, shallower areas (S^{a} de Arcos).

6. Conclusions

(1) The combined study, including Palaeontological (taxonomic-biostratigraphic), sedimentological and taphonomic analyses, allows a more accurate Palaeogeographical reconstruction and interpretation of the sedimentary evolution of the platform during the Callovian-Oxfordian interval. Such integrated study appears as a useful tool to interpret the sedimentary record, most particularly in the case of condensed sequences bounded by stratigraphic discontinuities involving widespread stratigraphic gaps.

(2) The development and distribution of the Callovian sequence across the Aragonese platform in the NE Iberian Range reflects the sharp block-partition of the platform into separate areas of differential degree of subsidence, as already demonstrated by Lardiés *et al.* (1988). In the NW, more subsident areas, thick carbonate and marly sequences developed up to the upper Callovian, lower Athleta Biozone, Trezeense Subbiozone. In areas located farther SE the Callovian sedimentation was stopped progressively earlier: Coronatum Biozone in the area of Aguilón-Tosos; Gracilis to Anceps Biozone in the area of Moneva, and most probably the Bullatus-Gracilis Biozone boundary in the Sierra de Arcos-Calanda area.

(3) From this point onwards, to the end of the Callovian, the different areas of the platform were submitted to intermittent discontinuous sedimentation under shallow subtidal bathymetric conditions. Iron ooid limestones predominated in the central and SE areas of the platform. They constitute generally short, irregular sedimentary episodes, represented by discontinuous lenticular beds, and show their maximum development in the areas around the emerged, uplifted massifs, as the Ejulve-Montalbán threshold. Sedimentary record of iron-ooid facies of Callovian age exists in some areas, such as Moneva (Anceps to Coronatum Chronozone) and in Ariño (?Anceps Chronozone). However, in most of the study area, the oolitic episode which tops the Callovian sequence was probably Oxfordian, either locally lower Oxfordian, Claromontanus Subchronozone, or more generally Middle Oxfordian, Paturattensis Subchronozone (Meléndez *et al.*, 2005).

(4) Ammonite biostratigraphy has allowed a detail dating of this tectonic differentiation of the platform during the Callovian. Taphonomic analysis carried out on ammonite recorded associations instead, has allowed precise the width of the stratigraphic and registratic gaps evidenced in the Callovian-Oxfordian transition sequences. High concentrations of ammonite remains in the iron-ooid *Arroyofrío Bed* resulted from the combination of three main factors: (1) Concentration of adult, drifted shells on shal-

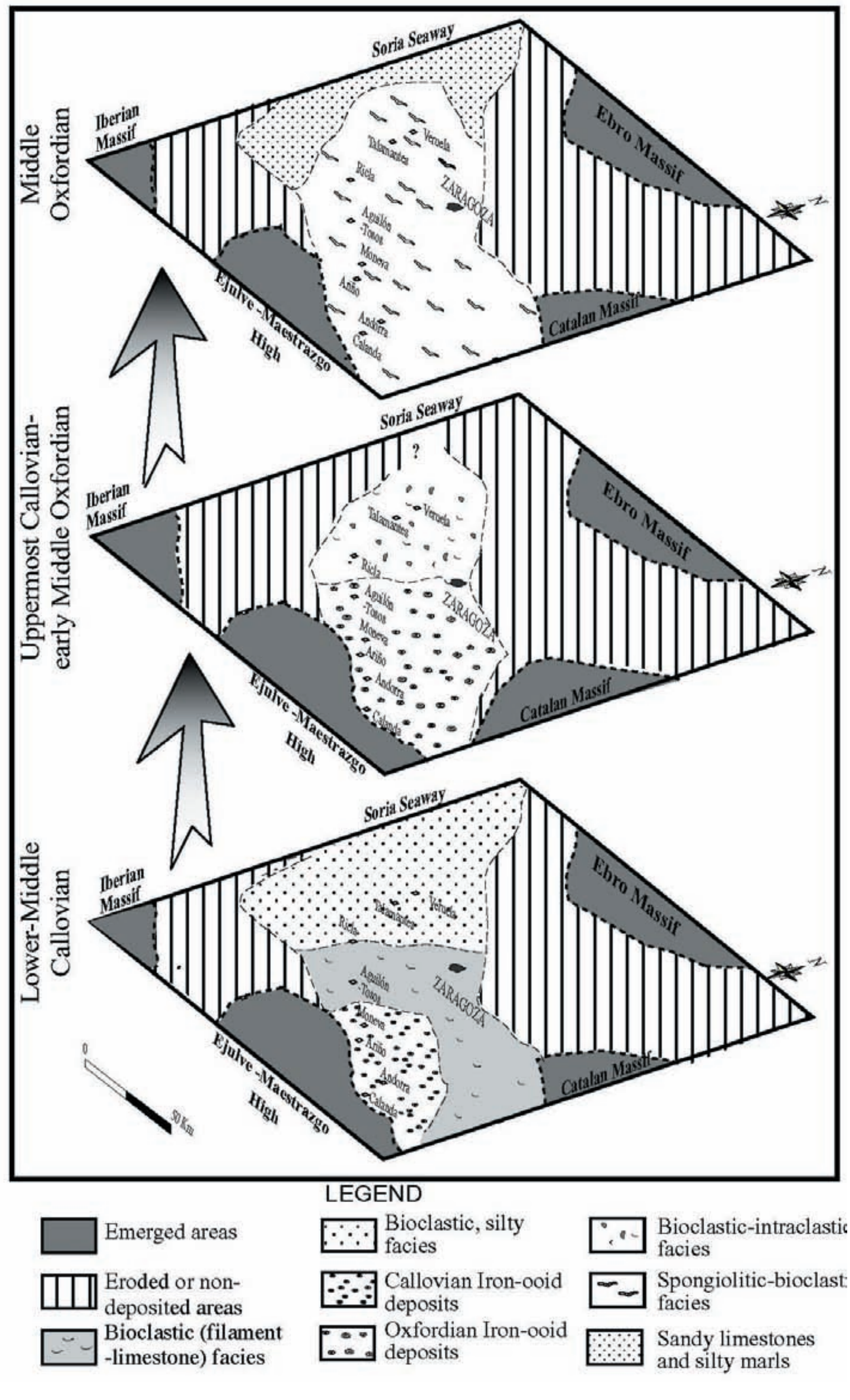

Fig. 9: Palaeogeographic evolution of the North-eastern Iberian platform from lower Callovian to middle Oxfordian. The carbonate platform would extend as a NW-SE narrow marine area between emerged massifs or shallow thresholds. Subaerial exposure of the platform and maximum extent of iron-ooid facies would take place between uppermost Callovian and lower or early middle Oxfordian times. In the middle Oxfordian a slow drowning of the platform would favour the development and generalized spread of sponge bioherm and biostrome facies.

Fig. 9: Evolución paleogeográfica de la Plataforma Ibérica nororiental, entre el Calloviense inferior y el Oxfordiense medio. La plataforma carbonatada se extendería como una banda marina estrecha en dirección NW-SE limitada por macizos emergidos o umbrales someros. Entre el Calloviense terminal y el Oxfordiense inferior o el Oxfordiense medio basal tuvo lugar la exposición subaérea de la plataforma y la máxima extensión de la facies de calizas con oolitos ferruginosos. Durante el Oxfordiense medio, el hundimiento lento de la plataforma favoreció el desarrollo de facies de calizas biostromales y biohermales de esponjas.

low marine areas near to emerged blocks. (2) Low values of sedimentation rate, which favoured a constant sweeping of sediment and concentration of fossils, and (3) the repeated processes of taphonomic reelaboration, resulting in the mixing of elements of different age within the same recorded association.

(5) Taphonomic features and abrasion surfaces carved on ammonite reelaborated internal moulds by water currents evidence that during a long interval of time, between the upper Callovian and middle Oxfordian the platform was submitted to subaerial exposition under intertidal to supratidal environment conditions with only few ephemeral episodes of flooding, which would be reflected by the record of thin layers of iron-ooid limestone and ammonites of lower and early middle Oxfordian. However, in the far SE areas, between Sierra de Arcos and Calanda, this process started much earlier, most probably at the Bullatus-Gracilis Chronozone boundary.

(6) Finally, at the middle Oxfordian, early Transversarium Chronozone the whole platform was homogeneized again and underwent a slow, uniform subsidence, favouring the recovery of subtidal conditions and development of sponge limestone bioherm and biostrome facies. The reasons for such events, which appear remarkably synchronous throughout the Tethyan Realm should probably be sought in extra-basinal factors, such as tectonic subsidence affecting the south of the European plate as a whole (D'Arpa *et al.*, 2006).

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