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AMMONOID SUCCESSION AT THE BAJOCIAN-BATHONIAN TRANSITION IN THE BAS AURAN AREA, DIGNE DISTRICT, SOUTH-EAST FRANCE

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Abstract. The uppermost Bajocian to lowermost Bathonian ammonoid succession has been studied in the Bas Auran area in view of choosing one of its sections as the Global Stratotype Section and Point (G.S.S.P.) of the Bathonian Stage. The Bas Auran ammonite assemblages display exceptional values of record quality. The stratigraphic distribution of 629 specimens referred to 63 species and 35 genera, collected during the last forty years from three sections (Ravin du Bès, Ravin d'Auran, Ravin des Robines), is plotted and analyzed, bed by bed. Over 85 stratigraphic levels, through 9 m in thickness, have been studied at the top of the "Marno-calcaires à *Cancellophycus*" formation, ranging from the latest Bajocian (Parkinsoni Zone, Bomfordi Subzone) to the earliest Bathonian (Zigzag Zone, Convergens Subzone) and the base of the Macrescens Subzone. Ammonoid assemblages are composed of Northwest European and Mediterranean elements, associated with Sub-Mediterranean ones, allowing chronocorrelation between the Northwest European Convergens Subzone and the Sub-Mediterranean Parvum Subzone. The basal boundary of the Zigzag Zone and of the Bathonian Stage is placed at the base of Sturani's bed 23 in the Ravin du Bès section and is identified by the first occurrence of *Gonolkites convergens,* and coincides with the lowest occurrence of *Morphoceras parvum.* Features of the ammonoid succession indicate relatively homogeneous and good record quality, gradual biostratigraphic change and high degree of taxonomic similarity between the Bomfordi and Convergens subzones. Palaeontological criteria also indicate relatively high values of palaeontological and stratigraphic completeness at the base of levels RB070-RB071 (= level 23 in Sturani 1967) which corresponds to the Bajocian/Bathonian boundary. The Ravin du Bès Section, with forty-six successive ammonoid fossil-assemblages of the Convergens Subzone belonging to three biohorizons through five metres of thickness, shows maximum values of biostratigraphic and biochronostratigraphic completeness, being one of the most complete in the world. Therefore, the Ravin du Bès Section should be chosen as the Global Stratotype Section and Point for the base of the Bathonian Stage. Two biostratigraphic logs summarize the ammonite content from the uppermost Bomfordi to basal Macrescens subzones. Three plates illustrate the most characteristic ammonoid taxa at the Bajocian-Bathonian passage in the Bas Auran succession.

Riassunto. La successione ad ammoniti dell'intervallo compreso tra il Baiociano superiore (Zona a Parkinsoni) e il Batoniano inferiore (Zona a Zigzag) dell'area del Bas Auran, nel Comune di Chaudon-Norante del Dipartimento delle Alpes-de-Haute-Provence, in Francia sudorientale, viene studiata nell'ottica di selezionare una sezione stratigrafica come Global Stratotype Section and Point (G.S.S.P.) del Piano Batoniano. Nell'ambito della parte alta della formazione "Marno-calcaires à *Cancellophycus*", sono state analizzate tre sezioni lungo i Ravin du Bès (RB), Ravin d'Auran (RA) e Ravin des Robines (RR). Le associazioni ad ammoniti della successione baiociano-batoniana del Bas Auran mostrano un'eccezionale qualità e completezza del record tafonomico e biostratigrafico. Il range di 629 esemplari di ammoniti per 63 specie e 35 generi, raccolti dalle suddette sezioni durante gli ultimi quaranta anni, è stato analizzato strato a strato e rappresentato in due log biostratigrafici estesi dalla Sottozona a Bomfordi (parte alta della Zona a Parkinsoni) alla Sottozona a Convergens e base della Sottozona a Macrescens (parte inferiore e media della Zona a Zigzag). Più di 85 livelli stratigrafici ad ammoniti sono stati campionati su uno spessore di circa 9 metri; di questi, 46 intervalli fossiliferi per 5 metri di spessore si riferiscono alla Sottozona a Convergens. 120 esemplari di ammoniti provengono dalla Sottozona a Bomfordi, 398 dalla Sottozona a Convergens, 111 dai primi strati della Sottozona a Macrescens. Le associazioni fossili sono composte da biota pertinenti a due province tetisiane, la NW Europea e la Mediterranea; a questi si associano elementi submediterranei che permettono la cronocorrelazione tra la Sottozona a Convergens della Provincia NW Europea e la Sottozona a Parvum della Provincia Submediterranea. La base della Sottozona a Convergens, quindi della Zona a Zigzag e del Piano Batoniano, è contrassegnato dalla prima comparsa di *Gonolkites convergens* e coincide con la prima presenza di *Morphoceras parvum.* Le caratteristiche della successione ad ammoniti indicano un record relativamente omogeneo, cambi biostratigrafici graduali e alto

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grado di somiglianza tassonomica tra le sottozone a Bomfordi e a Convergens. Il limite tra i piani Baiociano e Batoniano è fissato alla base del livello RB070-RB071 della sezione del Ravin du Bés (livello 23 di Sturani 1967), dove si registra un alto grado di completezza paleontologica e stratigrafica. La sezione del Ravin du Bés, per la completezza biostratigrafica e biocronostratigrafica e per le ricche associazioni ad ammoniti della Sottozona a Convergens distribuite in tre bio-orizzonti, risulta essere una delle più complete al mondo. In base a queste evidenze, la successione calcareo-marnosa del passaggio Baiociano-Batoniano, affiorante lungo il Ravin du Bés, risulta ottimale come riferimento per il limite inferiore della Zona a Zigzag e se ne raccomanda la scelta come G.S.S.P. del Piano Batoniano.

I dettagli biostratigrafici, relativi alle 63 specie di ammoniti determinate, sono riassunti in due log biostratigrafici. I range specifici permettono di fissare i limiti inferiori delle sottozone a Convergens e a Macrescens, rispettivamente alla base degli strati calcarei RB071 e RB025 della sezione del Ravin du Bés, degli strati calcarei RA085 e RA033 della sezione del Ravin d'Auran e degli equivalenti RA085 e RA033 della sezione del Ravin des Robines. Nella descrizione delle unità biocronostratigrafiche vengono discussi i taxa di ammoniti più significativi. Nella Sottozona a Bomfordi si registra lo sviluppo della coppia dimorfica *Lobosphinctes-Planisphinctes* associata agli ultimi *Prorsisphinctes-Vermisphinctes*. La Sottozona a Convergens, oltre ai rappresentanti delle sottofamiglie Parkinsoniinae (e.g., *G. convergens*) e Morphoceratinae (e.g., *M. parvum*), è caratterizzata dalla diversificazione del genere *Bigotites* con tre specie dimorfiche (*B. sturanii* e *B. diniensis* per il bio-orizzonte inferiore della sottozona, *B. mondegoensis* per quello intermedio) appartenenti a una linea filetica cronoclinale che anticipa l'estinzione del genere. Il bio-orizzonte sommitale della sottozona registra infine la comparsa del genere *Protozigzagiceras*, capostipite della sottofamiglia Zigzagiceratinae in sviluppo proprio a tetto della sottozona. La base della Sottozona a Macrescens è contrassegnata dalla prima comparsa della specie-indice *Morphoceras macrescens*, dall'ultima presenza di *G. convergens*, e dalla diversificazione delle Zigzagiceratinae con i generi *Protozigzagiceras* [M+m] e *Franchia* [M+m] che precedono lo sviluppo della coppia dimorfica *Zigzagiceras* [m] – *Procerozigzag* [M] tipica della sottozona. Tre tavole figurano le ammoniti più caratteristiche del passaggio Baiociano-Batoniano della successione del Bas Auran.

Résumé. La succession d'ammonites entre le Bajocien terminal (Zone à Parkinsoni) et la base du Bathonien (Zone à Zigzag) dans le secteur du Bas Auran (Chaudon-Norante, Alpes de Haute-Provence, Sud-Est de la France) a été étudiée en vue du choix de l'une des coupes comme Global Stratotype Section and Point (G.S.S.P.) de l'étage Bathonien. Dans la partie supérieure de la formation des «Marno-calcaires à *Cancellophycus*», trois coupes ont été analysées banc par banc: Ravin du Bès (RB), Ravin d'Auran (RA) et Ravin des Robines (RR). Les associations d'ammonites, au passage Bajocien-Bathonien, montrent une exceptionnelle qualité et une continuité du registrement taphonomique et biostratigraphique. La distribution des 629 ammonites récoltées banc par banc ces quarante dernières années, réparties en 63 espèces et 35 genres, couvre la Sous-zone à Bomfordi (partie terminale de la Zone à Parkinsoni), la Sous-zone à Convergens et la base de la Sous-zone à Macrescens (parties inférieure et moyenne de la Zone à Zigzag). Plus de 85 niveaux à ammonites ont été échantillonnés sur environ 9 m d'épaisseur. Parmi ceux-ci, les niveaux des 4 m de la Sous-zone à Bomfordi ont livré 120 exemplaires, les 46 niveaux des 5 m de la Sous-zone à Convergens ont fourni 398 exemplaires, enfin 111 exemplaires proviennent des premiers niveaux de la Sous-zone à Macrescens.

Les associations fossiles appartiennent à trois provinces téthysiennes avec un mélange d'éléments nord-ouest-européens, subméditerranéens et méditerranéens. Elles permettent la corrélation chronostratigraphique de la Sous-zone à Convergens de la province nord-ouest-européenne avec la Sous-zone à Parvum de la province subméditerranéenne. La base de la Sous-zone à Convergens, donc de la Zone à Zigzag et du Bathonien est marquée par la première apparition de *Gonolkites convergens* et de *Morphoceras parvum*.

Les caractéristiques de la succession des ammonites indiquent une constance de registrement taphonomique, des changements biostratigraphiques graduels et un haut degré de ressemblance taphonomique entre les sous-zones à Bomfordi et à Convergens.

La limite Bajocien-Bathonien est fixée à la base des niveaux RB 070-RB071 (niveau 23 de Sturani 1967) de la coupe du Ravin du Bès, où l'enregistrement paléontologique et stratigraphique est très complet. La coupe du Ravin du Bès, par sa continuité biostratigraphique et chronostratigraphique, par la richesse des associations d'ammonites de la Sous-zone à Convergens, distribuées en trois biohorizons, s'avère être l'une des plus complètes du monde. En conséquence, la succession calcaréo-marneuse du Ravin du Bès au passage Bajocien-Bathonien est la plus appropriée à servir de référence pour la limite inférieure de la Zone à Zigzag et est recommandée pour le choix du G.S.S.P. de l'Étage Bathonien.

Les données biostratigraphiques relatives aux 63 espèces d'ammonites déterminées sont résumées sur deux profils biostratigraphiques. L'extension des espèces permet de fixer la limite inférieure des Sous-zones à Convergens et à Macrescens, respectivement à la base des bancs calcaires RB 071 et RB 025 de la coupe du Ravin du Bès, RA 085 et RA 033 du Ravin du Bas Auran et aux équivalents RR 085 et RR 033 du Ravin des Robines. Dans chaque unité biostratigraphique sont décrits les taxons les plus significatifs. Pendant la Sous-zone à Bomfordi, le développement du couple dimorphe *Lobosphinctes – Planisphinctes* s'effectue parallèlement à celui des derniers *Prorsisphinctes - Vermisphinctes*. Au cours de la Sous-zone à Convergens, à côté des représentants de la sous-famille Parkinsoniinae (e.g., *G. convergens*) et de la sous-famille Morphoceratinae (e.g., *M. parvum*), s'effectue l'ultime diversification du genre *Bigotites* avec trois espèces dimorphes *(B. sturanii*, *B. diniensis* pour le biohorizon inférieur et *B. mondegoensis* pour le biohorizon intermédiaire de la sous-zone). Elles appartiennent à une lignée phylétique chronoclinale qui précède l'extinction du genre. Le biohorizon sommital de la sous-zone est marqué par l'apparition du genre *Protozigzagiceras* à l'origine de la sous-famille Zigzagiceratinae. La base de la Sous-zone à Macrescens est fixée par la première apparition de l'espèce-indice *Morphoceras macrescens*, l'ultime présence de *G. convergens* et la diversification des Zigzagiceratinae avec les genres *Protozigzagiceras* [m] et *Franchia* [M] qui précèdent le développement du couple dimorphe *Zigzagiceras* [m] – *Procerozigzag* [M] typique de la sous-zone. Trois planches illustrent les ammonites les plus caractéristiques du passage Bajocien-Bathonien dans le secteur du Bas Auran.

Introduction

The French marly-calcareous formation so-called "Marno-calcaires à *Cancellophycus*", cropping out between Digne and Castellane in the Alpes-de-Haute-Provence country below the "Terres Noires" Formation (Graciansky et al. 1982, 1998; Olivero & Atrops 1996), is well known in the Middle Jurassic palaeontological and stratigraphical literature for the ammonoid assemblages of the Aalenian, Bajocian and Bathonian stages (Caloo 1970; Pavia 1973, 1983a, 1984; Sturani 1967). The highly diversified taxonomic composition and the thickness of that lithostratigraphic unit allowed to propose biostratigraphic schemes as reference for Bajocian (Pavia & Sturani 1968; Dietl & Pavia 1984) and Bathonian (Sturani 1967; Torrens 1987). In more details, the topmost Bajocian beds, representing the upper portion of the Parkinsoni Zone, and the Lower Bathonian levels of the Zigzag Zone show a so rich and continuous succession of ammonoid assemblages that it was proposed as the reference for the basal boundary stratotype of the Bathonian Stage (Innocenti et al. 1990; Fernández-López 2007b).

In the frame of the International Subcommission on Jurassic Stratigraphy (ISJS) to get proposition for definition of the Global Boundary Stratotype Section and Point (G.S.S.P.) of each stage of the Jurassic System, after the informal proposal by Innocenti et al. (1990) at the 2nd International Symposium on Jurassic Stratigraphy of 1987 and the related discussion generated in the meeting of the Bathonian Working Group (BtWG: Mangold 1990a), the researches on the Bas Auran area were resumed during the last fifteen years by G. Pavia and collaborators and by colleagues of the BtWG. The target of these field activities was to improve the palaeontological records useful to complete the biostratigraphical scheme, and to the point that the objections raised at Lisboa (cit. ref.) on the possible presence of a discontinuity just below the first Bathonian bed could be eventually cancelled as well. In the last three years, we met different times in Lyon and Torino, and on the field too. The aim of these joint meetings was to test and complete the taxonomic study of the whole ammonite collection and to prepare a general, composite biostratigraphic log of the diverse Bas Auran sections. Two articles derived from this activity have been published, on the taphonomy of the ammonoid assemblages (Fernández-López 2007a) and on the taxonomy and phylogenetic arrangement of the Bigotitinae ammonoids from Lower Bathonian (Fernández-López et al. 2007).

The purpose of the present paper is thus (1) to describe the successive ammonoid assemblages of the uppermost Bajocian to lowermost Bathonian in the Bas Auran area, (2) to refine the subzonal biostratigraphic subdivision of the marly-calcareous succession, (3) to characterize the ammonoid content at the very base of the Zigzag Zone, (4) to demonstrate the general continuity of the ammonoid succession and thus (5) to attest the suitability of one of those sections to be selected as the G.S.S.P. of the Bathonian Stage.

Geographical and geological setting

The sections showing the Bajocian-Bathonian boundary crop out on the left side of the Asse valley at the Bas Auran area (BA), in the administrative district of Chaudon-Norante and in the central sector of the Geological Reserve of Haute-Provence, around 4 km west of Barrême and 25 km southeast of Digne-les-Bains, southeastern France (Fig. 1). The best known section is on the left side of the Ravin du Bès (RB) with geographic coordinates 43°57′38″N, 6°18′55″E, at altitude of 730 m (Fig. 2). Another important section is located on the left side of the Ravin d'Auran (RA), 43°57′21″N, 6°18′56″E, 790 m of altitude, 200 m southwest of the Bas Auran farm. A third discontinuous outcrop was sampled on the Ravin des Robines (RR), nearly 500 m upstream from the last section (Fig. 3). Sturani's specimens and the recent material were collected from these three Bas Auran sections where beds are exposed over several hundred of metres. All the sections lay on the north-eastern flank of the Bas Auran anticline, that show several outcrops delimited by small vertical faults; the stratigraphic succession is free from unconformities, displays a thickness of 13 m and ranges from the Bomfordi Subzone (Upper Bajocian) to the Tenuiplicatus (Sub)Zone (Lower Bathonian).

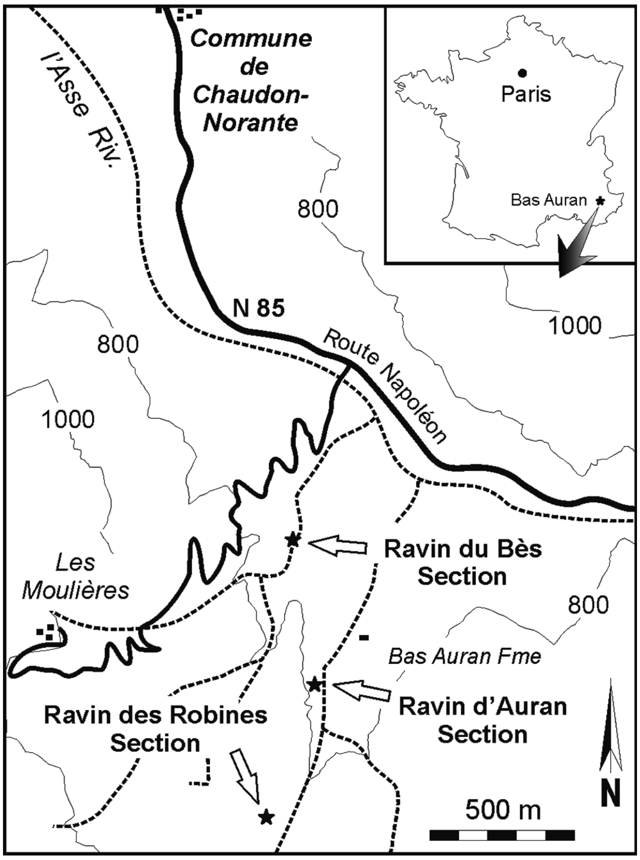


Fig. 1 - Location map of the three stratigraphic sections referring to the Bajocian/Bathonian boundary in the Bas Auran area (Alpes-de-Haute-Provence, SE France) (from Fernández-López 2007a).

The topmost part of the "Marno-calcaires à *Cancellophycus*" Formation at Bas Auran is composed of black or grey limestone beds alternating with marls (Fig. 4). Limestones are classified as calcisphere-mudstones to wackestones. The macrofossil content comprises common ammonoids, scarce sponges and rare nautiloids, brachiopods, bivalves, belemnites, echinoids, crinoids and gastropods. From a micropalaeontological point of view, the overall sedimentary facies shows a calcisphere-mudstone texture. The marls contain fora-

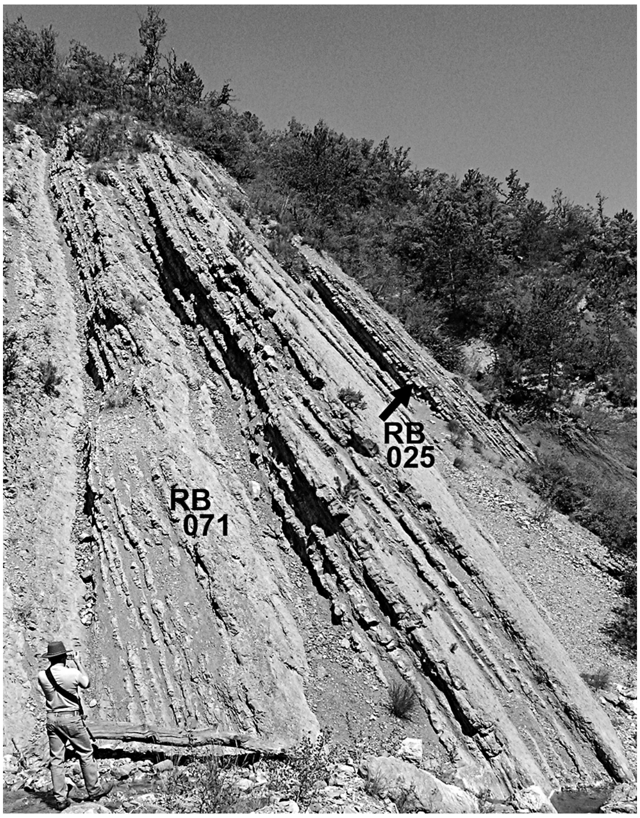


Fig. 2 - The section of the Ravin du Bès. The Bajocian-Bathonian boundary and the base of the Convergens Subzone are recognized at the base of Sturani's bed 23, i.e. base of bed RB071. The lower boundary of the Macrescens Subzone is also marked, at the base of bed RB025. Davide Olivero for scale.

minifers (*Lenticulina*, *Dentalina*), ostracods and molluscs (cephalopods, bivalves, gastropods) along with detrital minerals, quartz, muscovite and biotite (Corbin et al. 2000). The Bathonian deposits of this formation are interpreted as having been developed in a hemipelagic environment of the French Subalpine Basin, below storm wave base. The strong similarities in thickness, number and proportion of beds within subzones between the Ravin du Bès and Ravin d'Auran sections suggest that the patterns of bed distribution are of regional extent (Sturani 1967). However, the total thickness and number of elementary cycles of the Lower Bathonian in the Ravin des Robines and Ravin d'Auran sections is greater than in the Ravin du Bès Section and, consequently, accommodation space and water depth must have been greater in Ravin d'Auran area (Fernández-López 2007a).

Palaeoichnological studies have been carried out by Olivero (1994, 2003). Bioturbation textures are common, whereas bioturbation structures are scarce, indicating dominant softgrounds so that *Zoophycos*, *Chondrites* and *Planolites* occur from bed RB093 to bed RB001. A single variation was recently defined by Olivero (pers. comm.): the local concentration of these ichnotaxa in bed RB039 suggests the development of a soft- to firmground at this stratigraphic level. According to palaeoichnological interpretation, the sedimentation becomes irregular and condensed from bed RB093 in comparison with previous intervals where a more constant and expanded sedimentation may be suggested. At the Bajocian-Bathonian transition, however, no stratigraphic gaps or hiatuses have been recorded.

From a taphonomic point of view (Fernández-López 2007a) the occurrence of resedimented and reelaborated ammonoids implies that some form of current flow or winnowing affected the burial of concretionary internal moulds. The taphonomic features are indicative of low rate of sedimentation and low rate of accumulation of sediment, associated with sedimentary starving in deep environments. The marly-calcareous alternation is primary in origin. Lithologic differentiation between marls and limestones resulted from alternating episodes of carbonate input and starvation. Both lithologic terms may contain evidence for sedimentary and taphonomic reworking, that reflect low degree of stratigraphic condensation. However, the degree of taphonomic condensation in ammonoid assemblages (i.e. the mixture of fossils of different age or different chronostratigraphic units) is close to zero in the whole Upper Bajocian and Lower Bathonian.

Sedimentological data and sequence-stratigraphy interpretation of the Bas Auran succession is out of

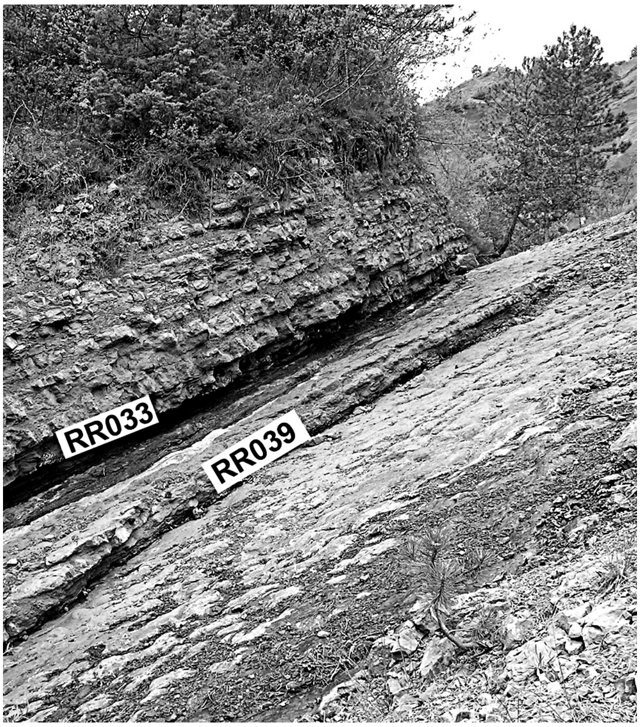


Fig. 3 - The middle part of the Ravin des Robines Section. The boundary between the Convergens and the Macrescens subzones is recognized at the base of Sturani's bed 12, i.e. base of bed RR033. RR039 refers to the middle part of the Protozigzagiceras Biohorizon.

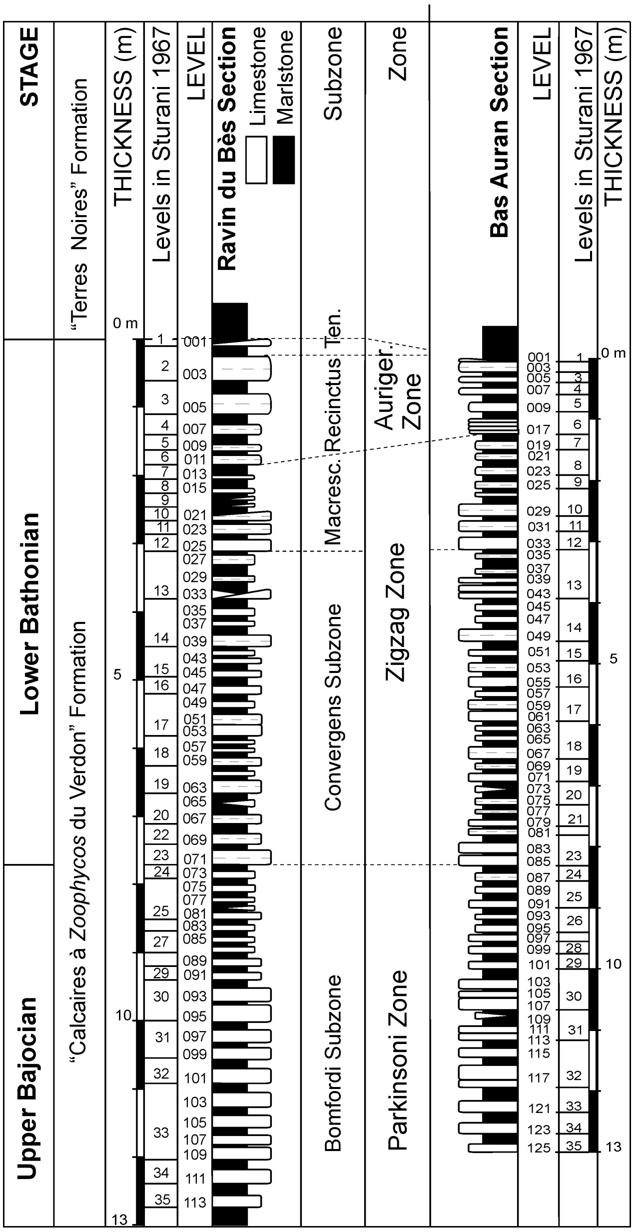


Fig. 4 - Correlation chart between the Ravin du Bès and Ravin d'Auran sections. The recent numbering is in turn correlated with the one stated by Sturani in 1967 (modified from Fernández-López 2007a).

purposes. References and comments on these topics could be found in the preliminary note by Fernández-López (2007a) and will be developed in the final proposal that would be submitted by the BtWG to ISJS by the end of 2007.

Material and methods

As to the (sub)zonal scheme followed in this paper for Early Bathonian, we refer to that reported by Mangold & Rioult (1997) who discussed the subzonal succession within the Standard Zigzag Zone, just above the Bomfordi Subzone at the topmost Bajocian (see also Fernández-López et al. 2006). They distinguished two subzones: the upper one is the Macrescens Subzone which is identified in the main three palaeobiogeographic provinces of the West Tethyan Subrealm (Northwest European, Sub-Mediterranean and Mediterranean provinces). On the contrary, the basal subzone of the Zigzag Zone is differently named according to palaeobiogeographic criteria: the Convergens Subzone (Sturani 1967, p. 12) well characterized by parkinsoniids in the Northwest European Province, and the Parvum Subzone (Mangold 1990b) mainly based on morphoceratid occurrence in the Sub-Mediterranean Province. These two basal subzones are not synonyms, though they are homotaxial units and equivalent in terms of biostratigraphic position: their lower boundaries are probably diachronous depending on the lowest occurrence of their index-species, respectively *Gonolkites convergens* and *Morphoceras parvum*. At present, nevertheless, these two taxa make first occurrence at the same level in the Bas Auran succession, and therefore the Convergens and Parvum subzones are coincident in this area. However, as discussed later, the first occurrence of *Gonolkites* (*G. convergens* and *G. subgaleatus*) in Bas Auran seems to represent an evolutive event of morphologic and taxonomic change from Bajocian parkinsoniids, whereas the first occurrence of *M. parvum* represents an immigration event from other Sub-Mediterranean areas. For these reasons, we shall adopt in this paper the original subdivision proposed by Sturani (1967) with the Convergens Subzone as the lowest unit at the base of the Zigzag Zone. Tab. 1 clarifies the biochronostratigraphic zonation and subzonation at the passage between the Bajocian and Bathonian stages in the Northwest European and Sub-Mediterranean provinces.

In a very recent paper on the subfamily Bigotitinae of the Early Bathonian from Bas Auran and Cabo Mondego (Fernández-López et al. 2007), we used the Sub-Mediterranean Parvum Subzone. Actually, in that case we were correlating the Sub-Mediterranean French ammonoid assemblages and successions with those of Cabo Mondego in Portugal, where the Convergens Subzone can not be recognized due to the scarcity of parkinsoniids. Moreover, in these areas, the Parvum Subzone assures a correlation of higher resolution by the three biohorizons distinguished, which are common to both Lower Bathonian successions.

Stratigraphical information and palaeontological records on the Middle Jurassic succession of Bas Auran were first produced by classic French authors (Garnier 1872; Haug 1891; Zurcher 1895; Guillaume 1938). Sturani, in 1967, published an innovative study that described in detail the Bajocian-Bathonian succession with a litho- and biostratigra-

	NW European Province		Sub-Mediterranean Province	
Lower Bathonian		Tenuiplicatus	Aurigerus	Tenuiplicatus
	Zigzag	Yeovilensis		Recinctus
		Macrescens	Zigzag	Macrescens
		Convergens		Parvum
Upper Bajocian	Parkinsoni	Bomfordi	Parkinsoni	Bomfordi
		Truellei		Densicosta
		Acris		Acris

Tab. 1 - Biochronostratigraphic scheme with standard subdivisions of the latest Bajocian and Early Bathonian: comparison of zones and subzones in the Northwest European (Callomon & Cope 1995) and Sub-Mediterranean (Mangold & Rioult 1997) provinces.

phical log settled from the whole outcrops of the Bas Auran area. A partial revision of Sturani's work was produced by Torrens (1987) mainly concentrated on the Tenuiplicatus (Sub)Zone at the uppermost part of the marly-calcareous succession and with description of a part of the new ammonites collected by Sturani up to his death in 1975. Contribution on the lowermost Bathonian beds was finally presented by Innocenti et al. (1990) that inserted in Sturani's log the new material derived from field work during the last ten years. More recent samplings, mainly concentrated on poorly documented and critical intervals, enlarged the Bas Auran record from the Zigzag Zone, and furnished basic material for the study on Bigotitinae (Fernández-López et al. 2007).

The ammonites from Bas Auran outcrops, prior to the samplings 2006, were collected following Sturani's statement according to which the succession is homogeneous and calcareous beds correspond through the whole area. As a consequence, he attributed and we continued to mark specimens with figures derived from a single numbering, e.g. "BA23" characterizes a specimen coming from bed 23 of Sturani's lithostratigraphic log and collected somewhere in the Bas Auran area, without possibility to recognize the exact outcrop. In June 2006, S. Fernández-López, D. Olivero and G. Pavia remeasured the stratigraphic succession in the three mentioned outcrops, i.e. the Ravin du Bès (RB), Ravin d'Auran (RA) and Ravin des Robines (RR), and produced new logs with a more detailed numbering which nevertheless results to be easily overlapped and correlated to the one stated by Sturani (Fernández-López 2007a, text-fig. 12). In details, Sturani numbered only the thickest, most characteristic and recognizable calcareous beds, whereas marls were regarded as interlayers comprising the thin, lenticular calcareous beds that cannot be traced over long distances.

Actually, Sturani's numbering starts from bed 50, but biostratigraphical information works from bed 35; the interval 35-24 refers to the uppermost portion of the Bajocian Parkinsoni Zone, whereas numbers 23 to 01 pertain to the Lower Bathonian Zigzag and Aurigerus zones. In the more recent field works (cf. Fernández-López 2007a) each marly or calcareous bed has been labelled with its own number. Two numberings have been defined, RB113 to RB001 for the Ravin du Bès Section, RA125 to RA001 for both Ravin d'Auran and Ravin des Robines sections. In particular, as to the equivalence of these different numberings (Fig. 4), the layer fixing the base of the Lower Bathonian is Sturani's bed 23 which corresponds to the base of beds RB071 and RA085 of the new format (for more details see the following discussions).

All the fossil material from the Middle Jurassic of Alpes-de-Haute-Provence country is currently stored in the Museo di Geologia e Paleontologia at the Dipartimento di Scienze della Terra of the Torino University. Three collections assemble the material studied in different works: Lower and Upper Bajocian of Digne and Chaudon outcrops (Pavia 1973, 1983a, 1983 b, 2000), Lower Bathonian of Bas Auran, Chaudon, les Blaches outcrops (Sturani 1967; Torrens 1987; Innocenti et al. 1990), Lower to Middle Bathonian of les Blaches, la Jabie, la Melle, la Palud outcrops (Innocenti 1975; Puma 1975; Pavia 1984; Innocenti et al. 1990; Romeo 1999). In the very recent times, particularly beginning from the present revisions of Bas Auran ammonites, a project of complete cataloguing of these collections started with the aim to formalize the position of fossils within the museum structure. The criteria fixed by Pavia & Pavia (2004) were adopted. Each specimen is marked by a code within a numerical sequence valid for the whole fossil material formally entered in the collections of the Museo di Geologia e Paleontologia of Torino; this code is composed of the acronym PU (Palaeontology University) combined with a progressive registration number specific of that single specimen. These codes are registered in an Access database which documents section and bed, collector name and so on, that is all the information which could characterize in space and time the specimen. For the study of the Upper Bajocian and Lower Bathonian, we registered 875 ammonites of which 629 refer to the uppermost Bajocian and lowermost Bathonian of Bas Auran (Sturani's beds 50 to 10). The remaining codes are for fossils useful for this study and coming from the upper part of the Bas Auran sections and of the Chaudon, les Blaches, la Palud localities studied by Sturani (1967), Innocenti (1975), Puma (1975), Innocenti et al. (1990), Romeo (1999).

Ammonite biostratigraphy

Biochronostratigraphic data and interpretations of the Bas Auran sections have been published by Sturani (1967), Torrens (1987), Innocenti et al. (1990), Olivero et al. (1997) and Fernández-López et al. (2007). Over 80 stratigraphic levels, through 9 m in thickness, of the Bomfordi and Convergens subzones have been studied, of which, along up to 5 metres, 46 successive fossiliferous stratigraphic intervals have been recognized in the Convergens Subzone. Five stratigraphic levels with 3 fossiliferous intervals have been studied in the Macrescens Subzone, just to complete upward the biostratigraphic analysis. Among the mentioned 629 ammonoid specimens, 120 pertain to the Bomfordi Subzone, 398 to the Convergens Subzone, 111 to the first beds of the Macrescens Subzone. Some general comments are needed.

In the French Subalpine Basin, Upper Bajocian and Lower Bathonian taxa of Phylloceratina and Lytoceratina suborders, which are characteristic elements of the Mediterranean Province, are common. They make a total of 125 specimens in the marl-limestone succession, from the Bomfordi to the base of the Macrescens subzones, with a mean value of 20% in the ammonoid assemblages. Nevertheless phylloceratids and lytoceratids are long-ranging and their biostratigraphic significance is usually very poor. For this reason, we have preferred to separate the biostratigratigraphic log showing their distribution through the whole studied succession (Fig. 5). The stratigraphic ranges of the 512 specimens of the suborder Ammonitina collected during the past forty years from the three mentioned sections (Ravin du Bès, Ravin d'Auran, Ravin des Robines) are plotted in Fig. 6, from the uppermost Bomfordi Subzone of the Parkinsoni Zone to the Zigzag Zone, namely the Convergens Subzone and the base of the Macrescens Subzone.

The lithostratigraphic log of Figs. 5 and 6 refers to the succession of the Ravin du Bès Section, but the correlation among Bas Auran sections has been already confirmed in the previous chapter, so that this litho- and biostratigraphic scheme can be easily assumed as representative of the Lower Bathonian for the whole Bas Auran area. According to that, the basal boundary of the Bathonian has been established at the base of limestone bed RB071 of the Ravin du Bès Section and at the base of the limestone beds RA085 of the Ravin d'Auran and RR085 of the Ravin des Robines sections, in both cases equivalent to the base of bed 23 of Sturani (1967), respectively 7.8 and 8.5 m below the "Terres Noires" Formation (Fernández-López 2007a, text-fig. 12).

The studied interval shows a high diversity of ammonoid taxa, which increases in the Convergens Subzone possibly due to palaeobiological and preservational factors during the Early Bathonian (cf. the following chapter): 34 taxa of the Bomfordi Subzone vs. 52 taxa of the Convergens Subzone. A corresponding diversity increase is at suprageneric level, with 7 (sub)families in the uppermost Bajocian vs. 11 in the lowermost Bathonian (Fig. 7) to which the new Bathonian subfamilies Hecticoceratinae and Zigzagiceratinae add in the Convergens Subzone.

The general pattern of the Upper Bajocian to Lower Bathonian ammonoid assemblages is a mixing of elements representatives of the Mediterranean and NW European provinces, associated with some Sub-Mediterranean ones. The Mediterranean palaeobiogeographic group characteristically refers to Phylloceratina and Lytoceratina, whereas Parkinsoniinae are peculiar taxa of the NW European Province. The Bathonian Bigotitinae were a terminal phylogenetic group characteristic of the Sub-Mediterranean Province. Other subfamilies, such as Morphoceratinae, Zigzagiceratinae, Leptosphinctinae or Cadomitinae, could give palaeobiogeographic information only at generic or subgeneric level. Thus, the intermediate Mediterranean pattern of the fossil-assemblages at Bas Auran allows chronocorrelation to the (sub)zonal scale with the Sub-Mediterranean and NW European provinces.

Parkinsoni Zone, Bomfordi Subzone (Pavia & Sturani 1968)

The index species *Parkinsonia bomfordi* is missing at Bas Auran; nevertheless, it is recorded in the coeval section of Chaudon, near the Bathonian basal boundary (Pavia 1973, p. 120).

In details, the ammonite taxonomic composition for the Bomfordi Subzone is parcelled out among 7 specific taxa with 16 specimens of Phylloceratina, 3 taxa with 14 specimens of Lytoceratina, 2 taxa with 6 specimens of Oppeliinae, 1 taxon with 1 specimen of Strigoceratinae, 13 taxa with 23 specimens of Cadomitinae, 6 taxa with 15 specimens of Parkinsoniinae, 8 taxa with 45 specimens of Leptosphinctinae.

The subzone is characterized by the abundance of Leptosphinctinae (37.5%), Cadomitinae (19.2%) and Parkinsoniinae (12.5%). Among Leptosphinctinae, significative taxa are the last representatives of *Prorsisphinctes* and *Vermisphinctes* (Pl. 3, fig. 5) and the development of dimorphic pair *Lobosphinctes* and *Planisphinctes* (e.g. *P. torrensi*: Pl. 3, fig. 1). The pair *L. costulatosus* - *P. tenuissimus* (Pl. 3, figs. 2-4) is frequently recorded at this level (Pavia 1973; Galácz 1980; Dietze & Dietl 2006) and thus could be regarded as the most useful, wide-ranging correlation tool for the uppermost Bajocian. Significative species belong to parkinsoniids, though most of them cross the Bajocian-Bathonian boundary at different layers, so that none of them is diagnostic. The only characteristic parkinsoniids seem to be the microconch specimens provisionally named as

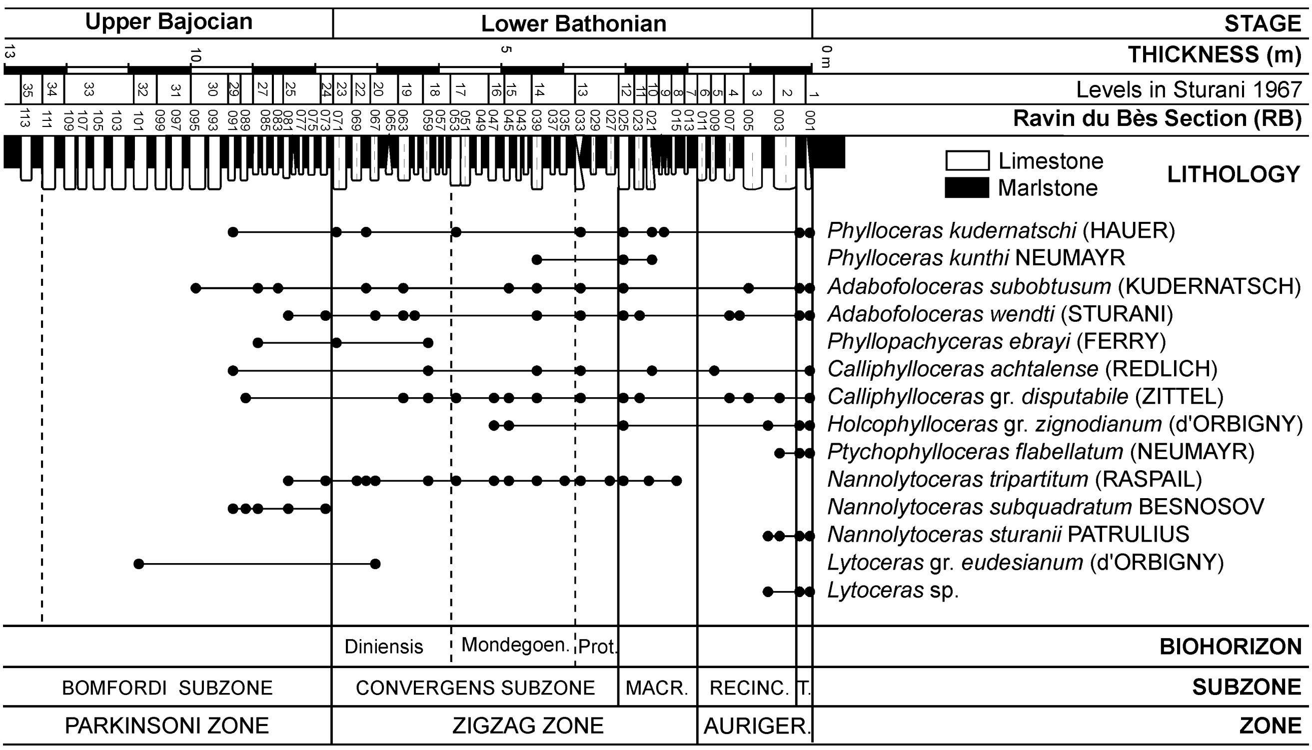


Fig. 5 - Phylloceratina and Lytoceratina composite succession and biochronostratigraphic data at the Bajocian/Bathonian boundary based on the Ravin du Bès Section.

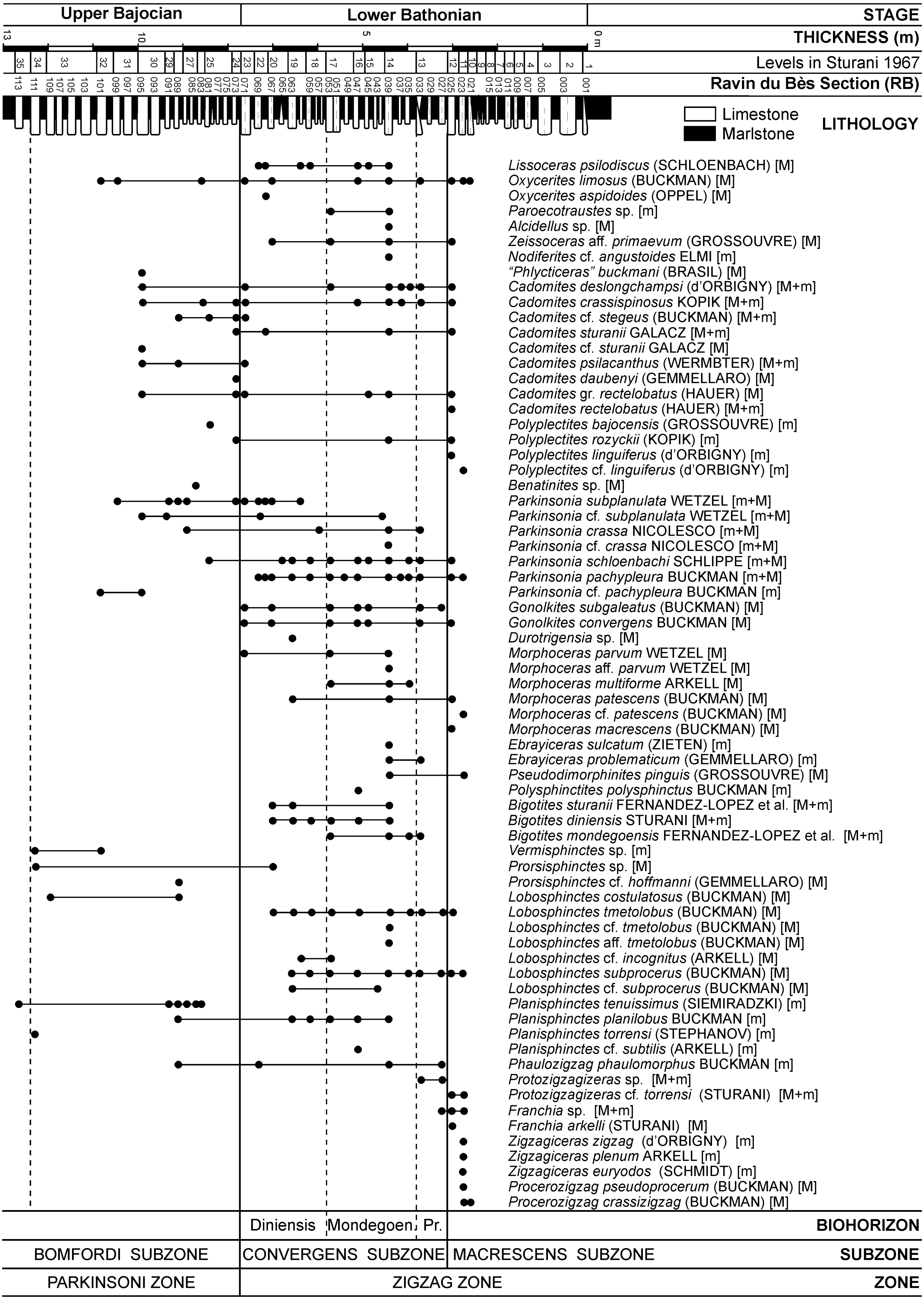


Fig. 6 - Ammonitina composite succession and biochronostratigraphic data at the Bajocian/Bathonian boundary based on the Ravin du Bès Section.

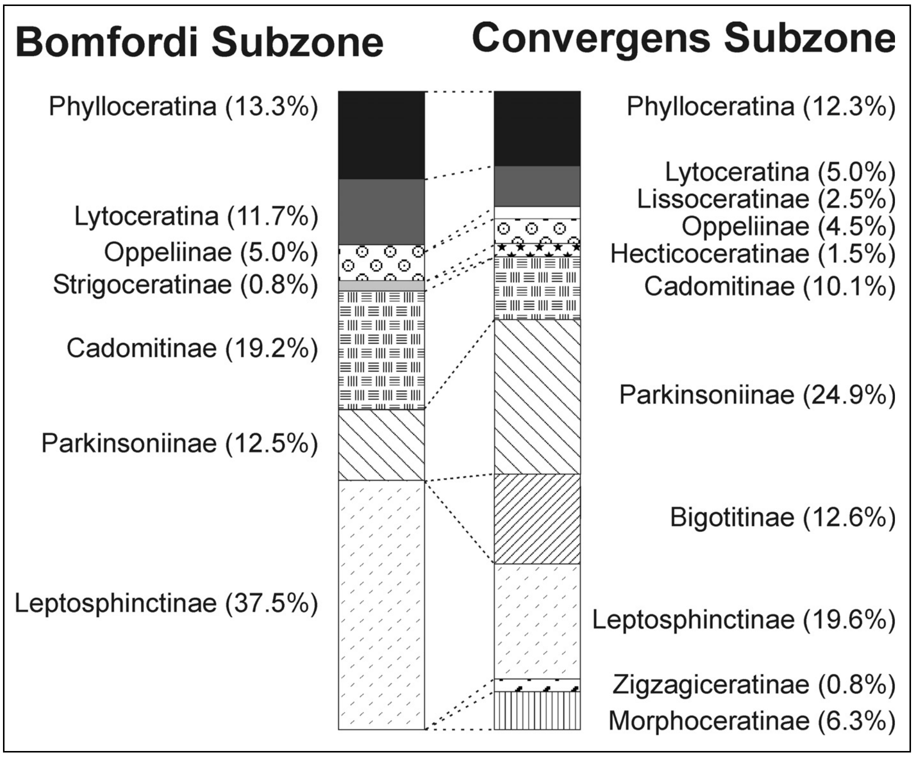


Fig. 7 - Distribution of percentage of ammonoid (sub)families in the Bajocian Bomfordi Subzone (120 specimens) and Bathonian Convergens Subzone (398 specimens) from the Bas Auran area.

Parkinsonia cf. *pachypleura* [m] (Pl. 2, figs. 1, 10) for which neither macroconch counterpart could be detected in the present collection, nor equivalent morphology has been found in the literature, except the specimen of *P. zatwornitzkii* figured by Dietze & Dietl (2006, pl. 4, fig. 1) which shows higher whorls and prorsiradiate ribbing. The Cadomitinae *Cadomites* [M] and *Polyplectites* [m] are the most diversified taxa, but they need a complete revision for both Upper Bajocian and Lower Bathonian fossil-assemblages; for this reason we tried to couple dimorphic morphologies, assigned them to available binomens, and left any decision to a further study (Pl. 1, figs. 6-11; Pl. 2, figs. 7, 8). In conclusion, at present, no cadomitids could serve for biostratigraphic subdivision, though they are to be of primary importance for correlation with various palaeobiogeographic provinces. Finally, it is worth noting the absence of any Bajocian morphoceratid, namely of the dimorphic group *Dimorphinites dimorphus* [M] - *Vigoriceras defrancei* [m] as already stated in the near and coeval section of Chaudon (Pavia 1973), though its presence at the topmost Parkinsoni Zone of the type-area of Bayeux, Normandy, i.e. in the NW European Province, is well known (Pavia 1994).

It is also worth noting the presence of *Benatinites* in bed RB083 with a single specimen (PU111228) which is too poorly preserved for a certain attribution to the macroconch *Benatinites* s.s. or the microconch *Lugariceras*; nevertheless, it confirms the range of this rare dimorphic taxon from the uppermost Bajocian dubitatively indicated by Schlögl et al. (2006).

Phylloceratina and Lytoceratina have no particular biochronostratigraphic meaning, except to confirm that the Bajocian-Bathonian boundary is approximated by the onset of different taxa such as *Adabofoloceras subobtusum*, *A. wendti* (Pl. 1, figs. 4, 5), *Phyllopachyceras ebrayi* (Pl. 1, fig. 1; possible senior synonym of *Partschiceras orbignyi* Pavia, 1973: Joly 2000, p. 66), *Calliphylloceras achtalense*, *Nannolytoceras tripartitum*. The *Nannolytoceras* species deserve separate attention. *N. tripartitum* (Pl. 1, fig. 2), one of the best known Mediterranean lytoceratid, occurs from Sturani's bed 25 (= RB081, RA091) and goes up through the whole Lower Bathonian, whereas Sturani (1967) and Innocenti et al. (1990) recorded it from the lowest bed 30. Best preserved specimens, recently collected, allow to identify the presence of *Nannolytoceras subquadratum* (Pl. 1, fig. 3) and to modify some of the previous specific assignments. Actually, the range of *N. tripartitum* has to be raised, and *N. subquadratum* occupies an intermediate position between Raspail's species and the typical Bajocian *N. polyhelictum*. It is worth noting that the transition from *N. polyhelictum* to *N. subquadratum* and further to *N. tripartitum* assumes high biochronostratigraphic correlation potential for Mediterranean latest Bajocian.

Zigzag Zone, Convergens Subzone (Maubeuge 1950)

The base of the Zigzag Zone and of the Bathonian Stage, in Bas Auran ammonoid succession, is identified by the first occurrence of *Gonolkites convergens* (Pl. 2, fig. 12) from Sturani's bed 23 (= RB071-RB072, RA085, RR085). *G. convergens* ranges through the whole subzone (Pl. 1, figs 12-14) up to the base of the Macrescens Subzone. The basal bed of the zone coincides also with the lowest occurrence of *Morphoceras parvum* (Pl. 2, fig. 4), thus the Bas Auran biostratigraphy assures a significant chronocorrelation between the NW European Convergens Subzone and the Sub-Mediterranean Parvum Subzone.

The ammonite taxonomic composition for the Convergens Subzone is parcelled out among: 8 specific taxa with 49 specimens of Phylloceratina, 2 taxa with 20 specimens of Lytoceratina, 1 taxon with 10 specimens of Lissoceratinae, 3 taxa with 18 specimens of Oppeliinae, 3 taxa with 6 specimens of Hecticoceratinae, 10 taxa with 40 specimens of Cadomitinae, 8 taxa with 99 specimens of Parkinsoniinae, 3 taxa with 50 specimens of Bigotitinae, 13 taxa with 78 specimens of Leptosphinctinae, 2 taxa with 3 specimens of Zigzagiceratinae, 9 taxa with 25 specimens of Morphoceratinae.

The basal Bathonian ammonite assemblage at the Ravin du Bès encloses the following ammonite species actually or virtually recorded, respectively from bed RB071 (*) or from beds below and above (**) (cf. Fig. 6):

(*) *Cadomites crassispinosus* [M+m]
(*) *Cadomites deslongchampsi* [M+m]
(*) *Cadomites psilacanthus* [M+m]
(*) *Cadomites* gr. *rectelobatus* [M]
(*) *Cadomites stegeus* [M+m]
(**) *Cadomites sturanii* [M+m]
(*) *Gonolkites convergens* [M]
(*) *Gonolkites subgaleatus* [M]
(*) *Morphoceras parvum* [M]
(*) *Oxycerites limosus* [M]
(**) *Parkinsonia crassa* [M+m]
(**) *Parkinsonia schloenbachi* [M+m]
(*) *Parkinsonia suplanulata* [M+m]
(**) *Parkinsonia* cf. *suplanulata* [M+m]
(**) *Phaulozigzag phaulomorphus* [m]
(**) *Planisphinctes planilobus* [m]
(**) *Polyplectites rozyckii* [m]

In particular, the base of Bathonian succession corresponds to the renewal of parkinsoniids in Bas Auran and other basins (e.g. Hahn 1970; Dietze & Schweigert 2000; Dietze et al. 2004; Dietze & Dietl 2006). In particular, besides the apparently limited range of *Parkinsonia pachypleura* (Pl. 2, figs. 9, 11) within the Bathonian layers, the main biostratigraphic input derives from the first occurrence of the genus *Gonolkites* whose appearance assumes the meaning of an evolutionary-differentiation event at the passage Bajocian-Bathonian. Among other groups, Leptosphinctinae reach the highest diversification with the dimorphic pair *Lobosphinctes-Planisphinctes* and different taxa that range over and characterize the whole Convergens Subzone. Macroconchs of *Morphoceras* are sufficiently well represented by *M. parvum* (Pl. 2, figs. 2, 3) and the long-ranging species *M. multiforme* and *M. patescens*, whereas the microconchs of *Ebrayiceras* are very scarce. A still indefinite morphotype (*Morphoceras* aff. *parvum*) could represent a new species (Pl. 2, figs. 5, 6). The onset of *Pseudodimorphinites pinguis* in the middle part of the subzone suggests another palaeobiological event of immigration. Further, the record of Hecticoceratinae is too scarce to be significative (1.5%); nevertheless the appearance of *Alcidellus* is noteworthy. The relatively low frequency of Phylloceratina (12.3%) somehow draws up a Sub-Mediterranean pattern of the ammonoid assemblages of the Alpes-de-Haute-Provence Middle Jurassic. This Sub-Mediterranean feature is in particular supported by the scattered range of several species, such as *Phylloceras kunthi* and *Phyllopachyceras ebrayi*, and by the reduced presence of the genus *Ptychophylloceras* which is represented only by *P. flabellatum* (Fig. 5) from the top of the Bas Auran succession (Aurigerus Zone). In contrast, *Ptychophylloceras* is represented by several species in the typical Mediterranean ammonoid assemblages, early occurring from the uppermost Bajocian (Galácz 1980; Pavia 1983b).

In this so diverse panorama of taxonomic groups, the ancestor of the Zigzagiceratinae could be found, as described by Fernández-López et al. (2007) in the phyletic lineage that is realized at the upper part of the Convergens Subzone with diversification of the genus *Protozigzagiceras* Fernández-López et al., whose type-species *P. torrensi* (Sturani) comes from the middle Macrescens Subzone. More in detail, *Protozigzagiceras* is first represented by the unnamed specimen PU31694 collected in Sturani's calcareous bed 13 (formerly cited as *Franchia* n. sp. ind. by Innocenti et al. 1990; see Fernández-López et al. 2007, text-fig. 10). A second specimen of the Convergens Subzone is a fragmentary, poorly preserved nucleus from bed RA035. Further representatives of *Protozigzagiceras* come from the lowermost Macrescens Subzone (RA31) with two specimens [M+m] provisionally named *P.* cf. *torrensi* (Plate 3, figs 9-12). The distinguished zigzagiceratid *Franchia* is thought to be derivate from this ancestral genus *Protozigzagiceras*, and makes first occurrence from the calcareous bed RA035 just below the base of the Macrescens Subzone. *Franchia* seems to be a short living taxon with different macro-and microconch morphotypes distributed across the Convergens-Macrescens boundary (Plate 3, figs. 6, 7). The type-species *F. arkelli* is limited to the very beginning of the Macrescens Subzone, at Sturani's bed 12, whereas a new unnamed species comes from bed 11 (Plate 3, fig. 13).

Further interesting data concern diversity and range of the genus *Bigotites*, which is represented by three dimorphic species, *B. sturanii*, *B. diniensis*, *B.*

mondegoensis. They are thought to belong to a chronoclinal lineage that anticipates the extinction of the genus and the subfamily during the latest Zigzag Biochron (Macrescens Subzone). These arguments have been deeply discussed by Fernández-López et al. (2007), and do not need further comments. It is just useful to recall here that it constitutes the ground for subdivision of the subzone in three biohorizons:

Diniensis Biohorizon. It is defined by the occurrence of *Bigotites diniensis* representatives (Pl. 3, fig. 8) and corresponds to the lowest part of the Bathonian Zigzag Zone in the Sub-Mediterranean and Mediterranean provinces (e.g., Cabo Mondego and Bas Auran). It encompasses the stratigraphic intervals RA085-RA062 in Ravin d'Auran Section and RB071-RB054 in Ravin du Bès Section (in both sections, Sturani's levels 23-18).

Mondegoensis Biohorizon. It is defined by the lowest occurrence of *Bigotites mondegoensis* representatives. It encompasses the stratigraphic intervals RA061-RA044 in Ravin d'Auran Section and RB053-RB034 in Ravin du Bès Section (in both sections, Sturani's levels 17-14), taking into account the first occurrence of *B. mondegoensis* at the level RA061.

Protozigzagiceras Biohorizon. It is defined by the lowest occurrence of Zigzagiceratinae representatives, in particular *Protozigzagiceras* [M+m] and *Franchia* [M+m]. It encompasses the stratigraphic intervals RA043-RA034 in Ravin d'Auran Section and RB033-RB026 in Ravin du Bès Section, taking into account the occurrence of *Protozigzagiceras* from Sturani's level 13 and *Franchia* from RA035.

Zigzag Zone, Macrescens Subzone (Sturani 1967)

The base of the Macrescens Subzone is fixed at the equivalent beds RB025 in Ravin du Bès Section and RA033 in Ravin d'Auran Section, taking into account the first occurrence of the index-species *Morphoceras macrescens* from Sturani's calcareous bed 12.

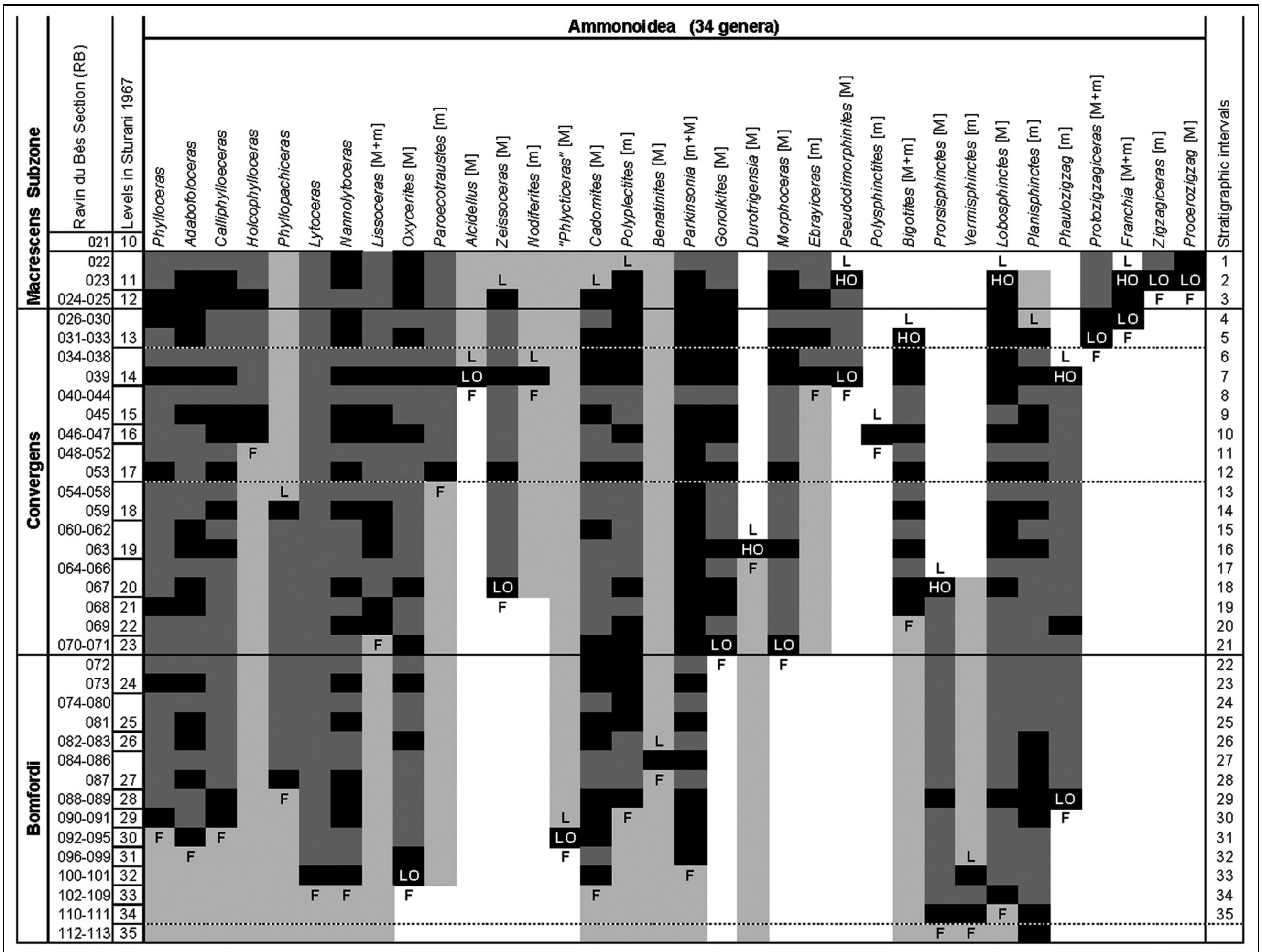
It is noteworthy that Sturani (1967, p. 12-13) suggested definition of his new subzone by the first occurrence of *M. macrescens* originally starting from bed 11; in this sense, the subzone was accepted in the Sub-Mediterranean and North European biostratigraphic schemes of the Bathonian (Mangold & Rioult 1997, p. 56). After our partial revision of the morphoceratids from Bas Auran, we rearranged taxonomic distinction and actually the index *M. macrescens* onsets at bed 12 (Pl. 2, fig. 13), so that we are forced to lower a bit the basal boundary of the Macrescens Subzone, at Sturani's bed 12. With such a modification, *Gonolkites convergens* becomes extending up to the base of the Macrescens Subzone, so that the Convergens Subzone fails the characteristic of range biostratigraphic unit formerly indicated by Sturani's work.

Our analysis is limited to the first beds of the Macrescens Subzone, at the intervals RB025-RB021 in Ravin du Bès Section and RA033-RA029 in Ravin d'Auran Section (in both sections, Sturani's levels 12-10), whereas the whole subzone goes up to the top of Sturani's bed 7, i.e. RB012 and RA018. The short layer here described shows a transitional pattern from the Convergens Subzone; in fact, we witness the disappearance of typical lowermost Bathonian taxa such as the genus *Parkinsonia* [M+m] and the dimorphic pair *Lobosphinctes-Planisphinctes*, as well as the diversification of Zigzagiceratinae, namely the occurrence of *Protozigzagiceras*, *Franchia* and several species of the dimorphic pair *Zigzagiceras-Procerozigzag*.

Record quality of ammonoid succession in Bas Auran area

The quality of the record in the biostratigraphic successions can be tested taken into account several palaeontological criteria, from the state of preservation and abundance of fossil-specimens to the number of successive fossil-assemblages. Values of these and other palaeontological attributes in the ammonoid biostratigraphic succession of Bas Auran area have been analyzed and interpreted, in order to assess the quality of the palaeontological and stratigraphic records, from the Bajocian Bomfordi Subzone towards the top of the Bathonian Zigzag Zone (Figs. 8, 9).

As to the preservation state of fossil-specimens, taphonic populations and fossil-assemblages (Fernández-López 2007a), ammonoids show similar preservational styles at the upper part of the Bomfordi Subzone and lower and middle parts of the Convergens Subzone in Bas Auran area (levels 14-29 in Sturani 1967, equivalent to levels RB39-RB91). At this stratigraphic interval, ammonoids are commonly preserved as calcareous concretionary internal moulds of unflattened shells, completely filled with relatively homogeneous lime mudstone up to the innermost whorls. Partially or locally phosphatized concretionary internal moulds or pyritic nuclei occur in some levels. Internal moulds can present asymmetrically deformed flanks due to compaction. Fragmentary, incomplete phragmocones with calcitic septa and complete suture-line are the dominant fossils, generally bearing no signs of rounding, incrustation or bioerosion. Ammonoid moulds rarely exceed 200 mm in diameter (mean size = 65 mm). Taphonic populations are of type 3, with predominance of adults and absence of juveniles (Fernández-López 1995). Macroconchs are more common and fragmentary than microconchs. Ammonoid fossil-assemblages are dominated by reworked elements, i.e. resedimented and reelaborated elements. Resedimented shells, displaced on the sea-bottom be-



	Phylloceras	Adabofoloceras	Calliphylloceras	Holcophylloceras	Phyllopachiceras	Lytoceras	Nannolytoceras	Lissoceras [M+m]	Oxycerites [M]	Paroecotraustes [m]	Alcidellus [M]	Zeissoceras [M]	Nodiferites [m]	"Phlycticeras" [M]	Cadomites [M]	Polyplectites [m]	Benatinites [M]
Specimens	11	35	24	3	3	1	32	10	24	3	1	5	1	1	38	38	1
Specimens %	2	6	4	0	0	0	5	2	4	0	0	1	0	0	6	6	0
Occurrences	7	15	10	3	2	1	17	8	12	2	1	4	1	1	16	16	1
Actual range	30	31	30	10	15	33	33	20	33	12	1	16	1	1	31	28	1
Actual gaps	23	16	20	7	13	32	16	12	21	10	0	12	0	0	15	12	0
Actual gaps %	77	52	67	70	87	97	48	60	64	83	0	75	0	0	48	43	0
Virtual gaps	5	4	5	25	20	2	2	15	0	21	6	2	17	30	4	7	34
Total records	35	35	35	35	35	35	35	35	33	33	7	18	18	31	35	35	35
Total gaps	28	20	25	32	33	34	18	27	21	31	6	14	17	30	19	19	34
Total gaps %	80	57	71	91	94	97	51	77	64	94	86	78	94	97	54	54	97
Completeness %	20	43	29	9	6	3	49	23	36	6	14	22	6	3	46	46	3
Constancy %	23	48	33	30	13	3	52	40	36	17	100	25	100	100	52	57	100
Persistence %	20	43	29	9	6	3	49	23	34	6	3	11	3	3	46	46	3

	Parkinsonia [m+M]	Gonolkites [M]	Durotrigensia [M]	Morphoceras [M]	Ebrayiceras [m]	Pseudodimorphinites [M]	Polysphinctites [m]	Bigotites [M+m]	Prorsisphinctes [M]	Vermisphinctes [m]	Lobosphinctes [M]	Planisphinctes [m]	Phaulozigzag [m]	Protozigzagiceras [M+m]	Franchia [M+m]	Zigzagiceras [m]	Procerozigzag [M]	
Specimens	85	31	1	30	6	2	1	50	6	2	74	42	3	2	15	11	22	614
Specimens %	14	5	0	5	1	0	0	8	1	0	12	7	0	0	2	2	4	
Occurrences	26	12	1	8	3	2	1	9	3	2	15	13	3	2	2	1	2	222
Actual range	32	21	1	21	7	6	1	15	18	3	33	31	23	5	2	2	2	
Actual gaps	6	9	0	13	4	4	0	6	15	1	18	18	20	3	0	1	0	327
Actual gaps %	19	43	0	62	57	67	0	40	83	33	55	58	87	60	0	50	0	
Virtual gaps	3	0	19	0	14	0	0	16	0	15	1	3	0	0	0	0	0	270
Total records	35	21	20	21	21	6	1	31	18	18	34	34	23	5	2	2	2	819
Total gaps	9	9	19	13	18	4	0	22	15	16	19	21	20	3	0	1	0	597
Total gaps %	26	43	95	62	86	67	0	71	83	89	56	62	87	60	0	50	0	
Completeness %	74	57	5	38	14	33	100	29	17	11	44	38	13	40	100	50	100	
Constancy %	81	57	100	38	43	33	100	60	17	67	45	42	13	40	100	50	100	
Persistence %	74	34	3	23	9	6	3	26	9	6	43	37	9	6	6	3	6	

Fig. 8 - Ranges of 34 ammonoid genera known in the Bas Auran area at the Bajocian/Bathonian boundary, showing the stratigraphic intervals of occurrence (black), actual gap (dark grey) and virtual gap (light grey) as well as first occurrence (F), last occurrence (L), lowest occurrence (LO) and highest occurrence (HO). The abundance of specimens, completeness, constancy and persistence of the stratigraphic ranges are indicative criteria of record quality for ammonoid genera.

fore their burial, are most frequent, whereas reelaborated internal moulds, exhumed and displaced before their final burial, may be locally common in the uppermost levels. The degree of reworking or removal (i.e., the ratio of reelaborated and resedimented elements to total recorded elements) is relatively high, but the degree of taphonomic heritage (i.e., the ratio of reelaborated elements to total recorded elements) is usually low. The degree of taphonomic condensation (i.e., mixture of fossils of different age or different chronostratigraphic units) reaches very low to zero values. All these palaeontological attributes indicate a relatively homogeneous and good record quality of the biostratigraphic succession, lacking biochronostratigraphic mixing at the Bajocian/Bathonian boundary.

Stratigraphic data of abundance and concentration of ammonoids are relevant. Across the Bajocian/Bathonian boundary in Bas Auran area, ammonoids commonly appear scattered, showing no pattern of imbricated or encased regrouping. The abundance and concentration of ammonoids increase towards the top of the "Marno-calcaires à *Cancellophycus*", although ammonoids are commonly recorded throughout the sections. In particular, the proportion of ammonoid specimens increase from the Bomfordi to the Convergens Subzone (114 vs. 392 respectively of 506 specimens = 22.5 vs. 77.5% in Figs. 8, 9). The degree of ammonoid packing displays high values (86%, estimated by the difference between the number of specimens and the number of fossiliferous levels divided by the number of specimens) and the ammonoid stratigraphic persistence displays very high values (100%, estimated by the proportion of fossiliferous levels).

Levels 14, 15, 17, 18, 19 and 20 are stacks of decimetric to centimetric elementary limestone-marl cycles, with an overall thinning upward. Both lithologic phases contain ammonoids, but unflattened concretionary internal moulds are common in limestone beds, whereas crushed shells are dominant in marly intervals (type-2 elementary cycles in Fernández-López 2007a, fig. 11). In this sense, limestone beds of these decimetric stratigraphic intervals have a better record than marly inter-

Subzone	Levels in the Ravin du Bès Section (RB)	Levels in Sturani 1967	**Specimens**	Specimens %	**Occurrences (O)**	Occurrences %	Palaeontological gaps: Actual gaps (A)	Relative actual gaps %	Virtual gaps (V)	Relative virtual gaps %	Total gaps (G = A + V)	Incompleteness %	Records (R = O + G)	Biostratigraphic changes: First occurrence (F)	Lowest occurrences (LO)	Lowest occurrences %	Last occurrence (L)	Highest occurrences (HO)	Highest occurrences %	Biostratigraphic turnover (BT = F - L)	SCHLOij = (HOi/Oi) * (LOj/Oj) * 100	CCHLO = (HO/O) * (LO/O) * 400	Stratigraphic intervals
Macrescens	022		3	0	3	1	13	54	8	33	21	88	24	0	0	0	0	0	0	0	0	0	1
	023	11	44	7	12	5	8	29	8	29	16	57	28	2	2	17	4	3	43	-2	0	17	2
	024-025	12	61	10	13	6	6	24	6	24	12	48	25	0	0	0	2	0	0	-2	0	0	3
Convergens	026-030		11	2	9	4	11	42	6	23	17	65	26	1	1	8	0	0	0	1	1	0	4
	031-033	13	53	9	13	6	8	31	5	19	13	50	26	1	1	8	2	1	14	-1	0	2	5
	034-038		12	2	7	3	13	52	5	20	18	72	25	0	0	0	0	0	0	0	0	0	6
	039	14	110	18	21	9	2	8	3	12	5	19	26	4	2	17	3	1	14	1	0	2	7
	040-044		1	0	1	0	18	75	5	21	23	96	24	0	0	0	0	0	0	0	0	0	8
	045	15	11	2	9	4	10	42	5	21	15	63	24	0	0	0	0	0	0	0	0	0	9
	046-047	16	27	4	12	5	8	32	5	20	13	52	25	2	0	0	1	0	0	1	0	0	10
	048-052		2	0	1	0	17	71	6	25	23	96	24	0	0	0	0	0	0	0	0	0	11
	053	17	40	7	13	6	5	21	6	25	11	46	24	1	0	0	0	0	0	1	0	0	12
	054-058		1	0	1	0	16	67	7	29	23	96	24	0	0	0	0	0	0	0	0	0	13
	059	18	14	2	8	4	10	42	6	25	16	67	24	0	0	0	1	0	0	-1	0	0	14
	060-062		6	1	5	2	13	54	6	25	19	79	24	0	0	0	0	0	0	0	0	0	15
	063	19	21	3	10	5	9	36	6	24	15	60	25	1	0	0	1	1	14	0	0	0	16
	064-066		1	0	1	0	17	68	7	28	24	96	25	0	0	0	0	0	0	0	0	0	17
	067	20	48	8	10	5	9	33	8	30	17	63	27	1	1	8	1	1	14	0	0	4	18
	068	21	13	2	6	3	12	48	7	28	19	76	25	1	0	0	0	0	0	1	0	0	19
	069	22	7	1	5	2	12	48	8	32	20	80	25	1	0	0	0	0	0	1	0	0	20
	070-071	23	14	2	6	3	10	40	9	36	19	76	25	2	2	17	0	0	0	2	0	0	21
Bomfordi	072		4	1	2	1	12	55	8	36	20	91	22	0	0	0	0	0	0	0	0	0	22
	073	24	11	2	7	3	7	32	8	36	15	68	22	0	0	0	0	0	0	0	0	0	23
	074-080		1	0	1	0	13	59	8	36	21	95	22	0	0	0	0	0	0	0	0	0	24
	081	25	10	2	5	2	9	41	8	36	17	77	22	0	0	0	0	0	0	0	0	0	25
	082-083	26	5	1	4	2	10	45	8	36	18	82	22	0	0	0	0	0	0	0	0	0	26
	084-086		4	1	3	1	12	55	7	32	19	86	22	1	0	0	1	0	0	0	0	0	27
	087	27	18	3	4	2	10	45	8	36	18	82	22	1	0	0	0	0	0	1	0	0	28
	088-089	28	25	4	9	4	4	18	9	41	13	59	22	2	1	8	0	0	0	2	0	0	29
	090-091	29	11	2	6	3	5	24	10	48	15	71	21	2	0	0	0	0	0	2	0	0	30
	092-095	30	9	1	4	2	6	29	11	52	17	81	21	2	1	8	1	0	0	1	0	0	31
	096-099	31	5	1	2	1	6	30	12	60	18	90	20	1	0	0	0	0	0	1	0	0	32
	100-101	32	5	1	5	2	3	15	12	60	15	75	20	4	1	8	1	0	0	3	0	0	33
	102-109	33	2	0	1	0	3	17	14	78	17	94	18	1	0	0	0	0	0	1	0	0	34
	110-111	34	4	1	3	1	0	0	15	83	15	83	18	2	0	0	0	0	0	2	0	0	35
			614		222		327		270		597		819	33	12		18	7					

Fig. 9 - Sampled specimens, occurrences, palaeontological gaps, records and diverse biostratigraphic changes of 34 ammonoid genera known in the Bas Auran area, from 35 successive stratigraphic intervals, to show variations in record quality of the ammonoid succession at the Bajocian/Bathonian boundary.

vals, also indicated by the larger number of specimens sampled in limestone beds (Fig. 9), due to a greater preservation potential of the ammonoid shells. Time intervals of lower rates of sedimentation and sediment accumulation, associated with sedimentary starving and sedimentary condensation during progressive deepening towards the top of a transgressive systems tract, favoured higher degrees of biodegradation, sedimentary infill, synsedimentary mineralization, reworking and regrouping of ammonoid shells, and enhanced their preservation potential (Fernández-López 2007a).

As to the analysis of gaps in the ammonoid record, Fig. 8 represents the known stratigraphic ranges, including gaps, for all ammonoid genera which are known from Bas Auran area at the Bajocian/Bathonian boundary. A gap in the fossil record occurs when a taxon is known from below and above, but not actually within, a given stratigraphic interval (Paul 1982, 1992, 1998). There are additional virtual gaps above or below the known ranges of the genera plotted, which can be detected taking into account 1) the stratigraphic ranges of the counterpart dimorphs in the same sections and 2) the biostratigraphic ranges of the taxa or dimorphic pairs in nearby sections or at regional scale.

The following four criteria provide a further estimation of record quality for ammonoid genera: relative abundance of specimens, completeness, constancy and persistence of the stratigraphic ranges. The completeness of a stratigraphic range may be estimated by the proportion of records, including actual and virtual gaps, represented by intervals of occurrence. Stratigraphic constancy is the proportion of stratigraphic ranges represented by intervals of occurrence. Stratigraphic persistence is the proportion of total stratigraphic intervals represented by intervals of occurrence (cf. Brower 1985). In the Bas Auran area, among the candidate taxa as guide fossils for the Bajocian/Bathonian boundary, these criteria suggest that the Parkinsoniidae have a better record than Morphoceratidae. In particular, *Parkinsonia* [m+M] and *Gonolkites* [M] show high values of relative abundance of specimens (14 and 5% respectively), stratigraphic completeness (74 and 57%), stratigraphic constancy (81 and 57%) and stratigraphic persistence (74 and 34%). In contrast, *Morphoceras* [M] and *Ebrayiceras* [m] show relatively low values of relative abundance (5 and 1% respectively), stratigraphic completeness (38 and 14%), stratigraphic constancy (38 and 43%) and stratigraphic persistence (23 and 9%).

Analysis of gaps in the total records of genera provides an estimate of completeness in the ammonoid biostratigraphic succession. The total records of 34 genera in 35 stratigraphic intervals are 819, the total occurrences 222 and the total gaps 597, hence the ammonoid succession is at least 73% incomplete at this scale of analysis. Nevertheless, the Convergens record is better (about 70% incompleteness) than average (74% incompleteness) while the Bomfordi record is worse (81% incompleteness). The levels of lowest incompleteness are 14 (= RB039, 19% in Fig. 9), 17 (= RB053, 46%) and 28 (= RB088-RB089, 59%). The stratigraphic intervals of highest proportion of actual gaps (67-75%) and highest incompleteness (95-96%) are in the upper part of levels 15 (= RB040-RB044), 17 (= RB048-RB052), 20 (= RB064-RB066) and 18 (= RB054-RB058).

In relation to the Bajocian/Bathonian boundary, the total records of all genera in the level 24 (= RB072-RB073) are 44, the total occurrences 9 and the total gaps 35, hence the fossil record of genera is at least 80% incomplete in this stratigraphic level. However, the total records of all genera in the level 23 (= RB070-RB071) are 25, the total occurrences 6 and the total gaps 19, hence the fossil record of genera is 76% incomplete in this stratigraphic interval. Consequently, analysis of palaeontological gaps within genera suggests relatively high values of completeness for the ammonoid succession at the boundary between Bomfordi and Convergens subzones.

Taxonomic diversity and biostratigraphic turnover in successive stratigraphic intervals are two criteria for determine the quality and variation of successive fossil-assemblages. Taxonomic diversity increase towards the top of the stratigraphic sections in Bas Auran area (Fig. 7): 28 genera of 11 subfamilies in the Convergens Subzone *versus* 17 genera of 7 subfamilies in the Bomfordi Subzone. Biostratigraphic turnover, defined as the number of first occurrences minus the number of last occurrences in each stratigraphic interval (BT= F-L in Fig. 9), shows positive or neutral values between the levels 34 and 19.

The number and proportion of first and last occurrences of taxa in successive stratigraphic intervals provide a test by which continuity or discontinuity of the biostratigraphic successions can be assessed. In the Ravin du Bès Section, within genera known from both subzones in diverse sedimentary basins, there is a moderately high proportion of last occurrences associated with virtual gaps in the upper part of the Bomfordi Subzone (3 of 5 = 60.0%, "*Phlycticeras*", *Benatinites* and *Vermisphinctes* in Bomfordi Subzone vs. *Phyllopachyceras* and *Planisphinctes* in Convergens Subzone: Fig. 8). However, the low proportion of first occurrences in the Convergens Subzone (5 of 18 = 27.8%: *Holcophylloceras*, *Lissoceras*, *Paroecotraustes*, *Durotrigensia* and *Bigotites* in Fig. 8) indicates relatively good record quality. Moreover, the absence of highest occurrences in the upper part of the Bomfordi Subzone and the low proportion of lowest occurrences in the Convergens Subzone (7 LO of 28 O = 25.0%: Figs 8 and 9) indicate good record quality, gradual biostratigraphic change and high degree of taxonomic similarity between the two successive subzones (cf. Sandoval et al. 2001).

Continuity or discontinuity of the stratigraphic successions can be assessed taking into account the biostratigraphic changes by clusters of lowest and highest occurrences of taxa at successive stratigraphic levels. These changes are relevant in sequence stratigraphy when they are due to lacunae or condensation processes. Lacunae and stratigraphic condensation can produce clusters of lowest occurrences stratigraphically consecutive to clusters of highest occurrences, above and below stratigraphic gaps (Brett 1995, 1998; Holland 1995, 2000a, 2000b; Kidwell & Flessa 1995; Kidwell & Holland 2002). In contrast, taphonomic condensation and sedimentary condensation can produce clusters of highest occurrences associated with clusters of lowest occurrences in the same stratigraphic intervals (Fernández-López 1997, 2004). Consequently, due to changes in the rate of sedimentation and the rate of accumulation of sediments, clustering of highest and lowest occurrences of taxa is not random in depositional sequences: successive clustering in consecutive stratigraphic intervals is commonest at the sequence boundary, whereas coincident clustering in the same stratigraphic interval is commonest towards the top of the transgressive systems tract.

Successive clustering of highest and lowest occurrences in consecutive stratigraphic intervals can be tested by index SCHLO (Fig. 9) which varies between 0 and 100. Its minimum value 0 means that there are not highest occurrences in the lower stratigraphic interval or lowest occurrences in the upper interval, whereas positive values indicate presence of highest occurrences in the lower stratigraphic interval and lowest occurrences in the upper interval. The maximum value 100 of SCHLO means presence of, exclusively, highest occurrences in the lower stratigraphic interval and lowest occurrences in the upper interval. In the Ravin du Bès Section, biostratigraphic changes by successive clustering have been identified only in the upper part of the level 13 (= RB026-RB030), where lowest occurrence of *Franchia* [M+m] is consecutive to highest occurrence of *Bigotites* [M].

Coincident clustering of highest and lowest occurrences in the same stratigraphic intervals can be tested by index CCHLO (Fig. 9) which varies between 0 and 100. Its minimum value 0 means that there is not coincidence of highest and lowest occurrences in the stratigraphic interval. Positive CCLHO values indicate stratigraphic coincidence of highest and lowest occurrences. The maximum value 100 means that highest and lowest occurrences are in the same proportion. In the Ravin du Bès Section, biostratigraphic changes of CCHLO have been identified only in the Macrescens and Convergens subzones, not at the Bajocian/Bathonian boundary. Maximum values have been detected at the levels 11 (= RB023), 13 (= RB031-RB033), 14 (= RB039) and 20 (= RB067). Biostratigraphic changes progressively increase towards the top of the "Marno-calcaires à *Cancellophycus*", by clustering of highest and lowest occurrences in coincident levels rather than in consecutive ones, may be due to increasing sedimentary and taphonomic condensation bias within the transgressive systems tract.

Biostratigraphic changes by clusters of lowest or highest occurrences of taxa at successive stratigraphic levels, as well as the values of biostratigraphic turnover, are relevant also for the analysis and interpretation of palaeobiological events. The cluster of lowest occurrences of *Gonolkites* [M] and *Morphoceras* [M] at the level 23, which is not associated with or consecutive to any biostratigraphic event of highest occurrence, can be interpreted as evidence for palaeobiological processes and faunal turnover instead of increasing preservation potential, taphonomic condensation, sedimentary condensation or stratigraphic lacunae. Another argument or evidence in support of these palaeobiological changes, rather than preservational or observational biases, is the relatively low proportion of virtual gaps at the levels 23 and 24 that is indicative of good record quality. The lowest occurrences of *Gonolkites* [M] and *Morphoceras* [M] at the level 23 may be evidences of palaeobiological events, respectively, of origination of *Gonolkites* (from a species of *Parkinsonia*) and immigration of *Morphoceras*.

From a biochronostratigraphic point of view, through five metres of thickness of the Convergens Subzone, forty-six successive ammonoid fossil-assemblages in Ravin du Bès Section and fifty-two in Ravin d'Auran Section have been recognized (Fernández-López et al. 2007). The Bomfordi Subzone attains a minimum thickness of five metres and includes at least forty-two successive ammonoid fossil-assemblages. Consequently, this ammonoid succession at the Bajocian/Bathonian boundary in the Bas Auran area shows a maximum value of biostratigraphic and biochronostratigraphic completeness.

In summary, the record quality of the ammonoid biostratigraphic succession in Bas Auran area can be tested taking into account the discussed palaeontological criteria, from preservation state of fossils to occurrence of taxa. Values of these twenty-one palaeontological attributes indicate relatively homogeneous and good record quality, gradual biostratigraphic change and high degree of taxonomic similarity between the Bomfordi and Convergens subzones. These criteria, applied to the ammonoid genera which are known from Bas Auran area, also indicate relatively high values of palaeontological and stratigraphic completeness at the base of levels RB070-RB071 (= level 23 in Sturani

1967), which corresponds to the Bajocian/Bathonian boundary. The ammonoid biostratigraphic succession of Bas Auran shows no evidence of biochronostratigraphic mixing, condensation, signs of non-sequence or biostratigraphic discontinuities across the Bajocian/ Bathonian boundary interval. Moreover, with forty-six successive ammonoid fossil-assemblages of the Convergens Subzone the Ravin du Bès Section displays maximum values of biostratigraphic and biochronostratigraphic completeness, being one of the most complete in the world.

Discussion

A few Lower Bathonian successions could be compared with the one exposed in the Bas Auran area in terms of completeness of palaeontological record, biochronostratigraphic information, and evidence of biotas from three palaeobiogeographical provinces of the West Tethyan Subrealm, namely the Northwest European, Sub-Mediterranean and Mediterranean provinces.

Close similarities and precise correlation can be traced with the coeval succession of Cabo Mondego, in Portugal, which shows Sub-Mediterranean ammonoid assemblages (Fernández-López et al. 2006). Though the scarcity of Hecticoceratinae and abundance of Phylloceratina and Lytoceratina assure a Mediterranean pattern to the Subalpine Basin, both for Bajocian (Pavia 1973, 1983 a, b) and Bathonian (Olivero et al. 1997), the Cabo Mondego and Bas Auran successions have in common a large amount of Perisphinctidae. The co-presence and the equivalent range of some Bathonian Bigotitinae, in particular the dimorphic species *Bigotites diniensis* and *Bigotites mondegoensis*, assure so high-resolution chronocorrelation that their compared analysis allow subdivision of the Convergens and Parvum subzones in three biohorizons (from bottom to top: Diniensis, Mondegoensis, Protozigzagiceras), the upper one being characterized by the correlatable onset of the genus *Protozigzagiceras*, i.e. the starting step of the Bathonian Zigzagiceratinae subfamily. Differences against Cabo Mondego are registered in the biostratigraphic range of the dimorphic pair *Lobosphinctes* [M] - *Planisphinctes* [m]. In particular, *L. costulatosus* [M] and *P. tenuissimus* [m] fit exactly in the Bas Auran succession as dimorphic counterparts characterizing the Bomfordi Subzone, whereas their ranges at Cabo Mondego are partially separate with *P. tenuissimus* present also in the Parvum Subzone. Further differences against Cabo Mondego concern the specific biodiversity and frequency of Parkinsoniinae *Parkinsonia* and *Gonolkites* of the Bomfordi and Convergens subzones, that assign more Northwest European than Sub-Mediterranean affinities to the Bas Auran ammonoid assemblages.

Biochronocorrelation criteria could also be specified with areas of the north-eastern Tethyan border (Donetz, Crimea, Caucasus, Great Balkhan, Turkmenistan, Tadzhikistan, Uzbekistan, Kazakhstan). In this respect, the Lower Bathonian parkinsoniids from Turkmenistan show a high degree of specific similarities and the presence of many species of the genus *Gonolkites* (namely *G. convergens*, *G. subgaleatus*) assures a good correlation of the basal Zigzag Zone (Besnosov & Mitta 1998, 2000). As to Turkmenistan, morphoceratids do not seem so useful due to the absence of both *M. parvum* and *M. macrescens* which are expected to mark the base of the homonym subzones. Moreover, further correlations are obstructed by the absence of Zigzagiceratinae, unless the type of "*Franchia*" *sibiriakovae* and the specimen of "*Franchia*" aff. *sibiriakovae* (Besnosov & Mitta 2000, respectively pl. 7, fig. 5 and pl. 9, fig. 3) can be demonstrated to be early forms of *Protozigzagiceras* from the uppermost Convergens Subzone. A similar possibility regards the specimen recorded as *Zigzagiceras* sp. by Seyed-Emami et al. (1985) from the Lower Bathonian of the Dalichy Formation in NW Iran: this ammonite was compared to "*Zigzagiceras*" *torrensi variecostatum* Sturani, and its morphology fits the characteristics described for *Protozigzagiceras* by Fernández-López et al. (2007). Finally, little similarities can be outlined with the Sub-Mediterranean ammonoid assemblages of Central Poland, from the Czestochowa sections, except for parkinsoniids of the Convergens Subzone such as *Parkinsonia schloenbachi* and *Gonolkites subgaleatus* (Matyja & Wierzbowski 2000).

General comparisons with the Mediterranean successions described by Krystyn (1972) from Eastern Austrian and by Wierzbowski et al. (1999) and Schlögl et al. (2005) from Western Carpathians are assured by the ammonite content of the uppermost Bajocian and the Lower Bathonian, in particular for the high frequency of Phylloceratina and Lytoceratina. Actually, the Western Carpathian biostratigraphy is not so finely traceable to assure correlation at subzonal level, and the Austrian section is too condensed for precise definition. Nevertheless, it is worth noting the Mediterranean ammonoid assemblages of the Polish Pieniny Klippen Basin (Wierzbowski et al. 1999) in which the presence of *Nannolytoceras tripartitum* across the uppermost Bajocian to lowermost Bathonian needs comparison with the transition *N. subquadratum* to *N. tripartitum* discussed in the Bas Auran succession. Similar general remarks could be traced for the Hungarian successions and ammonoid assemblages described by Galácz (1980) at the Bajocian-Bathonian passage, due to the reduced thickness (Rosso Ammonitico facies).

Among the contributions on the Lower Bathonian biostratigraphy of the Northwest European Province (e.g. Westermann 1958; Callomon et al. 1987; Callomon

& Cope 1995; Page 1996; Dietze & Schweigert 2000; Dietze et al. 2004), the recent work of Dietze & Dietl (2006) could be assumed as reference for affinity with the ammonite succession of Bas Auran area. In particular, the Ipf section shows a good record of ammonite fossil-assemblages dominated by parkinsoniids of the passage Bajocian to Bathonian, and in this respect the dimorphic pair *Lobosphinctes* sp. and "*Planisphinctes*" *tenuissimus* assure correlation within the Bomfordi Subzone at the uppermost Bajocian. Unfortunately, the assemblages biochronologically referable to the Lower Bathonian show so clear taphonomic condensation (op. cit, p. 11) that any biochronostratigraphic conclusion can be drawn, though the presence of *Gonolkites convergens* and *Parkinsonia pachypleura* supports comparison with the ammonoid assemblages of the Bas Auran Convergens Subzone. In this respect, the microconch *Planisphinctes acurvatus*, occurring in the upper part of the Convergens Subzone, "Exstinctus Horizon", of the Swabian Alb (op. cit, p. 13, pl. 7, fig. 4) and regarded as the possible dimorphic counterpart of the macroconch *Bigotites mondegoensis* (Fernández-López et al. 2007), seems to testify the record of the Mondegoensis Horizon, distinguished in the middle part of the Parvum Subzone of both Cabo Mondego and Bas Auran successions.

Conclusions

The target of this work has been the description of the ammonoid assemblages and their uppermost Bajocian to lowermost Bathonian succession in the Bas Auran area. In particular, it is focused on the definition of the ammonite content at the base of the Zigzag Zone in view of choosing one of those sections to be selected as the G.S.S.P. of the Bathonian Stage. Three sections were studied along the Ravin du Bès, Ravin d'Auran and Ravin des Robines. Over 85 stratigraphic levels, through 9 m in thickness, of the Bomfordi to the Macrescens subzones were studied, of which, along up to 5 metres, 46 successive fossiliferous stratigraphic intervals have been recognized in the Convergens Subzone. The ammonoid specimens from Bas Auran succession are inventoried within the huge fossil collection of Middle Jurassic of Alpes-de-Haute-Provence country stored in the Museo di Geologia e Paleontologia of the Torino University. Among this rich material, 120 ammonites pertain to the Bomfordi Subzone, 398 to the Convergens Subzone, 111 to the first beds of the Macrescens Subzone. The ammonite content of the succession from the Bomfordi Subzone of the Parkinsoni Zone (topmost Bajocian) to the Zigzag Zone, namely the Convergens Subzone and the base of the Macrescens Subzone, has been detailed in the biostratigraphic logs of Figs. 5 and 6.

The following conclusions can be summarized:

1) The basal boundary of the Bathonian has been established at the base of limestone bed RB071 of the Ravin du Bès Section and at the base of the limestone bed RA085 of the Ravin d'Auran and RR085 of the Ravin des Robines sections, in both cases equivalent to the base of bed 23 in Sturani (1967).

2) The ammonoid assemblages from Bas Auran area indicate relatively high values of palaeontological and stratigraphic completeness at the base of level RB071 (= level 23 in Sturani 1967), which corresponds to the Bajocian/Bathonian boundary. The ammonoid biostratigraphic succession of Bas Auran shows no evidence of biochronostratigraphic mixing, condensation, signs of non-sequence or biostratigraphic discontinuities across the Bajocian/Bathonian boundary interval.

3) With forty-six successive ammonoid fossil-assemblages, belonging to three biohorizons distinguished within the Convergens Subzone through five metres of thickness, the Lower Bathonian successions of the Bas Auran area, and in particular the Ravin du Bès Section, display maximum values of biostratigraphic and biochronostratigraphic completeness, being one of the most complete in the world.

4) According to these results, the Bajocian-Bathonian section cropping out along the Ravin du Bès results to be the best reference for defining the basal boundary of the Zigzag Zone, and thus we recommend it will be chosen as the Global Stratotype and Section Point for the Bathonian Stage. The last sentence is also supported by the biostratigraphic data derived from the study of the calcareous nannofossils content (Erba 1990; Erba & Tiraboschi 2007, pers. comm.). In particular, the basal boundary of the Bathonian Stage in the Ravin du Bès Section is placed between the first occurrences of *Stephanolithus speciosum octum* at bed RB076 and *Watznaueria barnesiae* at RB068; this datum is extremely important for correlation purposes. Further information in this direction could derived from the study of foraminifer content, both on benthic and planktic forms, which is in progress at the Torino University (D. Violanti, pers. comm.).

Acknowledgements. This paper is dedicated in memory of prof. Carlo Sturani who in 1967 published the monograph on the Bathonian ammonites and their biostratigraphy of Bas Auran. His activity was unluckily interrupted in 1975, but his results keep high degree of relevance. It is a great honour to have the opportunity to complete a part of Sturani's work.

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PLATE 1

Fig. 1 - *Phyllopachyceras ebrayi* (Ferry). Right view of a nearly complete, slightly crushed specimen (PU111717). Dmax = 58.0 mm; at D = 55.0 mm, H = 33.4 (0.61), U = 2,4 (0.04). Ravin d'Auran Section, RA085 (= Sturani's bed 23). Base of the Convergens Subzone (Zigzag Zone, Bathonian).

Fig. 2 - *Nannolytoceras tripartitum* (Raspail). Left view of an incomplete phragmocone (PU111516). Dmax = 44.0 mm, H = 11.3 (0.26), W = 8,3 (0.19), U = 22.8 (0.52). Bas Auran sections, bed BA14. Convergens Subzone (Zigzag Zone, Bathonian).

Fig. 3 - *Nannolytoceras subquadratum* Besnosov. Right view of an incomplete specimen (PU111476). Dmax = 38.4 mm; at D = 31.8, H = 8.1 (0.25), W = 6.0 (0.19), U = 17.5 (0.55). Bas Auran sections, bed BA29. Bomfordi Subzone (Parkinsoni Zone, Bajocian).

Figs. 4, 5 - *Adabofoloceras wendti* (Sturani). Oral and right views of an incomplete phragmocone (PU111726). D max 55 mm; at D = 44.1, H = 26.1 (0.59), W = 18.3 (0.41), U = 2.2 (0.05). Bas Auran sections, bed BA13. Convergens Subzone (Zigzag Zone, Bathonian).

Figs. 6, 7 - *Cadomites* [m] cf. *stegeus* (Buckman). Left and ventral views of an adult microconch specimen with lappets (PU111006). Dmax = 50.6 mm, H = 16.7 (0.33), W = 20.7 (0.41), U = 19.4 (0.38), PR = 12 x half whorl. At D = 40.5, H = 14.6 (0.36), W = 22.3 (0.55), U = 15.4 (0.38). Bas Auran sections, bed BA24. Topmost Bomfordi Subzone (Parkinsoni Zone, Bajocian).

Figs. 8, 9 - *Cadomites* [m] *crassispinosus* Kopik. Left and oral views of an adult microconch specimen with lappets (PU111180). Dmax = 41.8 mm, H = 13.2 (0.32), W = 18.1 (0.43), U = 15.7 (0.38), PR = 25 x whorl. At D = 36.3, H = 13.8 (0.38), W = 18.3 (0.50), U = 12.5 (0.34). Bas Auran sections, bed BA16. Convergens Subzone (Zigzag Zone, Bathonian).

Figs. 10, 11 - *Cadomites* [m] *deslongchampsi* (d'Orbigny). Left and oral views of an adult microconch specimen with lappets (PU111024). Dmax = 41.2 mm; at D = 31.0, H = 9.6 (0.31), W = 17.6 (0.57), U = 12.9 (0.42), PR = 23 x whorl. Ravin d'Auran Section, RA033 (= Sturani's bed 12). Base of the Macrescens Subzone (Zigzag Zone, Bathonian).

Figs. 12, 13 - *Gonolkites convergens* Buckman. Left and oral views of an incomplete phragmocone (PU111067). Dmax = 63.4 mm, H = 24.3 (0.38), W = 19.7 (0.31), U = 24.2 (0.38), PR = 31 x whorl. Bas Auran sections, bed BA15. Convergens Subzone (Zigzag Zone, Bathonian).

Fig. 14 - *Gonolkites convergens* Buckman. Left views of an incomplete phragmocone (PU111099). Dmax = 88.3 mm, H = 34.2 (0.39), W = 27.3 (0.31), U = 30.1 (0.34), PR = 35 x whorl. Bas Auran sections, bed BA17. Convergens Subzone (Zigzag Zone, Bathonian).

The specimens figured here and in subsequent plates have been whitened with ammonium chloride prior to photography.
PR = Number of Primary Ribs at the measured whorl. For Cadomitinae, whorl width is measured out of tubercles. Black asterisks mark the last septum of the phragmocone. Scale bar = 1 cm.

PLATE 2

Figs. 1, 10 - *Parkinsonia* cf. *pachypleura* Buckman. Oral and left views of an adult microconch specimen with very short lappets (PU111358). Dmax = 110.0 mm, H = 38.7 (0.35), Wmin = 28.5 (0.26), U = 47.0 (0.43), PR = 38 x whorl. At D = 84.0, H = 26.7 (0.32), Wmin = 21.7 (0.26), U = 38.3 (0.46). Bas Auran sections, BA30. Bomfordi Subzone (Parkinsoni Zone, Bajocian).

Figs. 2, 3 - *Morphoceras parvum* Wetzel. Right and oral views of a nearly complete specimen (PU111564). Dmax = 46.4 mm, H = 16.5 (0.35), W = 13.3 (0.28), U = 16.2 (0.34). Bas Auran sections, bed BA17. Convergens Subzone (Zigzag Zone, Bathonian).

Fig. 4 - *Morphoceras parvum* Wetzel. Left and oral views of a nearly complete specimen (PU31513). Bas Auran sections, bed BA23. Base of the Convergens Subzone (Zigzag Zone, Bathonian).

Figs. 5, 6 - *Morphoceras* aff. *parvum* Wetzel. Oral and right views of an incomplete specimen (PU31532). Dmax = 37.4 mm, H = 15.5 (0.41), W = 8.6 (0.23), U = 4.3 (0.11). Bas Auran sections, bed BA14. Convergens Subzone (Zigzag Zone, Bathonian).

Figs. 7, 8 - *Cadomites* [m] *psilacanthus* (Wermbter). Left and oral views of an incomplete microconch specimen (PU111002). Dmax = 31.6 mm, H = 12.6 (0.40), W = 16.7 (0.53), U = 12.3 (0.39). PR = 24 x whorl. Bas Auran sections, bed BA23. Base of the Convergens Subzone (Zigzag Zone, Bathonian).

Figs. 9, 11 - *Parkinsonia pachypleura* Buckman. Ventral and right views of an incomplete specimen (PU111091). At D = 78.0 mm, H = 24.5 (0.31), W = 22.8 (0.29), U = 38.3 (0.49). PR = 32 x whorl. Bas Auran sections, BA14. Convergens Subzone (Zigzag Zone, Bathonian).

Fig. 12 - *Gonolkites convergens* Buckman. Left view of a nearly complete, fragmentary specimen (PU111132). At D = 120.0 mm, H = 38.2 (0.32), W = 29.0 (0.24), U = 37.2 (0.31). PR = 21 x half whorl. Bas Auran sections, bed BA23. Base of the Convergens Subzone (Zigzag Zone, Bathonian).

Fig. 13 - *Morphoceras macrescens* (Buckman). Right view of a nearly complete specimen (PU111174). Dmax = 75.0 mm, H = 22.7 (0.30), U = 28.5 (0.38). At D = 62.0, H = 19.0 (0.31), U = 16.8 (0.27). Bas Auran sections, bed BA12. Base of the Macrescens Subzone (Zigzag Zone, Bathonian).

Specimens of figures 2, 3 and 5,6 were restored by Sturani in 1975 with plaster, corresponding to smooth sectors of the moulds.
PR = Number of Primary Ribs at the measured whorl. For Cadomitinae, whorl width is measured out of tubercles. Black asterisks mark the last septum of the phragmocone. Scale bar = 1 cm.

PLATE 3

Fig. 1 - *Planisphinctes torrensi* (Stephanov). Right view of an adult microconch specimen with long lappets (PU111192). Dmax = 67.7 mm, H = 20.6 (0.30), W = ?15.4 (?0.23), U = 31.1 (0.46). PR = 45 x whorl. Bas Auran sections, BA34. Bomfordi Subzone (Parkinsoni Zone, Bajocian).

Figs. 2, 3 - *Planisphinctes tenuissimus* (Siemiradzki). Left and ventral views of an incomplete phragmocone (PU111226). Dmax = 40.7 mm, H = 13.3 (0.33), W = 13.2 (0. 32), U = 17.9 (0.44). PR = 60 x whorl. Ravin du Bès Sections, RB083 (= Sturani's interbed 26-27). Bomfordi Subzone (Parkinsoni Zone, Bajocian).

Fig. 4 - *Lobosphinctes costulatosus* (Buckman). Left view of an incomplete specimen (PU111201). Dmax = 71.8 mm; at D = 60.8 mm, H = 21.2 (0.35), W = 17.5 (0.29), U = 25.7 (0.42). PR = 62 x whorl. Bas Auran sections, bed BA28. Bomfordi Subzone (Parkinsoni Zone, Bajocian).

Fig. 5 - *Vermisphinctes* sp. Right view of an incomplete specimen (PU111381). Dmax = 64.2 mm; at D = 62.4 mm, H = 16.9 (0.27), W = 18.4 (0.29), U = 32.8 (0.53). PR = 55 x whorl. Bas Auran sections, bed BA34. Bomfordi Subzone (Parkinsoni Zone, Bajocian).

Figs. 6, 7 - *Franchia* [m] *arkelli* Sturani. Ventral and right views of a nearly complete, slightly deformed microconch specimen (PU111322). Bas Auran sections, bed BA12. Base of the Macrescens Subzone (Zigzag Zone, Bathonian).

Fig. 8 - *Bigotites* [m] *diniensis* Sturani. Left view of a fragmentary, adult microconch specimen with long lappets (PU111543). Ravin d'Auran Section, RA075 (= Sturani's bed 20). Convergens Subzone (Zigzag Zone, Bathonian).

Figs. 9, 10 - *Protozigzagiceras* [M] cf. *torrensi* (Sturani). Right and oral views of an incomplete macroconch specimen (PU111577). At D = 38.9, H = 13.2 (0.34), W = 16.9 (0.43), U = 17.8 (0.46). PR = 20 x half whorl. Ravin d'Auran Section, RA031 (= Sturani's bed 11). Macrescens Subzone (Zigzag Zone, Bathonian).

Figs. 11, 12 - *Protozigzagiceras* [m] cf. *torrensi* (Sturani). Left and oral views of an adult microconch specimen (PU111573). Dmax = 32.7, H = 10.1 (0.31), W = 9.9 (0.30), U = 16.7 (0.51). Ravin d'Auran Section, RA033 (= Sturani's bed 12). Base of the Macrescens Subzone (Zigzag Zone, Bathonian).

Fig. 13 - *Franchia* n. sp. ind. Right view of an incomplete specimen (PU111399) possibly representing a new still unnamed species. Dmax = ca. 140 mm; at D = 108.0, H = 39.5 (0.37), W = ca. 46 (ca. 0.43), U = 46.1 (0.43). Bas Auran sections, bed BA11. Macrescens Subzone (Zigzag Zone, Bathonian).

PR = Number of Primary Ribs at the measured whorl. Black asterisks mark the last septum of the phragmocone. Scale bar = 1 cm.

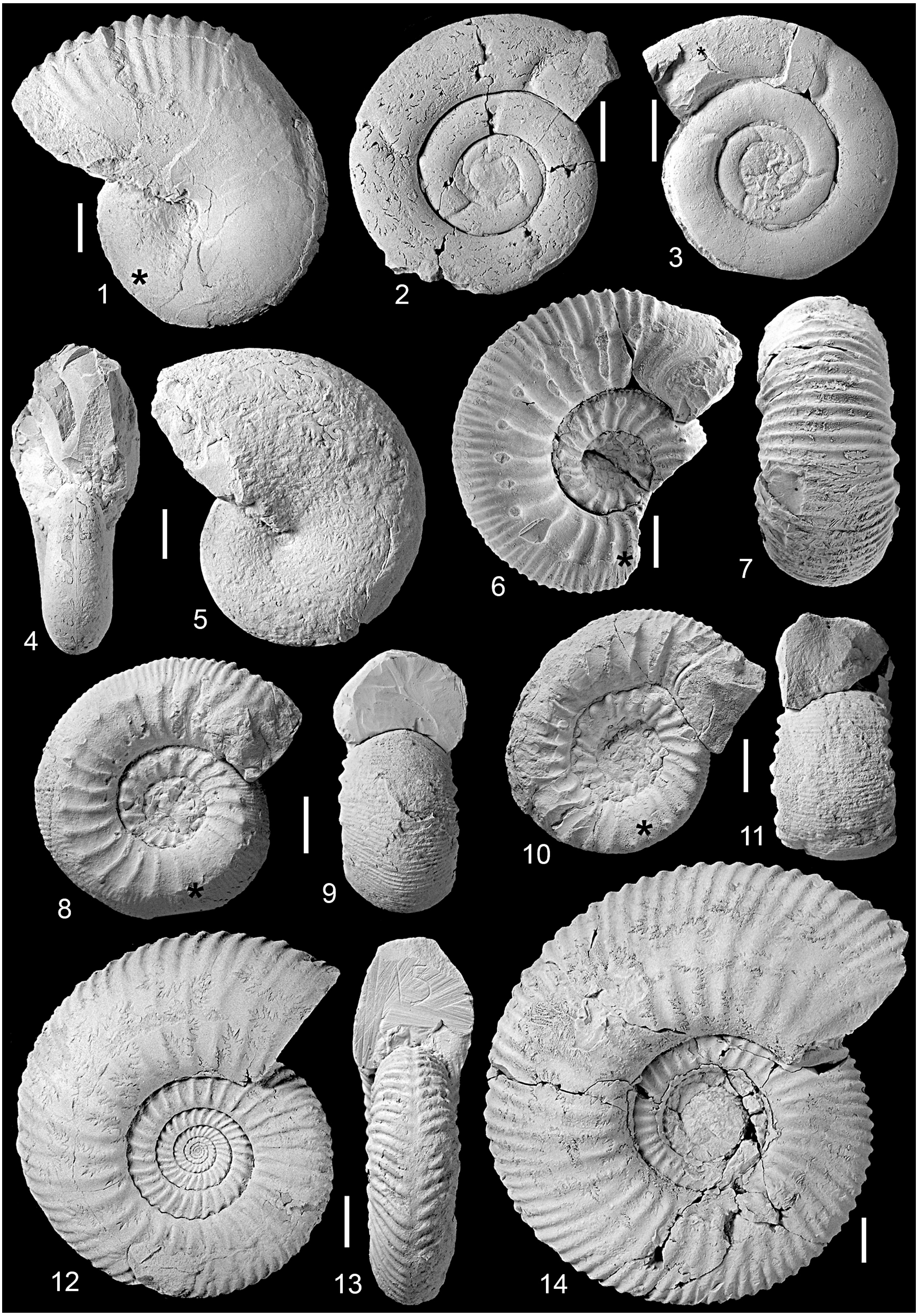

PLATE 1

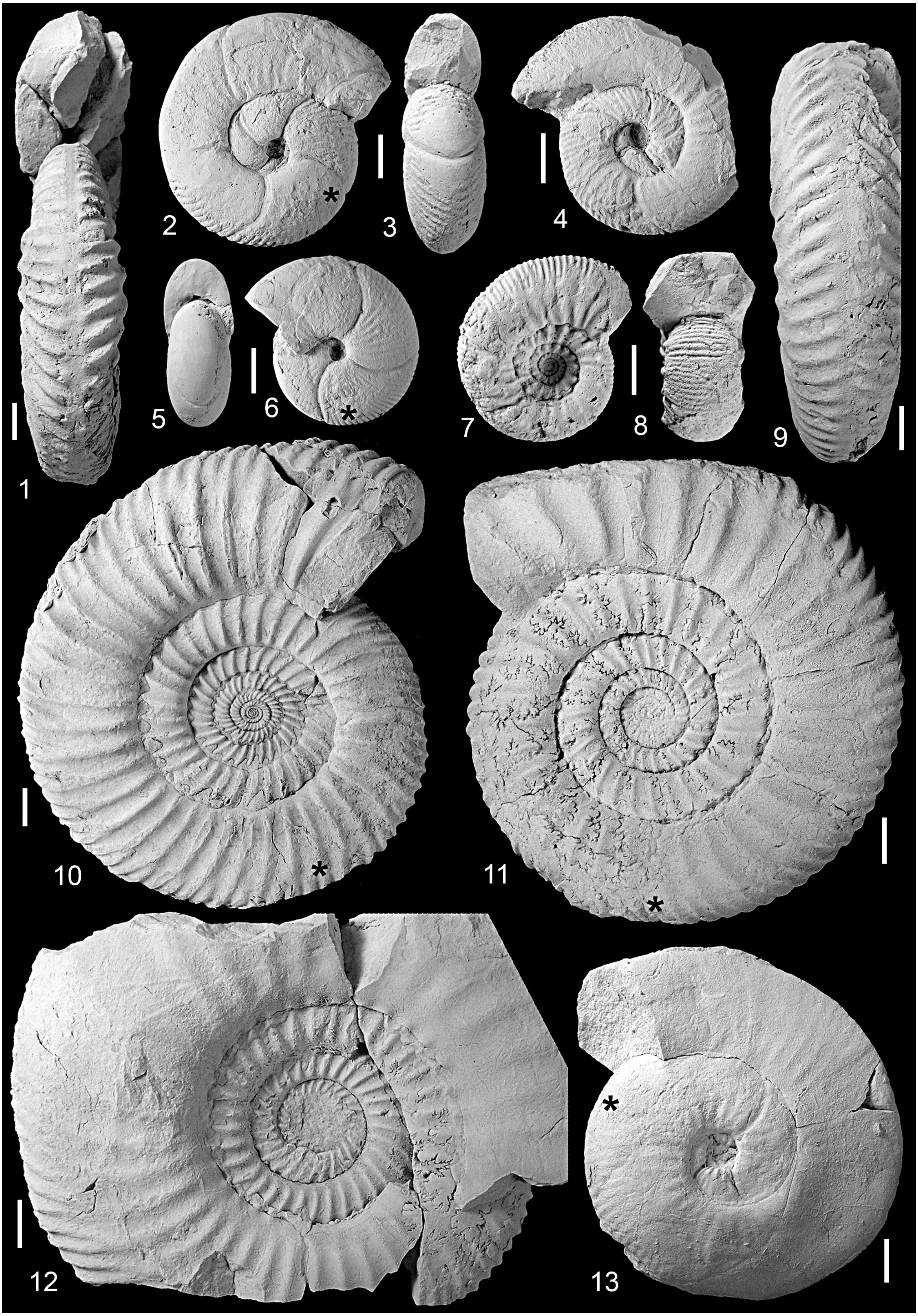

PLATE 2

PLATE 3

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