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The Global Boundary Stratotype Section and Point (GSSP) for base of the Bathonian Stage (Middle Jurassic), Ravin du Bès Section, SE France

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*The Bathonian GSSP is defined at the base of limestone bed RB071 in the Ravin du Bès Section, Bas-Auran area, southern Subalpine Chains (France). This section satisfies most of the requirements recommended by the International Commission on Stratigraphy. The exposure extends over 13 m in thickness. No vertical biofacies, ichnofacies or taphofacies changes, stratigraphic gaps or hiatuses have been recorded at the Bajocian-Bathonian transition. Structural complexity, synsedimentary and tectonic disturbances, or important alterations by metamorphism are not relevant constraints. There is a well-preserved, abundant and diverse fossil record, with key markers (ammonites and nannofossils). The base of Bathonian Stage and Zigzag Zone corresponds to the first occurrence level of *Gonolkites convergens* Buckman that coincides with the first occurrence of *Morphoceras parvum* Wetzel. Calcareous nannofossils are present in all beds. The GSSP is below the Tethyan calcareous nannofossil NJT10b/11 zonal boundary (lowest *Watznaueria barnesiae*) and above the Boreal nannofossil NJ10/11 boundary (lowest *Pseudoconus enigma*). Regional analyses of sequence stratigraphy and manganese chemostratigraphy are available. Spectral gamma-ray data corroborate interpretation of an Early Bathonian deepening half-cycle of second order. The*

criteria of accessibility, conservation and protection are assured by the “Réserve Naturelle Géologique de Haute Provence”. The Cabo Mondego Section (Portugal) is the Bathonian auxiliary section and point (ASSP). The proposal was voted by the Bathonian Working Group in December, 2007, and by the International Subcommittee on Jurassic Stratigraphy in March, 2008, approved by the ICS in June 2008, and ratified by the IUGS in July, 2008.

Introduction

For chronostratigraphic classification and correlation of the Jurassic, one fossil group is of prime importance – the ammonites. This is reflected in the GSSP for the base of the Bathonian Stage. One significant difference of usage between Jurassic stratigraphers and many others is that the standard ammonite zones and subzones are regarded as related to stages, namely as part of a hierarchy of chronostratigraphic units that do not overlap or leave gaps. In other words, a stage is a group of zones/subzones defined by reference to its basal standard zone or subzone. This does not remove the relevance of the base-stage GSSP – it simply moves it down to a lower level in the chronostratigraphic hierarchy.

The zones and subzones that are used in the Jurassic are assemblage zones based on the co-occurrence of several species of ammonites. First/last appearances of specific taxa are rarely used. The name given to a zone/subzone follows the precedent of Albert Opeel, who chose to use a fossil name to label his zones rather than a geo-

graphical name. This is normally reflected in the way the zone/subzone name is written – Zigzag Zone rather than *Zigzagiceras zigzag* Zone. It follows from this that the base of a zone/subzone is not necessarily recognised or defined by the first appearance of the taxon that gave its name to the zone/subzone; there may be other criteria.

The late Bajocian and early Bathonian was a time interval during which several groups of ammonites underwent rapid evolution and diversification, enabling very fine biochronological subdivision and precise correlation of strata of this age range. Thus, the primary marker for the base of the Bathonian is the evolution of *Gonolkites convergens* from late Bajocian *Parkinsonia*. However, the diversification was often accompanied by geographical variation and provincialization. Within most of the classical areas of Europe the provincialization did not lead to complete isolation, so that correlation through areas of mixed faunal assemblages remains possible. This is well illustrated in this GSSP, and reflected by the simultaneous definition, to consolidate correlation into the Mediterranean Province (where the first occurrence of *Morphoceras* is used to identify the base of the Bathonian), of an Auxiliary Stratotype Section and Point (ASSP). [This term is considered preferable to “Auxiliary Stratotype Point (ASP)” because it emphasizes the context of any point in a section; it is the small bodies of strata above/below the point that can be identified and correlated, not normally the point itself. Adoption of this modification of the term is recommended herein.]

However, geographical isolation did occur during the late Bajocian/early Bathonian. For example, direct correlation between the Boreal Province (Arctic) and the Northwest European Province is not possible even though the separation, from the northern North Sea to southern England, is only a few hundreds of kilometres. Recent studies, notably on the Russian Platform, have provided transitional links, enabling indirect correlation of the Boreal Province with the Western European and Sub-Mediterranean provinces. The current situation for correlation with other continents is also summarised; it should be possible to improve these in the future.

The range of secondary criteria for recognition and correlation of the base Bathonian boundary in the GSSP section is very limited, except for calcareous nannofossils and (possibly after further study), foraminifers. Although few secondary markers are available for this section (magnetostratigraphy, chemostratigraphy and biochronology based on other groups), it is possible to derive such data from other sections that can be correlated with high precision to the defined GSSP. Correlations already available for the zonal schemes of a number of fossil groups based on correlations with the ammonite zonal schemes in other areas are summarized here.

The area of the southern Subalpine Chains, which includes the defined GSSP, has been extensively remagnetized so that no consistent primary palaeomagnetic signal can be established. The limited data currently available for other regions, notably southern Spain, requires improved calibration with reference to the more detailed ammonite zonal and subzonal schemes. Similar comments apply to chemostratigraphy, for which future carefully focussed work will be required.

The primary purpose of the proposal by the Bathonian Working Group (convenor S. R. Fernández-López), and supported by the Jurassic Subcommittee, was to give the most precise definition practical and possible for this boundary. Since this must be based on

the ammonites, they have selected the best available section to fulfil this purpose.

Bathonian GSSP history

The Bathonian is the third of the four stages of the Middle Jurassic Series, above the Bajocian and below the Callovian. The name was introduced by d’Halloy (1843) and used as a stage by d’Orbigny (1850, pp. 607-608; 1852, pp. 491-492), derived from the “Bath Oolite”, in the vicinity of the city of Bath (SW England).

Zigzagiceras zigzag (d’Orbigny, 1846, p. 390, pl. 129, figs. 9-10; Arkell, 1958, p. 177, text-fig. 60, 1-3) and *Gonolkites convergens* Buckman (1925, pl. 546 A-B; Arkell, 1956, pl. 18, fig. 8; pl. 19, figs. 1-2) are the index species, respectively, of the Bathonian basal zone and subzone. The Zigzag Zone was distinguished from the underlying Parkinsoni Zone by Oppel (1857, p. 579, 1862), and later assigned to the “Bath-Gruppe” (Oppel, 1865, p. 309) in a discussion of the section at “Montagne de Crussol” in the Ardèche (France).

The Bajocian/Bathonian boundary established between the Parkinsoni and Zigzag zones was recommended at the two congresses called “Colloque du Jurassique” held in Luxembourg (1962, 1967; Rioult, 1964; Torrens, 1965, 1974a, b). The section at Bath (England) and the “Montagne de Crussol” (France), however, were considered unsuitable for a typological definition of the Bathonian Stage, because they are condensed sections with discontinuous and lenticular beds (Torrens, 1974a, b, 2002; Page, 1996b).

The Convergens Subzone was mentioned by Maubeuge (1950, p. 4), based on the “Convergens horizon” that was used in letters by Arkell (1951–59, p. 10; 1956, p. 62). The Parvum Subzone was proposed by Mangold (1990) to denote the first Bathonian subzone of the Zigzag Zone in the Sub-Mediterranean Province, equivalent to the Convergens Subzone of the Northwest European Province and below the Macrescens Subzone. Analogously, due to palaeobiogeographical changes, the Dimorphitiformis Subzone was proposed by Sandoval (1983) as the basal Bathonian subzone of the Zigzag Zone in the Mediterranean Province. Therefore, placing the basal boundary of the Bathonian at the base of the Northwest European Convergens Subzone of the Zigzag Zone can be justified because this is well preserved and recorded also in the Bas-Auran area, as is the Sub-Mediterranean Parvum Subzone. The bases of these subzones can be precisely correlated (Fernández-López et al., 2007; Pavia et al., 2008).

This paper summarizes relevant results published by specialists (Fernández-López et al., 2009) and incorporates comments and responses of the Bathonian Working Group and International Subcommittee on Jurassic Stratigraphy ballots (2007-2008) on the formal proposal for the Bathonian GSSP (Middle Jurassic) in the Ravin du Bès Section (Bas-Auran, SE France). The proposal was accepted by the International Commission on Stratigraphy (June, 2008) and ratified by the International Union of Geological Sciences in July, 2008.

Selecting the GSSP section and defining the boundary

The Bas-Auran locality was first mentioned by Haug (1891) and later visited by the French Geological Society (Zürcher, 1895). The Digne-Barrême area was noted by various authors as one of the most

important in the world for establishing the ammonite zonal succession of the Bathonian Stage (Garnier, 1872; Haug, 1891, p. 80; Guillaume, 1938; Arkell, 1956, p. 149). Sturani published in 1967 a detailed study of the Bajocian-Bathonian succession with a litho- and biostratigraphical log based on all the outcrops in the Bas-Auran area. Following the publication of Sturani (1967), the base of bed 23 in the Bas-Auran section, in which *Gonolkites convergens* Buckman, *Parkinsonia pachypleura* Buckman and *Morphoceras parvum* Wetzel first appear, was designated as the type locality at which to define the base for the Convergens Subzone of the Zigzag Zone and the base of the Bathonian Stage by several authors (Morton, 1974; Torrens, 1974a, b, 1987, 2002; Harland et al., 1982; Cox, 1990). Later, there was general agreement among Bathonian specialists that the Bathonian Stage should start with the Standard Zigzag Zone, whose base is defined by the Convergens Subzone (Horizon 1 of Mangold, 1984) followed by the Macrescens Subzone (Sturani, 1967). A partial revision of Sturani's work by Torrens (1987) was mainly on the Tenuiplicatus Subzone in the uppermost part of the marly-calcareous succession. This section was formally proposed as a candidate for the basal boundary stratotype of the Bathonian Stage by Innocenti et al. (1990) during the 2nd International Symposium on Jurassic Stratigraphy in Lisbon (1987). Contributions on the lowermost Bathonian beds were presented by Innocenti et al. (1990), inserting into Sturani's log new material derived from fieldwork over ten years.

Over the following 20 years, several meetings were organized by the Bathonian Working Group in Digne, La Palud, Budapest, Lyon and Torino. In the Bas-Auran area, the sections of Ravin du Bès, Ravin d'Auran and Ravin des Robines were reexamined and recollected for taphonomic, sedimentologic and palaeoichnological analyses during 2006 and 2007. Recent sampling, mainly concentrated on poorly documented and critical intervals, enlarged the Bas-Auran database from the Zigzag Zone, and furnished new and complementary results on the taphonomy of the ammonoid fossil-assemblages (Fernández-López, 2007), as well as on the taxonomy and phylogeny of Bathonian Bigotitinae and the origin of Zigzagiceratinae (Fernández-López et al., 2007). More recently Pavia et al. (2008): (1) Described the successive ammonoid assemblages of the uppermost Bajocian and lowermost Bathonian in the Bas-Auran area; (2) Refined the subzonal biostratigraphic subdivision of the marly-calcareous succession; (3) Detailed the ammonoid content of the very base of the Zigzag Zone; (4) Demonstrated the general continuity of the ammonoid succession; (5) Attested to the suitability of one of those sections to be selected as the GSSP of the Bathonian Stage.

Reports from the Bathonian Working Group were published by Mangold (from 1985 to 1999) and Fernández-López (from 2003 to 2007) as mentioned by Fernández-López (2009). Over all these many years, no other candidate section (except Cabo Mondego) was judged worthy of consideration.

A dossier, defining the GSSP for the Bathonian Stage at the base of the Zigzag Zone in the Ravin du Bès Section, was developed by several specialists and members of the Bathonian Working Group (BtWG). The proposal dossier was submitted for voting to all members of the Bathonian Working Group (S.R. Fernández-López, convenor) in December, 2007. The members of the Bathonian Working Group are: Alméras Y. (France), Bardhan S. (India), Bodergat A.M. (France), Callomon J.H. (UK), Cresta S. (Italy), Dietl G. (Germany), Dietze V. (Germany), Enay R. (France), Fernández-López S.R. (Spain), Galász A. (Hungary), Hall R.L. (Canada), Henriques M.H. (Portugal), Hillebrandt A. von (Germany), Lanza R. (Italy), Mangold C. (France),

Matyja B. (Poland), Meléndez G. (Spain), Mitta, V. (Russia), Mönnig, E. (Germany), Morton N. (France), Page K. (UK), Pandey D.K. (India), Pavia G. (Italy), Poulsen N. (Denmark), Poulton T.P. (Canada), Riccardi A.C. (Argentina), Rogov M.A. (Russia), Sandoval J. (Spain), Schlögl J. (Slovak Republic), Schweigert G. (Germany), Seyed-Emami K. (Iran), Wierzbowski A. (Poland), Yin J.-R. (China). The results of the vote (December 2007) were as follows: Total BtWG members = 33, YES votes = 31 (93.94%), NO votes = 1 (3.03%), ABSTAIN = 1 (3.03%), NO RESPONSE = 0. In order to achieve the formal ballot on the proposal of the Bathonian GSSP within the Voting Members of the International Subcommittee on Jurassic Stratigraphy (ISJS) during February-March 2008, an upgraded version of the dossier incorporating comments and responses of the BtWG ballot 2007 was presented (Fernández-López et al., 2009). The voting by the Voting members of the Jurassic Subcommittee (ISJS) on the proposal for the GSSP and ASSP for the base of the Bathonian Stage was completed on March, 2008: of 22 Voting Members, including the 3 Executive members, 21 (95.5%) returned a vote; of the 21 votes received 20 (95.2%) voted YES and 1 (4.8%) voted NO. The approved proposal, together with the dossier and a preface by the ISJS Chairman (N. Morton), were sent to the Secretary of the International Commission on Stratigraphy (J. Ogg), who forwarded it together with a voting form to all the members of the Commission, during May-June 2008. Voting result of the International Commission of Stratigraphy (ICS) was 13 YES (81%), approved in June 2008. Later, the ICS Secretary submitted the proposal to the Executive Committee of IUGS to ratify the Bathonian GSSP. The approved proposal was ratified by the IUGS in July, 2008.

The Ravin du Bès Section (Bas-Auran area)

The Bas-Auran sections are located in southeastern France, in the "Alpes de Haute Provence" French Department, in the Chaudon-Norante commune, approximately 25 km SSE of Digne-les-Bains (Fig. 1a). Three sections have been selected in two ravines (Fig. 1b). The first is the Ravin du Bès Section (RB), located near the l'Amata farm (the Bathonian GSSP site; coordinates: 43°57'38"N, 6°18'55"E, altitude 730 m). The second is the Ravin d'Auran Section (RA), located in front of the Bas-Auran farm (coordinates: 43°57'17"N, 6°18'56"E, altitude 790 m). The third, the Ravin des Robines Section (RR), is only 400 metres south of the RA section, along the Robines ravine (coordinates: 43°57'09"N, 6°18'50"E, altitude 830 m). All are located on the Castellane sheet of the "Carte géologique détaillée de la France" at the 1:80000 scale (Goguel, 1966), on the Digne sheet of the "Carte géologique de la France" at the 1:50000 scale (Graciansky et al., 1982) and on the topographic sheet, scale 1:25000, Barrême, no. IGN 3615.

Geological setting of the marly-calcareous succession from the Bajocian to Bathonian in the Digne area

The area studied is located in the French Subalpine Basin (FSB), corresponding to a gulf on the northwestern margin of the Tethyan Ocean (Fig. 2).

The basin is bordered by the "Massif Central" to the West and by the Alpine Chain to the East (Fig. 3a). During Middle Jurassic time, the basin margin was characterized by a network of tilted blocks similar

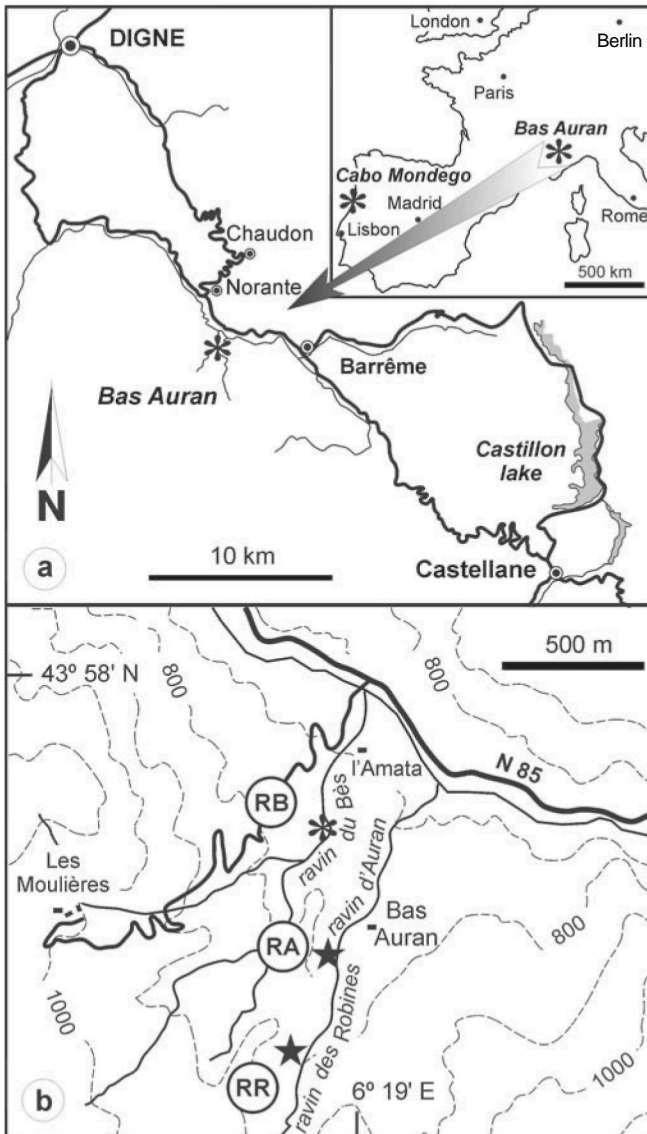


Figure 1. (a) Geographic location of the Bas-Auran area (France), (b) Topographic sketch of the Bas-Auran area and location of the three stratigraphic sections referring to the Bajocian/Bathonian boundary in the Bas Auran area. From north to south, Ravin du Bès Section ($43^{\circ}57'41''\text{N}$, $6^{\circ}18'58''\text{E}$; the Bathonian GSSP site), Ravin d'Auran Section ($43^{\circ}57'17''\text{N}$, $6^{\circ}18'56''\text{E}$) and Ravin des Robines Section ($43^{\circ}57'09''\text{N}$, $6^{\circ}18'50''\text{E}$).

to the present margin of the Atlantic Ocean (Lemoine, 1984, 1985). The maximum sea depth of the central part of the basin was probably about 700-800 metres (Ferry, 1990). The region was a transitional area between the epicontinental sea of the Paris Basin and the deep Piedmont oceanic domain. The thrust boundaries shown in the simplified tectonic map (Fig. 3b) correspond to the limits of the various tilted blocks. The Bas-Auran area, located in the middle of one of such block, was thus on the continental slope of the French Subalpine Basin. The succession studied is a cyclic marl-limestone alternation. In most previous works and on the geological map of Digne (Graciansky et al., 1982; Olivero and Atrops, 1996), it was described as the "Calcaires à *Cancellophycus*" Formation which, in this region, ranges from Aalenian to Bathonian and is covered by the "Terres Noires" Formation (Late Bathonian to Oxfordian). The "Calcaires à

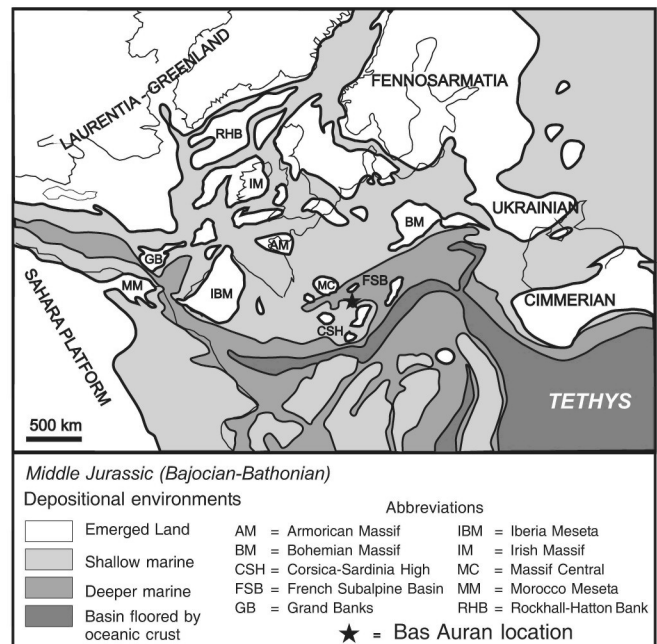


Figure 2. The northwestern margin of the Tethyan Ocean, with location of the French Subalpine Basin (modified from Ziegler, 1988).

Cancellophycus" Formation should not be mistaken for the partially coeval "Calcaires à *Zoophycos* du Verdon" Formation, Lower Bathonian to Middle Callovian in age, proposed by Olivero and Atrops (1996) in the southernmost transitional area, between the Subalpine Basin and the Provence Platform.

These sections, which are free of significant unconformities, range from the Bomfordi Subzone (Parkinsoni Zone, Upper Bajocian) to the Tenuiplicatua Subzone (Aurigerus Zone, Lower Bathonian) and are over 13 m thick. Structural complexity, syndimentary and tectonic disturbance, or significant alterations by metamorphism, are not relevant constraints in the Bas-Auran area.

Palaeoichnology, taphonomy, sedimentology and sequence stratigraphy of the upper Bajocian to lower Bathonian of the Bas-Auran area

In the Bas-Auran area, Lower Bathonian deposits comprise black or grey limestone beds alternating with marls usually known as "Marno-calcaires à *Cancellophycus*" (Graciansky et al., 1982; Olivero and Atrops 1996). Petrographically, and in terms of biofacies, these deposits are relatively uniform mudstones to wackestones, with common ammonoids, scarce sponges and very scarce nautiloids, brachiopods, bivalves, belemnites, echinoids, crinoids and gastropods. As to microfossils, the overall sedimentary facies shows a calcisphere-mudstone texture; the marls contain foraminifers (*Lenticulina*, *Dentalina*), ostracods and molluscs (cephalopods, bivalves, gastropods) along with detrital minerals, quartz, muscovite and biotite (Corbin et al., 2000).

Palaeoichnological studies have been carried out by Olivero (1994, 2003). Bioturbation textures are common and bioturbation structures are scarce, indicating dominant softgrounds. *Zoophycos*, *Chondrites* and *Planolites* occur in beds RB093 to o RB001. Local concentrations of trace fossils of these ichnotaxa in bed RB039 suggest

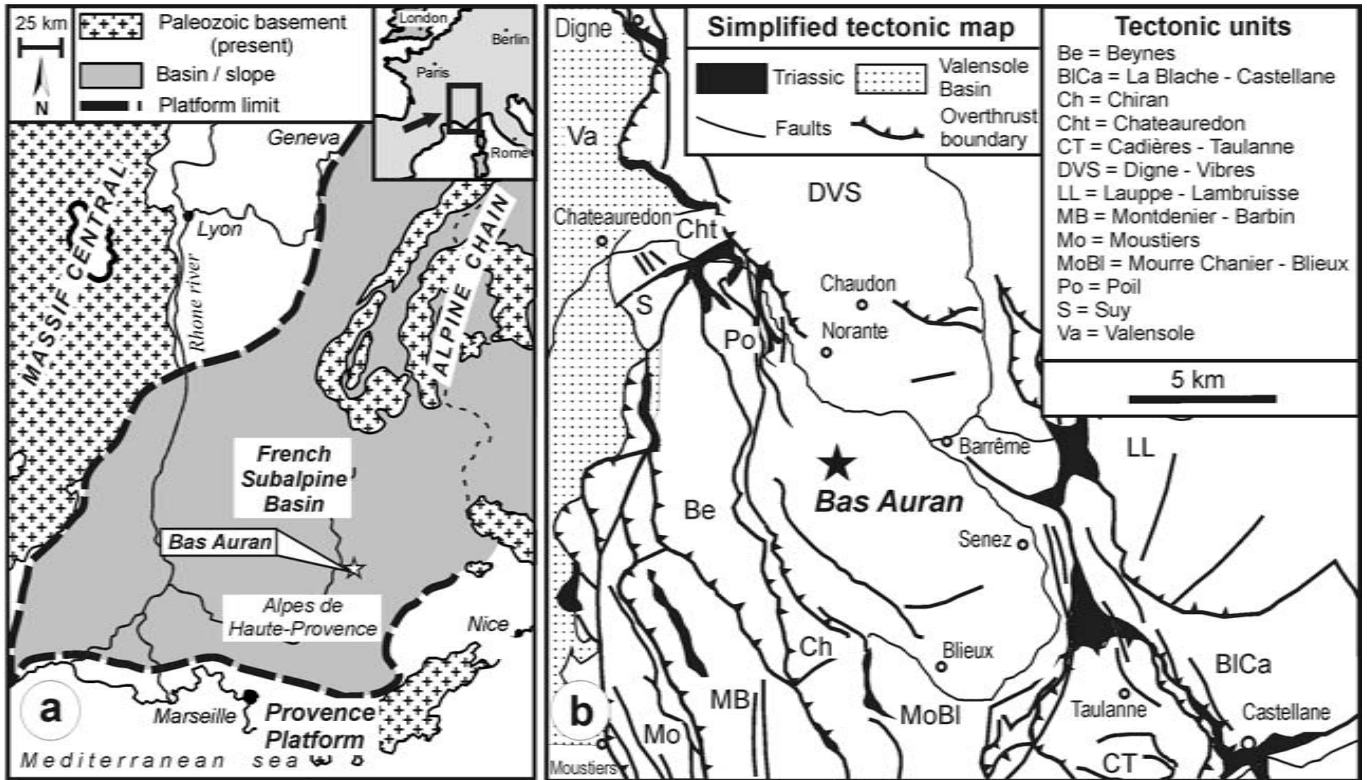


Figure 3. (a) The French Subalpine Basin, with the location of the Bas-Auran area (from Olivero 2003, modified). (b) Simplified tectonic map of the Bas-Auran region (Olivero, 2003; modified from Graciansky et al., 1982).

the development of a soft- to firmground at this stratigraphic level (Figs. 4-5). Bioturbation structures indicative of firmground (*Thalassinoides*, *Rhizocorallium*, *Zoophycos* and trace fossils related to large *Halimedes*) occur in a more calcareous layer just overlying the top of bed RB003. Biogenic borings indicative of hardground (*Zapfella*) are common, associated with very scarce encrusting serpulids, on the top of bed RB001 and the top of the whole RB section, indicating the exceptional development of a stratigraphic discontinuity at the top of the “Marno-calcaires à *Cancellophycus*” in the Bas-Auran area. Sedimentation appears irregular and condensed from bed RB093 towards the top of the Bathonian Zigzag Zone, compared with previous intervals where a more constant and expanded sedimentation is suggested. At the Bajocian-Bathonian transition, however, no stratigraphic gaps or hiatuses have been recorded.

From a taphonomic point of view (Fig. 6), the occurrence of reworked ammonoids (i.e. exhumed and displaced before their final burial) implies that some form of current flow or winnowing affected the burial of concretionary internal moulds (Fernández-López, 2007). Ammonoids show the following taphonomic characters at the Bajocian-Bathonian transition: (1) high values of stratigraphic persistence of ammonoid shells, (2) dominance of homogeneous concretionary internal moulds of phragmocones, completely filled with sediment, and (3) dominance of unflattened sedimentary moulds bearing no signs of rounding, bioerosion or dense encrusting by organisms (such as serpulids, bryozoans or oysters). These taphonomic features are indicative of a low rate of sedimentation and a low rate of accumulation of sediment, associated with sedimentary starvation in deep environments, according to the model of Fernández-López (1997, 2000a, 2008) and Fernández-López et al. (2002).

The bed-scale limestone-marl alternation is primary in origin, although accentuated by diagenetic redistribution of carbonate. Lithological differentiation between marly and limestone intervals resulted from alternating episodes of carbonate input and starvation. Both lithologies may contain evidence of sedimentary and taphonomic reworking, associated with scours, which reflect low rates of sedimentation and stratigraphic condensation. There is no evidence, however, of taphonomic condensation (i.e. mixture of fossils of different age or different chronostratigraphic units) in the ammonoid fossil-assemblages, except in level 002 (Fernández-López, 2007).

Sedimentological data and sequence-stratigraphy interpretations of these sections have been published by Ferry and Mangold (1995) and Olivero et al. (1997). In the Jurassic deposits of the French Subalpine Basin, sixth to second order cycles may be recognized (Ferry et al., 1989, 1991; Ferry and Mouterde, 1989; Mouterde et al., 1989; Zany et al., 1990; Ferry, 1991; Ferry and Dromart, 1991; Graciansky et al., 1993, 1998a, b; Ferry and Mangold, 1995; Olivero and Atrops, 1996; Hardenbol et al., 1998; Jacquín et al., 1998; Lemoine et al., 2000; Leonide et al., 2007; Olivero and Gaillard, 2007; De Baets et al., 2008).

Palaeoichnological, taphonomic and sedimentological results confirm, therefore, the development of a deepening phase associated with sedimentary starvation, within 3rd and 2nd order cycles, in the Bas-Auran area, during the Early Bathonian. The maximum deepening of a 2nd-order transgressive/regressive facies cycle (T/R 7, Upper Aalenian–Upper Bathonian, in Graciansky et al., 1993, 1998) is at the end of the Early Bathonian, which corresponds to an extensional and deepening phase of the basin. The outcrop successions at Bas-Auran show no obvious signs of non-sequence or discontinuity across the Bajocian/Bathonian boundary interval.

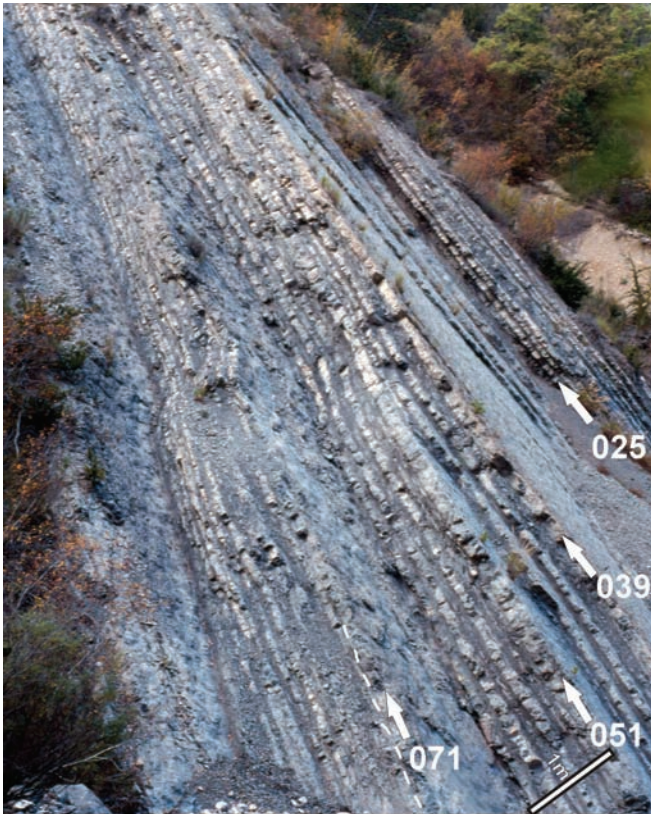


Figure 4. Ravin du Bès outcrop. Limestone bed 071 (above broken line) is the Bathonian GSSP level.

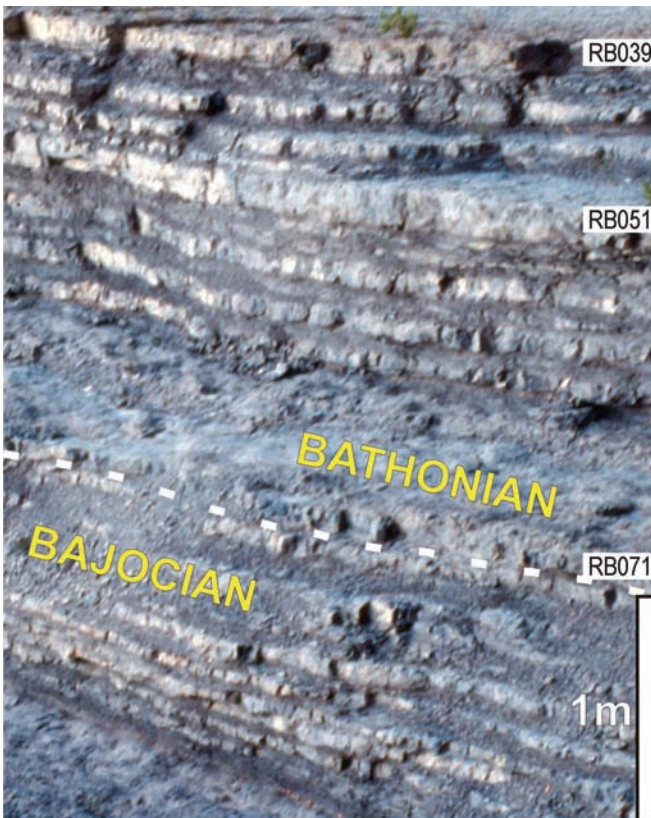


Figure 5. Detail of beds around the Bajocian/Bathonian boundary in the Ravin du Bès Section. Limestone bed 071 indicates (broken line) the base of the Bathonian. Scale bar 1 m.

Palaeontological records

The Bomfordi and Convergens subzones in the Bas-Auran area contain an ammonoid succession that displays a maximum value of biostratigraphic and biochronostratigraphic completeness. Additional macrofossil groups occur in the sections (e.g. sponges, bivalves, brachiopods and belemnites), although they are scarce and have not yet been studied in detail.

Ammonites

Biochronostratigraphic data on ammonoids of the Bas-Auran sections have been published by Sturani (1967), Pavia (1973, 1983a, b, 1984, 1994, 2000, 2007), Torrens (1987), Innocenti et al. (1990), Olivero et al. (1997) and Joly (2000). New and complementary results from the biochronostratigraphic analyses of ammonoid fossil-assemblages at the Bajocian/Bathonian boundary in Bas-Auran have been recently published (Fig. 7; Fernández-López et al., 2007, Pavia et al., 2008). In the French Subalpine Basin, the successive ammonoid fossil-assemblages are composed of Mediterranean and Northwest European representatives, associated with some Sub-Mediterranean ones. Upper Bajocian and Lower Bathonian Phylloceratina and Lytoceratina, which represent Mediterranean taxa, are relatively common (up to 25% at subzonal scale). Northwest European taxa, such as Parkinsoniinae, may surpass 25% at subzonal scale. Lower Bathonian Bigotitinae, endemic and characteristic of the Sub-Mediterranean Province, reach 13%. This complex palaeobiogeographical pattern of the Upper Bajocian and Lower Bathonian ammonoid fossil-assemblages enables recognition of diverse subzonal schemes and accurate chronocorrelation between the three main provinces of the West Tethyan Subrealm.

Biochronostratigraphic features of the Bathonian boundary in Bas Auran area are the low biostratigraphic and faunal turnovers of the ammonoid succession across the Bajocian/Bathonian transition. Among the possible guide fossils for the Bajocian/Bathonian boundary, Parkinsoniidae have a better record than Morphoceratidae. The lowest occurrences of *Gonolkites* [M] and *Morphoceras* [M] may be evidence of palaeobiological events, respectively, of origination of *Gonolkites* (from a species of *Parkinsonia*) and immigration of *Morphoceras*. The base of the Bathonian and of the Zigzag Zone corresponds to the first occurrence level of *Gonolkites convergens* and the renewal of parkinsoniids (first fossil assemblage including several species of *Parkinsonia* and *Gonolkites*) at the base of limestone bed RB071 (bed 23 in Sturani 1967) in the Ravin du Bès Section. Additionally, the base of the Bathonian in Bas-Auran sections also coincides with the lowest occurrence of *Morphoceras parvum*. Thus, the bases of the Northwest European primary standard Convergens Subzone and the Sub-Mediterranean secondary standard Parvum Subzone are in fact precisely coeval in the Bas-Auran area.

The basal ammonite assemblage includes the following ammonite species (Fig. 8):

- Oxycerites limosus* (Buckman) [M],
- Cadomites deslongchampsii* (d'Orbigny) [M+m],
- Cadomites crassispinosus* Kopik [M+m],
- Cadomites stegeus* (Buckman) [M+m],
- Cadomites psilacanthus* (Wermbter) [M+m],
- Cadomites* gr. *rectelobatus* (Hauer) [M],
- Parkinsonia subplanulata* Wetzel [m+M],
- Gonolkites subgaleatus* (Buckman) [M],
- Gonolkites convergens* Buckman [M],
- Morphoceras parvum* Wetzel [M].

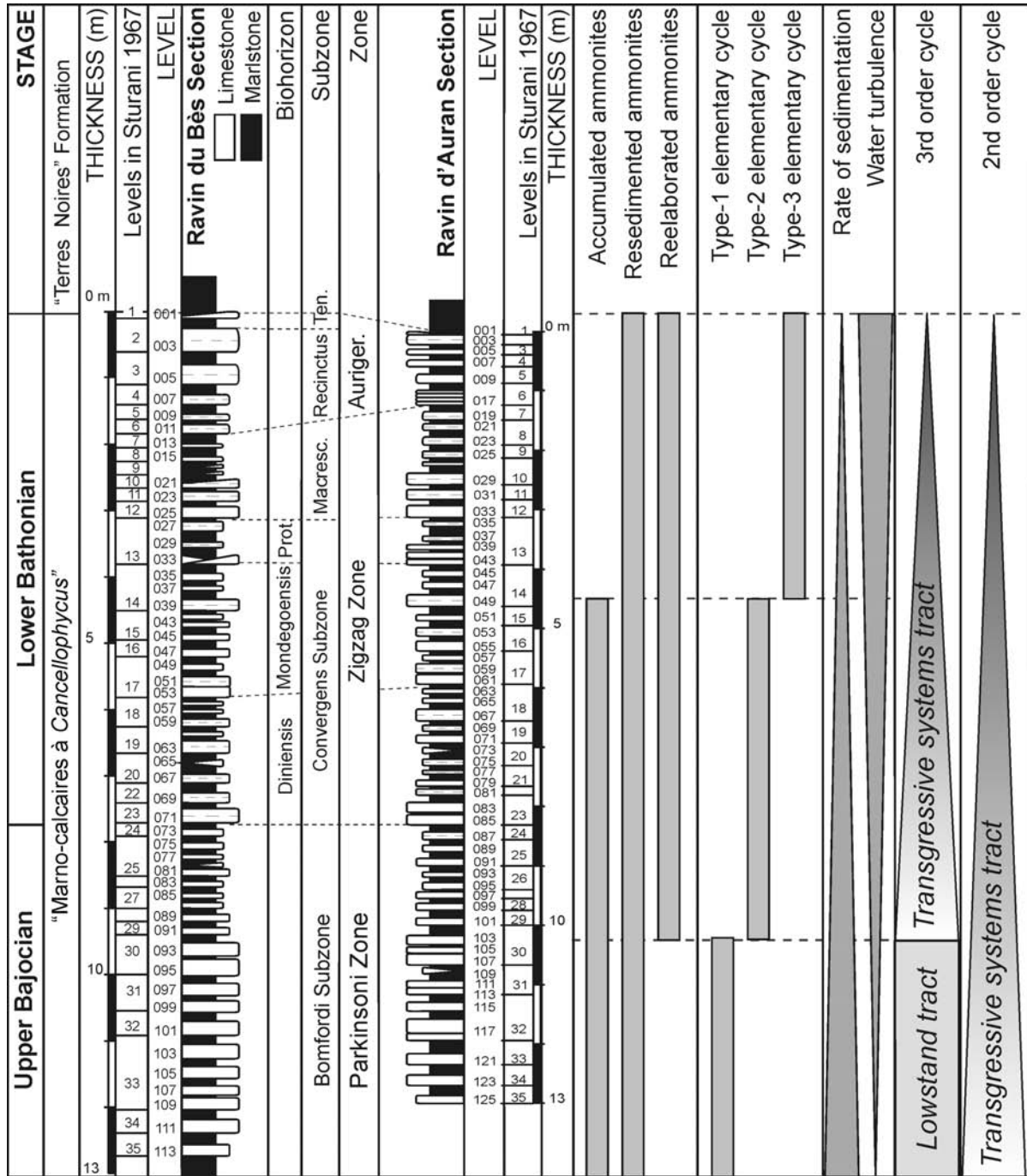


Figure 6. Ammonoid biostratigraphic data at the Bajocian/Bathonian boundary in the Ravin du Bès and Ravin d'Auran sections, indicating ammonoid preservation states, types of elementary cycles, and system tracts of 3rd and 2nd order cycles (modified from Fernández-López, 2007).

The potential ammonite content of the basal Bathonian fossil-assemblage could be enlarged by the following taxa, known from below and above but not actually in the basal bed:

- Cadomites sturani* Galácz [M+m],
- Polyplectites rozyckii* (Kopik) [m],
- Parkinsonia* cf. *subplanulata* Wetzel [m+M],
- Parkinsonia crassa* Nicolesco [m+M],
- Parkinsonia schloenbachi* Schlippe [m+M],
- Planisphinctes planilobus* Buckman [m],
- Phaulozigzag phaulomorphus* Buckman [m].

Similarly, the following species of Phylloceratina and Lytoceratina

could also be part of a basal Bathonian fossil-assemblage (Pavia et al., 2008; Fernández-López et al., 2009):

- Phylloceras kudernatschi* (Hauer),
- Adabofoloceras subobtusum* (Kudernatsch),
- Adabofoloceras wendtii* (Sturani),
- Phyllopachyceras ebrayi* (Ferry),
- Calliphylloceras ahtalense* (Redlich),
- Calliphylloceras* gr. *disputabile* (Zittel),
- Nannolytoceras tripartitum* (Raspail),
- Lytoceras* gr. *eudesianum* (d'Orbigny).

New palaeontological data about the youngest members of

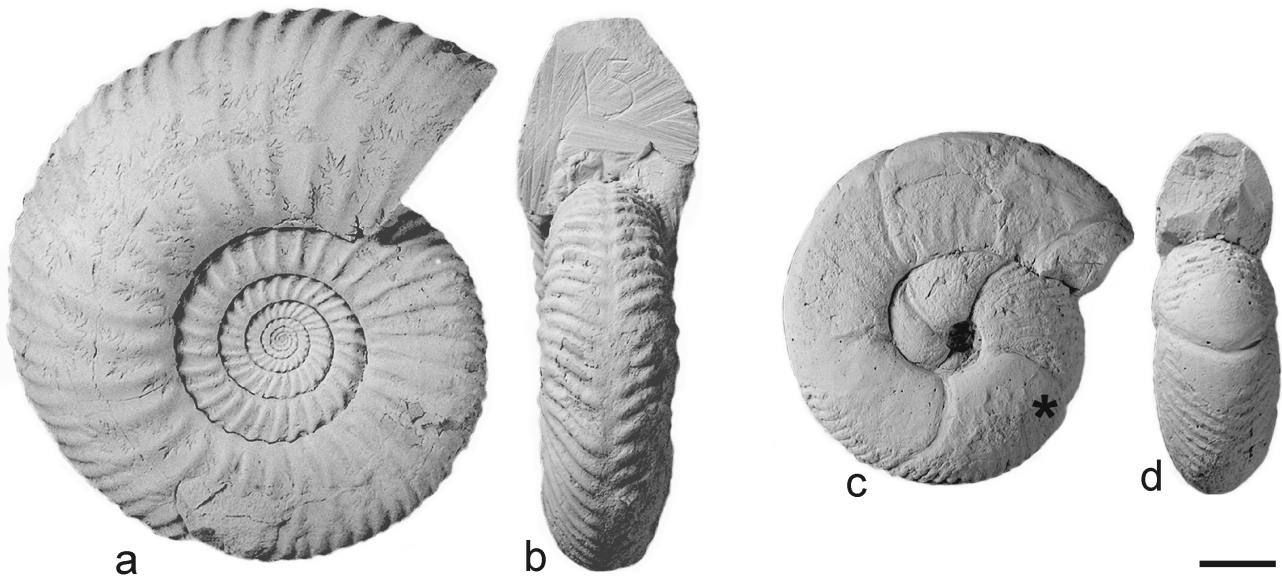


Figure 7. Lower Bathonian ammonites from Bas-Auran area. Specimens have been whitened with magnesium oxide prior to photograph. The black asterisk marks the last septum of the phragmocone. Scale bar 1 cm. (a) *Gonolkites convergens* Buckman [M], specimen PU111067, level BA15, *Convergens* Sbz. (b) *Morphoceras parvum* Wetzel [M], specimen PU111564, level BA17, *Convergens* Sbz. 8ab.

Bigotitinae and the oldest members of Zigzagiceratinae are of biochronostratigraphic importance for the subdivision and correlation of the basal Bathonian Zigzag Zone. Three successive biohorizons have been identified and chronocorrelated between the Bas-Auran (French Subalpine Basin) and Cabo Mondego (Lusitanian Basin) successions (Fernández-López et al., 2007; Pavia et al., 2008):

- (1) The Diniensis Biohorizon is characterized by the occurrence of *Bigotites diniensis* and corresponds to the lowest part of the Bathonian Zigzag Zone in the Sub-Mediterranean Province (e.g., Cabo Mondego and Bas-Auran). It encompasses the stratigraphic intervals RA085-RA062 (Fig. 6, levels 23-18 of Sturani 1967) in Ravin d'Auran Section and RB071-RB054 (Fig. 8, levels 23-18 of Sturani 1967) in Ravin du Bès Section.
- (2) The Mondegoensis Biohorizon is defined by the lowest occurrence of *Bigotites mondegoensis*. It comprises the stratigraphic intervals RA061-RA044 (Fig. 6, levels 17-14 of Sturani, 1967) in Ravin d'Auran Section and RB053-RB034 (Fig. 8, levels 17-14 of Sturani 1967) in Ravin du Bès Section.
- (3) The Protozigzagiceras Biohorizon is defined by the lowest occurrence of Zigzagiceratinae, in particular *Protozigzagiceras* [M+m] and *Franchia* [M+m]. It encompasses the stratigraphic intervals RA043-RA034 (Fig. 6, level 13 of Sturani, 1967) in Ravin d'Auran Section and RB033-RB026 (Fig. 8, level 13 of Sturani, 1967) in Ravin du Bès Section.

According to Pavia et al. (2008), the quality of the record of the ammonoid biostratigraphic succession in the Bas-Auran area can be tested with various palaeontological criteria: the preservation state of fossil-specimens, taphonic populations and fossil-assemblages; abundance, concentration, packing and stratigraphic persistence of fossil-specimens; completeness, constancy and persistence of stratigraphic ranges; completeness and taxonomic diversity of successive fossil-assemblages; biostratigraphic turnover; proportion of virtual and actual palaeontological gaps in successive stratigraphic intervals; proportion of first and last occurrences of taxa; proportion of lowest and highest occurrences of taxa; successive or coincident

clustering of last and first occurrences. Values of these twenty-one palaeontological attributes indicate a 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 the 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; i.e., the Bajocian/Bathonian boundary). The ammonoid biostratigraphic succession of Bas-Auran shows no evidence of biochronostratigraphic mixing, taphonomic 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, through up to 5 metres of thickness belonging to three biohorizons, the Ravin du Bès Section displays maximum values of biostratigraphic and biochronostratigraphic completeness.

Microfossils

The Bajocian/Bathonian boundary may be characterized by secondary (auxiliary) biostratigraphic markers, such as nannofossils. According to the results of Erba (1990a, b; Cobianchi et al., 1992; Mattioli and Erba, 1999), calcareous nannofossils are present in all beds and facilitate the characterization of the Bajocian-Bathonian transition. The Ravin du Bès Section appears to be suitable for the biostratigraphical study of microfossils, such as foraminifers or ostracods, but there are at present no published studies. According to preliminary results (Bodergat in Mangold, 1999), ostracods are present in all marly samples, but are badly preserved between bed RB071 and bed RB033. The marine taxa are different from those known in the Paris Basin and England. The Subalpine taxa, specially the genera *Pontocyprilla*, *Isobythocypris* and *Cordobairdia*, indicate deeper environments (more than 200 m). Palynomorphs are poorly preserved and are not yet stratigraphically useful across the boundary (Poulsen, 1997; Mangold, 1999).

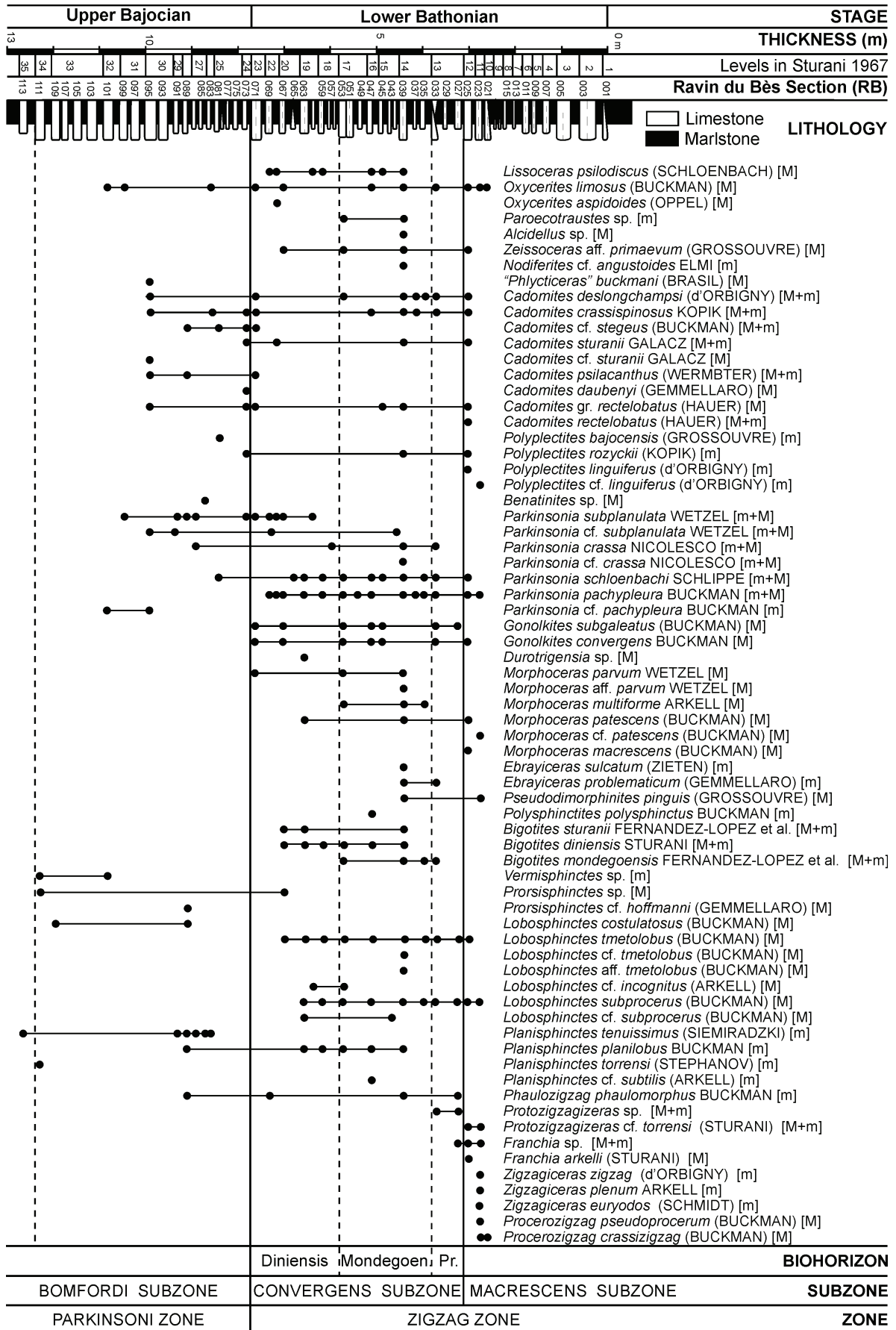


Figure 8. Ammonitina biochronostratigraphic data at the Bajocian/Bathonian boundary in the Ravin du Bès Section [M= macroconchs, m= microconchs] (from Pavia et al., 2008).

Calcareous nannofossils

Nannofossil biostratigraphic investigation was performed on 59 samples (approximately every 20 cm) collected from the Ravin du Bès section in the Bas-Auran area; sample figures correspond to the bed numbers of the lithostratigraphic column of Fig. 6. This study is a revision of the previous work by Erba (1990a, b), extended to limestone layers and additional marlstone beds (Erba and Tiraboschi in Fernández-López et al., 2009).

All studied samples contain calcareous nannofossils. A total of 37 taxa were identified. The nannofossil total abundance fluctuates from extremely rare to common; the preservation is poor to moderate, with evidence of dissolution and overgrowth. Limestone levels generally contain depauperated and poorly preserved nannofloras, with stronger overgrowth and dissolution.

The nannofloras are characteristic of the Upper Bajocian–Lower Bathonian interval. Assemblages are dominated by *Watznaueria britannica* and *Watznaueria communis*, with common *Schizosphaerella punctulata*, *Watznaueria* aff. *W. manivittiae*, *Watznaueria manivittiae*, *Cyclagelosphaera margerelii*, *Cyclagelosphaera deflandrei*, *Lotharingius crucicentralis*, *Lotharingius velatus*, *Lotharingius sigillatus* and *Ethmorhabdus gallicus*.

Based on absence of *Carinolithus superbus* and of *Watznaueria barnesiae*, the lowermost portion of the investigated interval (samples 110 through 68b) corresponds to the Tethyan *W. communis* Subzone (NJT 10b) indicating a Late Bajocian age (Mattioli and Erba, 1999). This subzone corresponds to the upper part of the Boreal NJ 10 Zone and the lower part of the NJ 11 Zone of Bown and Cooper (1998). The first occurrence (FO) of *Pseudoconus enigma* in sample 89 identifies the NJ10/NJ11 zonal boundary (Figs. 9–10). This taxon is rare and occurs only in limestones, with the only exception of a single specimen in marlstone sample 20, and this is why Erba (1990b) did not report this species.

The last occurrence (LO) of *Hexalithus magharensis* was observed in sample 82 indicating a latest Bajocian age (Mattioli and Erba, 1999). Similarly, Erba (1990b) recorded this event in the Parkinsoni Zone (latest Bajocian) of the Digne area, whereas in Portugal and Morocco de Kaenel et al. (1996) found an older age for the LO of *H. magharensis*, calibrated between the end of the Early Bajocian and the beginning of the Late Bajocian.

The FO of *Stephanolithion speciosum octum* was observed in sample 76; the taxon is extremely rare and scarce in the studied section. This event has been correlated to the base of the Parkinsoni Zone in NW Europe and Portugal (de Kaenel et al., 1996), but within the Zigzag Zone in SE France (Erba, 1990b). Bown et al. (1988) and Bown and Cooper (1998) report the FO of *S. speciosum octum* at the base of the Boreal NJ 11 Zone.

The FO of *W. barnesiae* (NJT11) was observed in sample 68a of earliest Bathonian age (Zigzag Zone). This event defines the base of the Tethyan NJT11 Zone (Mattioli and Erba, 1999), comparable to most of the Boreal NJ11 Zone and NJ12a Subzone (Bown et al., 1988; Bown and Cooper, 1998).

The uppermost portion of the studied interval corresponds to the Tethyan NJT 11 Zone (Mattioli and Erba, 1999), since *Cyclagelosphaera wiedmannii* was not observed.

From sample 89 upwards, rosette-shaped specimens likely to belong to the genus *Rucinolithus* were consistently observed. They show highest abundance in the interval between sample 45 through 22 (Fig. 9), both in limestone and marlstone beds. Two morphotypes

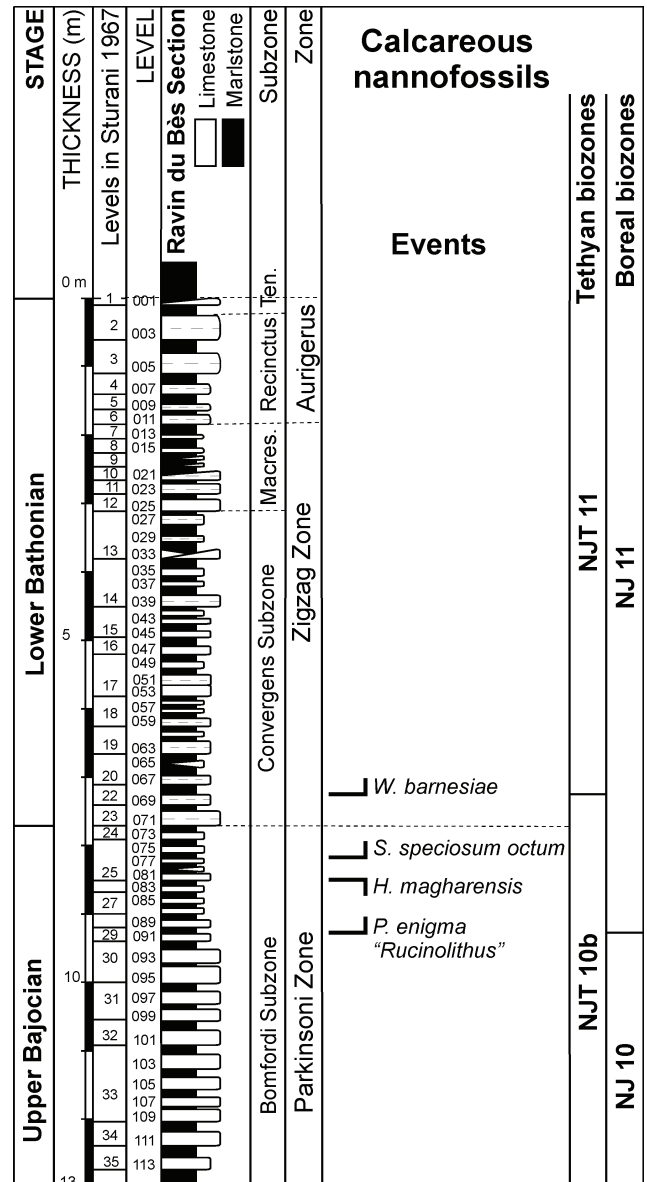


Figure 9. Nannofossil events detected in the Ravin du Bès Section (modified from Erba & Tiraboschi in Fernández-López et al. 2009). Tethyan biozones after Mattioli and Erba (1999) and Boreal biozones after Bown and Cooper (1998).

were distinguished, namely small (< 7.5 microns) and large (> 7.5 microns) "*Rucinolithus*" spp., based on their diameter (Tiraboschi and Erba, 2008). More detailed investigations are in progress to characterize the taxonomy of these morphotypes.

Our results are consistent with previous biostratigraphic data from the Upper Bajocian–Lower Bathonian interval in SE France (Erba, 1990b), Portugal, NW Europe (de Kaenel and Bergen, 1993; de Kaenel et al., 1996), Lombardian Basin (Chiari et al., 2007) and Boreal Realm (Bown and Cooper, 1998). For the first time *P. enigma* has been documented from mid to low latitudes allowing a direct calibration between Tethyan and Boreal nannofossil events and biozones (Figs. 9–10).

Correlation

Ammonites are the most relevant taxonomic group for global

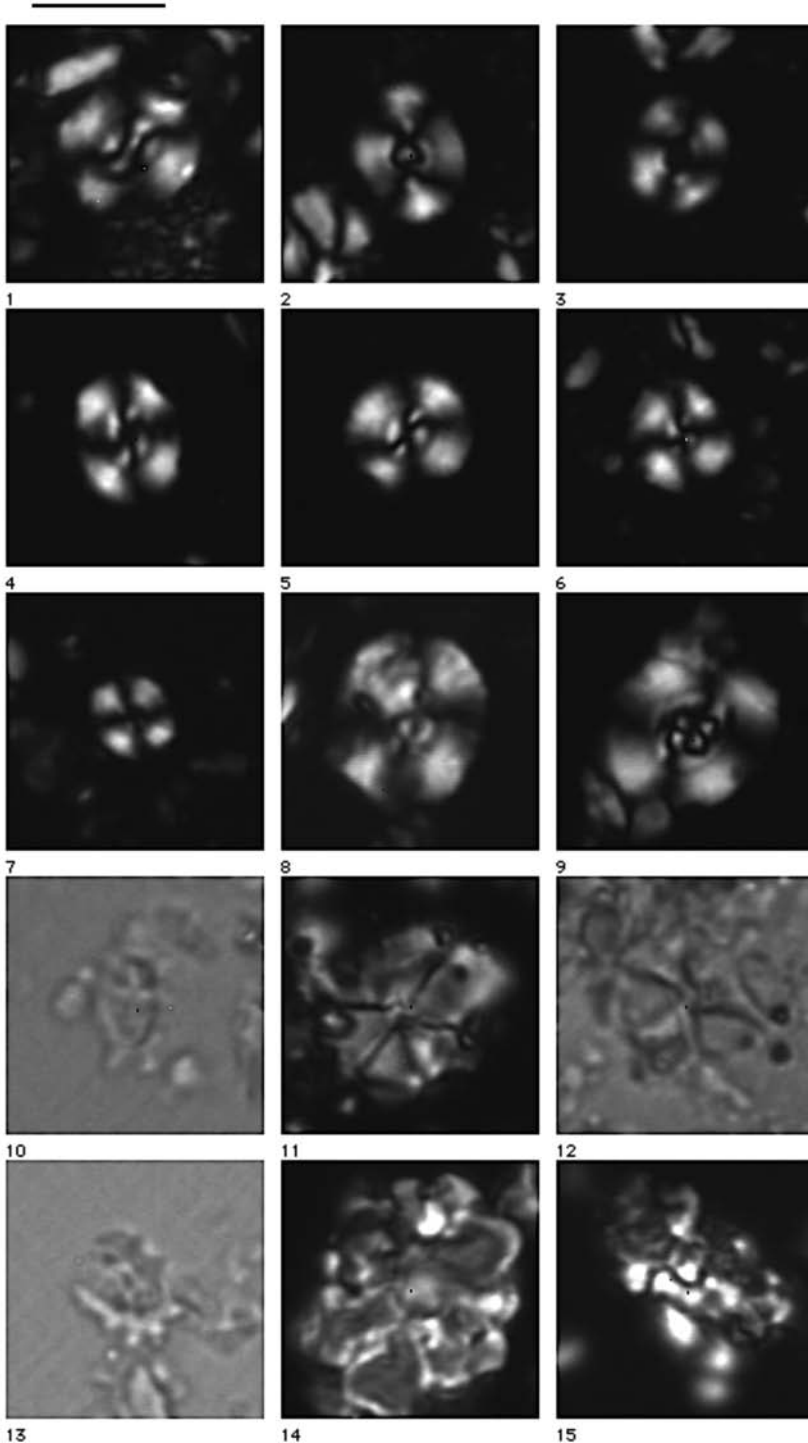


Figure 10. Upper Bajocian and Lower Bathonian calcareous nannofossils from the Bas-Auran area. All specimens at 1250x magnification. Scale bar 5.00 μm . 1. *Watznaueria communis*, crossed nicols, sample 1 10. 2. *Watznaueria britannica*, crossed nicols, sample 102. 3. *Watznaueria fossacincta*, crossed nicols, sample 110. 4. *Watznaueria* aff. *W. communis*, crossed nicols, sample 60. 5. *Watznaueria barnesiae*, crossed nicols, sample 68a. 6. *Watznaueria barnesiae*, crossed nicols, sample 10. 7. *Cyclagelosphaera margerelii*, crossed nicols, sample 40. 8. *Watznaueria manivitia*, crossed nicols, sample 67. 9. *Watznaueria* aff. *W. contracta*, crossed nicols, sample 48. 10. *Stephanolithion speciosum octum*, transmitted light, sample 76. 11. *Hexalithus magharensis*, crossed nicols, sample 110. 12. *Hexalithus magharensis*, transmitted light, sample 110. 13. *Stephanolithion speciosum speciosum*, transmitted light, sample 76. 14. “*Rucinolithus*” sp., crossed nicols, sample 6. 15. *Pseudoconus enigma*, crossed nicols, sample 53 (from Erba and Tiraboschi in Fernández-López et al., 2009, modified).

biochronostratigraphic correlation of the Bajocian/Bathonian boundary. Nevertheless, various other taxonomic groups of macroinvertebrates and microfossils are also of biochronostratigraphic relevance.

Ammonites

Late Bajocian and Early Bathonian ammonites are found worldwide in the three major, oceanic or marine, palaeobiogeographical units: Tethyan, Pacific and Boreal domains or realms (Fig. 11; Cariou et al., 1985; Hillebrandt et al., 1992a, b; Taylor et al., 1992; Westermann, 1993a, 2000; Page 1996a, 2008; Enay and Cariou, 1999; Zakharov et al., 2003). The most difficult problem in biochronocorrelation of the boundary is not the low biostratigraphic turnover of the ammonoid succession across the boundary in Bas Auran area (defined as the number of first occurrences minus the number of last occurrences in each stratigraphic interval; Pavia et al., 2008) or the low faunal turnover at the Bajocian/Bathonian transition (as defined by Guex, 1987; Sandoval et al., 2001), but the strong provincialism with three separate realms.

Figure 12 shows standard zonations for the three ammonite biogeographical provinces represented in western Europe. Ammonites of the Zigzag Zone have a wide distribution through the Northwest European, Sub-Mediterranean and Mediterranean provinces of the West Tethyan Subrealm. In the Bas-Auran area, where Northwest European and Sub-Mediterranean taxa are relatively common, the primary standard Convergens Subzone and the secondary standard Parvum Subzone can be recognized.

The Northwest European Province, in which parkinsoniids are common, comprises the following epeiric areas: England (Torrens, 1980; Callomon, 1995, 2003; Callomon and Cope, 1995; Page, 1996b, 2001; Dietze and Chandler, 1998; Chandler et al., 1999), Normandy, Boulonnais, Lorraine, Alsace, northern Jura (Mangold and Rioult, 1997; Rioult et al., 1997; Thierry, 2003), northern Germany (Westermann, 1958; Metz, 1990, 1992), northern and central Poland (Kopik, 2006; Zaton, 2007, 2008).

The Sub-Mediterranean Province, in which Bathonian *Morphoceras* [M] - *Ebrayiceras* [m] occur associated with parkinsoniids and scarce phylloceratids and lytoceratids, includes the following epeiric areas: Lusitanian Basin (Fernández-López et al., 2006a, b), Iberian Basin (Fernández-López, 2000b, 2001), Aquitaine, Causses, Centre-west France, Nièvre (Delance et al., 1979; Courville et al., 1999; Enay et al., 2001), Mâconnais, Ardèche, southern Jura (Elmi, 1967; Mangold, 1971a, b, c, 1997a, b; Rulleau, 2006), western Alps and Subalpine Basin (Sturani, 1967; Pavia and Sturani, 1968; Pavia, 1973, 1984; Torrens, 1987; Innocenti et al., 1990; Zany et al., 1990; Joly, 2000), southern Germany (Dietl, 1978, 1981, 1982, 1983, 1986, 1988; Dietl et al., 1978, 1983; Dietl and Hugger,

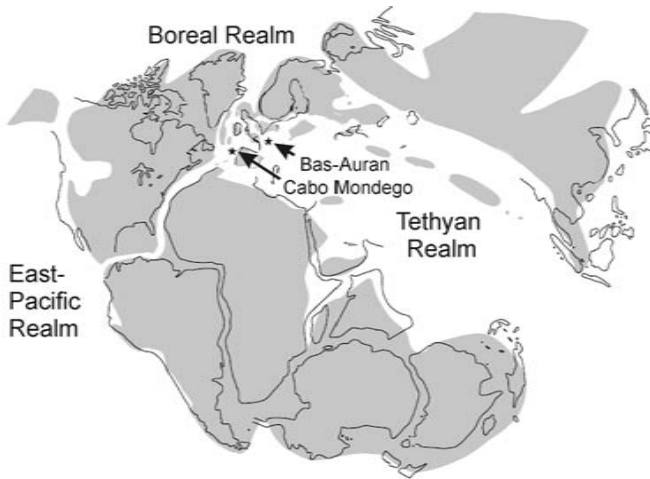


Figure 11. Principal palaeobiogeographical units during Bajocian/Bathonian transition, with location of Bas-Auran and Cabo Mondego areas (modified from Moyne and Neige, 2007).

1979; Dietl and Kapitzke, 1983; Callomon et al., 1987; Schairer, 1987, 1994; Dietze and Chandler, 1996; Köstler and Schairer, 1996; Dietze et al., 1997, 2002, 2004, 2007; Schweigert and Dietze, 1998; Dietze, 2000; Dietze and Schweigert, 2000; Arp, 2001, Schweigert et al., 2002, 2003, 2007; Ohmert et al., 2004; Dietze and Dietl, 2006), South Poland (Luczynski et al., 2000; Matyja and Wierzbowski, 2000, 2001; Zaton and Marynowski, 2006; Wierzbowski and Joachimski, 2007), Pieniny Klippen Belt (Wierzbowski et al., 1999, 2004; Schlögl and Rakús, 2004; Schlögl et al., 2005, 2006), South Transdanubian Mecsek (Galácz, 1995a; Geczy and Galácz, 1998), Romania (Galácz, 1994; Patruşiuş, 1996), Balkans (Stephanov, 1972) and Iran (Seyed-Emami et al., 1985, 1989, 1991, 1994, 1998a, b; Majidifard, 2003).

The Mediterranean Province, in which Late Bajocian and Early Bathonian morphoceratids occur associated with common phylloceratids and lycoceratids, comprises the following shelfal or

oceanic areas: Betic Basin (Mangold, 1981; Sandoval, 1983, 1986, 1990; Sandoval et al., 2001), Majorca (Sandoval, 1994), Sicily (Wendt, 1963, 1971; Galácz, 1985, 1999a, b; Pavia and Cresta, 2002; Pavia et al., 2002; Martire and Pavia, 2004; Pavia, 2007), Alps (Sturani, 1971; Krystyn, 1972; Joly 2000; Martire, 1989; Mangold and Gygi, 1997), North Transdanubian Bakony (Galácz, 1980, 1993, 1995b).

In the northeastern Tethyan border (Crimea, Caucasus, Great Balkhan, Turkmenistan, Tadjikistan, Uzbekistan, Kazakhstan) latest Bajocian to Early Bathonian perisphinctids, parkinsonids and morphoceratids have been described, below Middle Bathonian specimens of *Bullatimorphites*, *Procerites* and *Siemiradzka* (Beznosov and Mikhailova, 1981; Beznosov, 1982; Beznosov and Kutuzova, 1982, 1990; Rostovtsev, 1985; Tseretely, 1989; Beznosov and Mitta, 1995, 1998, 2000; Topchishvili et al., 1998; Mitta, 2001; Mitta and Beznosov, 2007; Galácz and Szente, 2008).

In Tibet and South-East Asia, Bathonian *Siemiradzka*, *Procerites* and *Wagnericeras* have been identified (Cariou and Enay, 1999; Yin et al., 2000; Yin, 2005). Upper Bajocian *Leptosphinctes* and *Cadomites* have been recognized in Japan, below Upper Bathonian *Pseudo-neuquenicerases* (Sato, 1992).

Lower Bathonian morphoceratids, parkinsoniids and phylloceratids have been recognized in several basins of the southern Tethyan border: Morocco, Algeria and Tunisia (Elmi, 1971; Elmi and Alméras, 1984; Enay et al., 1987b; Ouahhabi, 1994; Soussi et al., 2000). *Oraniceras*, *Micromphalites* and *Oxycerites* occur in Lower Bathonian, whereas *Ermoceras*, *Leptosphinctes* and *Oppelia* characterize Upper Bajocian deposits.

In the Ethiopian Province, including Libya, Egypt, Israel, southern Turkey, southern Iran and Saudi Arabia (Parnes, 1981, 1984, 1988; Enay et al., 1986, 1987a, 2007; Enay and Mangold, 1994, 1996), the Lower Bathonian comprises the Tuwaiqensis (*Tulites*) and Clydocromphalus (*Micromphalites*) zones of the Arabian Province, including *Procerites* and *Zigzagiceras* in basal levels. Upper Bajocian deposits with *Ermoceras*, *Thambites*, *Leptosphinctes* and *Spiroceras* represent the Runcinatum (*Ermoceras*), Mogharensis (*Ermoceras*) and Planus (*Thambites*) zones.

In the Indo-Malgach Province, Late Bajocian and Middle Bathonian ammonites, but not Early Bathonian, have been described from Kenya, Madagascar and India (Singh et al., 1982, 1983; Jaitly and Singh, 1983, 1984; Pandey and Agrawal, 1984; Pandey and Westermann, 1988; Galácz, 1990; Pandey and Callomon, 1995; Prasad et al., 2007; Roy et al., 2007; Jain, 2008).

In southwestern Pacific areas, Sula, Irian Jaya and New Guinea, latest Bajocian to Early Bathonian *Pretulites* and Early to Middle Bathonian *Satoceras*, as well as Bathonian specimens of *Asphinctites*, *Rugiferites* and *Bullatimorphites* have been described (Westermann and Getty, 1970; Westermann and Callomon, 1988; Sukanto and Westermann, 1992; Westermann, 1995; Callomon and Rose, 2000).

Separate Late Bajocian and Early Bathonian ammonoid faunas have been distinguished, associated with characteristic Eurycephalitinae, in the southern East-Pacific Subrealm of the Tethyan Realm: New Zealand (Westermann and Hudson, 1991; Westermann 1993b; Westermann et al., 2000, 2002), Argentina, Chile and Peru (Westermann and Riccardi, 1980; Westermann et al., 1980; Riccardi, 1985, 1991, 2008; Riccardi et al., 1990a, b, 1991, 1992, 1994; Riccardi and Westermann, 1991a, b, 1999; Hillebrandt et al., 1992a, b; Fernández-López et al., 1994; Gröschke and Hillebrandt, 1994; Hillebrandt, 1995, 2001; Gröschke, 1996; Parent, 1998). *Leptosphinctes*, *Lupherites*, *Strenoceras*, *Spiroceras* and

		NW European Province	Sub-Mediterranean Province	Mediterranean Province
		England, Normandy, Boulonnais, Lorraine, Alsace, northern Germany, northern and central Poland	Portugal, Iberian Basin, Aquitaine, Causses, Central-west France, Nièvre, southern Jura, Maconnais, Ardeche, southern Germany, southern Poland, Balkans, northern and central Iran	Betic Basin, Sicily, Appennines, Switzerland, Austria, Hungary p.p. (Villany and Mecsek), Hellenids, Serbia
Lower Bathonian	Zigzag	Tenuiplicatus	Aurigerus	Tenuiplicatus
		Yeovilensis		Recinctus
		Macrescens	Zigzag	Macrescens
		Convergens		Parvum
Upper Bajocian	Parkinsoni	Bomfordi	Parkinsoni	Bomfordi
		Truellei		Densicosta
		Acris		Acris
				Postpolubrum
				Recinctus
				Macrescens
				Dimorphitiformis
				Dimorphus
				Daubenyi

Figure 12. Ammonite zones and subzones of the Uppermost Bajocian and Lower Bathonian in different palaeobiogeographical provinces: Northwest European (Westermann and Callomon, 1988, Callomon and Cope, 1995, Callomon, 2003), Sub-Mediterranean (Mangold, 1990, Rioult et al., 1997, Mangold and Rioult, 1997) and Mediterranean (Galácz, 1980, 1993; Sandoval, 1983, 1990; Sandoval et al., 2001; O’Dogherly et al., 2006) provinces.

		Ammonite NW European standard zonation	Argentina	Northern Chile	Eastern Oregon	British Columbia
L. Bathonian	Zigzag	Tenuiplicatus	Cadomites-Tulitidae Assemblage	?Zigzagiceras	Cobbanites Parareinekeia	
		Yeovilensis				
		Macrescens				
		Convergens				
U. Bajocian	Parkinsoni	Bomfordi	Lobosphinctes	"Cobbanites"	Parachondreceras + Sohlites	Iniskinites? costicensis
		Truellei				
		Acris				

Figure 13. Uppermost Bajocian and Lower Bathonian ammonite horizons in several palaeobiogeographical areas of the East-Pacific Realm (modified from Imlay, 1981, 1984; Callomon, 1984; Hall, 1988; Westermann and Riccardi, 1991; Hillebrand et al., 1992a, b; Gröschke and Hillebrandt, 1994; Hillebrandt, 2001; Riccardi, 2008).

Megasphaeroceras occur in the Upper Bajocian of the Andean Province. Lobosphinctes intersertus Buckman has been identified in Chacay Melehue (Argentina) below a Bathonian Cadomites-Tulitidae mixed assemblage. The first occurrence of several genera such as Oxycerites, Zeissoceras, Prohecticoceras and Rugiferites, below the oldest representatives of Bathonian Bullatimorphites, have been used to recognize Lower Bathonian deposits. New species of Bathonian ?Zigzagiceras and Morphoceras have been proposed (Fig. 13; Gröschke and Hillebrandt, 1994; Riccardi and Westermann, 1999).

In Mexico (Sandoval and Westermann, 1986; Sandoval et al., 1990) Upper Bajocian begins with the upper Floresi Zone of Oaxaca, containing the Mediterranean Subcollina lucretia (Orbigny). The overlaying Zapotecum Zone includes Parastrenoceras, Leptosphinctes and Oppelia. The Upper Bathonian Retrocostatum Zone has been identified by Prohecticoceras blanazense, associated with Epistrenoceras, Lilloettia and Neuquenoceras.

In the Western Interior of the United States of America (Shoshonean Province, Imlay, 1981), western Canada and southern Alaska (Athabaskan Province; Imlay, 1980, 1982, 1984; Hall and Westermann, 1980; Hall and Stronach, 1981; Callomon, 1984; Hall, 1984, 1988, 1989; Poulton et al., 1991, 1994) the Upper Bajocian Rotundum Zone includes Leptosphinctes, Luperites, Spiroceras and Megasphaeroceras, below the Epizigzagiceras-Parareineckeia association. The Parachondrocera-Sohlites assemblages from Oregon may be Upper Bajocian or Lower Bathonian (Fig. 13; Imlay, 1984).

Euricephalitinae belonging to Umaltites (= Megasphaeroceras in Westermann, 1992) and Loucheuxia occur at the Upper Bajocian and Lower Bathonian, respectively, in the Far East of Russia (Sey et al., 2004). Upper Bajocian Cranocephalites have been recognized in North-East Russia, below Bathonian Arctocephalites (Sey et al., 1992; Meledina et al., 2009).

The Boreal Realm (Eastern Greenland, Barents Sea, Pechora Basin, Northern Siberia, Northeastern Russia, Northern Alaska and Northern Canada) became clearly differentiated in the Late Bajocian and several zonation for the Early Bathonian have been proposed. The Cardioceratidae, in particular Cranocephalites and Arctocephalites, constituted characteristic elements of the Boreal Realm at the Bajocian/Bathonian boundary. The lowest three Boreal zones (Borealis, Indistinctus and Pompeckji) are Upper Bajocian at the ESE of Shetlands (Callomon, 2003). The Zone of Arctocephalites arcticus (Newton and Teall), above the Zone of Cranocephalites pompeckji (Madsen), may represent the basal Bathonian zone in the

Boreal Realm (Callomon, 1993, 1994, 2003; Meledina, 1994; Zakharov et al., 1998; Mitta 2006, 2009; Repin et al., 2006, 2007; Meledina et al., 2009). The Zone of Arctocephalites spathi from northern Yukon probably is coeval with the Boreal Articus Zone of Eastern Greenland (Poulton, 1987).

Boreal Arctocephalitinae are associated with parkinsoniids in the south-eastern part of the Russian platform, allowing the correlation between the regional Michalskii-Besosovi zonal boundary and the Boreal Arcticus-Greenlandicus boundary or the Northwest European Parkinsoni-Zigzag boundary (Krymholts, 1989; Meledina, 1989; Mitta, 2004, 2005, 2007; Mitta and Seltzer, 2002; Mitta et al., 2004; Saltykov, 2007, 2008; Saltykov et al., 2008; Rogov et al., 2009).

Other taxonomic groups

Several authors have proposed diverse biozonations for the Upper Bajocian and Lower Bathonian based in different taxonomic groups of macroinvertebrates (Fig. 14): brachiopods (Manceñido and Dagys, 1992; Vörös, 2001; Alméras et al., 2007, Alméras and Fauré, 2008), belemnites (Challinor, 1992; Challinor et al. 1992; Combémoré, 1997), nautiloids (Branger, 2004), bivalves (Damborenea et al., 1992; Hallam, 1994; Damborenea, 2002; Ruban, 2006), echinoderms (Thierry et al. 1997, Moyne et al., 2005), corals (Beauvais, 1992).

		Ammonite NW European standard zonation	Brachiopods		Belemnites
			North-western Tethyan border	Southern Tethyan border	
L. Bathonian	Zigzag	Tenuiplicatus	Cymatothyndia reynesi	Rugitela Cadomensis	Duvallia disputabilis (partim)
		Yeovilensis		Tubithyrus whatleyensis	
		Macrescens		Caucasella voutensis	
		Convergens			
U. Bajocian	Parkinsoni	Bomfordi		Callirhynchia oranensis	Megateuthis elliptica (partim)
		Truellei		Cymatothyndia reynesi	
		Acris			

Figure 14. Zonations for brachiopods and belemnites (from Alméras et al., 2007 and Combémoré, 1997).

The following taxonomic groups of microfossils are of biochronostratigraphic relevance also (Fig. 15): foraminifera (Bassoulet, 1997; Ruget and Nicollin, 1997; Gräfe, 2005; Cai et al., 2006; Saltykov, 2007; Wernli and Görög, 2007), ostracods (Braun and Brooke, 1992; Bodergat, 1997; Tesakova et al., 2009), dinoflagellate cysts (Riding and Thomas, 1992; Fauconnier, 1997; Poulsen and Riding, 2003), radiolarians and calcareous nannofossils

		Ammonite NW European standard zonation	Ostracoda	Foraminifera	Dinoflagellate cysts
L. Bathonian	Zigzag	Tenuiplicatus	Lewis - Bathonica (partim)	Quasicitrella (partim)	Ctenidodinium predae (partim)
		Yeovilensis		Bessinensis -Malzi-Bessinensis	
		Macrescens			
		Convergens			
U. Bajocian	Parkinsoni	Bomfordi	Regularis Fichten (partim)	L. quenstedtii, L. galeata, L. polymorpha and L. argonauta (partim)	Acanthaulax crispa (partim)
		Truellei			
		Acris			

Figure 15. Zonations for ostracods (from Bodergat, 1997), foraminifera (from Ruget and Nicollin, 1997) and dinoflagellate cysts (from Riding and Thomas, 1992; Fauconnier, 1997).

(Pessagno and Mizutani, 1992, Baumgartner et al., 1995; Cordey et al., 2005; Chiari et al., 2007; O'Dogherty et al., 2009). Palaeobotanical and palynological data have been recently published by: Kimura et al., (1992), Sarjeant et al., (1992), Cleal and Rees (2003), Wang et al., (2005), Vaez-Javadi and Mirzaei-Ataabadi (2006) and Jana and Hilton (2007).

Isotope stratigraphy

From a geochemical point of view, in the French Subalpine Basin during the Jurassic Period, several authors have emphasized that the manganese content of pelagic carbonates is related to second-order sea-level changes and episodes of hydrothermal activity that affected the chemistry of global sea water. According to this interpretation, the main transgressive phases are marked by a manganese content increase, whereas regressive phases are characterized by decreasing trends (Corbin, 1994; Corbin et al., 2000). In the Chaudon-Norante section, 4 km north of the Bas-Auran area, the Early Bathonian maximum transgressive is marked by sedimentary condensations, associated with high manganese content (from 300 to 1370 mg kg⁻¹). In contrast, the Middle and Late Bathonian regressive phase coincides with low manganese content periods. However, these stratigraphical patterns in divalent manganese can be of either local or regional significance, being concentrated, most probably as a very early diagenetic phase, only in oxygen-depleted waters that typically underlie zones of elevated organic productivity (Jenkyns et al. 2002). No data are currently available for strontium isotope (⁸⁷Sr/⁸⁶Sr ratio), oxygen isotope ($\delta^{18}\text{O}$) or carbon isotope ($\delta^{13}\text{C}$) chemostratigraphy.

Volcanogenic deposits suitable for direct radio-isotope dating are not known in the section. The age of the Bajocian/Bathonian boundary 167.7 ± 3.5 Ma is an interpolated estimate (cf. Gradstein and Ogg, 2004; Gradstein et al., 2005; Ogg, 2005; Pálffy, 2007).

Magnetostratigraphy

Bajocian and Bathonian deposits have been remagnetized with a steady normal polarity (Lanza in Fernández-López et al., 2009). The requirement of suitability for magnetostratigraphy and geochronometry, however, can be indirectly satisfied by reference to the Bathonian magnetostratigraphic scale of Steiner et al. (1987), O'Dogherty et al. (2006) as defined in the Subbetic Cordillera.

Gamma-ray spectrometry

Field gamma-ray spectrometry data have been obtained by G. Pavia, P. Lazarin and L. Leroy (April 2007) and are presented in Fig. 16. Spectral gamma-ray data from the Ravin du Bès Section show an increase in the total gamma-ray counts at the Aurigerus Zone. The values are relatively low and display insignificant variation at the Bajocian-Bathonian boundary, but they show a positive peak at the top of the Lower Bathonian. Total gamma-ray logs have been used in sequence stratigraphy on the basis that gamma-ray peaks commonly correspond to maximum flooding surfaces (cf. Parkinson, 1996; Deconinck et al., 2003; Pawellek and Aigner 2003, 2004; Pellenard et al., 2003; Raddadi et al., 2005; Ruf et al., 2005; Schnyder et al., 2006). High gamma-ray counts, low sedimentation rates and high concentrations of ammonites may be associated with the development of condensed sections in carbonate environments. These features, however, developed both in condensed deposits of deep

carbonate environments during transgressions or episodes of relative sea-level rise and in expanded deposits of shallow carbonate epicontinental platforms during regressions or episodes of relative sea-level fall (Fernández-López et al., 2002). The stratigraphic trend in spectral gamma-ray data associated with sedimentary condensation on the Bas-Auran area, from the Bajocian Bomfordi Subzone towards Bathonian Tenuiplicatus Subzone, provides support for an Early Bathonian deepening half-cycle of second order, lacking evidence of stratigraphic gaps at the Bajocian-Bathonian transition.

Therefore, the current data do not support the existence of “a gap of the order of a whole biohorizon or even a subzone” at the Bathonian GSSP. The base of bed RB071 represents a minor sedimentary and stratigraphic discontinuity (tested with sequence stratigraphy and sedimentological data, as well as with palaeoichnological and

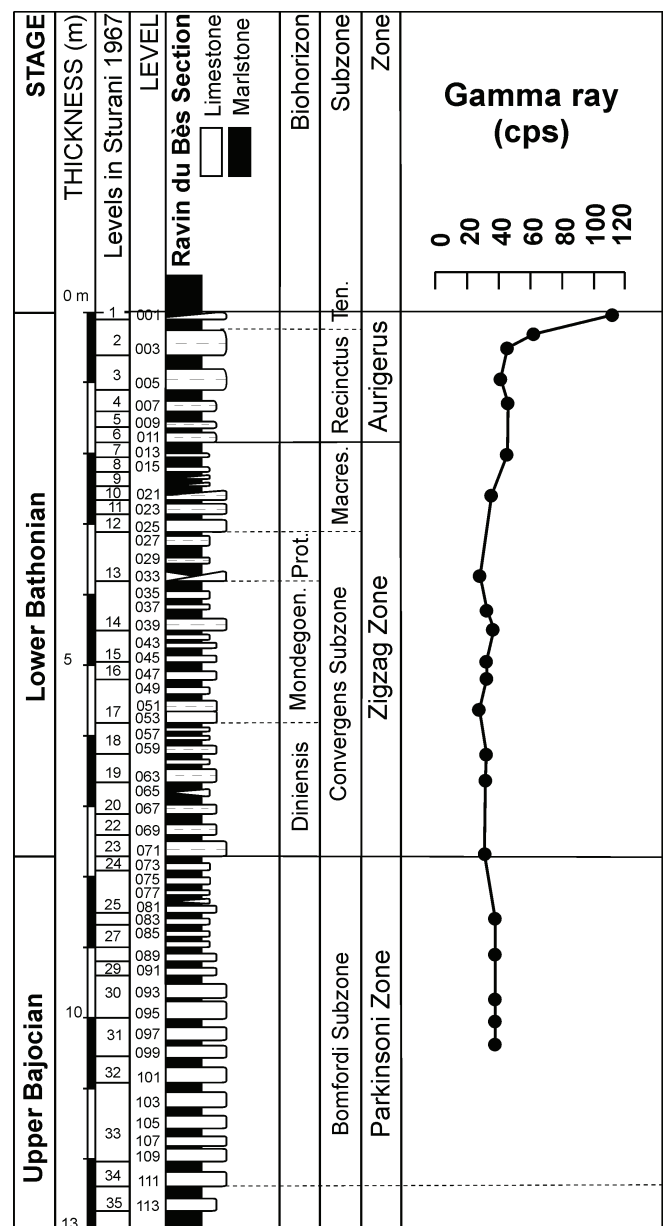


Figure 16. Gamma-ray log of the Ravin du Bès Section, showing a positive peak at the top of the “Marno-calcaires à Cancellophycus” in the Lower Bathonian Tenuiplicatus Subzone (Aurigerus Zone) (modified from Fernández-López et al., 2009).

taphonomic analyses), lacking evidence of significant hiatus (such as a peak in the spectral gamma-ray data shown in Fig. 16), non-existing evidence of biostratigraphic gap (as argued with diverse criteria in the chapter of record quality by Pavia et al., 2008) or missing biostratigraphic unit (the first subzone at the base of the Zigzag Zone, with three successive biohorizons, shows the highest biostratigraphic completeness, so far only recognized in the Cabo Mondego and Bas Auran sections, Fernández-López et al., 2007).

Protection of the site

The sites of Bas-Auran and Le Bès are part of the protected territory of “La Réserve Naturelle Géologique de Haute Provence”. The Geological Reserve, which covers 55 communes in the “Alpes de Haute-Provence” and Var departments, has been entrusted with the main missions of protecting, enhancing and raising awareness of the environment and supporting economic development of this heritage (Guiomar in Fernández-López et al., 2009).

The Bathonian ASSP in Cabo Mondego Section (Portugal)

An auxiliary section and point (ASSP) for the base of the Bathonian Stage is located in Cabo Mondego, 40 km west of Coimbra, 7 km north of Figueira da Foz (40°11'18"N, 8°54'30"W, Section 02 in Fig. 1a). It provides complementary data about the ammonite succession and biostratigraphic subdivision of the Sub-Mediterranean Parvum Subzone and the Northwest European Convergens Subzone (Fernández-López et al., 2006a, b, 2009). Accessibility, conservation and protection are guaranteed, after the classification of the Cabo Mondego area as a Natural Monument of the Portuguese Republic in 2007.

Summary

The Global Boundary Stratotype Section and Point for the base of the Bathonian Stage is defined at the base of limestone bed RB071 in the Ravin du Bès Section, Bas-Auran area, southern Subalpine Chains (France). This GSSP satisfies most of the requirements recommended by the ICS (Remane et al., 1996; Gradstein et al., 2003, 2005; Morton, 2006, cf. Fig. 17):

- The exposure extends over 13 m in thickness, comprising five metres of fossiliferous levels below the boundary and eight metres above. The stratigraphic succession can be recognized laterally over several hundred metres distance.
- At the Bajocian-Bathonian transition, no vertical biofacies, ichnofacies or taphofacies changes, stratigraphic gaps or hiatuses have been recorded. There is no evidence of taphonomic condensation (i.e. mixture of fossils of different age or different chronostratigraphic units). In relation to the rate of sedimentation, the Bomfordi and Convergens subzones are over 10 m thick.
- Structural complexity, syndimentary and tectonic disturbances, or important alterations by metamorphism are not relevant constraints in the Bas-Auran area.
- The hemipelagic, bed-scale limestone-marl alternations show a maximum value of biostratigraphic completeness for the Bajocian/Bathonian transition. The Northwest European primary

The requirements for a GSSP (ICS)	Ravin du Bès Section (Bas Auran)
GEOLOGICAL REQUIREMENTS	
Exposure over an adequate thickness	Yes
Continuous sedimentation No gaps or condensation close to boundary	Yes
Rate of sedimentation	About 4.5 m for the Convergens Subzone and at least 5 m for the Bomfordi Subzone
Absence of syndimentary and tectonic disturbances	Yes
Absence of metamorphism and strong diagenetic alteration	Yes (for macrofossils)
BIOSTRATIGRAPHIC REQUIREMENTS	
Abundance and diversity of well-preserved fossils	Abundant and well-preserved ammonites
Absence of vertical facies changes at or near the boundary	Yes
Favourable facies for long range biostratigraphic correlations	Yes
OTHER METHODS	
Radio isotopic dating	No information
Magnetostratigraphy	No significant result
Geochronometry	No information
Sequence stratigraphy	Graciansky et al., 1983, 1998
Gamma ray spectrometry	Yes, supporting sequence-stratigraphy results
OTHER REQUIREMENTS	
GSSP indicated by permanent fixed marker	Yes
Physical and logistical accessibility	Yes
Free access for research	Yes
Permanent protection for the site	Part of the European Geopark; Réserve Naturelle Géologique Haute de Provence'

Figure 17. Summary of the requirements of the International Commission on Stratigraphy for Ravin du Bès Section (Bas-Auran).

standard Convergens Subzone and the Sub-Mediterranean secondary standard Parvum subzones are in fact precisely coeval in the Bas-Auran area. Through five metres of thickness, 46 successive ammonoid fossil-assemblages in Ravin du Bès Section belonging to three biohorizons of the Parvum Subzone have been recognized. The Bomfordi Subzone attains a minimum thickness of 5 m and includes 42 successive ammonoid fossil-assemblages.

- The boundary has been characterized by both primary and secondary (auxiliary) biostratigraphic markers. There is a well-preserved, abundant and diverse fossil record across the boundary interval, with key markers (ammonites and nannofossils) for worldwide correlation of the uppermost Bajocian and Lower Bathonian. The section appears to be suitable for biostratigraphic study of microfossils, such as foraminifera, but as yet there are no published studies.
- Regional analyses of sequence stratigraphy and manganese chemostratigraphy are available. A transgressive systems tract associated with a deepening phase and sedimentary starvation, within 3rd and 2nd order deepening/shallowing cycles, was developed in the Bas-Auran area of the French Subalpine Basin, during the Early Bathonian. No data are currently available for strontium isotope ($^{87}\text{Sr}/^{86}\text{Sr}$ ratio), oxygen isotope ($\delta^{18}\text{O}$) or carbon isotope ($\delta^{13}\text{C}$) chemostratigraphy.
- The stratigraphic trend in spectral gamma-ray data provides support for an Early Bathonian deepening half-cycle of second order, lacking evidence of stratigraphic gaps at the Bajocian-Bathonian transition.
- Bajocian and Bathonian deposits have been remagnetized with a steady normal polarity. The requirement of suitability for magnetostratigraphy and geochronometry, however, can be indirectly satisfied by reference to the Bathonian magneto-

stratigraphic scale of [Steiner et al. \(1987\)](#) and [O'Dogherty et al. \(2006\)](#) as defined in the Subbetic Cordillera.

- Volcanogenic deposits suitable for direct radio-isotope dating are not known in the section. According to the data published by [Gradstein and Ogg \(2004\)](#) and [Ogg \(2004\)](#), the age of the Bajocian/Bathonian boundary is 167.7 ± 3.5 Ma, an interpolated estimate.
- The criteria of accessibility, conservation and protection are assured by the “Réserve Naturelle Géologique de Haute Provence”, protected under national law and recognised by UNESCO. The park is managed by the “Centre de Géologie de Digne”.
- The Cabo Mondego Section is the Bathonian ASSP, providing complementary data about the ammonite succession and biostratigraphic subdivision of the Sub-Mediterranean Parvum Subzone and the Northwest European Convergents Subzone, at the basal Bathonian Zigzag Zone.

Acknowledgements

We would like to thank all members of the Bathonian Working Group, and in particular J.H. Callomon, V. Dietze, V. Mitta, K. Page, D.K. Pandey, T.P. Poulton and A. Wierzbowski, for constructive comments and suggestions which improved the original dossier. We are grateful to G. Pieńkowski (Polish Geological Institute, Warszawa), an anonymous referee and M. Jayananda (editor of *Episodes*) for constructive suggestions on the manuscript. This work has been supported by the CGL2004-0694/BTE (MEC-CSIC) and CGL2008-01273/BTE (MICINN) projects, and grants from the 2006 and 2007 Geoconservation Projects, respectively coordinated at the Madrid and Torino universities.

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Cover

Ravin du Bès outcrop, in Bas-Auran area, southern Subalpine Chains (SE France), a part of the protected territory of “La Réserve Naturelle Géologique de Haute Provence”, in the Chaudon-Norante commune, around 25 km SSE of Digne-les-Bains. The Global Stratotype Section and Point (GSSP) of the Bathonian Stage (Middle Jurassic) is now formally defined at this stratigraphic section of the “Calcaires à Cancellophycus” Formation (Photo courtesy: Sixto R. Fernández-López).



Vol.32 No.4 December 2009

Episodes

Journal of International Geoscience