Rivista Italiana di Paleontologia e Stratigrafia	volume 110	no. 1	pp. 191-200	April 2004

THE STRATIGRAPHY OF THE UPPER BATHONIAN TO MIDDLE OXFORDIAN SUCCESSION OF THE ARAGONESE BRANCH OF THE CORDILLERA IBÉRICA (SPAIN) AND ITS EUROPEAN CONTEXT

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Received September 19, 2002; accepted October 4, 2003

Key words: Jurassic, Bathonian, Callovian, Oxfordian, ammonites, stratigraphy, Cordillera Ibérica, Aragón, Spain.

Abstract. The Upper Bathonian-Middle Oxfordian succession of the Aragonese branch of the Cordillera Ibérica is one of the most completely developed in Europe and includes localities of international importance for Jurassic bio- and chronostratigraphy. Of particular importance are a potential stratotype for the Upper Bathonian of North West Europe and reference sections for a number of Submediterranean Province Middle Oxfordian biostratigraphic units. The intervening Callovian sequence, albeit locally strongly condensed, also includes faunas of key stratigraphical importance. The sequence of stratigraphically important ammonite faunas for this interval is here reviewed and placed in its European context.

Riassunto. La successione del Bathoniano superiore - Oxfordiano medio del ramo aragonese della Cordigliera Iberica è una delle più complete e sviluppate in Europa, ed include località di importanza internazionale per la bio- e cronostratigrafia del Giurassico. Di particolare importanza sono un potenziale stratotipo per il Bathoniano superiore dell'Europa nord-occidentale e delle sezioni di riferimento per numerose unità biostratigrafiche medio-oxfordiane della Provincia Submediterranea. Anche l'interposta sequenza calloviana, sebbene localmente molto condensata, include faune di importanza chiave per la stratigrafia. La sequenza di faune ad ammoniti stratigraficamente importanti per questo intervallo viene qui passata in rassegna e posta in un contesto europeo.

Introduction

The Upper Bathonian to Middle Oxfordian succession of the Cordillera Ibérica in Aragón (north east Spain) is characterised by very variable subsidence rates as a consequence of block faulting of the sedimentary basin (Lardiés et al. 1988). This activity led to the establishment of two well-delimited sedimentary realms: a south eastern area characterised by great stratigraphical condensation and a north western area, where sequences are relatively expanded due to a higher terrigenous input. The region includes some of the most complete Upper Bathonian and late Middle-Upper Oxfordian sequences known in Europe. Callovian and Lower Oxfordian successions are, in contrast, typically highly condensed, with the latter substage locally absent. They nevertheless frequently yield rich ammonite faunas which provide a detailed insight into the palaeogeographic evolution of the Iberian Basin during the late Middle and early Upper Jurassic.

These successions were deposited on a shallow epicontinental carbonate platform bounded on the west, north west and north east by Palaeozoic massifs but connected by a narrow marine seaway (the "Soria Seaway") to the Cantabrian Basin in the north and hence the Aquitaine Basin. To the east and south east, the Aragonese Platform was open to the Submediterranean Province influences of the western Tethys - although separated by the shallow, temporarily emergent "Maestrazgo High" from the "Tortosa Platform" of the "Catalan Basin", immediately to the east (Fig. 1). The present study has been developed through a detailed analysis of ammonite successions in numerous sections along a NW-SE band of Jurassic outcrops following the north eastern margin of Cordillera Ibérica. The main localities studied in the area are Veruela, Talamantes and Ricla in the north west; Aguilón, Tosos and Aladrén in the central area, south of

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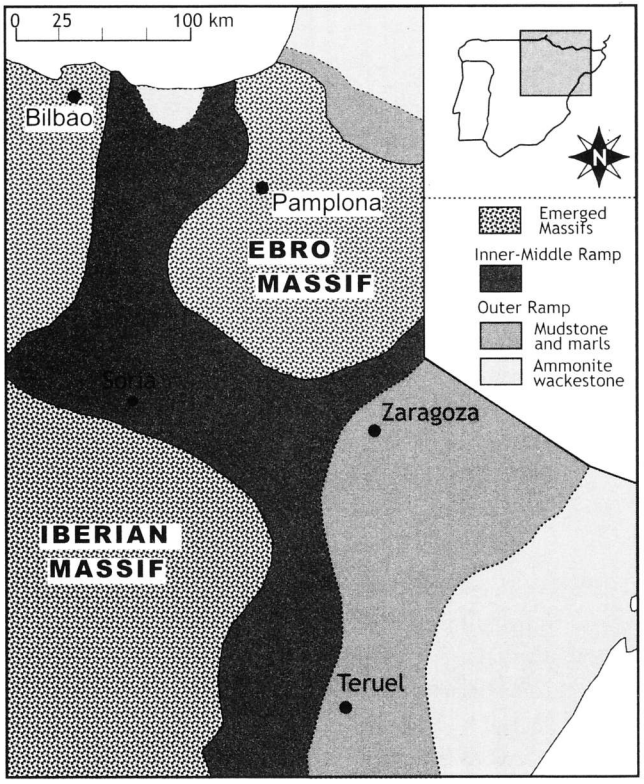

Fig. 1 - Palaeogeographical reconstruction of the north-eastern Iberian (Aragonese) platform for the late Bathonian to Middle Oxfordian interval.

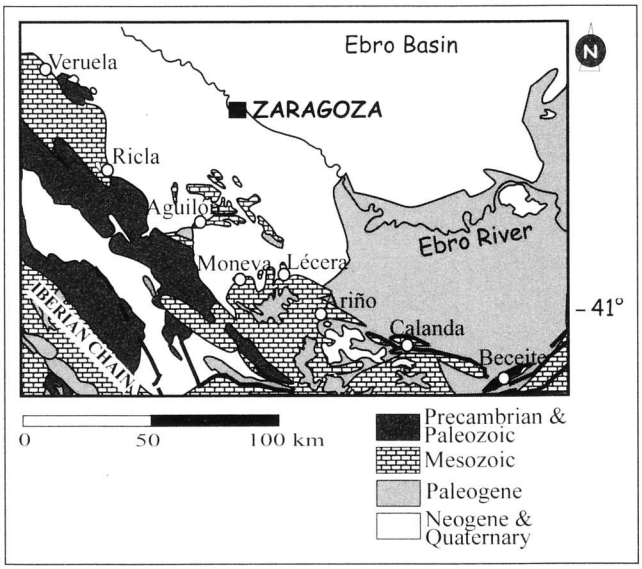

Fig. 2 - Geological map of the study area in the Aragonese branch of the Iberian Cordillera showing the location of key localities.

Zaragoza; Moneva and Ariño (Barranco de las Estacas) in the area of Sierra de Arcos (south west of Zaragoza); and Calanda and Ráfales in the extreme south east, close to the Tortosa Platform in Catalonia (Fig. 2).

The late Bathonian to Callovian sequence of north western areas, as typified by the localities of Ricla and Aguilón, is dominated by limestone-marl rhythms of the Chelva Formation, which in this area ranges up to the Upper Callovian. Although minor non-sequences can be recognised, the succession is relatively complete and includes a potential Upper Bathonian stratotype, or reference section, at Aguilón. To the south east, however, a considerable stratigraphical thinning takes place, although the development of a thick block of massive bedded, pale grey to white limestone in the early Upper Bathonian (Quercinus Subchronozone) of the Andorra-Ariño-Calanda area is characteristic. Overlying the latter unit, is a latest Bathonian-Middle Callovian sequence, ranging from late Retrocostatum to Anceps, or locally, lower Coronatum Chronozone (Meléndez et al. 2002) characterise a relatively thin sequence of bedded limestones, often with abundant ammonites, but also with levels containing ferruginous ooliths and even glauconite. This sequence is terminated, as it is to the northwest, by a thin sequence of ferruginous oolith-packed limestones, often with intraclasts and reelaborated (i.e. taphonomically reworked; Fernández-López, 1984, 1985) fossils indicating ages ranging from Upper Callovian to early Middle Oxfordian Plicatilis Chronozone, Paturattensis Subchronozone (Fig. 3) (Lardiés 1988; Meléndez 1989; Aurell et al. 1994).

The Middle Oxfordian, Transversarium Chronozone is marked by the widespread development of sponge-limestone facies of the Yátova Formation (Meléndez 1989), marking a return to more uniform conditions throughout the Aragonese Platform. Rich ammonite successions from these and succeeding Oxfordian facies have been crucial to the development of a refined zonation for the late Middle and Upper Oxfordian of the Submediterranean Province.

The aim of this paper is to provide a stratigraphical review of the succession of ammonite associations recorded in the Aragonese branch of the Cordillera Ibérica and their lithostratigraphical context and thereby demonstrate their potential for wider correlation, especially international.

Lithostratigraphic framework

The standardised lithostratigraphic framework for the Middle and Upper Jurassic carbonate units of the study area is that established by Gómez & Goy (1979) with minor modifications by subsequent authors (e.g. Aurell 1990). Bathonian to Callovian deposits form part of the Chelva Formation, a carbonate unit spanning the entire Middle Jurassic, from Aalenian or uppermost Toarcian to Upper Callovian or lowest Middle Oxfordian (Meléndez 1989). This unit is widespread throughout the Iberian (Aragonese and Castillian) platforms and includes a thick (20 to 300+ m), somewhat uniform succession of regularly bedded limestones, in units ranging from tens of centimetres to several metres thick. Occasional interbeds of argillaceous siltstone and marl are more common

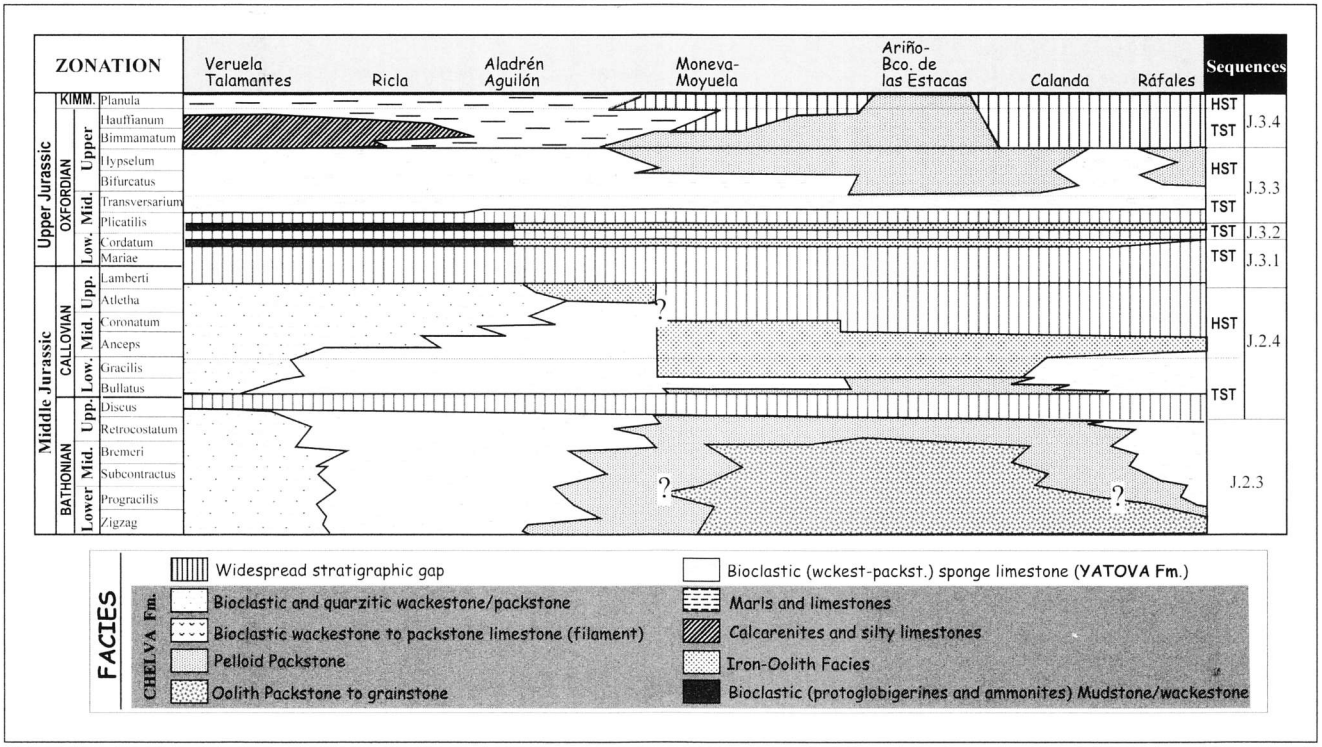

Fig. 3 - Correlation of the main facies of the late Middle to early Upper Jurassic successions of the Aragonese branch of the Iberian Cordillera.

and important in north western areas where terrigenous input was higher.

To the south-east, however, in the Sierra de Arcos area, there is a greater development of bioclastic to pelloidal or oolitic packstone facies. The top of this unit is marked by a thin (15-20 to 80–110 cm) development of yellowish limestone comprising several lenticular layers with ferruginous ooliths and known as the "Arroyofrío Bed". This level includes an important stratigraphic discontinuity which marks the Callovian-Oxfordian boundary and a stratigraphic gap of variable range (Aurell et al. 1994). North west of the Aguilón-Aladrén region, this bed is progressively replaced by a 25 to 40 cm thick, black mudstone to wackestone with protoglobigerine (*Globuligerina*) remains and common ammonites. The latter are generally preserved as reelaborated elements (fragmented internal moulds and phosphatic mould fragments) of Upper Callovian and Lower Oxfordian age, forming a mixed and condensed recorded association.

Above this important and widespread discontinuity, Middle to Upper Oxfordian deposits are represented by sponge-limestones (bioclastic fossiliferous wackestone) of the Yátova Formation. This uniform lithostratigraphic unit is widespread throughout the Iberian platforms and normally comprises two lithological intervals (Fig. 3): a lower interval (2 to 5 m) formed by massive sponge limestone banks, frequently showing the development of sponge bioherms, and generally corresponding to the Transversarium Chronozone and an upper interval, characterised by a lesser development of bioherms and regular limestone beds (tens of centimetres in thickness) with argillaceous and marl intercalations, generally ranging from Bifurcatus to Bimammatum chronozone. In the study area the latter unit is generally 10 to 20 m thick, although in the south eastern sections near Calanda, it may be reduced to only 3-4 m. In the Sierra de Arcos region, between Moneva, Ariño and Andorra and further south east, sponges are restricted to the lower unit of the formation and the upper interval is formed by a pelloid and markedly glauconitic packstone. The age of this formation ranges from lower Transversarium Chronozone (Parandieri to Luciaeformis Subchronozone) to uppermost Oxfordian (Hauffianum to lower Planula Chronozone). In north western areas, in the Veruela-Talamantes and Ricla sections, the upper levels of this formations are replaced by siliceous sandstones or calcarenitic limestones and argillaceous siltstone deposits of the Aldealpozo Formation. The latter unit, which can reach a thickness over 50 m in the extreme north west (Veruela area), shows a dramatic thickness reduction in the vicinity of Ricla , to only 5 to 10 m, and quickly wedges out to the south east.

Chronostratigraphy and ammonite faunas

Upper Bathonian (KP)

The discovery of a remarkably expanded and ammonite-rich sequence of alternating marls and limestones in the Upper Bathonian of Aragón, near Aguilón, facilitated a review of the Standard Zonation of the substage

Stage	Chronozone	Subchronozone	Horizons
UPPER BATHONIAN	DISCUS	Discus	Discus
		Hollandi/ (Angulicostatum)	Hollandi/ (Angulicostatum)
	RETROCOSTATUM	Histricoides	Hannoveranus
			Hemigarantiana
			Histricoides
			Aff. Hannoveranus
			Contrarium
			Compressus
		Hodsoni	Aff. twinhoensis
			Hodsoni
		Quercinus	Cadomites sp. 1
MIDDLE BATHONIAN	BREMERI	Fortecostatum	
		Bullatimorphus	

Fig. 4 - Latest Middle to Upper Bathonian chronostratigraphical framework (North West European Province), as proposed by Page & Meléndez (2000).

for NW Europe (Page 1996; Page & Meléndez 1997, 2000). Crucially, it was possible to demonstrate that a single North West European zonal scheme was applicable throughout the region on the basis of widespread species of *Procerites* and *Homeoplanulites*, even in Britain where faunal impoverishment can be linked to the development of unfavourable environments or facies (e.g. including restricted marine and quasi-marine conditions; Page 1996, 2001).

It is only in the Discus Chronozone that real differences in the faunas are apparent, with *Clydoniceras* being common and characteristic of northern areas (England – northern France – northern Germany) and rare or absent in the south (Iberia – southern France - southern Germany). At this level there is still some justification for the use of a separate Angulicostatum Chronozone (e.g. in Mangold & Rioult 1997 and Fernandéz-López (2001).

Similarly expanded sequences relatively close to Aguilón, for instance at Tosos and Aladrén, are in contrast less faunally rich and correlations with the proposed standard at Aguilón are consequently incomplete. North westwards, expansion of the Upper Bathonian sequence is accompanied by a further decrease in faunal content, and the relatively thick sequences of Ricla have to date only yielded diagnostic faunas from a relatively small number of levels. To the south-east, a thinning of the sequence is accompanied by the development of gaps in the succession of ammonite faunas and a number of condensed ammonite-rich beds (e.g. Moneva, Andorra, Calanda district, Ariño), the latter yielding ammonite assemblages of great taxonomic importance. The sequence of ammonite association recorded in the region is as follows, assigned to the zonal framework of Page & Meléndez (2000) (Fig. 4):

Retrocostatum Chronozone, Quercinus Subchronozone. Proposed Stratotype: base of Bed Ag3B-94, section 3B, Aguilón (Page & Meléndez 2000). Ammonite associations: common large *Procerites* ex gr. *quercinus* sensu Arkell ?non Terquem & Jourdy, with some *Bullatimorphites*, *Prohecticoceras* and *Oxycerites*. Includes the *Cadomites* sp. 1 Biohorizon (with *P. quercinus*, *Bullatimorphites* (B.), *Prohecticoceras* ex gr. *blanazense* (Elmi) - including *Proh. dominyoni* (Elmi), *Oxycerites* and *Cadomites* - small, very finely ribbed form). Records include: Ricla, Tosos, Aladrén, Aguilón (e.g. Ag3B, beds 94-125; Page & Meléndez 1997, 2000), Ariño.

Hodsoni Subchronozone. Proposed Stratotype: base of Bed Ag B-126, section 3B, Aguilón (Page & Meléndez 2000). Ammonite associations include: *hodsoni* Biohorizon (with *Procerites hodsoni* Arkell and *Bullatimorphites* sp.) and aff. *twinhoensis* Biohorizon (with *P.* aff. *twinhoensis* Arkell (sensu Page & Meléndez), *Oxycerites* sp. and *?Prohecticoceras* sp.). Records include: *hodsoni* Biohorizon – Ricla, Aguilón (e.g. Ag3B, beds 126-130; Page & Meléndez 1997, 2000); aff. *twinhoensis* Biohorizon - Aguilón (e.g. Ag3B, beds 132-138; Page & Meléndez 1997, 2000).

Histricoides Subchronozone. Proposed Stratotype: base of Bed Ag3A-24, section 3A, Aguilón (Page & Meléndez 2000). Ammonite associations include: *compressus* Biohorizon (with *Cadomites compressus* de Groussouvre, *Proh.* cf. *blanazense*, *Oxycerites* sp. and *Homeoplanulites* sp.), *contrarium* Biohorizon (with *Epistrenoceras* sp. aff. *contrarium* (Behr.), *Oxycerites* sp., *Bullatimorphites* (B.) sp., *Homoeoplanulites* sp. and *Procerites* sp.), *pseudoannularis* Biohorizon (with *H.* ex gr. *rotundatus* (Roemer), *H.* cf. *pseudoannularis* (Lissajous), *Oxycerites* sp., *Bullatimorphites* sp. and *Proh.* cf. *retrocostatum* (de Groussouvre)), aff. *hannoveranus* Biohorizon (with *H.* cf. *praecursor* (Mangold), *?Procerites* sp., *Oxycerites* sp. and *Bullatimorphites* (*?B.*) aff. *hannoveranus* sensu Mangold (1970, text figs. 96, 97) non Roemer), *histricoides* Biohorizon (with *Epistrenoceras* cf. *histricoides* (Rollier), *Ox. orbis* Gumbel and *B.* ex gr. *hannoveranus*), *Hemigarantia* Biohorizon (with *Eohecticoceras* [*Alcidellus*] *costatus* (Roemer), *Ox. orbis*, *Homoeoplanulites* sp. and *Hemigarantia* sp.) and *hannoveranus* Biohorizon (with *Homoeoplanulites* ex gr. *rotundatus* – common, including *H.* aff. *vicenti* Mangold - *Proc.* cf. *twinhoensis* Arkell - rare, *B.* (*Kheraiceras*) *hannoverannus* Roemer sensu stricto, *Ox.* cf. *orbis* and *?Prohecticoceras* sp.). Records include: *compressus*, *contrarium*, *pseudoannularis* and aff. *hannoveranus* biohorizons – Aguilón (e.g., respectively: Ag3A, bed 26; Ag3A, beds 30-33; Ag3A, beds 56-58; Ag3B, beds 170-174; Page & Meléndez 1997, 2000); *histricoides* Biohorizon – Aguilón (e.g. Ag3B, beds 176-178; Page & Meléndez 1997, 2000), Ariño (e.g. AR.1, Bed 107); *Hemigarantia* Biohorizon – Aguilón (e.g. Ag3B, Bed 186; Page & Meléndez 1997, 2000); *hannoveranus* Biohorizon - ?Ricla, Aguilón (e.g. Ag3B, beds 191-192; Page & Meléndez 1997, 2000), ?Aladrén, Belchite, Lécera.

Discus/Angulicostaum Chronozone. Ammonite associations include: ex gr. *homeomorphus* Biohorizon (with *Homoeoplanulites* (*H.*) ex gr. *homoeomorphus* (Buckman) - including *Homeoplanulites* sp. cf. *kranaiformis* Arkell, *Hecticoceras* (*Jeanneticeras*) sp., *Parapatoceras tenuie* (Baugier & Sauzé) and *?Oxycerites* sp.. Records include: Aguilón (e.g. Ag3A, beds 102-103; Page & Meléndez 1997, 2000). Comment: despite the absence of *Clydoniceras*, a perisphinctid fauna typical of the Discus Chronozone in England is present. Notably, *Clydoniceras* itself has recently been recorded for the first time in Iberia, in the Sierra de la Creu and at Cap Salou (province of Tarragona) to the south east (Fernández-López 2001). A few *Bullatimorphites* (*Kheraiceras*) sp. are also present at similar levels, below the first Callovian-style perisphinctids ("*Elatmites*" spp. (m)) which characterize the overlying Bullatus Chronozone. As there are currently no further records of the Discus/Angulicostatum interval in Aragón, however, it is presumed that in the south east of the study region, in the area of the Sierra de Arcos, the terminal Bathonian is missing in a wide spread non-sequence (Figure 3).

Lower Callovian (KP, MDL, GM)

The Lower Callovian of Aragón is well developed, although due to local stratigraphical gaps and poorly fossiliferous intervals, a complete sequence of ammonite faunas has yet to be established. Where relatively expanded sequences are present, for instance at Ricla, ammonite associations are often less well preserved or less abundant (Cariou et al. 1988). Elsewhere, however, for instance near Moneva, Ariño and Calanda, extremely rich assemblages are present in thin, condensed successions, with many non-sequences. The following is therefore a review of the current state of knowledge, key published sources including: Sequeiros (1982a, b, 1984), Sequeiros & Cariou (1984), Cariou et al. (1988), Lardiés (1988, 1990), Meléndez & Ramajo (2001). The zonal framework reviewed by Thierry et al. (1997) for the Submediterranean Province Lower Callovian of France is applicable (Fig. 5), although rich ammonite associations from the Bullatus Chronozone in Aragón suggest that some refinement at the level of "horizon" (= "zonule" sensu Page 1995), and certainly at the level of Biohorizon, will ultimately be possible.

Bullatus Chronozone. Ammonite associations include: *Macrocephalites* spp., *Oxycerites* spp., *Paralcidia* cf. *subdiscus* (d'Orbigny), *Homeoplanulites* spp. (including *H.* aff. *petitclerci* (Spath), *H.* aff. *pseudaurigerus* (Siemiradzki) , *H. furculus* and *H.* aff. *demariae* (Parona and Bonearelli)) and *Bullatomorphites bullatus* (Ricla). Includes the basal cf. *verus* Biohorizon at Aguilón with *Macrocephalites* aff. *verus* Buckman (= *M. verus* in Page 1995), *Homeoplanulites* aff. *furculus* (Neumayr), *Bullatimorphites* (*Kheraiceras*) ex gr. *bullatus* (d'Orbigny), *Paralcidia subcostarius* (Oppel) and *Hecticoceras* (*Jeanneticeras*) ex gr. *prahecquense* (Petitclerc). Records include: Ricla (e.g. Ricla (III), beds 23-?64: Cariou et al. 1988), Aguilón (Ag3A, Bed 104 (= cf. *verus* Biohorizon; Page & Meléndez 1997, 2000), Belchite (Beds 343-344 of Sequeiros 1982b), Moneva (beds 6a-7a of Aurell et al. 1999). Comment: the absence of associations with basal Callovian *M. jacquoti* (Douvillé) below *M.* ex gr. *verus*, suggests the presence of a small non sequence at Aguilón. Elsewhere in the Aragonese Branch of the Cordillera, and especially to the south-east, the aff. *verus* association is also missing and the Callovian typically begins somewhere in the succeeding Gracilis Chronozone.

STAGE		CHRONOZONE	SUBCHRONOZONE		HORIZONS
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. 5 - Callovian chronostratigraphic framework (Submediterranean Province), modified from Thierry et al. (1997).

Gracilis Chronozone, Prahecquense Subchronozone, Prahecquense Horizon. Ammonite association includes: *Bullatimorphites* (*Bomburites*) ex gr. *prahecquense* (Petitclerc), *Homeoplanulites* spp. (abundant), *Hecticoceras* sp., *Paralcidia* sp. and *Macrocephalites* sp.. Records include: Ricla (e.g. Ricla (III), beds 63/64; Cariou et al. 1988), Aguilón (e.g. Ag1), Moneva (?Bed 12 of Sequeiros 1982a), Ariño (e.g. Ar1, Bed 107, upper part).

Grossouvrei Subchronozone, Grossouvrei Horizon. Ammonite associations include: *Reineckeia* (*Rehmannia*) cf. *grossouvrei* (Petitclerc), *R.* (*Rh.*) *rehmanni* (Oppel), *Bullatimorphites* (*Bomburites*) *globuliforme* (Gemmellaro), *Macrocephalites* spp. (including *M.* aff. *gracilis* Spath and *Macrocephalites macrocephalus* (Schlotheim)), *Hecticoceras* sp. and *Parapatoceras* sp.. Records include: Ricla (e.g. Ricla (III), beds 71-87; Cariou et al. 1988), Aguilón (e.g. Ag3A, Beds 106-?110).

Pictava, Laugieri and Michalskii subchronozones. Ammonite associations include: *Macrocephalites* ex gr. *gracilis* (locally abundant), also *Reineckeia* spp. (including *R.* (*Tyrannites*) spp.), *Paralcidia* sp., Hecticoceratinae (including *Chanasia* spp.), *Strungia voultensis* Lissajous and Pseudoperisphinctinae spp.. Records include: Ricla (e.g. Ricla (III), Bed 96 to Ricla (II), Bed 10; Cariou et al. 1988), Aguilón (e.g. Ag1, beds 41-?80 of Sequeiros & Meléndez 1981), Aladrén, Ventolano massif, Belchite (beds 346-353 of Sequeiros 1982b), Moneva (beds 7b-8a of Aurell et al. 1999), Ariño (e.g. Ar1, 108A-B of Meléndez 1978). Comment: above the Grossouvrei Subchronozone, assemblages with common *M.* ex gr. *gracilis* are typical and span the Pictava to Michalskii subchronozone interval (teste Thierry et al. 1997). At least three different assemblages of *M.* ex gr. *gracilis* 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 subchronozonal assignment is currently uncertain.

Patina Subchronozone. Ammonite associations include: Boginense Horizon (with *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 and *H.* (*J.*). *girodi* Bonarelli) and Pamprouxensis Horizon (with "*I.*" *patina* (Neumayr), *R.* (*C.*) *oxyptycha* and *H.*(*Z.*) *pseudolunula*). Records include: Boginense Horizon - Ricla (e.g. Ricla (III), beds 27- ?30 and Ricla (IV), beds 72-?76; Cariou et al. 1988); Pamprouxensis Horizon - Ricla (IV), Bed 77-?; Cariou et al. 1988). Patina Subchronozone (undifferentiated) – Aguilón (e.g. Ag1, Bed 81-? of Sequeiros and Meléndez 1981), Belchite (Bed 354? of Sequeiros 1982b), ?Moneva (beds 14-?15 of Sequeiros 1982a). Comment: the terminal Lower Callovian, Posterius Horizon of Thierry et al. (1997) is not recognisable at Ricla, based on the records of Cariou et al. (1988).

Middle and Upper Callovian (KP, GM, MDL)

Above the Lower Callovian sequence, development of the Middle and Upper Callovian is mainly limited to the relatively expanded sequences of the Aguilón – Ricla area as described by Sequeiros & Meléndez (1981), Cariou et al. (1988) and Meléndez et al. (2002). To the south-east, the interval is missing in a non-sequence which includes the Lower Oxfordian. The Submediterranean zonal scheme utilised in France for the Middle and Upper Callovian (as most recently reviewed by Thi-

erry et al. 1997) is applicable in the Iberian Cordillera and many of its component horizons (= "zonules" sensu Page 1995) are recognisable. Hecticoceratinae are often abundant, with a variety of Pseudoperisphinctinae, Reineckeiidae and Peltoceratinae at appropriate levels. Currently the most completely known sequence is at Ricla, although ammonite associations from other sites in the north-western part of the outcrop are likely to yield additional important material.

Anceps Chronozone, Stuebeli Subchronozone. Ammonite associations include: Bannense Horizon (with *Reineckeia stuebeli*, *Hecticoceras* (*Zieteniceras*) *pseudolunula*, *H.* (*Z.*) cf. *balinense* Bonarelli, *H.* (*Chanasia*) spp. - including *C. hartmanni* Zeiss, *C.* aff *turgidum* (Locz.) and *C. bannense* Elmi, "*Choffatia*" sp., *Grossuvria steinmanni* (Parona & Bonarelli), "*Indosphinctes*" spp. - including "*I.*" aff. *petaini* (Lemoine) and "*I.*" aff. *choffati* (Parona & Bonarelli), *Parapatoceras* sp. and *Macrocephalites* sp.) and Turgidulum Horizon (with *Reineckeia anceps* (Reinecke), *R.* (*Loczyceras*) *greppini* (Oppel), "*Choffatia*"sp., "*Indosphinctes*"sp., *H.* (*Rossiensiceras*) spp. - including *R. metomphalum* Bonnarelli and *R. loczyi* Zeiss, *H.* (*Lemoineiceras*) sp., *H.*(*Lunuloceras*) aff. *lunula* (Reinecke), *H.*(*Zieteniceras*) spp. - including *Z.* aff. *kiliani* Petitclerc, *Z. karpinskyi* Tsytovitch, *Z. sarasini* Tsytovitch and *Z. evolutum* Lee, *H.* (*Putealiceras*) spp. - including *P. krakoviense* Neumayr, *P. rectangulare* Tsytovitch and *P. virile* Zeiss, *H.* (*Sublunuloceras*) *didieri* Petititclerc, *H.* (*S.*) *crassicostatum* (Ch.), *H.* (*Chanasia*) *turgidum*, *H.* (*Orbygniceras*) *pseudopunctatum* Lahusen and *Phlycticeras poygonium* Zieten). Records include: Bannense Horizon - Ricla (e.g. Ricla (III), beds 32-51; Cariou et al. 1988); Turgidulum Horizon – 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. 1999; = Bed 16 of Sequeiros 1982a?).

Tyranniformis Subchronozone. Ammonite associations include?: *Hecticoceras* (*R.*) *tsytovitchi* Zeiss, *H.* (*R.*) aff. *multicostatum* Tsytovitch, *H.* (*Brightia*) *submatheyi* Lee and *H.* (*B.*) *difforme* Tystovitch. Records include: Ricla (e.g. Ricla (IV), Bed 92+; Cariou et al. 1988), ?Belchite (?Bed 353 of Sequeiros 1983). Comment: the fauna recorded at Ricla by Cariou et al. (1988) is not definitively of this age and neither component horizon (Blyensis and Richei of Thierry et al. 1997) is currently recognisable.

Coronatum Chronozone, Baylei Subchronozone. Ammonite associations include: Villanyensis Horizon (with *Flabellisphinctes* spp. - including *F. villanyensis* Till. and *F. tsytovitchae* Mangold, *Hecticoceras* (*Rossieniceras*) spp. - including *R. metomphalum* Bonarelli, *R. multicostatum* Tsytovitch and *R. savoiense* Zeiss, *H.* (*Orbignyceras*) *bronni* Zeiss, *H.* (*Or.*) *schloenbachi* Tsytovitch, *H.* (*Brightia.*) spp. - including *B. difforme* Tsytovitch, *B. tenuinodosum* Zeiss and *B. scaphitoides* Tsytovitch, *H.* (*Putealiceras*) *virile* Zeiss, *Collotia gigantea* (Bourquin) and "*Choffatia*" sp.) and Baylei Horizon (with *Erymnoceras* spp. - including *E. baylei* Jeannet, *Reineckeia fehlmanni* Jeannet, *Grossouvria* sp. and *Lytoceras* sp.). Records include: Villanyensis Horizon - Ricla (e.g. Ricla (II), 70-?76; Cariou et al. 1988), ?Moneva (Bed 9b? of Aurell et al. 1999; Meléndez et al. 2002). Baylei Horizon - Ricla (e.g. Ricla (II), 77-?79; Cariou et al. 1988).

Leuthardti and Rota subchronozones. Ammonite associations include: *Hecticoceras* (*Rossieniceras*) *regulare* Till. (Leuthardi Subchronozone). Records include: Aguilón (reelaborated assemblage of Leuthardi Subchronozone age in beds 106-107; Sequeiros et al. 1984). Comment: no component horizons 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 faunas (Cariou et al. 1988). The reelaborated assemblage (i.e. reworked as intraclasts) of beds 106-107 at Aguilón includes elements characteristic of the Leuthardi, Trezeense, Collotiformis and Poculum subchronozones and also of Lower Oxfordian age (Sequeiros et al. 1984).

Athleta Chronozone, Trezeense Subchronozone. Ammonite associations include: *Hecticoceras* (*Orbygniceras*) *trezeense* (Gérard & Contaut), *Hecticoceras* (*Sublunuloceras*) sp., *H.*(*Putealiceras*) *lugeoni*, *Pseudopeltoceras* sp., *Peltoceras* (*Rursiceras*) cf. *stolleyi* (Priest), *Collotia thiebauti* (Gérard & Contaut), *Orionoides* sp., *Pseudopeltoceras* sp. and *Distichoceras pasdejeuensis* (Gérard & Contaut). Records include: Ricla (e.g. Ricla (I), beds 87-89; Cariou et al. 1988); Aguilón (reelaborated assemblage in beds 106-107; Sequeiros et al. 1984; Meléndez et al., 2002). Comment: component horizons are not yet recognisable.

Collotiformis Subchronozone. Ammonite association includes: *Collotia fraasi* (Oppel). Records include: Aguilón (reelaborated assemblage in beds 106-107; Sequeiros et al. 1984; Meléndez et al., 2002). Comment: component horizons not recognisable.

Lamberti Chronozone. Poculum and Lamberti subchronozones. Ammonite association includes: *Hecticoceras* (*Sublunuloceras*) *lairense* Spath and *H.* (*S.*) *nodosulcatum* (Lahusen) (Poculum Subchronozone). Records include: Aguilón (reelaborated assemblage of Poculum Subchronozone age in beds 106-107; Sequeiros et al. 1984; Meléndez et al. 2002).

Lower and Middle Oxfordian (GM, JB)

Mariae and Cordatum chronozones (Lower Oxfordian). Lower Oxfordian ammonite associations of the Cordillera Ibérica were first described by Meléndez et al. (1982) from a thin iron-oolith rich limestone bed, ranging in thickness from 15-20 cm to 40-50 cm and spanning the Callovian-Oxfordian boundary and the Lower to early Middle Oxfordian (the "Arroyofrío Bed"). In the north western areas of the Cordillera, however, around Ricla and Talamantes, this interval is represented by a 25 to 30 cm thick black, micritic limestone unit without iron ooliths (Fig. 2) containing common planktonic foraminifera (*Globuligerina*) and a mixed ammonite association including reelaborated ammonites of different ages. The latter indicate a high level of taphonomic condensation, thereby hindering the precise dating of the unit. Detailed analyses of this interval include studies on the Ricla district by Ramajo & Meléndez (1996), Aguilón by Sequeiros et al. (1984), Tosos & Moneva, by Lardiés (1988, 1990), Meléndez & Ramajo (2001) and Meléndez et al. (2002) and on the Ariño-Sierra de Arcos area by Meléndez et al. (1997). A widespread non-sequence of upper Lamberti to Mariae chronozone age, spanning the Callovian-Oxfordian stage boundary, has also been detected across the entire Iberian Basin and has been interpreted as an episode of extreme shallowing of the platform, even local subaerial exposure (Aurell et al. 1994; Meléndez et al. 1997) (Fig. 6).

Ammonite associations include: Claromontanus Subchronozone, Cordatum Chronozone (with *Neocampylites delmontanus* (Op-

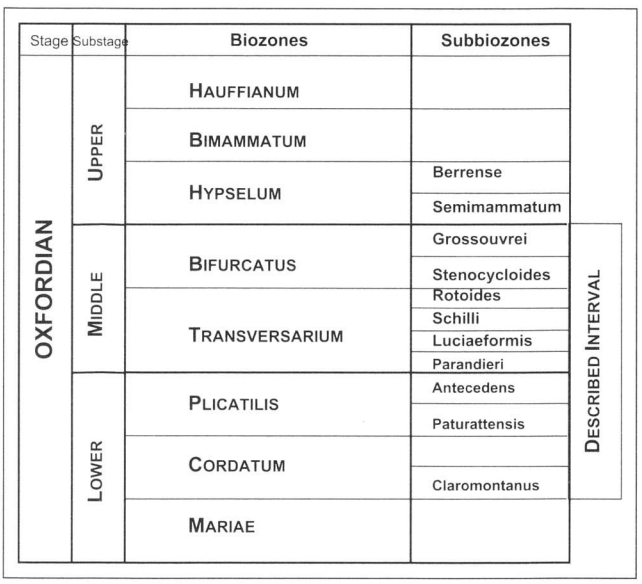

Fig. 6 - Oxfordian chronostratigraphical framework (Submediterranean Province); see text for sources.

pel), *Prososphinctes claromontanus* (Bukowski), *Passendorferia czestochowiensis* (Bukowski) and *Perisphinctes* (*Otosphinctes*) or *Properisphinctes* (?) of the group *moeschi* Brochwicz-Lewinski – *spathi* Meléndez, with rare *Peltoceratoides* (M) sp. and *P.* (*Parawedekindia*) (m) spp.). Records include: Ricla, Aguilón, etc.. Comments: the claromontanus association is the first recorded above the widespread non-sequence and closely matches the assemblage described by Bukowski (1887) from Czestochowa (Polish Jura) which, according to Brochwicz-Lewinski (1981), would characterise the Bukowskii Subchronozone, lower Cordatum Chronozone (the Claromontanus Subchronozone is its equivalent in the Mediterranean Realm). The occurrence of occasional *Prososphinctes* at a number of different sections in the central Iberian Cordillera, preserved as resedimented (hence, non-reelaborated) elements, seems to indicate that a first flooding episode took place during early Cordatum Biochron, favouring the arrival of ammonite shells and sedimentation of iron-oolith rich mud.

Plicatilis Chronozone, Paturattensis Subchronozone. A second, upper layer within the ferruginous oolith interval (the Arroyofrío Bed) has yielded at most of the studied localities, most notably in the Sierra de Arcos area, ammonites indicating the Plicatilis Chronozone in the lowest part of the Middle Oxfordian (Meléndez et al. 1982; Meléndez 1989; Meléndez & Fontana 1993; Ramajo et al. 1999; Meléndez et al. 2002). Ammonite associations include: Patturatensis Subchronozone (with *Perisphinctes* (*Otosphinctes*) of the *paturattensis* Loriol – *montfalconensis* Loriol groups, *Tornquistes* cf. *helveticus* (Tornquist) and ?*Kranaosphinctes* ex gr. *kranaus* Buckman). Records include: ?Ricla (upper black micritic layer of the Arroyfrío Bed); Moneva (level 9.b) and Ariño (AR.1, level 109.b) in the Sierra de Arcos area (uppermost Fe-oolitic level, below the base of the sponge limestone of Yátova Formation). Comments: as the precise stratigraphic position of Buckman's holotype of *K. kranaus* is uncertain, stratigraphical conclusions based on the single specimen from Ariño may require revision. Nevertheless, the general ammonite association at this level is characteristic of the lower Plicatilis Chronozone, Vertebrale Subchronozone, according to Bourseau (1977). The widespread occurrence of this characteristic association in the Submediterranean Province might justify the use of *Per.* (*O.*) *paturattensis* De Loriol as a subzonal index species for a unit equivalent to the Boreal Vertebrale or Tenuicostatum Subchronozone in Mediterranean areas, where cardioceratids are virtually absent.

Transversarium Chronozone. Parandieri Subchronozone. Lower levels of the sponge limestone, Yátova Formation in north west sections (Ricla) have yielded a few [M] (= macroconch) and [m] (= microconch) forms showing rounded serpenticone and somewhat evolute inner whorls and thick primaries on their middle and outer whorls and thereby close to the species *P. parandieri* De Loriol (and from below the first levels with typical *Perisphinctes* of the *martelli* Oppel - *luciaeformis* Enay groups). Ammonite associations include: *Perisphinctes* sp. cf. *parandieri*, *Per.* (*Otosphinctes*) ex gr. *siemiradzkii* Enay (including "*Kranaosphinctes* spp." macroconch forms), *Gregoryceras* ex gr. *toucasianum* (D'Orbigny) (Meléndez 1989; Meléndez & Fontana 1993). Records include: Ricla (levels Ri. 4-16, lower part of Yátova Formation). Comments: component horizons of this subchronozone are not yet recognisable.

Luciaeformis Subchronozone. The lower interval of the Yátova Formation generally corresponds to this subchronozone, formerly referred to as "Wartae Subzone" (Meléndez 1989) in other sections across the Iberian platforms. Ammonite association includes: Common perisphinctids including *Perisphinctes* ex gr. *martelli* (Oppel), *Passendorferia birmensdorfensis* (Moesch) [m] and *Pass. ziegleri* Brochwicz-Lewinski [M], also *Glochiceras subclausum* (Oppel), *Neomorphoceras collinii* (Oppel), *Trimarginites* ex gr. *arolicus* (Oppel) [M] – *stenorhynchus* (Oppel) [m], *Ochetoceras canaliculatum* (von Buch) – *hispidum* (Oppel); *Gregoryceras riazi* (De Grossouvre) and *Euaspidoceras* aff. *oegir* (Oppel) – *perarmatum* Arkell. *Per.* (*Otosphinctes*) *nectobrigensis* Meléndez [m] and its presumable [M] (= *Kranaosphinctes* n.sp. A in Meléndez 1989) is typically found in the lower part of this subchronozone and characterises a Nectobrigensis Horizon (Meléndez, loc. cit.), whilst in the upper part, a Luciaeformis Horizon is characterised by and *Perisphinctes martelli* [M] - "*Dichotomosphinctes*" ex gr. *luciaeformis* Enay - *elisabethae* De Riaz. with *Per.* (*Otosphinctes*) *vermicularis* De Loriol ([m] and [M]) and *Subdiscosphinctes* [M] of the *aeneas* (Gemmellaro) - *aguilonensis* (Meléndez). Records include: all studied localities in both the Aragonese and Castillian platforms (Meléndez & Fontana 1993; Meléndez et al. 1997). Comments: despite its superficial morphological homogeneity, the perisphinctid assemblage of the Luciaeformis Subchronozone still requires a full taxonomic review, especially in realtion to dimorphism and intraspecific variation. Nevertheless, the unit remains one of the most widely correlatable of the Middle Oxfordian across europe, from the Polish "Jura" to the Swiss and French Jura, to SE France (Vocontien Basin) and Aquitaine. In the latter area it corresponds to the Collinii Horizon, as remarked by Cariou et al. (1991).

Schilli Subchronozone. This interval, recognised by the common occurrence of the genus Larcheria Tintant, is widely represented in south western Europe. Ammonite association includes: common *Larcheria* spp., also *Peisphinctes* ex gr. *luciae* De Riaz, *Per. michalski* De Loriol, *Per. marcoui* De Loriol (with *Per. ultimus* Enay in the upper part of the subchronozone), *Passendorferia ericensis* Meléndez ([M] and [m]), *Sequeirosia* ex gr. *brochwiczi* ([M] and [m]) Sequeiros, *Trimarginites* ex gr. *arolicus* (Oppel) [M] – *stenorhynchus* (Oppel) [m], *Ochetoceras canaliculatum* (von Buch) – *hispidum* (Oppel), *Glochiceras* spp. and probably also very rare *Gregoryceras transversarium* (Quenstedt). Comments: in the Iberian Cordillera, the succession of species of *Larcheria* facilitates the recognition of three successive horizons, respectively: Schilli Horizon (with *L. schilli* (Oppel)), Iberica Horizon (with *L. iberica* Fontana) and Subschilli Horizon (with *L. subschilli* (Lee)) (Meléndez & Fontana 1993).

Rotoides Subchronozone. Above the Schilli Subchronozone, a sharp change in ammonite assemblages is generally recorded in the Iberian Cordillera, with *Larcheria* being replaced by coarser ribbed *Perisphinctes* spp., with less abundant oppeliids, aspidoceratids and Passendorferiinae. Ammonite assemblages include: Jelskii Horizon (with "*Perisphinctes jelskii*" sensu Siemiradzki (1899) (probably including [M] figured by Meléndez 1989, p. 242, pl. 28, figs. 1-4) and *Per. kreutzi*, Ronchadzé non Siemiradzki) and Wartae Horizon (with *Per. wartae* Bukowski ([M] and [m]) with scarcer *Per. rotoides* Ronchadzé – this assemblage includes forms showing features transitional to *Dichotomoceras*). Associated taxa in the subchronozone include *Passendorferia* sp. aff. *ericensis* Meléndez (more evolute, crassicostate form) and very rare *Gregoryceras* sp. (with forms showing an early trend to develop single, subradial ribs) are sometimes recorded.

Records include: widespread throughout the Iberian Cordillera, including Ricla (levels 40-50 of section Ri.1), Aguilón (levels 35-40 of section Ag.2), Moscardón (levels 40-50 of section 3M) (Cariou et al., 1991). In the region of Sierra de Arcos, between Moneva and Ariño, this interval is affected by a stratigraphic discontinuity and representatives of this assemblage are frequently preserved only as fragmented reelaborated internal moulds within the lower levels of the overlying Bifurcatus Chronozone.

Bifurcatus Chronozone. This interval is characterised by the widespread development of the last representatives of subfamily Perisphinctinae, including *Perisphinctes* (sensu stricto) [M] of the *P. panthieri* Enay - *P. variocostatus* (Buckland) groups and the [m] counterpart "*Dichotomoceras*" Buckman. Passendorferiinae (*Passendorferia*, and *Sequeirosia*), certain Oppeliidae (*Ochetoceras*) and Euaspidoceratinae (*Euaspidoceras* and *Paraspidoceras*) are also relatively common, whilst forms such as *Glochiceras*, *Trimarginites*, *Gregoryceras*, and *Mirosphinctes* are now rarer.

Stenocycloides Subchronozone. Ammonite associations include: *P.* (*Dichotomoceras*) ex gr. *bifurcatoides* Enay - *stenocycloides* Siemiradzki groups (with *P.* (*Per.*) *panthieri* Enay [M]) common and characteristic. The local abundance of *P. bifurcatoides* in the lower part of the subchronozone permits the recognition of a Bifurcatoides Horizon, whilst the presence of a smaller, compressed and somewhat more

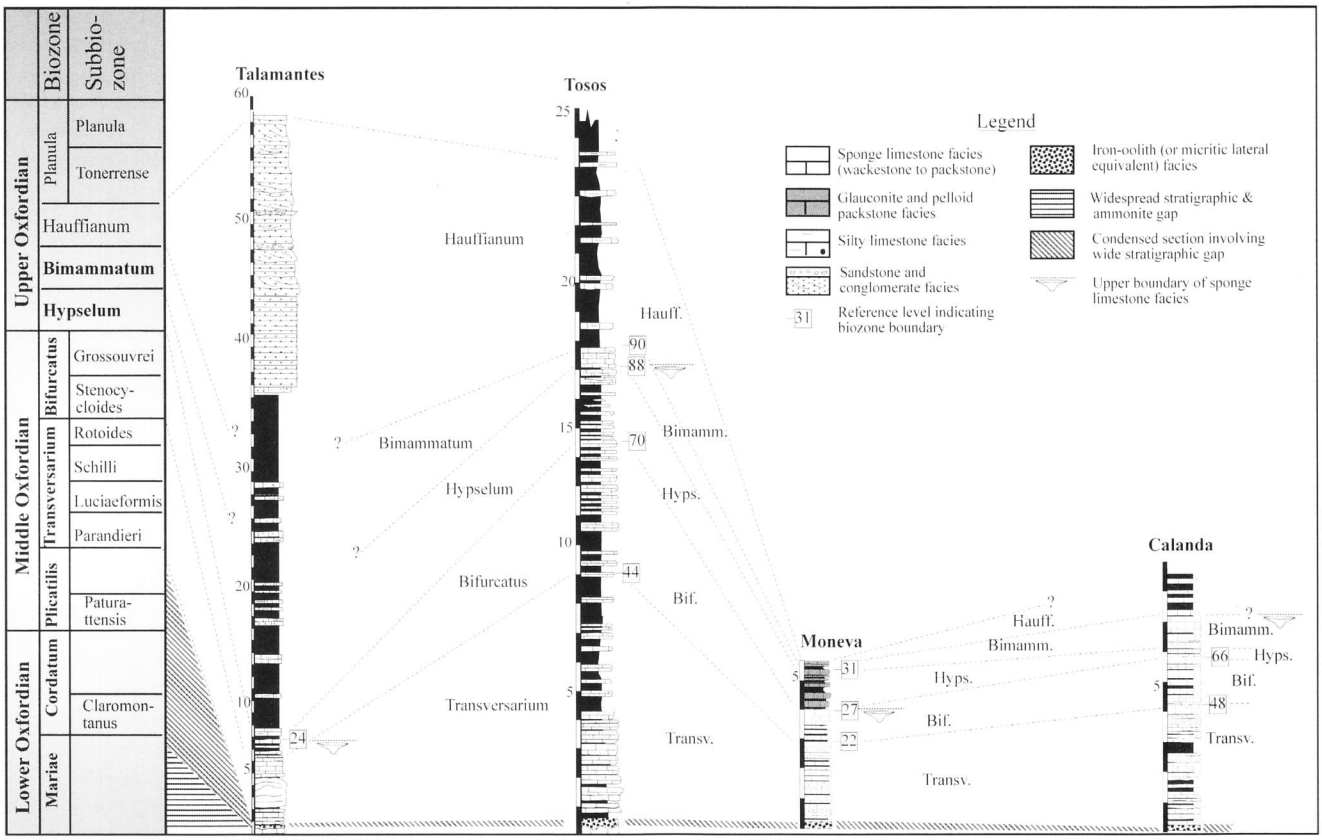

Fig. 7 - Correlation of key Oxfordian successions on the north-eastern margin of the Iberian Cordillera (Aragonese Platform); note the marked increase in thickness and clastic content of north-western areas.

involute form, *P.* (*Dichotomoceras*) *duongi* Meléndez in the upper part, characterises a Duongi Horizon. Also characteristic of this upper level is *Passendorferia torcalense* (Kilian) ([M] and [m]). Records include: Ricla (levels 50 and 55), Moscardón and Frías de Albarracín in equivalent (levels 50 to 56; Cariou et al. 1991). Comment: in south eastern, external areas (Moneva, Ariño and Calanda) where the Oxfordian facies are relatively condensed facies, the subchronozone is represented only by reelaborated specimens in the lower part of overlying units.

Grossouvrei Subchronozone. Characterised by common *P.* (*Dichotomoceras*) spp.. Ammonite associations include: Grossouvrei Horizon (with *Per.* (*D.*) *grossouvrei* Siemiradzki), Bifurcatus Horizon (with *Per.* (*D.*) *bifurcatus* (Quenstedt)), Malinowskae Horizon (with small *Per.* (*Ampthillia*) cf. *malinowskae* Brochwicz-Lewinski). Associated forms include *Ochetoceras* ex gr. *raixense* - *basseae* Fradin, *Passendorferia* ex gr. *teresiformis* Brochwicz-Lewinski - *uptonioides* Enay (the latter already showing features transistional to *Orthosphinctes*) and *Sequeirosia* spp. Meléndez (Meléndez & Fontana, 1993; Ramajo et al., 1999). Records include: the subchronozone is well developed throughout the Aragonese Platform and also in the central and southern Iberian Cordillera (Castillian Platform). The unit is best exposed at Ricla, Tosos and Aguilón (outcrops Ag.4 and AG.5), although in eastern, more external areas (Ariño, Calanda, etc.), it is characterised by reduced and incomplete condensed sequences (Meléndez, 1989). Comments: the succeeding Ariniensis Horizon of Meléndez & Fontana (1993), defined on the basis of *Orthosphinctes* [ex. *Passendorferia*] *ariniensis* (Meléndez) is now considered to be basal horizon Hypselum Chronozone (Upper Oxfordian in a Submediterranean sense).

Concluding remarks

The Upper Bathonian to Middle Oxfordian succession of the Aragonese branch of the Cordillera Ibérica is one of the most completely developed in Europe and includes localities of international importance for Jurassic bio- and chronostratigraphy, including a potential stratotype for the Upper Bathonian of North West Europe and reference sections for a number of Submediterranean Province, Middle Oxfordian biostratigraphic units. The intervening Callovian sequence, although often very incomplete and strongly condensed, also includes assemblages of stratigraphical and taxonomic importance and has the potential to make important contributions to studies of the geology and palaeontology of the Submediterranean Province in Europe (Fig.7).

Acknowledgements. This work is a contribution to the Projects BTE 2000-1148 (MCT-CSIC) and OTRI 2000-448 (Fundación Conjunto Paleontológico de Teruel). Thanks are due to the Instituto de Estudios Turolenses, CSIC (Diputación Provincial, Teruel) for financial support. The authors would also like to thank the reviewers J. Caracuel and I. Fozy for their critical reviews and suggestions that improved the manuscript.

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