Depositional sequences and ammonoid assemblages in the upper Cenomanian-lower Santonian of the Iberian Peninsula (Spain and Portugal)

M. SEGURA [1] **F. BARROSO-BARCENILLA** [1] [2] **P. CALLAPEZ** [3] [4] **J. GARCÍA-HIDALGO** [1] **J. GIL** [1]

[1] Grupo de Investigación IBERCRETA, Universidad de Alcalá de Henares

28871 Alcalá de Henares, España – Spain. Segura E-mail: manuel.segura@uah.es

Barroso-Barcenilla E-mail: fbarroso@uah.es García-Hidalgo E-mail:

jose.garciahidalgo@uah.es Gil E-mail: javier.gil@uah.es

[2] Departamento de Paleontología, Universidad Complutense de Madrid

28040 Madrid, España – Spain. E-mail: fbarroso@geo.ucm.es

[3] Departamento de Ciências da Terra, Universidade de Coimbra

3000-272 Coimbra, Portugal. E-mail: callapez@dct.uc.pt

[4] Centro de Geofísica, Universidade de Coimbra

3000-134 Coimbra, Portugal. E-mail: callapez@dct.uc.pt

ABSTRACT

A clear relationship exists between eustatic sea-level rises and falls recorded as cyclical depositional sequences and ammonite faunas during the Cenomanian-Santonian in the Iberian and West Portuguese basins. Most of the faunal turnovers correlate with stratigraphic intervals related to marine transgressions, maximum flooding of the shelf (locally associated to anoxic events), and the marine regressions. Specifically, within each depositional sequence, three distinct and identical events of morphological change occur, involving ammonoids belonging to different groups. Transgressive sediments are characterized by moderately ornamented, inflated and evolute shells, which are replaced by smooth, involute and compressed oxycones (the most hydrodynamic shells) during maximum flooding (and to a lesser extent at the early highstand) of the sequences, which in turn are replaced by coarsely ornamented and evolute shells during late highstands. We conclude that ammonoid faunal analysis can be used to trace sea-level changes and provide an additional tool for sequence stratigraphy.

KEYWORDS **Depositional sequences. Ammonoid assemblages. Upper Cenomanian-lower Santonian. Spain. Portugal.**

INTRODUCTION

During the Late Cretaceous, the Iberian Peninsula was a relatively independent tectonic block. Its privileged palaeogeographical location favoured the arrival of boreal faunas from the Protoatlantic and temperate-warm faunas from the Tethys to its epicontinental flooded regions. As it enabled the development of rather confined marine environments, endemic species arose in its waters as well. The combined incidence of eustatic changes and local tectonics generated several depositional sequences with characteristic faunal assemblages (particularly well-recorded during major sea-level rises) from upper Cenomanian to lower Santonian in The Iberian and the West Portuguese basins. The upper Cenomanian to lower Turonian sequences and their ammonoid assemblages, were studied by (Barroso-Barcenilla *et al.*, 2011a), have been related and interpreted in detail for the first time here, considering the narrow relationship that can be established in the epicontinental platforms between palaeoenvironmental changes (*e.g.*, sea-level oscillations, anoxic events) and palaeontological successions (Fernández-López, 1999; Hirano *et al.*, 2000).

GEOGRAPHICAL AND GEOLOGICAL SETTING

The Iberian Peninsula contains thick Upper Cretaceous sedimentary sequences, mainly composed of marls and limestones with several terrigenous and dolomitic intervals, which yield fossils in many sections of the Iberian and the West Portuguese basins (Fig. 1A-C)., the Iberian Basin (IB) was a relatively stable intracratonic platform, and comprised the northern, central and south-eastern regions of the Iberian Peninsula that were temporally or permanently flooded by the Protoatlantic, the Tethys or both (Fig. 1B-C). During the late Cenomanian-early Santonian it corresponded to a basin with high subsidence and sedimentation rates, mainly controlled by sea-level eustatic changes (Floquet *et al.*, 1982; Segura *et al.*, 2001, 2002; Barroso-Barcenilla *et al.*, 2011a). In the northern part of the basin (southern Cantabrian Ranges), the sedimentary and palaeontological successions shows a continuous record in marly materials of relatively deep and open inner platform with ammonites, inoceramids and other benthic, non-rudist bivalves. In the southern part of the IB (northern Central System and western Iberian Ranges) nodular carbonates (limestones and dolostones) of relatively shallow and restricted inner platform, containing thinner and less abundant levels with ammonites, rudists (mainly Coniacian) and other molluscs, and a narrow coastal siliciclastic belt, with scarce palaeontological content, predominate (Gil *et al.*, 2006; García-Hidalgo *et al.*, 2007) (Fig. 1C).

The West Portuguese Basin (WPB) included the western-central regions of the Iberian Peninsula temporally or permanently flooded by the Protoatlantic (Fig. 1B-C). It was part of an active continental margin controlled by reactivated Late Hercynian faults and halokinetic structures with Triassic-Lower Jurassic evaporites. Nevertheless, as in the Iberian Basin, the main depositional episodes and faunal assemblages were related to global sea-level changes, but the sedimentary infill was less continuous and influenced by local tectonics and continental influx episodes (Ferreira Soares, 1980; Callapez, 1998, 2008; Rey *et al.*, 2006; Dinis *et al.*, 2008; Barroso-Barcenilla *et al.*, 2011a). During the Cenomanian a carbonate platform with different domains developedoccurred. At the northern part of The basin (Beira Litoral Ranges) there was a nodular carbonate shelf with ammonites, and a related micaceous littoral plain. The southern part of the basin (Estremadura Ranges) was occupied by a rimmed carbonate platform with coral and rudist fringes, and a lagoonal system with other molluscs and echinoids. After a hiatus related to regional uplift, carbonate sedimentation was temporarily re-established on the northern part of the basin at the middle lower Turonian. The remaining record was alluvial and littoral, but punctuated by a single and short eustatic episode with middle upper Coniacian ammonites (Fig. 1C).

DEPOSITIONAL SEQUENCES

Stratigraphic studies have allowed us to recognize the main depositional episodes and to reconstruct the architecture of the 2nd- and 3rd-order sequences in the upper Cenomanian-lower Santonian of the Iberian and West Portuguese basins, recognizing and correlating the larger and most extensive sea-level oscillations, and valuating the depositional hiatuses towards the coastal margins.

In the Iberian Basin, six 3rd-order depositional sequences, belonging to the UZA-2 and UZA-3 (*sensu* Haq *et al.*, 1988) 2nd-order megasequences, have been recognized mainly in carbonates with ammonites. These are the sequences UZA-2.4 (lower upper Cenomanian, although its base seems to be upper middle Cenomanian), UZA-2.5 (uppermost Cenomanian-lower Turonian) and UZA-2.6+2.7 (middle Turonian) and, after a marked sedimentary discontinuity corresponding to the middle/upper Turonian boundary, UZA-3.1 (upper Turonian) and UZA-3.2 (lower Coniacian-lowermost Santonian) (Floquet, 1998; Gräfe, 1999; Segura *et al.*, 2001

) (Fig. 2).

In the West Portuguese Basin, the UZA-2 megasequence is also recorded by carbonates with ammonites, but the succession is incomplete due to local tectonics. The UZA-2.4 is well recognized in a carbonate platform bearing a cephalopod assemblage with *Neolobites and Angulithes*. The UZA-2.5 starts with an uppermost Cenomanian interval with *Vascoceras-Spathites* (*Jeanrogericeras*), but it was truncated due to a regional tectonic uplift, and in its upper part a middle lower Turonian ammonite assemblage with *Choffaticeras* (*Leoniceras*) is locally recognized. Finally, the UZA-2.6+2.7 has only been recorded in the northern part of the basin with littoral to alluvial micaceous sandstones. Concerning the UZA-3 megasequence, the lack of carbonates with marine faunas hinders an accurate stratigraphic control, except for a middle upper Coniacian event with *Hemitissotia*. Nevertheless, the UZA-3.1/UZA-3.2 boundary can be located into a discontinuity related with the transition to coarser siliciclastic sediments (Callapez, 1998) (Fig. 2).

AMMONOID ASSEMBLAGES

Detailed ammonite zones and assemblages of both boreal and temperate-warm affinities have been established for the upper Cenomanian-lower Santonian of the Iberian and West Portuguese basins, which have been compared and correlated with those identified in Western Europe, North Africa and the Western Interior of USA. Systematic and biostratigraphic data provided by the specimens collected by the authors of this paper (>2500) and other researchers in the region (*e.g.*, Karrenberg, 1935; Wiedmann, 1960; Mojica and Wiedmann, 1977; Wiedmann and Kauffman, 1978; Santamaría-Zabala, 1992; Callapez, 2003; Callapez and Ferreira Soares, 2001; Gallemí *et al.*, 2007; Barroso-Barcenilla *et al*., 2009, 2011a, in press.) have been analyzed. The main part of these cephalopods do not present signs of taphonomic resedimentation or reelaboration (*sensu* Fernández-López, 2000), and the few that show any of these signs do not seem to have suffered notable alterations. Therefore, it has been considered that all of them maintain their respective original stratigraphic positions (Callapez, 1998; Barroso-Barcenilla, 2006; Barroso-Barcenilla *et al*., 2011a).

The stratal architecture and the palaeontological successions of the above mentioned 3^{rd}-order deposition sequences show that their Maximum Flooding Surfaces (mfs) are coincident, both in the Iberian and West Portuguese basins (although the stratigraphic record in the latter is somewhat incomplete due to local tectonics), with four especially rich and widespread ammonitiferous intervals. These acme-type intervals are laterally continuous in every sequence all along the main part of both basins, and successively contain numerous specimens of *Neolobites vibrayeanus Angulithes mermeti* (UZA-2.4 mfs), *Choffaticeras* (*Choffaticeras*) *quaasi pavillieri* (UZA-2.5 mfs), *Coilopoceras requienianum* (UZA-3.1 mfs), and *Hemitissotia ceadouroensis/celtiberica-turzoi* (UZA-3.2 mfs) (Figs. 2-3).

The first interval (*N. vibrayeanus* and *A*. *mermeti*) coincides with the mfs (lower upper Cenomanian) of the UZA-2.4, providing specimens of these cephalopods both in the northern and southern parts of the Iberian Basin. It can be also recognized in the West Portuguese Basin, where the assemblage of *N. vibrayeanus A*. *mermeti* is abundant as well. The second interval (*Ch*. (*Ch*.) *quaasi pavillieri*) corresponds to the mfs (lowermost Turonian) of the UZA-2.5, containing ammonites even in farther southern areas of the IB (up to the Cuenca Section). In the WPB this interval coincides with the local tectonic uplift and emersion of the carbonate platform. After a major stratigraphic discontinuity, the third interval (*C*. *requienianum*) corresponds to the mfs (lower upper Turonian) of the UZA-3.1, being less extensive than the previous ones, and recognized only in the northern part of the IB. Its location and reduced extension is related to its sequence stratigraphic context (the transgressive base of a 2nd-order megasequence after the major sea-level fall at the middle/upper Turonian transition, corresponding to the UZA-2/UZA-3 boundary: Gil *et al*., 2006). The same interval is unknown in the WPB, where correlative series are terrigenous, lacking marine fossils. The fourth interval (*H*. *ceadouroensis/celtiberica turzoi*) corresponds to the mfs (middle upper Coniacian) of the UZA-3.2, providing specimens of these ammonite species in the northern and central parts of the IB (up to the Castrojimeno-Castroserracín Section). In the WPB, this transgression is recorded by sandstones with *H. ceadouroensis/celtiberica* (in the Ceadouro Section) and coarse alluvial sediments (Figs. 2-3).

DISCUSSION

The relationship of these ammonites with mfs of specific sequences can be contrasted through the analysis of their distributions out of the Iberian Peninsula. Thus, *N*. *vibrayeanus* has been identified in the upper Cenomanian (*Calycoceras* (*Calycoceras*) *naviculare* Zone *sensu* Gradstein *et al*., 2004) of South-Western Europe, North Africa, Middle East, Niger and, possibly, Peru (Kennedy and Simmons, 1991; Callapez and Ferreira Soares, 2001; Wiese and Schulze, 2005; Barroso-Barcenilla, 2006).,The co-occurrence and abundance of *Neolobites* and *Angulithes* in this interval has been observed by different authors in other basins (*e.g*., Benavides-Cáceres, 1956; Meister and Rhalmi, 2002), and seems to be related to important palaeoenviromental changes (Barroso-Barcenilla *et al*., 2011a). *Ch*. (*Ch*.) *quaasi-pavillieri* have been collected in the lower Turonian (*Watinoceras devonense* Zone *sensu* Gradstein *et al*., 2004) of North Africa, Middle East, South-Western Europe, Madagascar, USA and, probably, Rumania and Nigeria (Chancellor *et al*., 1994; Amédro *et al*., 1996; Meister and Abdallah, 2005; Barroso-Barcenilla and Goy, 2007). *C*. *requienianum* has been identified in the upper Turonian (*Subprionocyclus neptuni* Zone *sensu* Gradstein *et al*., 2004) of South-Western Europe, North and West Africa, Madagascar, Middle East, Pakistan, North America, Trinidad and Tobago, and South-Western America (Kennedy and Wright, 1984; Kassab and Obaidalla, 2001; El-Hedeny, 2002; Hewaidy *et al*., 2003; Nagm *et al*., 2010). *H*. *ceadouroensis/celtiberica-turzoi* have been collected in the upper Coniacian (*Paratexanites serratomarginatus* Zone *sensu* Gradstein *et al*., 2004) of South-Western Europe, Madagascar, Saudi Arabia and, possibly, Morocco (Wiedmann and Kauffman, 1978; Wiedmann, 1979; El-Asa'ad, 1991; Santamaría-Zabala, 1995; Gallemí *et al*., 2007; Barroso-Barcenilla *et al*., in press.). Most of these ammonites are so abundant in their respective intervals that some of them, such as *N*. *vibrayeanus*, *Ch*. (*Ch*.) *quaasi*, *C*. *requienianum* and *H*. *turzoi*, are considered as biostratigraphic markers in numerous basins of the Western Tethys (*e.g.*, Wiese and Schulze, 2005; Meister and Abdallah, 2005; Nagm *et al*., 2010; Barroso-Barcenilla *et al*., in press.).

The morphology of these ammonoids (Fig. 3) corresponds to smooth and compressed oxycones (morphogroup 11 *sensu* Batt, 1989; Westermann, 1996) and, therefore, to nektonic forms, well adapted to active swimming. Then, the relationship of oxycones with mfs seems to be an adaptive response to sea-level changes (maximum depths in the basin), since hydrodynamically, a smooth and compressed form usually has a lower drag coefficient and higher swimming velocity, developing more efficient locomotion than an ornamented and depressed one (Chamberlain, 1980; Westermann, 1996). This morphological relationship can be established both in intracratonic (Iberian Basin) and active marginal (West Portuguese Basin) basins and has been suggested in other basins (*e.g.*, Middle Jurassic of Germany: Bayer and McGhee, 1984; Upper Cretaceous of USA: Jacobs *et al*., 1994), relating sea-level changes with ammonoid morphologies (ecophenotypic variations: Diedrich, 2000; Wilmsem and Mosavinia, 2011) and turnovers (O'Dogherty *et al*., 2000; Sandoval *et al*., 2001, 2002; Yacobucci, 2008).

The UZA-2.5 and UZA-3.2 are the most extensive sequences, representing the transgressive/regressive transition of two consecutive megasequences (2nd-order). They contain, by coincidence with their respective mfs, the megasequence mfs, and show three other important particularities. Firstly, they have well-developed Transgressive Systems Tracts (TST) with abundant ammonites, containing numerous specimens of *Vascoceras gamai-Spathites* (*Jeanrogericeras*) *subconciliatus* (uppermost Cenomanian) in the UZA-2.5, and of *Tissotiodes hispanicus-Prionocycloceras iberiense-Protexanites bourgeoisi* (lower upper Coniacian) in the UZA-3.2 (Fig. 3). The presence of abundant morphologically less hydrodynamic ammonites with moderately ornamented and evolute discocones and platycones (close to morphogroups 6, 9 *sensu* Batt, 1989; Westermann, 1996) in the TST is interpreted here as related to sea-levels markedly lower than those of the maximum flooding stages, even during the superimposition of the highstand portions of the high-frequency cycles (4th-order). Secondly, they present, close to the mfs of these two sequences, the dark levels corresponding to the Oceanic Anoxic Event 2 (OAE-2) of the Cenomanian/Turonian transition and to the less known and more controversial Oceanic Anoxic Event 3 (OAE-3) of the Coniacian/Santonian transition (Schlanger and Jenkyns, 1976; Jenkyns, 1980; Jenkyns *et al*., 1994; Schlanger *et al*., 1987; Arthur *et al*., 1988, 1990) (Fig. 2). Both events are characterized by the hypoxic character of the oceanic waters and the reduced abundance and diversity of their macrofaunas (Sepkoski, 1986; Barroso-Barcenilla *et al*., 2011b). Thirdly, they also have well-developed and complex Highstand Systems Tracts (HST) with abundant ammonites, which can be divided in two intervals: early and late. The early HST contains numerous specimens of *Choffaticeras* (*Leoniceras*) *luciae-barjonai* (middle lower Turonian) in the UZA-2.5, and of *Hemitissotia dullai-lenticeratiformis* (uppermost Coniacian) in the UZA-

3.2 (Fig. 3), coinciding to oxyconic, involute and moderately compressed species with hydrodynamically efficient shells (morphogroup 11 *sensu* Batt, 1989; Westermann, 1996) with efficient hydrodynamism, and making the characterization/differentiation of mfs and early HST difficult on the exclusive basis of the cephalopod morphologies. The late HST has less abundant ammonites, mostly representatives of *Mammites nodosoides* (upper lower Turonian) in the UZA-2.5, and of *Texanites hispanicus* (lowermost Santonian) in the UZA-3.2 (Fig. 3), corresponding to coarsely ornamented planorbicones and similar (close to morphogroup 1 *sensu* Batt, 1989; Westermann, 1996) with very low hydrodynamism. The presence of progressively fewer hydrodynamic ammonites in the HST is also interpreted here as related to sea-levels lower than those of the maximum flooding stages, as a result of the loss of accommodation, even during the superimposition of the highstand portions of the high-frequency cycles (4th-order).

Among those ammonoids characterizing even lower sea-level intervals are coarsely ornamented ammonites with very low hydrodynamic efficiency predominate. A good example of this can be observed in the reduced sea-level interval of the middle Turonian (UZA-2.6+2.7), characterized by the progradation of shallower inner platform and coastal margin facies with thin levels containing bivalves and scarce heavily ornamented ammonites (*e.g.*, *Romaniceras*, Fig. 3) in the northern part of the Iberian Basin (Wiedmann, 1960, 1979; Wiedmann and Kauffman, 1978; Santamaría-Zabala, 1995; Küchler, 1998).

CONCLUSIONS

In the upper Cenomanian-lower Santonian of the Iberian and West Portuguese basins (although with incomplete record in the latter), four mfs corresponding to 3rd-order sequences with abundant cephalopods (UZA-2.4 with *N*. *vibrayeanus-A*. *mermeti* in the lower upper Cenomanian; UZA-2.5 with *Ch*. (*Ch*.) *quaasi-pavillieri* in the lowermost Turonian; UZA-3.1 with *C*. *requienianum* in the lower upper Turonian; UZA-3.2 with *H*. *ceadouroensis/celtiberica-turzoi* in the middle upper Coniacian) can be identified. The morphology of these ammonites (well adapted active swimmers with smooth and compressed oxycones) is explained in this paper by their close relationships with the deeper facies of every studied sequence, corresponding to their maximum flooding surfaces. This trend is further observable in the early HST as well (UZA-2.5 with *Ch*. (*L*.) *luciae-barjonai*, and UZA-3.2 with *H*. *dullai-lenticeratiformis*), since they also have deep facies. This relationship can additionally be observed in other basins of Western Tethys. Other systems tracts representing different portions of the sea-level curve of the sequence (particularly the TST and late HST) contain abundant ammonites with fewer hydrodynamic morphologies. Thus, the TST of UZA-2.5 with *V*. *gamai-S*. (*J*.) *subconciliatus*, and of UZA-3.2 with *T*. *hispanicus-P*. *iberiense-P*. *bourgeoisi*; and the late HST of UZA-2.5 with *M*. *nodosoides* and of UZA-3.2 with *T*. *hispanicus*. These results clearly suggest that the presence or absence of ammonoids in these basins, their morphologies and, therefore, their evolutionary trends are influenced mainly by eustatic variations, and demonstrate the interest and utility of integrated studies on depositional sequences and faunal assemblages for basinal analyses and correlations.

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FIGURE CAPTIONS

Figure 1 A) Geographic location and stratigraphic context of the Spanish and Portuguese studied areas (red polygons) in Western Europe. B-C) Palaeogeographic situation of the Iberian Peninsula during the maximum transgression of the late Cenomanian-early Turonian C:, with The approximate locations of the main studied Spanish and Portuguese C) composite-sections and the facies distribution. Fig. 1B-C is modified from Philip and Floquet (2000), Stampfli *et al*. (2001) and Gelabert *et al*. (2002).

Figure 2 Dip cross-section of the upper Cenomanian-lower Santonian 3rd-order depositional sequences (UZA-2.4 to UZA-3.2) in the Iberian and West Portuguese basins, showing the depositional architecture and the main ammonoid assemblages relative to the reference surfaces (Maximum Flooding Surfaces and sequence boundaries) and the systems tracts (Transgressive Systems Tracts and Highstand Systems Tracts). Ceno.: Cenomanian, S.: Santonian. Approximate locations of the represented composite-sections and horizontal scale can be observed in Fig. 1D-F.

Figure 3 Sea-level cycles and characteristics of their main cephalopods, with lateral and ventral or dorsal views of some representative taxa and remarks on their characteristics. TST: Transgressive Systems Tracts, mfs: Maximum Flooding Surfaces, EHST: Early Highstand Systems Tracts, LHST: Late Highstand Systems Tracts. Morphogroups *sensu* Batt, 1989; Westermann, 1996. All the figured specimens are held in the Departamento de Paleontología of the Universidad Complutense de Madrid, and taxonomical discussions on most of them were given by Barroso-Barcenilla (2006) and García-Hidalgo *et al*. (2012).