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Taphonomic analysis and sequence stratigraphy of the *Albarracinites* beds (lower Bajocian, Iberian range, Spain). An example of shallow condensed section

SIXTO RAFAEL FERNÁNDEZ-LÓPEZ¹

Key words. – Taphonomy, Stratigraphic condensation, Palaeobiogeography, Sub-Mediterranean province, Jurassic.

Abstract. – Several ammonite fossil assemblages from Sierra de Albarracín (Teruel, Castilian Branch) contain abundant specimens of the *Ovale* and *Laeviuscula* zones (lower Bajocian, Middle Jurassic), including microconchs and macroconchs of the characteristic genus *Albarracinites*. Over 1500 ammonites from the type horizon of the species *A. albarraciniensis*, in the outcrop of Masada Toyuela, have been studied.

Ammonites are commonly preserved as phosphatized, calcareous, concretionary internal moulds (mean size = 50.5 mm) of unflattened shells, partially or completely filled with relatively heterogeneous mudstone to wackestone sediment. Incomplete, fragmented phragmocones with calcitic septa are the dominant remains, generally bearing traces of rounding, incrustation and bioerosion. Taphonomic data, such as the predominant taphonomic populations of type 3, composed of reelaborated, relatively heterogeneous concretionary internal moulds, isolated concretionary body chambers and hollow ammonites, bearing traces of abrasion, bioerosion and encrusting organisms, are indicative of low rate of sedimentation and occasional high rate of sediment accumulation, due to sedimentary winnowing and bypassing interrupted by storm depositional events, in shallow-water marine environments. The exceptional occurrence of taphonic populations of type 2 belonging to *Albarracinites* and *Hebetoxyites*, with dominant shells of pre-adults and absence of juveniles, suggests autochthonous biogenic production of shells by indigenous populations of Sub-Mediterranean taxa at the Iberian platform system.

In the outcrop of Masada Toyuela, the *Albarracinites* beds correspond to a condensed section, developed in shallow-water, open-marine, carbonate environments of the External Castilian platform. The sharp, irregular base of beds and the normal grading of reworked elements suggest these carbonate deposits were affected by tractive currents, scouring and redeposition. Limestone beds represent storm-related sedimentary events, whereas the local marly intervals represent background-sedimentation time-intervals of winnowing and bypassing on the seafloor. This condensed section is composed of at least four, decimetric or centimetric, expanded-deposit intervals, stacked and showing an overall thinning upward, which constitute a deepening sequence developed during two biochrons. Taphonomic results also corroborate the development of an incipient-deepening phase, which represents the first episode of a deepening half-cycle of third order, in the Albarracín area within the Castilian platform, during the *Ovale* and *Laeviuscula* biochrons (early Bajocian).

Analyse taphonomique et stratigraphie séquentielle des couches à *Albarracinites* (Bajocien inférieur, Chaîne ibérique, Espagne). Un exemple de section condensée d'eaux peu profondes

Mots clés. – Taphonomie, Condensation stratigraphique, Paléobiogéographie, Province subméditerranéenne, Jurassique.

Résumé. – Plusieurs associations d'ammonites de la Sierra de Albarracín (Teruel, Chaîne ibérique castillane) montrent des spécimens remarquablement conservés et abondants, des zones à *Ovale* et à *Laeviuscula* (Bajocien inférieur, Jurassique moyen), y compris des microconques et macroconques du genre *Albarracinites*. Plus de 1500 ammonites de l'horizon type de l'espèce *A. albarraciniensis*, dans la coupe de Masada Toyuela, ont été étudiées.

Les ammonites sont généralement conservées comme moules internes concrétionnels, phosphatés (taille moyenne = 50,5 mm), de coquilles non aplaties, partiellement ou entièrement remplis de sédiments calcaires (mudstones – wackestones) relativement hétérogènes. Les fragments de phragmocônes, avec cloisons calcitiques, sont les restes dominants, généralement avec facettes de troncature ou d'arrondissement par abrasion et traces de bioérosion. Les données taphonomiques, tels que la prédominance des populations taphoniques de type 3, composées de moules internes, phosphatés et réélaborés, de coquilles partiellement ou entièrement remplies de sédiment calcaire relativement hétérogène, et portant des traces d'abrasion, de bioérosion et d'encroûtement, indiquent de faible taux de sédimentation et occasionnellement des taux élevés d'accumulation des sédiments dans des environnements marins relativement peu profonds. La présence exceptionnelle des populations taphoniques de type 2, appartenant à *Albarracinites* et *Hebetoxyites*, avec une prédominance de pré-adultes et l'absence d'individus jeunes, suggère une production biogénique de coquilles par des populations autochtones au système de la plate-forme ibérique, et appartenant à des taxons subméditerranéens.

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Les couches à *Albarracinites* dans la coupe de Masada Toyuela correspondent à une section condensée, développée dans un milieu marin de plate-forme externe carbonatée, ouvert et peu profond, à faune pélagique et à salinité normale. Les surfaces d'érosion en base de banc et le classement normal des éléments réélaborés suggèrent que ces dépôts carbonatés ont été affectés par l'action de courants de traction, avant redépôt. Les bancs calcaires, bien individualisés lithologiquement entre deux discontinuités stratigraphiques, représentent des dépôts de tempête, alors que les intervalles marneux locaux correspondent à des dépôts mixtes de décantation et de remaniement sur le fond marin, affectés par l'action répétée de la houle. Cette section condensée est constituée d'au moins quatre dépôts de tempête, décimétriques ou centimétriques, témoignant d'un environnement sédimentaire à énergie hydraulique décroissante, et constituent une séquence d'approfondissement engendrée au cours de deux biochrons. Les résultats taphonomiques confirment également le développement d'une phase d'approfondissement, qui représente le premier épisode dans un demi-cycle d'approfondissement de troisième ordre sur le système de plate-forme Ibérique, au cours des biochrons à Ovale et à *Laeviuscula* du Bajocien inférieur.

INTRODUCTION

Ammonites of the Ovale and *Laeviuscula* zones (lower Bajocian, Middle Jurassic) are scarce in the Iberian range mainly due to gaps in the geological record. Nevertheless, several ammonite fossil assemblages from Sierra de Albarracín (Teruel, Castilian Branch) show abundant specimens of these zones, including microconchs and macroconchs of the characteristic genus *Albarracinites* (fig. 1). The beds containing specimens of this distinct stephanoceratid can be called *Albarracinites* beds. The outcrop of Masada Toyuela, located on the west side of the Monterde rambla, around 600 m south from Masia de Toyuela and 6 km to the north of Albarracín (fig. 2), is the type locality of *Albarracinites albarraciniensis* FERNÁNDEZ-LÓPEZ (1985), the type species of this genus. The outcrop is located in the 1: 50.000 topographic sheet of Cella (566, 26-22) [Hernández *et al.*, 1983], coordinates: 40°27'41''N, 1°25'58''W, altitude 1200 m. Over 1500 ammonite specimens from four successive beds, through 1 m in thickness, of the Ovale and *Laeviuscula* zones have been collected and studied in the Masada Toyuela area during the last 35 years.

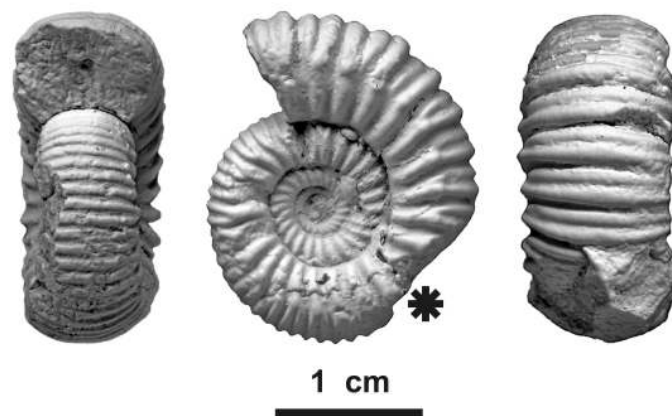


FIG. 1. – *Albarracinites albarraciniensis* FERNÁNDEZ-LÓPEZ. Holotype. Ovale zone, lower Bajocian. Masada Toyuela (Albarracín, Teruel). Coll. SRFL, specimen MT2a/69. The asterisk indicates the beginning of the body chamber. Specimen whitened with magnesium oxide prior to photography. Incomplete microconch with body chamber and phragmocone.

FIG. 1. – *Albarracinites albarraciniensis* FERNÁNDEZ-LÓPEZ. Holotype. Zone à Ovale, Bajocien inférieur. Masada Toyuela (Albarracín, Teruel). Coll. SRFL, spécimen MT2a/69. L'astérisque indique le début de la loge d'habitation. Le spécimen a été blanchi à la fumée de magnésium. Microconque incomplète avec chambre d'habitation et phragmocône.

Less than 100 of these ammonoids are derived from collections previously studied for biostratigraphic and chronostratigraphic purposes since 1975 [Fernández-López, 1985]. Most specimens and new observations correspond to recent field samplings of this section during 2008 and 2009.

The main purpose of the present work is to interpret from a taphonomic point of view the successive ammonite fossil assemblages at the Ovale and *Laeviuscula* zones in the Masada Toyuela outcrop, one of the best sections of the *Albarracinites* beds, in order to test and improve the available data for ammonite palaeobiogeography, biostratigraphic continuity, palaeoenvironmental setting and sequence stratigraphy of this Bajocian time-interval.

GEOLOGICAL SETTING

The *Albarracinites* beds correspond to the lower part of El Pedregal Formation (Chelva Group) [Gómez and Fernández-López, 2004, 2006]. This lithostratigraphic unit of the External Castilian and Aragonese platforms consists of lime mudstones and wackestones with bioclasts, mainly bivalves (microfilaments), echinoderms and pellets. *Zoophycos* and *Thalassinoides* are common. Chert nodules are locally common. Deposits are generally organized into shallowing-upward sequences, coarsening- and thickening-upwards, showing in the uppermost terms hardgrounds with biogenic borings, ferruginous crusts, phosphatic nodules, glauconitic and bioclastic carbonates, as well as reworked fossils. Interbedded horizons of limestones with ferruginous and/or phosphatic ooids are common at the base of this formation. The base of El Pedregal Formation corresponds to the uppermost Murchisonae Zone, although Aalenian and lower Bajocian deposits are usually included in condensed, basal intervals, whereas the top of the formation corresponds to the upper Bajocian Niortense and Garantiana zones.

The Middle Jurassic Iberian carbonate platform system was affected by tensional tectonics and differentially subsiding blocks [Fernández-López and Gómez, 1990a]. Aalenian and lowermost Bajocian deposits are represented by condensed sections on most Iberian platforms. In the NW External Castilian platform, peritidal dolomitic limestones and mudstones, showing microbial laminae and mud-cracks [Fernández-López, 1997a, b], as well as oolitic grainstones, are interbedded in the lower part of the sections. On the Central External Castilian platform or Albarracín sector, however, this unit varies between 60 and 80 m with upper Aalenian and lower Bajocian deposits represented by expanded sections developed on a downthrown

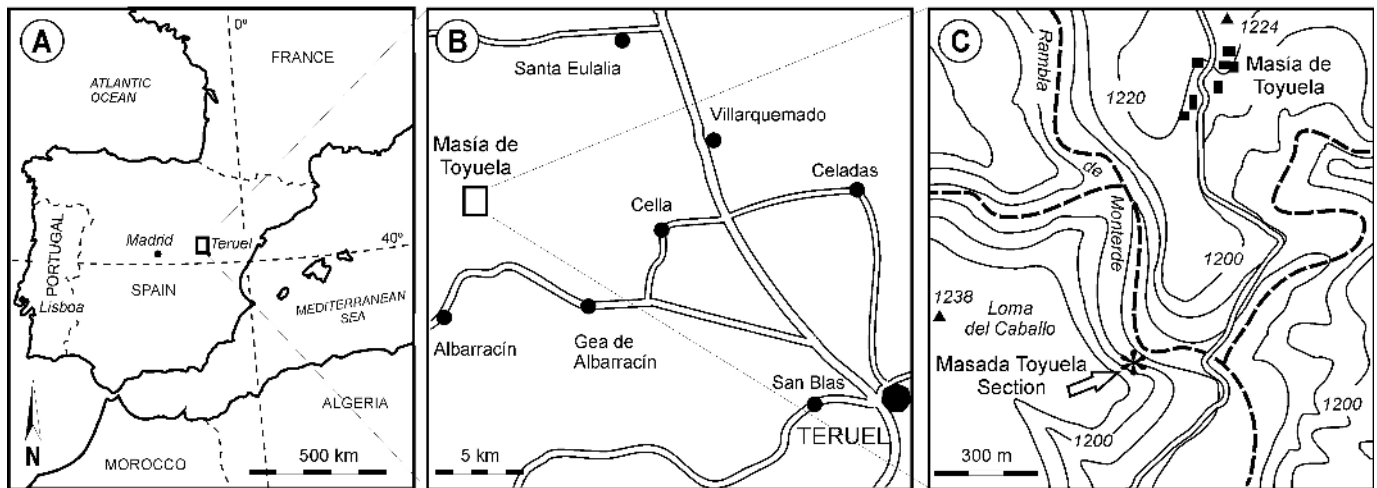


FIG. 2. – Geographic location of the section of Masada Toyuela (Albarracín, Teruel, Spain).
 FIG. 2. – Situation géographique de la coupe de Masada Toyuela (Albarracín, Teruel, Espagne).

block, where remains of ammonites, belemnites and benthic organisms, such as bivalves, brachiopods, echinoderms, serpulids, gastropods, bryozoans, sponges and calcareous algae are abundant. Microbial laminae, mud-cracks and karstification surfaces indicate local, occasional emersions [Fernández-López, 1985, 1997a, b; Fernández-López and Gómez, 1990b, 2004]. Therefore, the basal terms of El Pedregal Formation were developed on an outer platform system, dominated by low-energy, open-marine, normal salinity, very shallow to shallow-water environments, occasionally affected by storms. In the Iberian, carbonate, platform system, a Middle Jurassic second-order cycle is recorded as a transgressive-regressive, long-term mega-sequence, the deepening half-cycle spanning through the Aalenian and Bajocian stages. Third-order depositional sequences within this half-cycle are mainly composed of highstand systems tracts. Small-scale, metric, carbonate shallowing-upward sequences, showing coarsening- and thickening-upward patterns characterize these highstands [Fernández-López, 1997b, 2004; Fernández-López and Gómez, 2004]. This study, however, focuses on certain local lower Bajocian, *Ovale* and *Laeviuscula* deposits which are neither organized into a shallowing-upward sequence nor exhibiting a coarsening- and thickening-upward trend.

The *Albarracinites* beds, generally 0.1 to 2.5 m thick, from the *Ovale* and *Laeviuscula* zones in Albarracín sector, represent a lithologically distinct interval, with concave-up basal surface, intercalated between lime mudstones (fig. 3). The lowest limestone beds either wedge out or increase laterally in thickness over a few hundred of meters, whereas the highest beds display higher lateral continuity. These beds are made up of yellow-brown, wackestone to packstone limestones (containing microfilaments, echinoderms, foraminifera, ostracods and pellets) ranging in thickness from 10 to 40 cm and interbedded with discontinuous to lenticular bioclastic marls. Limestones may correspond to simple or complex beds, comprising several amalgamated intervals, and show sharp boundaries. Textures and structures of bioturbation are common (*Zoophycos*, *Chondrites* and *Thalassinoides*, in particular) indicating

softgrounds to firmgrounds. Macrofossils comprise ammonites, bivalves, crinoid ossicles, irregular echinoids, belemnite guards, gastropods, terebratulid and rhynchonellid brachiopods, nautiloids, irregular echinoids, bryozoans, serpulids, sponges and solitary corals. Several isolated fragmentary bones, of decimetric or centimetric size, have been found in the lowest beds, whereas very few carbonized plant macro-remains occur in the highest beds. Therefore, the *Albarracinites* beds exhibit a small-scale fining-upward and bedding thinning-upward pattern. Besides Masada Toyuela outcrop, the *Albarracinites* beds have also been identified in the following sections of the Iberian range [Fernández-López, 1985; Fernández-López *et al.*, 1985; Fernández-López and Aurell, 1988; Fernández-López and Gómez, 1990a, b; Gómez and Fernández-López, 1994; Meléndez *et al.*, 2002]: Barranco La Canaleja (C10-C12), Moscardón (1M10-1M12), Rambla La Gotera (G10-G12), Barranco La Hontanilla (4BH27-4BH33), Gea de Albarracín (G21), Albarracín (19AL25-19AL35), Alustante (1AT5 – 1AT17), Aguatón (AG45), Obón (ON16) and Ricla (RI19-RI24).

MECHANISMS OF TAPHONOMIC ALTERATION AND RESULTS ON AMMONITES

Taphonomic analysis of the ammonite fossil assemblages from the *Albarracinites* beds in Masada Toyuela outcrop includes more than 60 preservational features mainly related to biostratigraphic and syndimentary modifications, according to the model of Fernández-López [1997a, b, 2000, 2004, 2008]. The taphonomic analysis is described in terms of preservation state of fossil specimens, taphonic populations and fossil assemblages, specifically the degree and nature of mechanisms of alteration such as: biodegradation-decomposition, incrustation, sedimentary infilling, mineralization, abrasion, bioerosion, dissolution, taphonomic distortion, necrokinesis and fossildiagenetic displacement (reorientation, disarticulation, dispersal, regrouping and remobilization, fig. 4).

Ammonite remains are dominated by shells, whereas aptychi are very scarce and less than 1%. Ammonite shells are commonly preserved as internal moulds that rarely exceed 300 mm in diameter (less than 1%, mean size = 50.5 mm; fig. 5). Fragmentary body chambers and incomplete phragmocones are abundant, whereas complete peristomed shells are scarce and commonest among the smallest ammonites. Reworked elements (i.e. resedimented or reelaborated elements sensu Fernández-López [1995, 2007]) are dominant. Non-reworked or accumulated elements (showing no evidence of reworking after laying on the seafloor, such as the presence of shell fractures or

sedimentary infill in the body chamber) are absent. Reelaborated internal moulds (i.e. exhumed and displaced

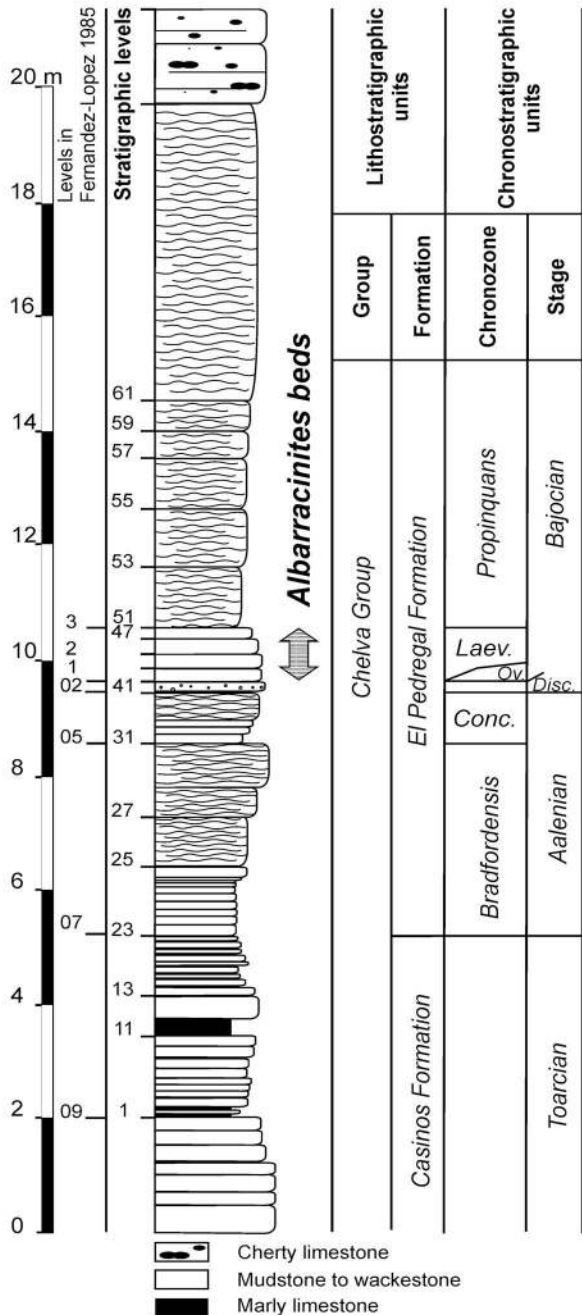


FIG. 3. – Stratigraphic log of the upper Toarcian – lower Bajocian transition in the section of Masada Toyuela, with the position of the *Albarracinites* beds.

FIG. 3. – Colonne stratigraphique du passage Toarcien supérieur – Bajocien inférieur de la coupe de Masada Toyuela, avec la position des couches à *Albarracinites*.

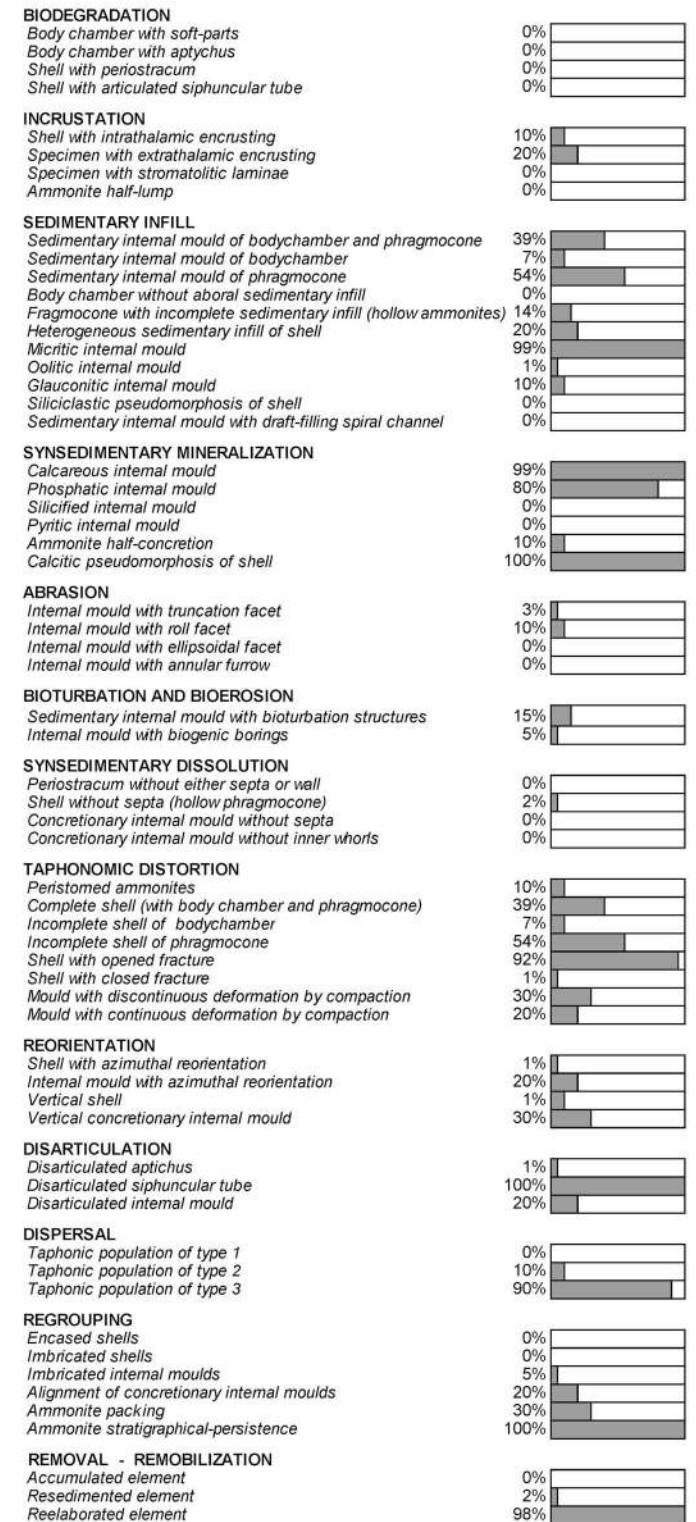


FIG. 4. – Taphonomic features of the ammonites of the *Albarracinites* beds in Masada Toyuela section.

FIG. 4. – Caractéristiques taphonomiques des ammonites des couches à *Albarracinites* sur la coupe de Masada Toyuela.

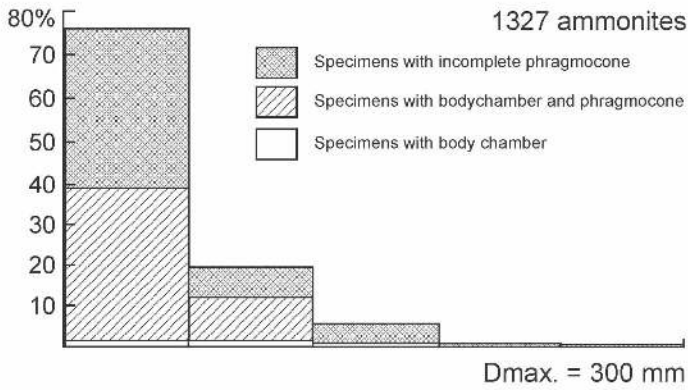


FIG. 5. – Size-frequency distribution of the ammonites of the *Albarracinites* beds in the section of Masada Toyuela, to show the proportion of body chambers, complete shells and incomplete phragmocones.
 FIG. 5. – Histogramme de variabilité de taille entre les ammonites des couches à *Albarracinites* de la coupe de Masada Toyuela, montrant la proportion des chambres d'habitation, coquilles complètes and phragmocônes incomplets.

before their final burial) are dominant (up to 98%), showing distinctive white or reddish colour, structural discontinuity with the sedimentary matrix, and original shape lacking extensive deformation by compaction (figs. 6-8). In contrast, resedimented shells (i.e. displaced on the seafloor before their burial) can be locally common in the highest beds,

displaying textural and structural continuity between the sedimentary infill and the matrix, and showing compression by diagenetic compaction. Note that the terms reelected, reworked and remanié or derived are not synonyms in a taphonomic context. The French word “remanié” meaning “reworked” or “rehandled”, applied in geology to fragments or entities derived from older materials, in particular to fossils removed from or washed out of an older bed and redeposited in a new one, is a stratigraphic term [cf. Jackson, 1997]. Reworked or derived fossils, meaning fossils from rocks of one age that have been eroded, transported, and redeposited in sediments of a younger age, also is a stratigraphic term [cf. Jackson, 1997]. In contrast, the taphonomic terms remobilized or reworked, as antonymous of accumulated and meaning resedimented or reelected, allows recognizing the relationships between the fossils and their sedimentary matrix even in the case of fossiliferous lithoclasts. From a stratigraphic point of view every fossil included in a lithoclast is a reworked or derived fossil, whereas from a taphonomic point of view it can be identified as an accumulated, resedimented or reelected fossil in relation to the sedimentary matrix or the enclosing rock [Fernández-López, 1991, 1995, 2007].

Biostratinomic processes of biodegradation-decomposition in oxic conditions were intense and ammonite shells usually lost the soft parts, aptychus and periostracum before burial. Aptychi have hardly ever been found within the

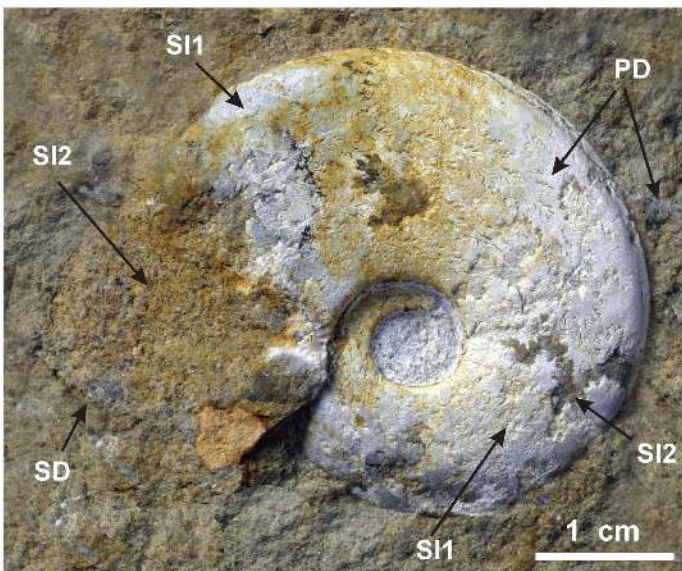


FIG. 6. – *Witchellia* sp., macroconch. Laeviuscula Zone, lower Bajocian. Masada Toyuela (Albarracín, Teruel). Coll. SRFL, specimen MT2/1089. Reelaborated internal mould (i. e., mould exhumed and moved before the final burial) of an incomplete phragmocone showing: (SI1, SI2) several phases of sedimentary infill and cementation; (PD) petrographic difference between the sedimentary infill and the enclosing sedimentary rock; and (SD) structural discontinuity between the sedimentary infill and the sedimentary matrix.
 FIG. 6. – *Witchellia* sp., macroconque. Zone à *Laeviuscula*, Bajocien inférieur. Masada Toyuela (Albarracín, Teruel). Coll. SRFL, spécimen MT2/1089. Moule interne, réélecté (c'est-à-dire, moule exhumé et déplacé avant de l'enfouissement définitif), d'un phragmocône incomplet montrant : (SI1, SI2) plusieurs phases de remplissage sédimentaire et cimentation, (PD) différence pétrographique entre le remplissage sédimentaire et la roche, et (SD) discontinuité structurale entre le remplissage sédimentaire et la matrice sédimentaire.

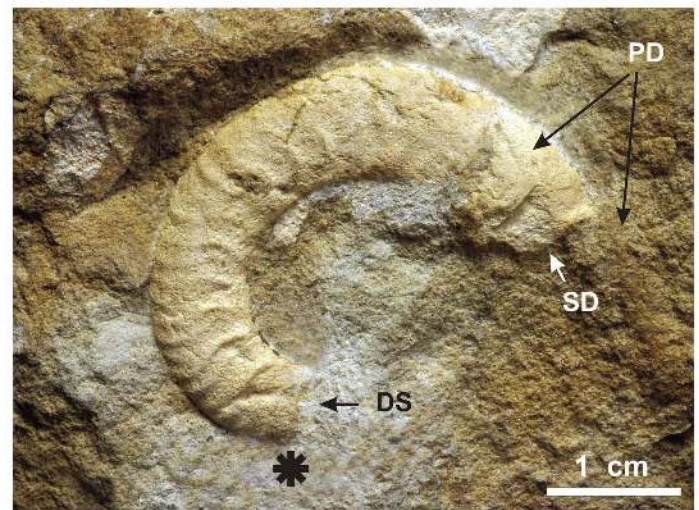


FIG. 7. – “*Fontannesia*” sp., microconch. Laeviuscula Zone, lower Bajocian, Masada Toyuela (Albarracín, Teruel). Coll. SRFL, specimen MT2/700. The asterisk indicates the beginning of the body chamber. Reelaborated, concretionary internal mould of an isolated body chamber showing: (PD) petrographic difference between the phosphatic sedimentary infill and the enclosing sedimentary rock, (SD) structural discontinuity between the sedimentary infill and the sedimentary matrix, and (DS) disarticulation surface developed along the boundary between sedimentary infills of body chamber and phragmocone, after dissolution of the last septum and the wall, and before the final burial.
 FIG. 7. – “*Fontannesia*” sp., microconque. Zone à *Laeviuscula*, Bajocien inférieur, Masada Toyuela (Albarracín, Teruel). Coll. SRFL, spécimen MT2/700. L'astérisque indique le début de la loge d'habitation. Moule interne concrétionnel, réélecté, de la chambre d'habitation montrant : (PD) différence pétrographique entre le remplissage sédimentaire et la roche, (SD) discontinuité structurale avec la matrice sédimentaire, et (DS) surface de désarticulation entre la chambre d'habitation et le phragmocône, développée à la limite des remplissages sédimentaires des chambres voisines, après la dissolution de la dernière cloison du phragmocône et de la muraille, et avant l'enfouissement final.

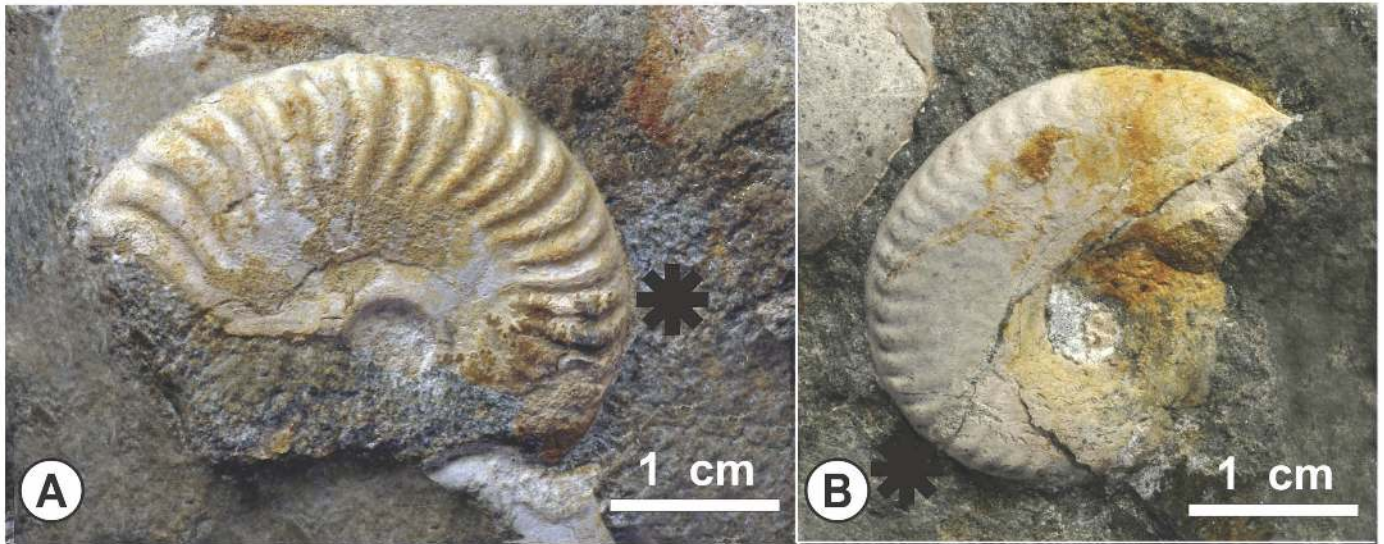


FIG. 8. – Reelaborated internal moulds of *Hebetoxyites* sp. Laeviuscula Zone, lower Bajocian. Masada Toyuela (Albarracín, Teruel). Coll. SRFL. The asterisk indicates the beginning of the body chamber. A) macroconch, MT2/301, incomplete shell with body chamber and phragmocone. B) microconch, MT2d/306, complete shell with body chamber and phragmocone.

FIG. 8. – Moules internes concrétionnelles, réélaborés, de *Hebetoxyites* sp. Zone à *Laeviuscula*, Bajocien inférieur. Masada Toyuela (Albarracín, Teruel). Coll. SRFL. L'astérisque indique le début de la loge d'habitation. A) macroconque, MT2/301, coquille incomplète avec chambre d'habitation et phragmocone. B) microconque, MT2d/306, coquille complète avec chambre d'habitation et phragmocone.

ammonite shells. Also siphuncular tubes are generally disarticulated.

Shells bearing signs of intrathalamic and/or extrathalamic encrusting organisms (such as serpulids, bryozoans, oysters or crinoids) [Tintant, 1984] are common. Biogenic borings and remains of epilithic organisms commonly occur on the largest-size, reelaborated, concretionary internal moulds. However, dense encrusting, pisolitic or oncolitic ammonoids, ammonite half-lumps [Fernández-López *et al.*, 2002] or microbial stromatolitic laminae [Olóriz *et al.*, 2004] have not been observed.

Internal moulds of shells completely filled with relatively heterogeneous sediments are common, indicating low rate of sedimentation. However, shells with incomplete sedimentary infill (hollow ammonites) are common among the smallest ammonites (14%) and isolated concretionary internal moulds of body chambers are relatively common (surpassing 7%), indicating low rate of sedimentation and occasional high rate of sediment accumulation. Internal moulds showing asymmetrically preserved flanks, varying in clay content, are commonest in the highest beds. Internal moulds with a local infill channel on the ventral region [Seilacher, 1971; Fernández-López, 2008] are very scarce. Body chambers without aboral sedimentary infill or siliciclastic pseudomorphosis of shells are absent. This abundance of relatively heterogeneous concretionary internal moulds, associated with isolated concretionary body chambers and hollow ammonites, are indicative of low rate of sedimentation and occasional high rate of sediment accumulation during biostratinomic processes [Fernández-López *et al.*, 2002; Fernández-López, 2008].

Processes of syndimentary mineralization were intense and indicative of low rate of sedimentation. Ammonites are generally preserved as calcareous and phosphatized, concretionary, internal moulds of shells

(80-90%). Glauconitic internal moulds are locally common (10%). Calcareous half-concretions and asymmetrically compressed concretions of ammonite shells occur (10%). Pyritic or silicified concretionary internal moulds are absent.

Traces of abrasion on shells and internal moulds are abundant in the lowest levels. Truncation facets on a flank occur preferentially among the largest-size ammonites, whereas abrasion roll facets preferentially developed on the most prominent portions of concretionary internal moulds are relatively common among the smallest specimens. The occurrence of worn surfaces of this type is due to the higher mechanical stability and the higher probability of abrasion of the largest specimens during the processes of syndimentary exhumation by sedimentary winnowing. Internal moulds with abrasion ellipsoidal facets or annular furrows are virtually absent [Fernández-López and Meléndez, 1995].

Concretionary internal moulds of phragmocones with calcitic septa are the dominant fossils. Hollow phragmocones [i.e. shells without septa; sensu Seilacher *et al.*, 1976; Maeda and Seilacher, 1996] are scarce (2%), usually compressed by sedimentary loading during early diagenesis, and preferentially located in the highest stratigraphic levels. Aragonitic walls of the shells were dissolved during later diagenetic processes than septa. Septa of hollow phragmocones may have disappeared by early dissolution, while the walls of the shells still persisted, giving rise to compressed elements showing discontinuous deformation of the wall by gravitational compaction [Hagdorn and Mundlos, 1983; Fernández-López, 1997a]. Concretionary internal moulds without septa [Fernández-López, 2000], indicative of syndimentary dissolution of septa, are absent. No signs of biostratinomic or syndimentary dissolution of the aragonitic remains have been recognized. Aragonitic shells were dissolved during later diagenetic processes.

Moldic porosity resulting from dissolution processes of shells and septa, and millimetric cracks of the sedimentary matrix due to lithostatic decompression, were partially filled by recent spar cement.

Ammonoid assemblages show a high proportion of incomplete phragmocones (up to 66%) and scarce complete shells with peristome (10%; fig. 4). Fragmented specimens of resedimented shells are present (2%), but generally bearing no signs of rounding, incrustation or bioerosion, due to low turbulence near the water/sediment interface. Reelaborated internal moulds are abundant (up to 98%), often showing reverse geopetal sedimentary infill and disarticulation surfaces with sharp margins along dissolved septa. Ammonoid shells occur in both limestone and marly intervals, but unflattened concretionary internal moulds are dominant in limestone beds, whereas crushed shells occur in marly intervals. Discontinuous (30%) or continuous (20%), compressed, concretionary internal moulds, resulting from diagenetic compaction, occur preferentially in the highest levels. Discontinuous deformations, with sign of breaking of the shell and compression by diagenetic compaction, or continuous deformations on the flanks of internal moulds commonly are asymmetrically arranged, as the degree of deformation is proportional to the clay content of sedimentary infill.

Stratigraphic data on high abundance and concentration of ammonoids are also relevant for taphonomic analysis [Tomasovych and Schlögl, 2008]. Packing density and stratigraphic persistence of ammonites display very high and maximum values (30% and 100%, respectively). Ammonites commonly appear scattered in the deposits, but locally show patterns of imbricated (arranged so as to overlap each other) or encased (enclosed within another one) re-grouping and normal grading. Concretionary internal moulds can show vertical attitude, especially in lower terms of the beds, but they are horizontally reoriented and form alignments in the marly intervals.

Taphonic populations of type 3 are dominant, whereas types 2 or 1 are very scarce and virtually absent,

respectively [Fernández-López and Mouterde, 1994, 1997; Fernández-López, 1995; Fernández-López and Meléndez, 1996; D'Arpa and Meléndez, 2004; Meléndez *et al.*, 2009]. Taphonic populations of type 3 show uni- or polymodal and asymmetric distribution of size frequencies, with negative skew and predominant adult shells, juvenile shells being virtually absent. Taphonic populations of type 1, dominated by juvenile shells and indicative of eudemic taxa and autochthonous biogenic production, have not been recognized [Fernández-López and Gómez, 2004; Fernández-López and Meléndez, 2004; Reboulet *et al.*, 2003, 2005]. However, adult microconchs are quite common in some taxonomic groups (*Maceratites*, *Pelekodites* and *Otoites*). Most of these lower Bajocian ammonite shells represent ademic organisms and are interpreted as allochthonous elements arrived at their present location by necroplanktic drift from northern, more open marine or oceanic areas. In contrast, *Albarracinites* (fig. 9) and *Hebetoxyites* (fig. 10) are represented by taphonic populations of type-2 (i.e. composed of mono- or polyspecific shells, showing unimodal and normal distribution of size-frequencies with dominant pre-adults and absence of juveniles; microconchs represent a low proportion). The occurrence of taphonic populations of type 2, showing no trace of sorting by necroplanktic drift or transport, is indicative of autochthonous biogenic production of shells.

The degree of remobilization, reworking or removal (i.e. the ratio of reelaborated or resedimented elements to total recorded elements) reaches 100% in the four successive beds. The degree of taphonomic heritage (i.e. the ratio of reelaborated elements to total recorded elements) [Fernández-López and Meléndez, 1995; Fernández-López and Mouterde, 1997] decreases upwards, reaching a value below 50% in the highest stratigraphic interval. The degree of taphonomic condensation (i.e. mixing of fossils of different chronostratigraphic units) reaches the highest values in the lowest beds. Ammonoid mixed-assemblages composed of specimens representing several biohorizons in a single bed have been identified in the lowest levels.

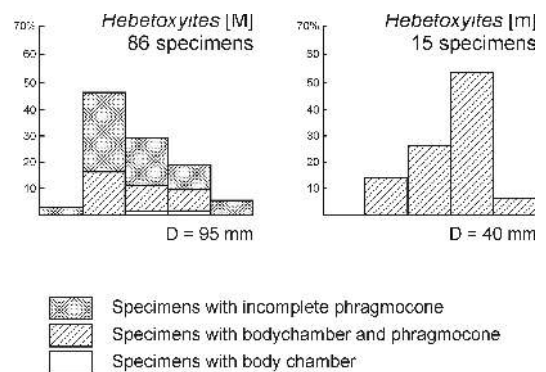
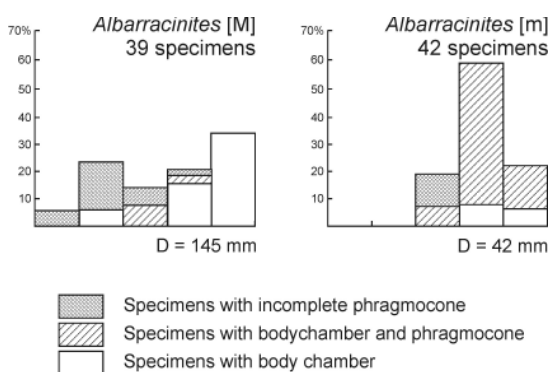


FIG. 9. – Size-frequency distributions of macroconchs and microconchs of *Albarracinites*, in the section of Masada Toyuela, indicating the proportion of body chambers, complete shells and incomplete phragmocones.

FIG. 9. – Comparaison de la variabilité de taille par histogramme entre les formes macroconques et les microconques de *Albarracinites*, de la coupe de Masada Toyuela, avec la proportion des chambres d'habitation, coquilles complètes and phragmocônes incomplets.

FIG. 10. – Size-frequency distributions of macroconchs and microconchs of *Hebetoxyites*, in Masada Toyuela section, indicating the proportion of body chambers, complete shells and incomplete phragmocones.

FIG. 10. – Comparaison de la variabilité de taille par histogramme entre les formes macroconques et les microconques de *Hebetoxyites*, de la coupe de Masada Toyuela, avec la proportion des chambres d'habitation, coquilles complètes and phragmocônes incomplets.

PALAEOENVIRONMENTAL SETTING AND SEQUENCE STRATIGRAPHY

Taphonomic analysis of ammonoid fossil assemblages and taphofacies are of stratigraphic interest since they provide an independent test of the palaeoenvironmental cycles inferred in sequence stratigraphy [Brett and Baird, 1986; Fernández-López, 1991, 1995, 1997a, b, 2000, 2004, 2008; Fürsich and Oschmann, 1993; Aurell *et al.*, 1994; Gómez and Fernández-López, 1994; Pavia, 1994; Brett, 1995, 1998; Martire and Pavia, 1996; Pavia and Martire, 1997, 2009; Monaco, 1999, 2000; Caracuel *et al.*, 2000; Monaco and Giannetti, 2001, 2002; Courville and Collin, 2002; Olóriz *et al.*, 2002, 2004, 2008; Maeda *et al.*, 2003, 2010; Wani, 2003; Bello, 2005; Meléndez *et al.*, 2005, 2007; Metodiev and Koleva-Rekalova, 2005; Reolid, 2005; Reolid *et al.*, 2005, 2010; García-Frank, 2006; Ramajo, 2006; Fürsich *et al.*, 2007; Paul *et al.*, 2008; Coimbra *et al.*, 2009; Kietzmann and Palma, 2009].

Taphonomic data from Masada Toyuela section, such as predominance of taphonic populations of type 3, composed of re-laborated, heterogeneous concretionary internal moulds, isolated concretionary body chambers and hollow ammonites, bearing traces of abrasion, bioerosion and encrusting organisms, are indicative of low rate of sedimentation and occasional high rate of sediment accumulation, due to sedimentary winnowing and bypassing in shallow-water, marine environments [incipient-deepening taphorecords in Fernández-López, 1997b, 2004]. In contrast, due to sedimentary starving in deep-water environments, condensed associations included in condensed deposits developed during transgressive trends are characterized by the occurrence of taphonic population of type 1 (dominated by juvenile shells), composed of re-laborated, non-hollow ammonites and homogeneous concretionary internal moulds, bearing no signs of abrasion, bioerosion or encrusting organisms (such as serpulids, bryozoans or oysters) [advanced-deepening taphorecords in Fernández-López, 1997b, 2004; Fernández-López *et al.*, 2002; Fernández-López and Meléndez, 2004; Fernández-López, 2007].

The four, decimetric to centimetric, elementary, limestone-marl cycles commonly differentiated in the *Albarracinites* beds are stacked tempestites, which show an overall fining and thinning upward gradient. The sharp, irregular base of beds and the normal grading of reworked elements suggest these carbonate deposits were affected by tractive currents, scouring and redeposition. Carbonate tempestites represent expanded sediments generated under brief episodes of high rate of sediment accumulation, whereas marly intervals correspond to condensed stratigraphic intervals developed under lasting episodes of low sedimentation rate. The limestone beds represent storm-related sedimentary events, whereas the local marly intervals represent background-sedimentation time-intervals of winnowing and bypassing on the sea-bottom.

The *Albarracinites* beds at the outcrop of Masada Toyuela constitute a condensed sequence, developed in a shallow, open-marine, carbonate platform (the External Castilian Platform). Time intervals of lower rate of sedimentation, associated with sedimentary winnowing and bypassing during progressive infilling towards the top of a transgressive systems tract, favoured higher degrees of biodegradation, encrusting, sedimentary infill, syngenic mineralization,

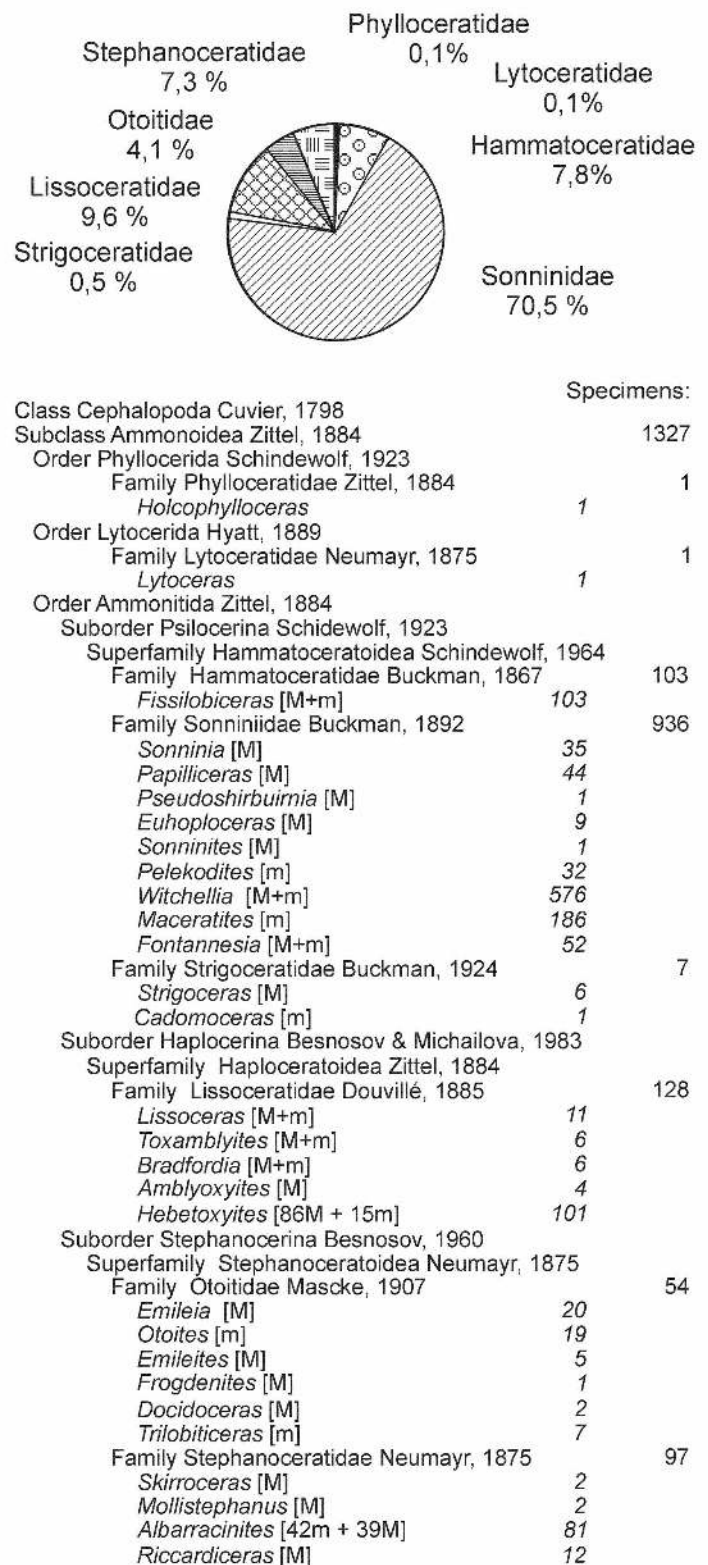


FIG. 11. – Relative abundance of different ammonite families in the *Albarracinites* beds in the section of Masada Toyuela. Orders of the subclass Ammonoidea and suborders of the order Ammonitida according to Shevyrev [2006]. The family Hammatoceratidae includes the genus *Fissiloboceras*, according to Chandler *et al.* [2006].

FIG. 11. – Diagramme circulaire de répartition des pourcentages des familles d'ammonites dans les couches à *Albarracinites* de la coupe de Masada Toyuela. Ordres et subordres d'après Shevyrev [2006]. La famille Hammatoceratidae inclut le genre *Fissiloboceras*, d'après Chandler *et al.* [2006].

reworking and regrouping of ammonoid shells, and enhanced the preservation potential of the ammonite shells. This condensed section is composed of at least four, decimetric or centimetric, expanded-deposit intervals, stacked one upon the other with an overall thinning upward pattern, which constitute a deepening sequence developed during two biochrons. Taphonomic analysis of successive ammonite fossil assemblages and taphofacies corroborate the development of an incipient-deepening phase, which characterizes the first episode within a deepening half-cycle of third and second order cycles, in the Albarracín area of Castilian platform during the Ovale and Laeviuscula biochrons (early Bajocian).

PALAEOBIOGEOGRAPHICAL IMPLICATIONS

The general pattern of the early Bajocian ammonoid assemblages on the External Castilian platform was a mixing of elements representatives of NW European and Mediterranean provinces, associated with some Sub-Mediterranean ones [Fernández-López, 1985; Fernández-López and Gómez, 1990b, 2004]. In the NW and Central sectors of the External Castilian platform, the successive ammonoid assemblages were mostly the result of regional necrokinesis from septentrional and meridional epeiric seas and oceans. Early Bajocian submarine environments were inadequate for the ontogenic development of the ammonites, although some stenotopic organisms were able to ephemerally proliferate in these sectors. Ammonite-shell supply took place preferentially from more septentrional epicontinental seas, although the proportion of mesogean elements increased during the early Bajocian.

At the outcrop of Masada Toyuela, in particular, the total number of the ammonites studied from the *Albarracinites* beds is up 1500 (fig. 11). Families Sonniniidae and Hammatoceratidae are dominant (70.5 and 7.8%, respectively), the genera *Witchellia* [M] and *Maceratites* [m] being the most common. Lissoceratidae and Stephanoceratidae are scarce (9.6 and 7.3%), but *Hebetoxyites*

[M+m] and *Albarracinites* [M+m] are well represented. Otoitidae and Strigoceratidae are very scarce (4.1 and 0.5%). Phylloceratidae and Lytoceratidae are extremely scarce (0.1%). Mediterranean palaeobiogeographic groups characteristically refer to Phyllocerida and Lytocerida, whereas some genera of Sonniniidae such as *Witchellia* [M] and *Maceratites* [m] are characteristic taxa of the NW European Province. Most of these early Bajocian ammonoids of the Castilian platform, dominated by adult individuals, were the result of regional necrokinesis and/or local immigration, without evidences of colonization. *Albarracinites* and *Hebetoxyites*, however, are represented by pre-adult shells and show no trace of sorting by necroplanktic drift or transport, which is indicative of autochthonous biogenic production of shells. Therefore, they can correspond to indigenous populations of the Iberian platform system including Sub-Mediterranean species.

CONCLUSIONS

The *Albarracinites* beds at the outcrop of Masada Toyuela may be considered as an example of condensed section, composed of expanded deposits and containing high concentrations of ammonites, developed in shallow-water, open-marine, carbonate environments of outer platform during an incipient-deepening phase, which represents the first episode of a deepening half-cycle of third order.

Ammonite taphonomy is a useful tool in sequence stratigraphy of carbonate epicontinental platforms to discern between condensed sections formed by 1) expanded deposits of shallow environments and 2) condensed deposits of deep environments.

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