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Ammonites from the latest Aalenian–earliest Bathonian of La Baume (Castellane area, SE France): palaeontology and biostratigraphy

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Key words: ammonites, Aalenian–Bathonian interval, France, biodiversity, taxonomy, biostratigraphy

ABSTRACT

Middle Jurassic strata are naturally exposed around the village called La Baume, near Castellane (Alpes de Haute Provence, SE France). We have realized both a detailed log and a bed-by-bed sampling for ammonite biostratigraphy in a 68 metres thick succession of subpelagic marls and limestones ("Calcaires à Zoophycos") that spans the Middle Jurassic from uppermost Aalenian to lowermost Bathonian. The subpelagic succession can be roughly subdivided into three members. Ammonites from the Upper Aalenian Concavum Zone, all Lower Bajocian Zones (Discites Zone, Laeviuscula Zone including Ovale Subzone, Humpriesianum Zone), one Upper Bajocian Zone (Parkinsoni Zone) and probably one lower Bathonian Zone (Zigzag Zone) were found. A major gap of both the Niortense Zone and the Garantiana Zone, which was not previously described, was detected at the boundary between members 2 and 3. The main palaeontological interest of the ammonite fauna from La Baume is the richness and diversity of the family Sonniniidae, which is the subject of a systematic study and figurated along with some biostratigraphically significant forms. Biostratigraphical results and open problems are discussed.

Introduction

The Jurassic successions in the area of the Réserve Géologique des Alpes de Haute Provence are widely known because of the excellent quality of the exposures, the abundance of ammonoids and the easy access. In particular, the Middle Jurassic outcrops exposed around Castellane, have been published repeatedly (Sturani 1966; Pavia 1969, 1973, 1983; Pavia & Sturani 1968; Torrens 1987; Innocenti et al. 1988; Olivero 1989, 1994; Olivero & Atrops 1996; Olivero et al. 1997; Fernández-López 2007).

The natural outcrop of La Baume (Fig. 1), where Jurassic formations are exposed, has been included in a regional program of natural conservation. The stratigraphy and the ammonoid content from the Aalenian to Bathonian strata of the "Calcaires à *Zoophycos*" formation has been the main object of our field work, whose results are presented here.

The aims of this work are: 1) to shortly describe the lithology of the succession; 2) to describe and figure representatives of the ammonite family Sonniniidae; and 3) to document the biostratigraphical subdivisions of the geological formations exposed.

Geological setting

The study area is located in the Western Alps, more specifically in the southern Subalpine Chains. Here, the Mesozoic strata have been deformed during two tectonic phases, namely the pre-Oligocene Pyreno-Provençal and the Alpine phases (Kerckhove 1976; Lemoine et al. 2000). Locally, the Southern Subalpine Chains are represented by the Castellane Arc, a Cenozoic fold-and-thrust belt consisting of several overthrust units (Fig. 1). These tectonic/structural units are separated by major faults linked to the original Mesozoic rifting system (Olivero & Atrops 1996). The outcrop of La Baume (Fig. 2) itself is located in one of these units, the Lauppe Unit, which has been thrusted upon the Lower Cretaceous of the La Blache/Castillon unit (Kerckhove 1976).

The morphology of the southern margin of the Dauphinois Basin at the end of the Triassic is that of an emerging platform,

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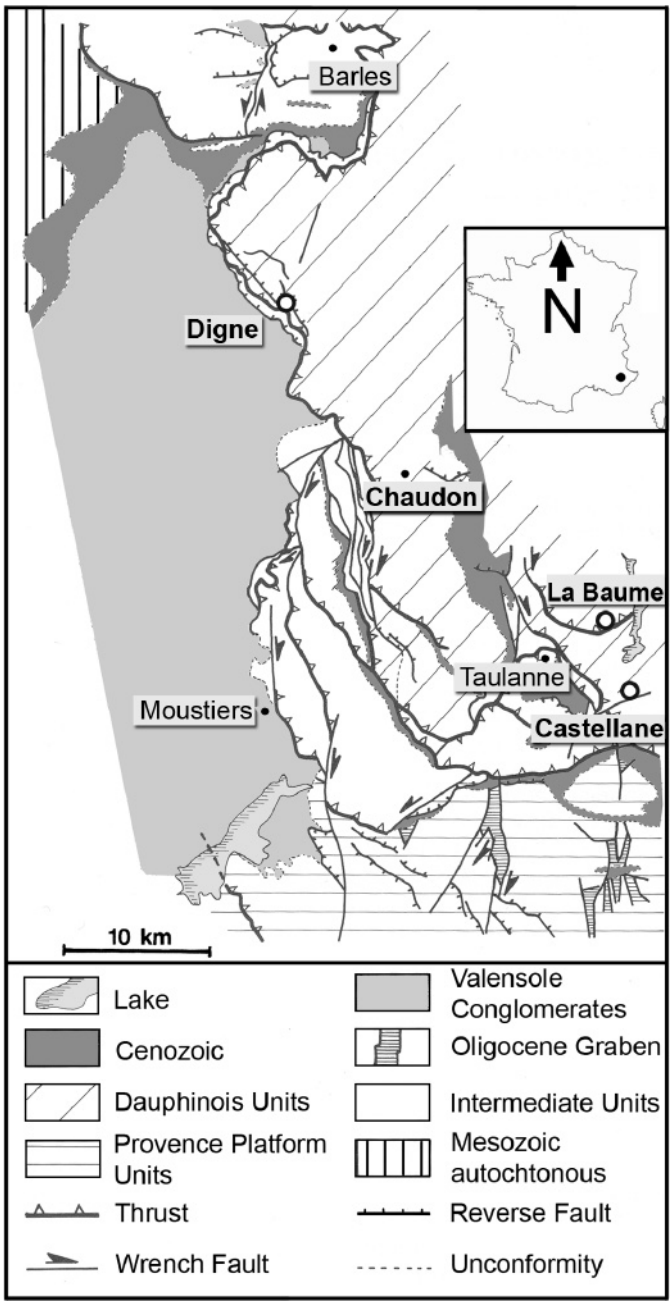

Fig. 1. Structural sketch map with the distribution of Dauphinois (subpelagic), Provence Platform and intermediate units (Modified from Graciansky et al. 1993), around the study area of La Baume (Alpes de Hautes Provence, SE France). Localities mentioned in the text in bold and indicated by a circle with a black edge and white filling.

which is progressively fragmented under the effect of the Early Jurassic Tethyan rifting (Graciansky et al. 1993). Until the late Bajocian, the margin of the platform is not as fragmented and there is a uniform sedimentation of limestones in a southern platform domain, which passes progressively to the north to a thick sedimentation of marl-limestone alternations in the subsiding basin. During the upper Bajocian and lower Bathonian, the margin is broken into a set of tilted blocks (which later give rise to the tectonic/structural units of the Castellane Arc). New phases of tectonic activity in the transition zone are recorded in the upper Bathonian to lower Callovian and upper Callovian to lower Oxfordian associated with new block movements (Olivero & Atrops 1996; Atrops et al. 1989).

The Jurassic lithologies in the Castellane Arc (Fig. 1) typically grade from a neritic facies in the south (deposited on the Provençal Platform) to a subpelagic facies (deposited in the Dauphinois Domain) to the north, through intermediate mixed and condensed sequences that were deposited in the transitional area (Atrops et al. 1989; Olivero 1989, 1994; Graciansky et al. 1993; Fernández-López 2007).

In the studied area, the Middle Jurassic is represented by limestone-marl alternations, which are traditionally called "Calcaires à *Cancellophycus*". The most recent studies (Olivero 1989, 1994, 1996, 2003; Zany et al. 1990; Olivero & Atrops 1996; Olivero et al. 1997) have focused on the *Zoophycos*-rich alternations deposited in the transition zone, where the deposits are basically of Bathonian–Callovian age and are overlain by Oxfordian limestone deposits ("Calcaires grumeleux").

Olivero & Atrops (1996) introduced a new name for these alternations in the transition area, "Calcaires à *Zoophycos*" du Verdon Formation, and restricted its use to the *Zoophycos*-bearing part of these alternations. Sturani (1966), Pavia & Sturani (1968), Pavia (1973, 1983), Torrens (1987) and Innocenti et al. (1988) have studied the *Zoophycos*-bearing limestone/marl alternations in the Dauphinois domain. Towards the basin, the alternations are thicker, less rich in *Zoophycos* and older than those in the transition zone. These alternations are essentially of Bajocian age (Pavia 1973, 1983), but Bathonian and Callovian can be partly represented (Sturani 1966; Pavia 1984), and are covered with black marls ("Terres Noires") on top of a more or less extensive hiatus.

These studies have shown that the top of the marl-limestone alternation is progressively younger from north to south: partly lower Bathonian in the north (near Digne and Chaudon) and partly middle Callovian in the south (near Teillon; Olivero & Atrops 1996). Kerckhove (1976) claims that the "Calcaires à *Zoophycos*" span the uppermost Aalenian (Concavum Zone) to the lowermost Bathonian (Zigzag Zone) interval in the Lauppe unit. To our knowledge, no detailed bed-by-bed stratigraphy from the Lauppe Unit has yet been published.

The Jurassic succession of La Baume

The Lower Jurassic of La Baume was studied in detail by Assenat (1972). A paraconformable contact, which has been locally exposed by erosion, separates the liassic "Calcaires à Silex" Formation from the "Calcaires à *Zoophycos*". Two discontinuities can be recognised in the Lower Jurassic at the section of La Baume.

The first discontinuity marks the contact between the Calcaires à Silex (Pliensbachian) and a 10 to 20 cm thick condensed/lacunous iron and phosphate-bearing unit characterized by the

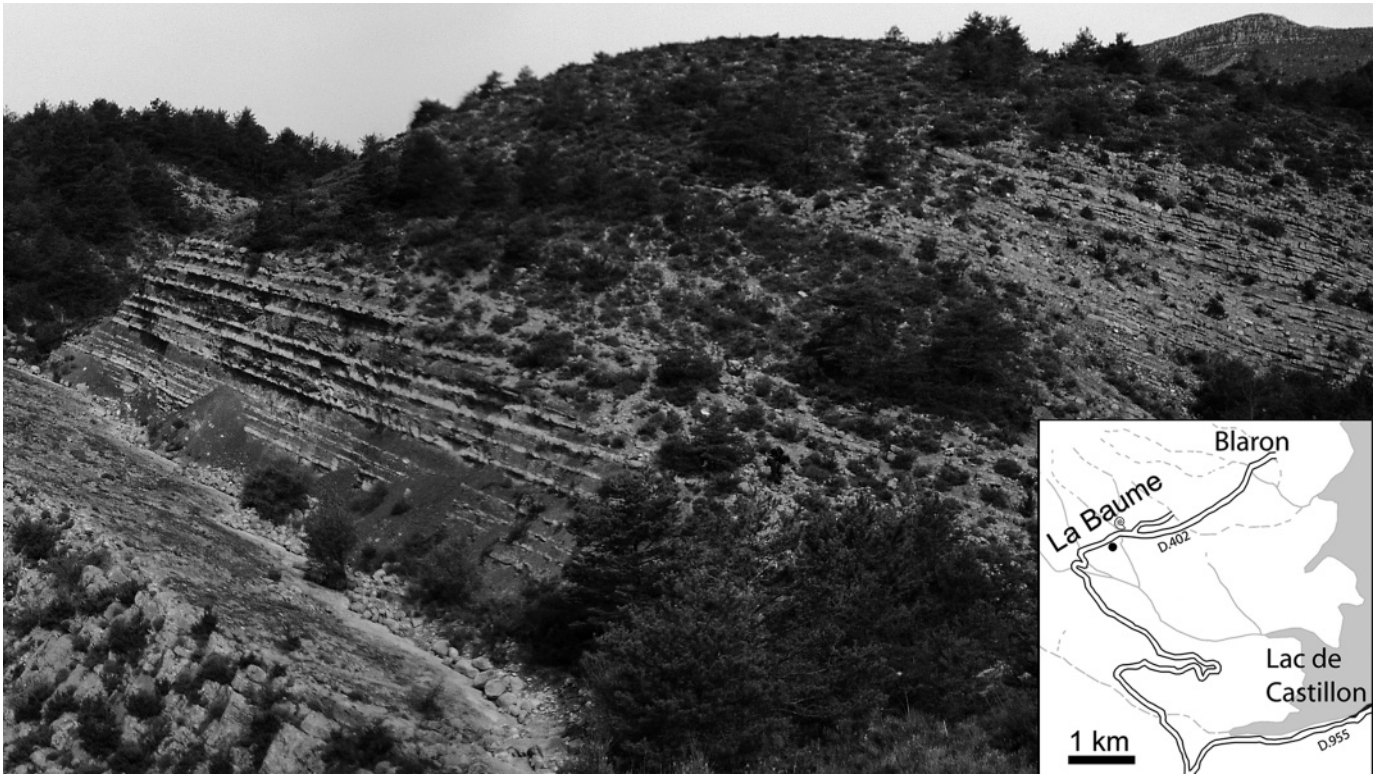

Fig. 2. The Middle Jurassic (Aalenian–Bathonian) outcrop of La Baume (Alpes de Hautes Provence, SE France); inset with the geographical location of the study locality indicated by an ammonite symbol, near La Baume (black dot) lack solid lines: roads, grey: water.

occurrence of oncoids and middle and Upper Toarcian ammonites (Assenat 1972). The top of the Calcaires à Silex itself consists of a reddish, perforated hardground, where early Toarcian ammonites of the genus *Dactylioceras* have been found (Assenat 1972). This indicates a stop of sedimentation during the lower Toarcian (or even before). During this survey, we found middle Toarcian ammonites of the genus *Hildoceras* and pleurotomarid gastropods in the condensed/ lacunous unit.

The second discontinuity separates the condensed/lacunous unit from the Calcaires à *Zoophycos* and is marked by an irregular surface, which is fractured and encrusted with stromatolitic structures (Leonide 2007). The associated hiatus seems to correspond to the maximum regression at the top of the hemicycle R6 of Graciansky et al. (1993) and Jaquin et al. (1998).

The Calcaires à *Zoophycos,* whose lowermost bed contains Upper Aalenian ammonites, is found to overlay this Toarcian unit. The lithology of the Middle Jurassic outcrop at La Baume was recorded bed-by-bed and is presented in Figure 3. It has been subdivided into 122 beds. We collected many ammonites, ca. 400, which enable us to propose strong biostratigraphical assignments.

In the La Baume outcrop, the "Calcaires à *Zoophycos*" Formation is rich in nektonic fossils (mostly ammonites, belemnites and very rare nautiloids), but also benthic fossils were found (bivalves, pleurotomariid gastropods, rhynchonellid, and terebratulid brachiopods, and sponges). The sediment is strongly bioturbated and contains *Zoophycos* traces in its middle part (Figs. 3a, b). The aragonitic shells have typically been dissolved. Therefore, only internal (often composite) moulds remain, while calcitic shells have been preserved. Oblique or (sub)vertical ammonites and other cephalopods are not uncommon, revealing intense bioturbation prior to the final lithification (cf. Pavia 1983; Olivero 1994).

We subdivided the Calcaires à *Zoophycos* into three members (Figs. 3a, b):

1) A lower marly member (from bed 01 to bed 24), where the marl interbeds are clearly thicker than the limestone beds with the first occasional occurrences of *Zoophycos* at the top;
2) an intermediate, more calcareous, member (from bed 24 to bed 109) with thinner marl and limestone beds that are clearly bioturbated by *Zoophycos*. No bivalves have been found in this member;
3) an upper, more marly member (bed 109 to bed 122) with even thinner limestone and marl beds without *Zoophycos*.

The Calcaires à *Zoophycos* Formation itself is overlain by the marls of the Terres Noires Formation. The contact is paraconformable: a hiatus spanning the interval from the lower Batho-

Fig. 3. a, b) Lithological succession of the La Baume section (Aalenian–Bathonian) with proposed biostratigraphy, fossil occurrences, range of the trace fossil *Zoophycos* and ammonite ranges. a) Concavum Zone (lower Aalenian)–Propinquans Zone (Lower Bajocian). b) Propinquans Zone (Lower Bajocian)–Convergens Zone (lower Bathonian); legend on Figure 3b.

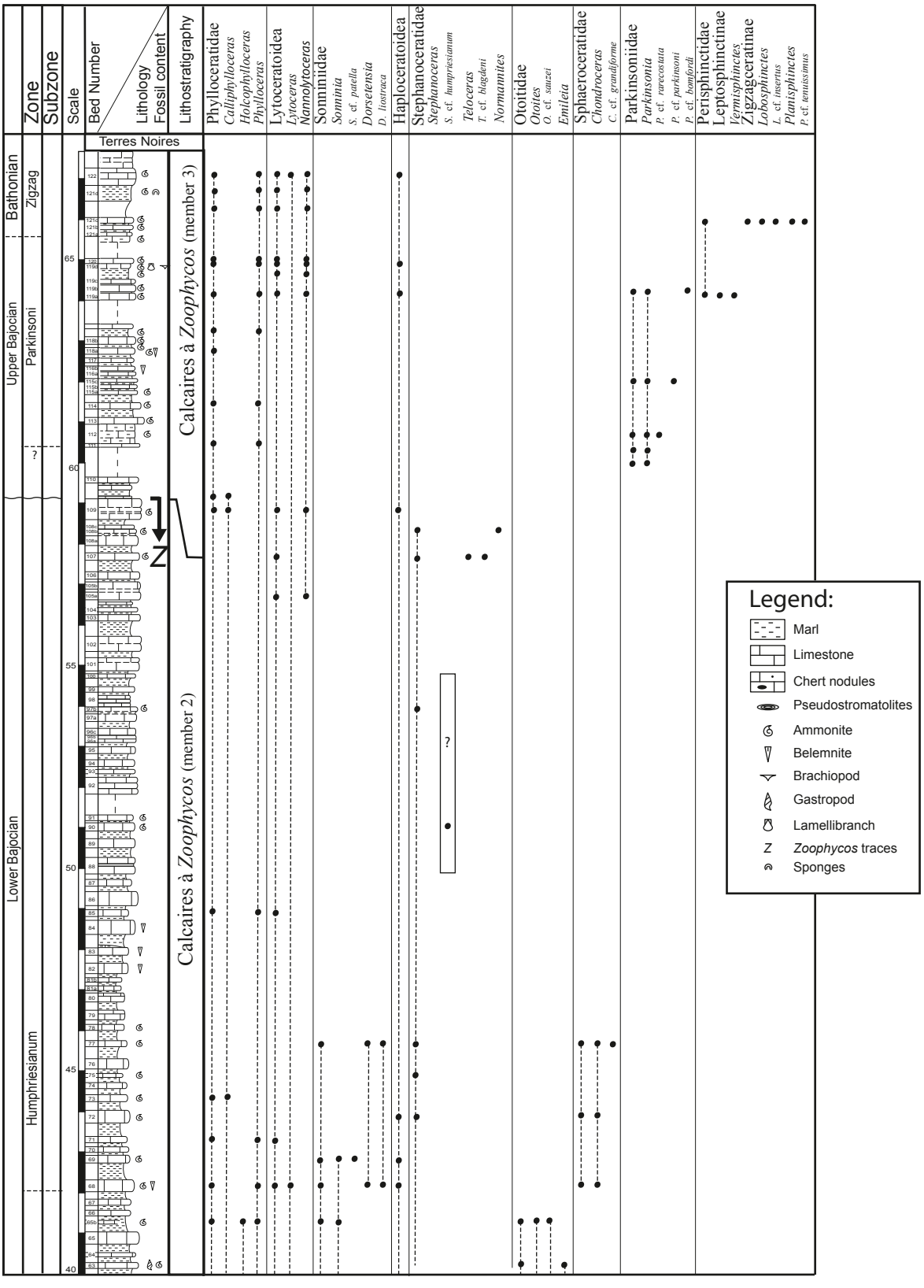
Lower Bajocian
Upper Bajocian
Bathonian
Zone
Subzone
Zigzag
Humphriesianum
Parkinsoni
?
Scale
Bed Number
Lithology
Fossil content
Lithostratigraphy
Terres Noires
Calcaires à Zoophycos (member 2)
Calcaires à Zoophycos (member 3)
Z
65
60
55
50
45
40
Phylloceratidae
Calliphylloceras
Holcophylloceras
Phylloceras
Lytoceratoidea
Lytoceras
Nannolytoceras
Sonniniidae
Sonninia
S. cf. patella
Dorsetensia
D. liostraca
Haploceratoidea
Stephanoceratidae
Stephanoceras
S. cf. humpriesianum
Teloceras
T. cf. blagdeni
Normannites
?
Otoitidae
Otoites
O. cf. sauzei
Emileia
Sphaeroceratidae
Chondroceras
C. cf. grandiforme
Parkinsoniidae
Parkinsonia
P. cf. ravecostata
P. cf. parkinsoni
P. cf. bomfordi
Perisphinctidae
Leptosphinctinae
Vermisphinctes
Zigzagceratinae
Lobosphinctes
L. cf. insertus
Planisphinctes
P. cf. tenuissimus
Legend:
Marl
Limestone
Chert nodules
Pseudostromatolites
Ammonite
Belemnite
Brachiopod
Gastropod
Lamellibranch
Zoophycos traces
Sponges

Fig. 3b.

nian to the lower Callovian has been reported by Kerckhove (1976) and Atrops et al. (1989).

Systematic descriptions (by K. De Baets)

The main interest of the fauna collected at La Baume is the rich and highly diverse ammonite family Sonniniidae, deserving an accurate systematic description of its representatives. Biostratigraphically significant forms belonging to other families are figured but are not the subject of a systematic description. These have been already revised in several important monographs on Bajocian–Bathonian ammonites collected in the Castellane area (Sturani 1966; Pavia 1973, 1983; Torrens 1987).

The standard dimensions are given in millimetres and as percentages of the diameter. The following abbreviations correspond to the shell parameters commonly used in ammonoid literature (e.g. Arkell et al. 1957; Cecca 1997): D = maximum diameter; d = diameter at which the measurements were taken when < D; Uw = umbilical width; Wh = whorl height; Wb = whorl breadth; Wb/Wh = degree of compression of the whorl section; the nomenclature of the sutural elements in the systematic description follows Cecca (1997).

The specimens are housed in the collection of the "Réserve Géologique de Haute Provence". Specimens were numbered in ascending order per bed with number in front of the dash corresponding to the bed number.

Family Sonniniidae Buckman 1892

Description. – Shell shape ranges from platycones to fastigate to almost oxyconic. Ornamentation ranges from strongly sculptured (with ribs, tubercles and/or spines) to almost completely smooth forms. At least one ontogenetic stage is ornamented. They all possess keels (in a certain stage of their ontogeny) which may fade on the adult body chamber or in earlier stages.

Discussion. – The systematics of the European Sonniniidae has been treated both in monographic studies (Dorn 1935; Hiltermann 1939; Oechsle 1958; Westermann 1966; Huf 1968; Morton 1972, 1975; Dietze et al. 2003) and in publications dealing with other ammonite groups (Gillet 1937; Maubeuge 1951; Arkell et al. 1957; Westermann 1969; Westermann & Riccardi 1972; Donovan et al. 1981; Pavia 1983; Fernández-López 1985; Schlegelmilch 1985; Sadki 1996; Rioult et al. 1997; Ohmert 2004), but authors did not reach a consensus. The most recent papers dealing with the systematics of the Sonniniidae were published by Dietze et al. (2005, 2007) and Chandler et al. (2006). Dietze et al. (2005) assigned *Fissilobiceras* to the family Hammatoceratidae. *Fissilobiceras* is homoemorphic to some large sonniniids, but has a more complicated, more incised suture line and a lower variability. Géczy (1966) already considered the suture line as the main criterion to distinguish the Hammatoceratidae from the Sonniniidae. Two forms of dimorphism have been reported in the Sonniniidae. In one type, the two morphotypes only differ in size and the microconchs do not possess lappets as in *Euhoploceras* (Dietze et al. 2005; Chandler et al. 2006). In the second type, there is a clear distinction between macroconchs (M) and microconchs (m) that develop lappets, like in the dimorphic pair *Witchellia* [M] – *Pelekodites* [m].

The large variability of some Sonniniidae, already observed by Buckman (1887–1907), ultimately motivated Westermann (1966) to introduce the Buckman's Law of Covariation. A quantitative variability study of the Sonniniidae would require a lot of material and is beyond the scope of this study. The main goal of this paper is to present the Sonniidae, which are abundant elements of the La Baume section, but were not described or figured previously. We will focus on the macroconchs that were not figured by Pavia (1983). The included genera are: *Dorsetensia*, *Euhoploceras*, *Nannina* (m), *Pelekodites* (m), *Pseudoshirbuirna*, *Shirbuirna*, *Sonninia*, *Witchellia*.

Genus *Euhoploceras* Buckman 1913

Type species. – *Sonninia acanthodes* Buckman 1889; Original designation by Buckman (1913).

Description. – Evolute to moderately involute planulates with rectangular to ovate, rather compressed whorl section. The venter is typically subtabulate to slightly bisulcate, with a low, hollow keel. The inner whorls typically posses weak, primary ribs and often posses well developed tubercles or spines. The extent of this spinose/tuberculate stage is highly variable and sometimes is lacking altogether (some specimens of *Euhoploceras modestum*). Ribbing is also highly variable, ranging from forms with strong ribbing beyond the end of the phragmocone (*Eu.* gr. *acanthodes*) to forms becoming smooth (or only slightly ornamented) on the middle and outer whorls (*Eu.* gr. *modestum*). Secondary ribs range from strong to weak. The suture line is relatively complex with a ramified deep L, and slightly retracted U2 and U5 lobes.

Discussion. – Dietze et al. (2005) have described more compressed morphs ("*Papilliceras*") that intergrade with *Euhoploceras* and considered the latter as a subgenus of *Sonninia*. However, here we maintain the distinction between these two genera, until a more quantitative and well illustrated study. A typical *Euhoploceras* can be separated from the younger *Sonninia* by its broader, more subtabulate whorls, distinct subtabulate venter (instead of fastigate) and a rather low keel.

The associated microconchs do not bear lappets. The earliest forms belong to the "*Sonninia" subdecorata* group (Westermann 1966; Dietze et al. 2005).

***Euhoploceras modestum* (Buckman 1892)**
(Fig. 4d)

* 1892 *Sonninia modesta* – Buckman: 325, pl. 68; pl. 70, fig. 5.
· 2000 *Euhoploceras modestum* Buckman – Sandoval & Chandler: 520, Pl. 10, figs. 1–4; Pl. 11, figs. 1–2; Pl. 12, figs. 1–3; Pl. 13, figs. 1–4.

For older references we refer to Sandoval & Chandler (2000).

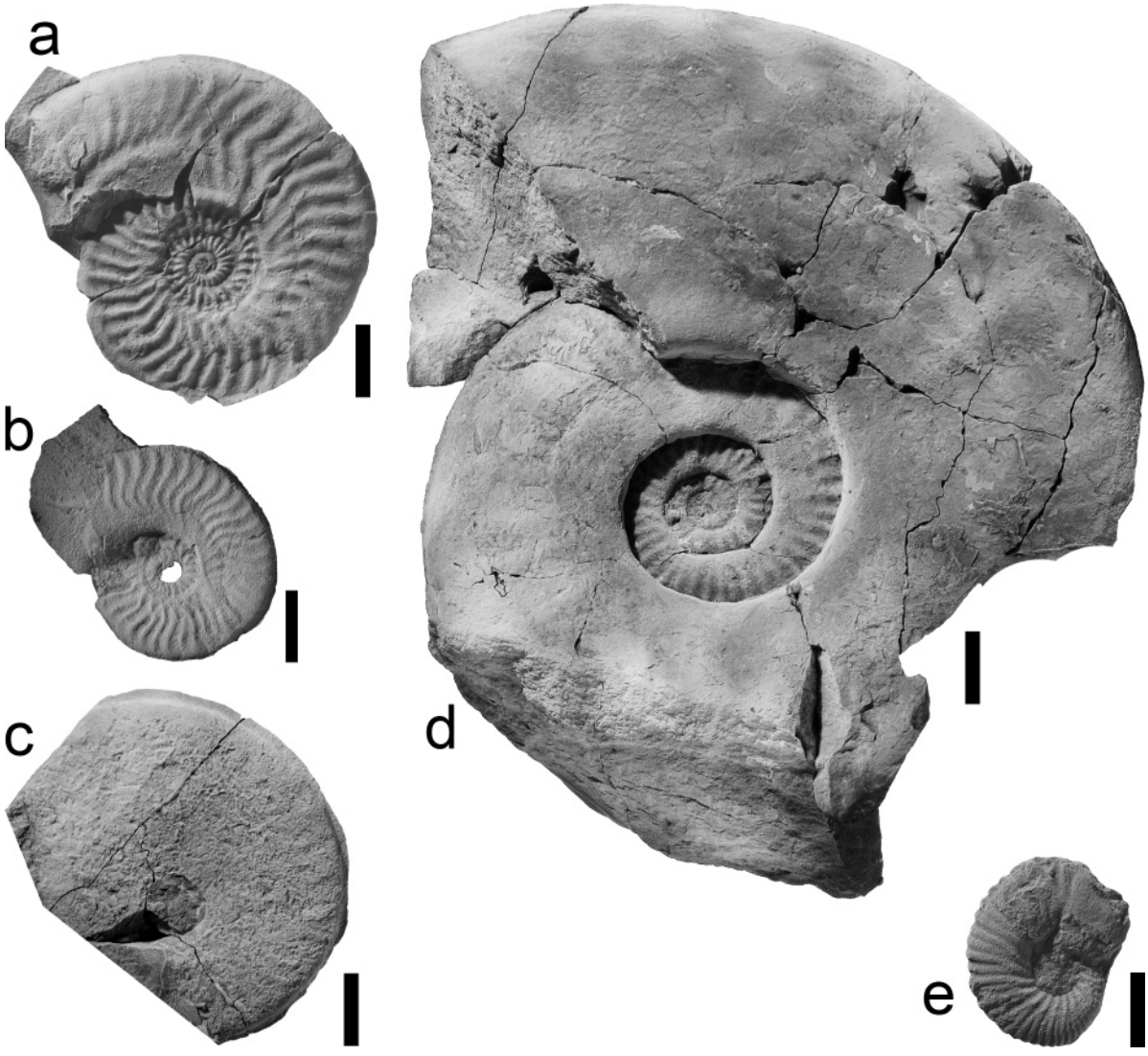

Fig. 4. Concavum (Upper Aalenian) to Laeviuscula Zone (Lower Bajocian) ammonites from La Baume section. a) *Graphoceras* cf. *decorum*, specimen 6/3, Concavum Zone; internal mold of the phragmocone. b) *Hyperlioceras* cf. *curvum,* specimen 17/8, Discites Zone; internal mold of the phragmocone. c) *Hyperlioceras* sp., specimen 22/1, Discites Zone; internal mold of the phragmocone. d) *Euhoploceras modestum*, specimen 22/2, Discites Zone; internal mold of the phragmocone and part of the body chamber. e) *Otoites* cf. *douvillei*, 24b/2, Laeviuscula Zone (Ovale Subzone); internal mold of the phragmocone and body chamber with lappets. Scale bars: 10 mm.

Material. – 3 specimens: 2 in bed 17 (17/6 and 17/7) and 1 in bed 22 (22/2).

Description. – Discoidal shells, which become more evolute towards the outer whorls with a typically compressed, subtabulate whorl section with rounded shoulders and a low, blunt keel. On the inner whorls, the whorl section can be more ovate with converging flanks. The umbilical wall is vertical and the umbical edge is rounded. *Euhoploceras modestum* typically has finely ribbed inner whorls, whereas middle and outer whorls are smooth. Tubercles can be present on the inner whorls, but disappear before the disappearance of the ribs.

Discussion. – The suture line of *Euhoploceras modestum* has a deeply incised lateral lobe and a slightly retracted umbilical lobe. The portions of the suture line, which are visible on the specimen (22/1) show the same characteristics. *Euhoploceras acanthodes* Buckman and *Eu. marginatum* Buckman are more strongly ornamented, this ornamentation persists longer in ontogeny, they have more pronounced keels and show a different coiling. *Euhoploceras* gr. *adicrum* (Waagen) has a stronger ornamentation, is differently coiled and has a wider whorl section. For a more thorough review of *Euhoploceras*, we refer to Sandoval & Chandler (2000)

Table 1. Measurements (mm) and ratios of *Euhoploceras modestum* (Buckman 1892), Family Sonniniidae; Discites Zone (Lower Bajocian). See text (section "systematic descriptions") for abbreviations.

Specimen	D	Wh	Wh/D	Uw	Uw/D	Wb	Wb/Wh
22/2	105.0	44.1	0.42	31.6	0.30	31.0	0.70
	69.1	31.8	0.46	21.7	0.31		

and, for the forms of the Ovale Subzone, to Dietze et al. (2005).

Genus *Shirbuirnia* Buckman 1910

Type species. – *Sonninia trigonalis* Buckman 1910; Subsequent designation by Arkell et al. (1957).
Description. – Large, discoidal forms with moderately involute to moderately evolute coiling and a low keel. The internal whorls are typically ribbed, but sometimes almost smooth or tuberculate, while the middle and outer whorls are smooth. The umbilical wall is typically steep with a fairly sharp but rounded umbilical edge. The venter is rounded to fastigate with ventrolateral edges, which are never well differentiated. The whorl section is typically ovate, ranging from subquadrate to high ovate in *Shirbuirna gingensis* and from ovate to triangular in *Shirbuirna trigonalis*. The maximum whorl width is reached much lower on the whorl side in the latter, which has a subtriangular whorl section at the adult body chamber. The septal suture is moderately incised and complex with a main trifid lateral lobe. For a more thorough review on *Shirbuirna* we refer to Dietze et al. (2005). *Shirbuirna gingensis* can be differentiated from *Shirbuirna trigonalis* because of the more involute coiling, the different whorl section, the higher whorl-height/whorl-width ratio at comparable diameter and slight differences in suture line.

Shirbuirna cf. *trigonalis* Buckman 1910
(Fig. 5b)

cf. 1910 *Shirbuirna trigonalis* – Buckman: 92, pl. 10, figs. 2–3.
cf. 1924 *Shirbuirna trigonalis* Buckman – Buckman: pl. 517.
cf. 1975 *Shirbuirna trigonalis* Buckman – Morton: 54, pl. 6, fig. 4.
cf. 2005 *Shirbuirna trigonalis* Buckman – Dietze et al.: 42, figs. 21–22.

Material. – 2 specimens in bed 34 (34/4 and 34/5).
Description. – Large planulates with a poorly differentiated, slightly fastigate venter and a low keel. The whorl cross section changes from ovate in the inner and middle whorls to subtriangular on the body chamber (with the highest values of the whorl width near the umbilical edge), which shows a clear egression of the umbilical seam. The umbilical wall is steep and the umbilical edge is sharply rounded. Inner whorls are not preserved in the reported specimens, but blunt, broadly spaced, radial undulations as in the specimen figured by Dietze et al. (2005) appear to be present on the middle whorls of one specimen.
Discussion. – *Pseudoshirbuirnia* has a more involute coiling, less sculptured inner whorls, a more ovate to discoidal whorl section and a simpler, less incised suture line then *Shirbuirnia*. The reported specimens seem to be very close to *Shirbuirna trigonalis* in coiling and other shell characteristics, especially the subtriangular whorl section (clearly visible in specimen 34/7).

Genus *Sonninia* Bayle 1879

Type species. – *Waagenia propinquans* Bayle 1878; Original designation by Bayle 1879.
Description. – Discoidal planulates with a simple peristome and a moderately evolute to involute coiling. The whorl section is rather compressed and more or less subovate. The venter is rather narrow and fastigate (at least on the outer whorls), and it is not delimited by clear ventrolateral shoulders. The inner whorls possess a high, hollow keel and are often ornamented with tubercles and ribs. Ribs are typically sigmoidal to falcoid and may branch in two or more secondary ribs. The ribbing usually weakens throughout ontogeny and the shell is therefore smooth on the adult body chamber.
Discussion. – The "*Papilliceras*" from the Sauzei Zone (or *Prepapillites*) were traditionally separated from *Sonninia*, because they develop lateral tubercles (papillae) on the body chamber. Some specimens, however, apparently lack these tubercles altogether, and Dietze et al. (2005) consider it as a subgenus of *Sonninia*.

Sonninia cf. *corrugata* (Sowerby 1824)
(Fig. 6a)

cf. 1824 *Ammonites corrugatus* – Sowerby: 74, pl. 451, fig. 3.
cf. 1985 *Sonninia corrugata* Sowerby – Fernández-López: figs. 4C, 5; pl. 8, figs. 4–8.

Material. – 5 specimens: 50/4, 53/4, 56/1, 60/2 and 61/1.
Description. – Moderately involute, discoidal planulate shells of medium size. The inner whorls are rather depressed, subquadrate, whereas middle and outer whorls are more ovate and compressed with a narrow venter. They posses a high keel on the outer whorls and a rounded umbilical edge. The ornamentation consists of radiate to prorsiradiate, sigmoidal ribs, which are projected towards the aperture on the venter and bundled near the umbilical edge. Tubercles are not developed. Ribs slowly fade out on the outer whorls.
Discussion. – The species *Sonninia corrugata* is based on a poorly preserved, incomplete, fully septate specimen figured by Sow-

Table 2. Measurements (mm) and ratios of *Shirbuirna* cf. *trigonalis* Buckman 1910, Family Sonniniidae; Laeviuscula Zone (Lower Bajocian). See text (section "systematic descriptions") for abbreviations.

Specimen	D	Wh	Wh/D	Uw	Uw/D	Wb	Wb/Wh
34/4	216	80.2	0.37	68.1	0.31	48.1	0.22
34/5	181.3	67.9	0.37	55.8	0.31	36.0	0.20

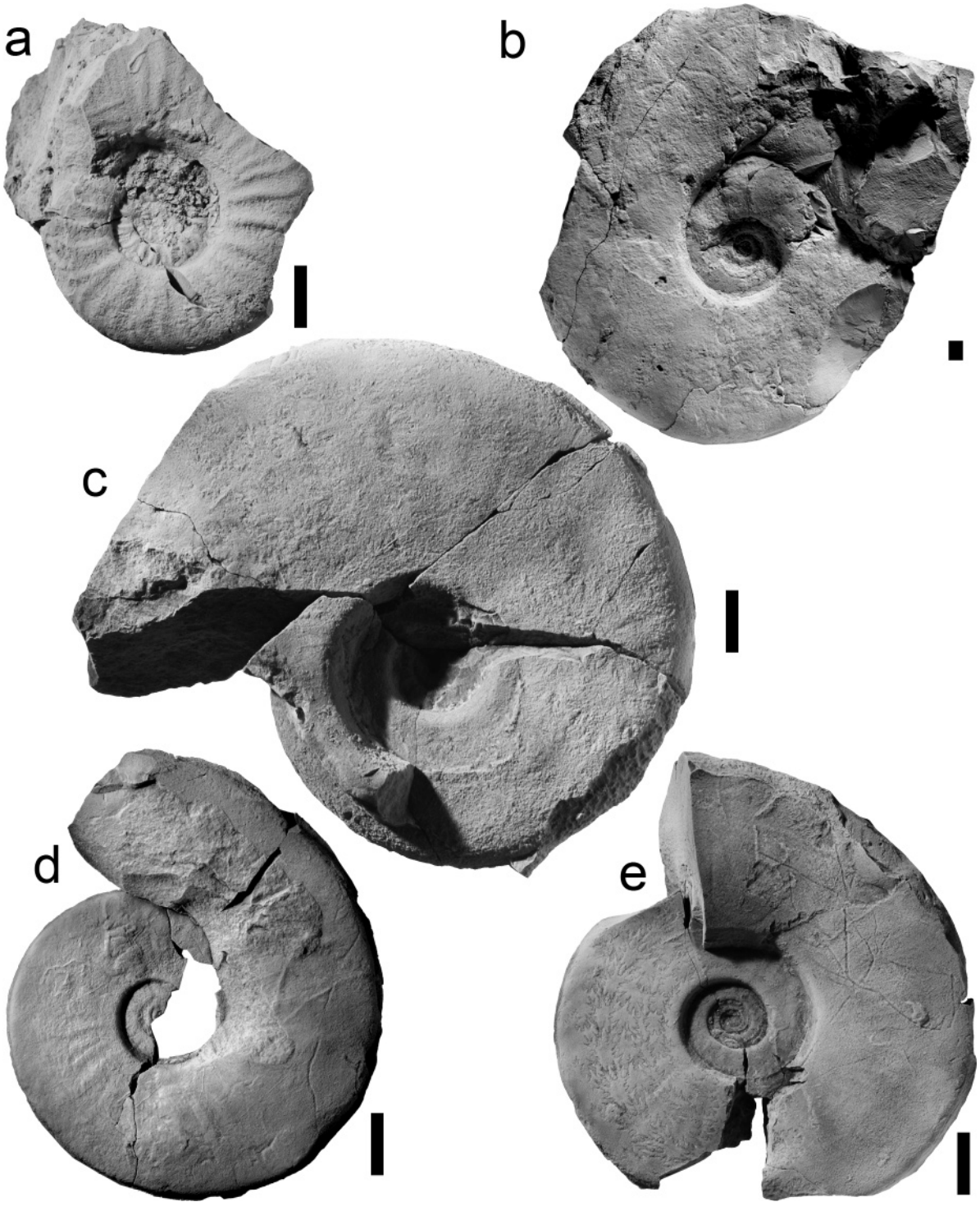

Fig. 5. Laeviuscula Zone (lower Bajocian) ammonites from La Baume section. a) *Witchellia* cf. *jugifera*, specimen 34/9, Laeviuscula Zone (Trigonalis Subzone); internal mold of the phragmocone and part of the body chamber. b) *Shirbuirna* cf. *trigonalis*, specimen 34/5, Laeviuscula Zone (Trigonalis Subzone); internal mold of the phragmocone and part of the body chamber. c) *Fissilobiceras* sp., specimen 34/1, Laeviuscula Zone; internal mold of the phragmocone. d) *Witchellia* cf. *pseudoromanoides* (smoother variety), specimen 35/7, Laeviuscula Zone (Trigonalis Subzone); internal mold of the phragmocone. e) *Witchellia* cf. *sayni* (faintly ribbed variety), specimen 37/1, Laeviuscula Zone (Trigonalis Subzone); internal mold of the phragmocone and part of the body chamber. Scale bars: 10 mm.

Table 3. Measurements (mm) and ratios of *Sonninia* cf. *felix* (BUCKMAN 1923), Family Sonniniidae; Propinquans Zone (Lower Bajocian). See text (section "systematic descriptions") for abbreviations.

Specimen	D	Wh	Wh/D	Uw	Uw/D
53/2	67.5	33.7	0.50	15.2	0.22

erby (1824). The suture line is unknown and the mode of coiling and ornamentation indicate that it could be a microconch. According to the literature, the interpretation of the species has changed considerably from very broad forms (Buckman 1926; Dorn 1935; Hiltermann 1939) including several larger morphs, to more restricted or small forms (Morton 1975). Some even included specimens with tubercles (Morton 1975), but to include these forms does not appear reasonable. Nevertheless, the reported specimens closely resemble the specimens figured by Fernández-López (1985: fig. 8) as *Sonninia corrugata*.

Sonninia cf. felix (BUCKMAN 1923)
(Fig. 6c)

cf. 1923 *Sonninites felix* – Buckman: Type Ammonites 5, pl. 428B.
cf. 1985 *Sonninia felix* (BUCKMAN) – Fernández-López: 46, fig. 4D; pl. 8, figs. 1 & 3.

Material. – 2 specimens (53/2 and 53/12).
Description. – Moderately involute, compressed shells with a rather high keel. The venter is rather narrowly fastigate on the inner whorls, but becomes more broadly rounded on the outer whorls. They have a steep umbilical wall and a rounded umbilical edge on the outer whorls. The inner whorls are ornamented with sigmoidal ribs, which are bundled near the umbilical edge and can be intercalated by secondary ribs. Some ribs are stronger near the umbilical wall, where they are bundled without developing tubercles. Ribs fade out rather quickly and disappear on the outer whorls, where only lateral striae remain.
Discussion. – The ornamentation on the inner and middle whorls resembles forms figured by Buckman (1923) as "*Sonninites*" *felix* (TA 5, pl. 428) and *Sonninia corrugata*. The smaller specimen figured by Buckman (1923) as *Sonninia felix* (Pl. 428B) could be the microconch of the bigger species (Pl. 428A), but there is no direct evidence. With its compressed whorl section, high keel and rather involute coiling, the reported specimen apparently belongs to *Sonninia* ("*Sonninites*"). The ornamentation of the inner whorls of bigger specimen figured by Buckman (1923) Type Ammonites 5, pl. 428A) are not clearly visible, but the ornamentation of the reported specimen is similar to the ornamentation of the smaller specimen illustrated by Buckman (1923) (Type Ammonites 5, pl. 428B) and especially the forms figured by Fernández-López as *Sonninia felix*. Nevertheless, it is more complete and differs because of its larger size and the smoothing of the ornamentation. The whorl section of *Witchellia laeviuscula* differs from that of the reported specimen in its lower keel and the presence of tubercles on the inner whorls. Most authors synonymised *Sonninites* with *Sonninia* but this is still debated (Chandler et al. 2006).

***Sonninia patella* (WAAGEN 1867)**
(Fig. 6b)

* 1867 *Ammonites patella* – Waagen: 597, pl. 25, figs. 1 & 2.
· 1935 *Sonninia patella* (WAAGEN) – Dorn: text-fig. 5, figs. 1–2; pl. 14, figs. 1 & 6.
· 1985 *Sonninia patella* (WAAGEN) – Schlegelmilch: pl. 18, fig. 2.
· 1997 *Sonninia patella* (WAAGEN) – Rioult et al.: 131, pl. 14, figs. 3a, b.

Material. – 1 specimen (50/1).
Description. – Discoidal, planulate, large shell with a compressed high-ovate, rather fastigate whorl section and a fairly narrow, but rounded venter with a pronounced, high keel. The umbilicus is rather wide and possesses a sharp umbilical edge. The inner whorls are ornamented with irregular, often bundled, small, radial sigmoidal ribs. The ribs weaken throughout the ontogeny and disappear at a diameter of 60 mm.
Discussion. – The specimen is rather badly preserved, but size, ornamentation, involute coiling and sharp umbilical edge make it similar to *Sonninia patella*. The latter is characterized by less pronounced ribs, the absence of tubercles and papillae, and a different coiling compared to *Sonninia* ("*Papilliceras*") *mesacantha* or *Sonninia* ("*Papilliceras*") *arenata*. The ribs seem to fade out earlier than in the specimens figured in the literature.

Witchellia (BUCKMAN 1889)

Type species. – *Ammonites laeviusculus* SOWERBY 1824; original designation by Buckman (1889).
Description. – Involute to moderately evolute platyconic shells with a simple peristome, a prominent keel and typically a rather compressed whorl section. They are rather small compared to other contemporary Sonniniidae. The venter is (sub)tabulate to bisulcate, but in some cases more fastigate with a less well defined venter as in the holotype of *Witchellia laeviuscula*. The ornamentation consists of ribs in earlier ontogenetic stages. The ribs are irregularly raised, sinuous, radial or slightly prorsiradiate. The ribs are often fasciculate near the umbilical edge and typically fade out later in ontogeny: the adult whorls can be totally smooth. The inner whorls may possess tubercles or are totally smooth.
Discussion. – The interspecific variability is large, spanning from rather evolute, strongly ornamented forms to rather involute, less ornamented forms. Through time we can see a shift from the primitive, more evolute, less ornamented (*Witchellia romanoides*) from the Ovale Subzone to more involute, more ornamented forms (*W. laeviuscula*) from the Laeviuscula Subzone. Dietze et al. (2005) consider ?*Dorsetensia romani* as a *Witchellia* of the Humpriesianum Zone. ? *Witchellia hebridica* is morphologically closer to *Witchellia* than the type species of *Dorsetensia*.

The associated, strongly lappeted microconchs have been traditionally classified as *Pelekodites*.

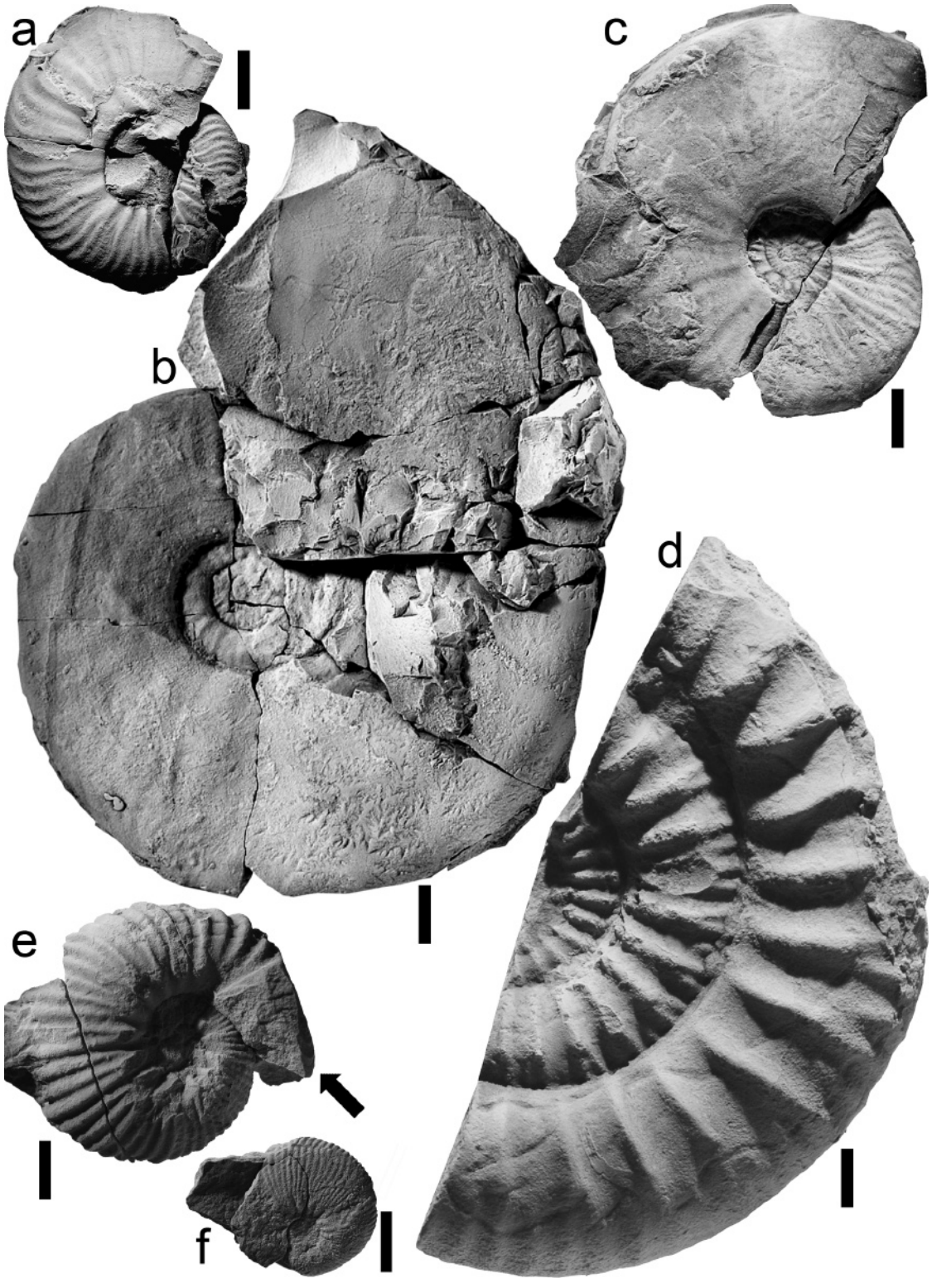

Fig. 6. Propinquans (lower Bajocian) to Humpriesianum Zone (upper Bajocian) ammonites from La Baume section. a) *Sonninia* cf. *corrugata*, specimen 50/2, Propinquans Zone; internal mold of the phragmocone and part of the body chamber. b) *Sonninia patella*, specimen 50/1, Sonninia propinquans Zone; internal mold of the phragmocone. c) *Sonninia* cf. *felix*, specimen 53/1, Propinquans Zone; internal mold of the phragmocone and part of the body chamber. d) *Kumatostephanus perjucundus*, specimen 57/2, Propinquans Zone; internal mold of part of the phragmocone and the body chamber. e) *Otoites* cf. *sauzei*, specimen 65b/2, Propinquans Zone; internal mold of the phragmocone and the body chamber with part of lappet (arrow). f) *Chondroceras* sp., specimen 68/4, Humpriesianum Zone; internal mold of the phragmocone. Scale bars: 10 mm.

Witchellia cf. *jugifera* (Waagen 1867)
(Fig. 5a)

cf. 1867 *Ammonites jugiferus* – Waagen: 596, pl. 26, fig. 3 (LT).
cf. 1935 *Sonninia jugifera* (Waagen) – Dorn: 46, figs. 5–6, pl. 8, fig. 5.
cf. 1937 *Sonninia jugifera* (Waagen) – Gillet: 38, pl. 4, fig. 2.
cf. 1985 *Sonninia jugifera* (Waagen) – Schlegelmilch: 60, pl. 16, fig. 2.
cf. 2005 *Witchellia jugifera* (Waagen) – Dietze et al.: 58, fig. 34a.

Material. – 1 specimen (34/9).
Description. – Moderately involute platycone with a highly rectangular whorl section with a rounded tabulate venter with low keel. The inner and middle whorls are ornamented with irregularly raised, sigmoidal ribs, which are often bundled near the umbilical edge.
Discussion. – The specimen resembles *Witchellia jugifera* (Waagen) in ornamentation and whorl section, but seems to be more involute. The keel is also less pronounced then in other *Witchellia*. *Witchellia sutneri* (Branco) is more evolute.

Witchellia cf. *sayni* Haug 1893/ *pseudoromanoides* Dietze, Chandler & Schweigert 2003
(Figs. 5d, e)

cf. 1885 *Ludwigia corrugata* Sowerby – Douvillé: pl. II, fig. 1–4.
cf. 1893 *Witchellia sayni* Haug – Haug: p. 308.
cf. 1985 *Witchellia sayni* Haug – Fernández-López: fig. 8j; pl. 5, fig. 3.
cf. 1988 *Witchellia sayni* Haug – Fernández-López et al.: pl. 1, fig. 5.
cf. 1990 *Witchellia sayni* Haug – Sandoval: fig. 5.
cf. 2003 *Witchellia pseudoromanoides* – Dietze et al.: pl. 5, fig. 2; pl. 1, fig. 3; pl. 2, fig. 2; pl. 3; pl. 4, fig. 2, pl. 5.

Material. – 1 specimen from bed 34 (34/6), 3 specimens from bed 35 (35/6, 35/7, 35/8), 10 specimens from bed 36 (36/4, 36/6, 36/7, 36/8, 36/9, 36/10, 36/11, 36/12, 36/13, 36/16, 36/17) and 2 specimens from bed 37 (37/1, 37/2).
Description. – Moderately involute platycones with a clearly differentiated tabulate to subtabulate venter with a prominent keel, without lateral sulci. The whorl section is compressed, subrectangular to subtrapezoidal. The umbilical wall is steep and the umbilical edge rounded. There is a morphological intergrading from involute, compressed, weakly ornamented to evolute, more ornamented forms. The more ornamented forms are ribbed on the middle whorls, while less ornamented forms are seemingly smooth or sometimes show fine striae. The ribs, when present, are slightly sigmoidal, simple or fasciculate and clearly projected near the venter.
Discussion. – The reported forms differ from those illustrated in the literature by their compressed, subrectangular to trapezoid whorl section and their weak ornamentation, especially on the inner whorls. The more strongly ornamented forms come close to a specimen from Portugal figured as *Witchellia sayni* Haug in Fernández-López et al. (1988), but the actual *W. sayni* is different. The type specimen of the latter species is ribbed across a diameter of 11 mm and does not develop tubercles as in some of the specimens erroneously figured in the literature as *W. sayni*. Furthermore, *W. romanoides* is also rather smooth but more evolute and has a more rectangular whorl section up to the outer whorls. The reported smooth forms resemble specimens figured by Dietze et al. (2005) that they identified as *W. pseudoromanoides* (smooth variety); however, no whorl section is given by the authors and the reported specimens are seemingly smooth on the inner whorls of the internal mould.

Table 4. Measurements (mm) and ratios of *Witchellia* cf. *sayni* Haug 1893/ *pseudoromanoides* Dietze, Chandler & Schweigert 2003, Family Sonniniidae; Laeviuscula Zone (Lower Bajocian). See text (section "systematic descriptions") for abbreviations.

Specimen	D	Wh	Wh/D	Uw	Uw/D	Wb	Wb/Wh
35/6	40.2	14	0.35	10.3	0.26		
	31.0	12.3	0.40	8.3	0.27		
35/8	53.1	21	0.40	21.2	0.40		
	53	19.2	0.36	21.4	0.40		
	50.2	19.5	0.39	19.7	0.39		
36/6	44.5	20.6	0.46	12	0.27		
	43.5	20.1	0.46	11.93	0.27	8.6	0.20
	32.3	13.5	0.42	9.26	0.29	7.7	0.24
	28.3	12.8	0.45	8.9	0.31	7.1	0.25
36/8	62.9	27.6	0.44	17.2	0.27	11.7	0.19
	59.6	27.3	0.46	15.2	0.26	11.1	0.19
	58.5	26.6	0.45	14.9	0.25	10.9	0.19
36/11	117.4	38.8	0.33	37.4	0.32	17	0.14
	114.5	42.8	0.37	38.67	0.34	17.4	0.15
	105.8	40.6	0.38	35.38	0.33	17.3	0.16
36/12	71.9	29.3	0.41	21.7	0.30		
	54.8	23.5	0.43	15.3	0.28		
37/1	69.3	26.9	0.39	21	0.30		
	65.1	26.8	0.41	19	0.29		
37/2	94.5	38.5	0.41	27.4	0.29		
	93.8	38.96	0.42	25.4	0.27		
	91.1	38.48	0.42	26.5	0.29	15.5	0.17
	86.5	35.92	0.42	24	0.28		
	84	35.49	0.42	23.1	0.28	15.8	0.19
35/7	69.5	30.8	0.44	16.5	0.24		
	66.7	29.3	0.44	16.6	0.25		
36/4	65.1	30.1	0.46	15.9	0.24		
	62.8	28.8	0.46	16.3	0.26		
36/6	32.9	12.4	0.38	12	0.36		
	28.4	11.3	0.40	9.4	0.33		
	44.5	20.6	0.46	12	0.27		
36/7	43.5	20.1	0.46	11.9	0.27	8.6	0.20
	32.3	13.5	0.42	9.3	0.29	7.7	0.24
36/9	28.3	12.8	0.45	8.9	0.31	7.1	0.25
	64	27.2	0.43	16.9	0.26		
36/13	56.1	24.8	0.44	14.5	0.26	6.2	0.11
	49.9	21.3	0.43	13	0.26	6	0.12
	42.8	17.6	0.41	10.8	0.25		
	40.4	17.4	0.43				
	31.8	15.5	0.49	7.7	0.24		
	31.1	14.8	0.48	7.8	0.25		
	45.1	18.9	0.42	11.8	0.26	6.3	0.14
	43.8	19.6	0.45	11.8	0.27		

Their coiling seems to be intermediate between *W. sayni* and *W. pseudoromanoides*.

Biostratigraphy

We followed the biozonation schemes proposed for the Submediterranean by Contini et al. (1997) for the Aalenian, by Rioult et al. (1997) for the Bajocian and by Mangold & Rioult (1997) the Bathonian. For recent discussions on the Lower Bajocian and reinvestigations on the stratigraphical position of the Buckman' specimens, we refer to Dietze et al. (2005, 2007) and Chandler et al. (2006). Additionally, Fernández-López et al. (2006) revised the knowledge about the stratigraphy around the Bajocian/Bathonian boundary at Cap Mondego (Portugal).

At the base of the subpelagic succession at La Baume, *Haplopleuroceras* gr. *mundum*, *Graphoceras limitatum* and *G.* cf. *decorum* (Fig. 4a) indicate the Late Aalenian Concavum Zone. Representatives of *Sonninia* (*Euhoploceras*), *Phylloceras* and *Lytoceras* also occur. At metre 10 (bed 14), we have found *Hyperlioceras* cf. *mundum*, which allows us to draw the base of the Bajocian. This is corroborated by the occurrence of *Hyperlioceras* cf. *aspera* and of *H.* cf. *curvum* (Fig. 4b) around metre 13.5 (bed 17), *Euhoploceras modestum* (Fig. 4d) and of *H.* sp. (Fig. 4c) in bed 22 (metre 21).

The beginning of the Laeviuscula Zone is tentatively drawn at metre 12.5 (bed 24) where *Otoites* cf. *douvillei* (Fig. 4e) occurs. This boundary would coincide with the beginning of member 2. *Fissilobiceras* sp. (Fig. 5c) and *Shirbuirna* cf. *trigonalis (*Fig. 5b*)* occur in bed 34, whereas representatives of the genus *Witchellia* are particularly abundant in beds 34 to 37 and characterize the ammonite fauna up to metre 33 (bed 50). The base of the Propinquans Zone is drawn at metre 34 (bed 50), on the basis of the appearance of *Sonninia corrugata* (Fig. 6a) and large specimens of other *Sonninia* species occurring in beds 50 (*Sonninia patella;* Fig. 6b) and 53 (*Sonninia* cf. *felix;* Fig. 6c). In bed 57 we found *Kumatostephanus perjucundus* (Fig. 6d). The last specimen of *Otoites (Otoites* cf. *sauzei*; Fig. 6e*)* is recorded in bed 65 and we have tentatively drawn the base of the Humphriesianum Zone at metre 43 (bed 68), on the basis of the co-occurrence of *Chondroceras* (Fig. 6f) and *Dorsetensia*. *Chondroceras* was also recorded in bed 72 and *Dorsetensia* was recorded in bed 77 (Fig. 7a).

A major gap of both the Niortense and the Garantiana Zone has been recognized at metre 59 (top of bed 109), at the boundary between members 2 and 3. The marl-dominated member 3, which contains ammonites of the Parkinsoni Zone (*Parkinsonia* cf. *rarecostata* in bed 114; Fig. 7b; *Parkinsonia* cf. *parkinsoni* in bed 118a and *Parkinsonia* cf. *bomfordi* in bed 120; Fig. 7f), overlies the top of member 2, ascribed to the top of the Humphriesianum Zone on the basis of the occurrence of *Teloceras* cf. *blagdeni* (Figs. 7c, d) in bed 109 and *Normannites* in bed 108b. The Bajocian/Bathonian boundary has been tentatively drawn within bed 121 on the basis of both the disappearance of *Parkinsonia* after bed 120 and the occurrence of *Lobosphinctes* cf. *insertus* (*sensu* Torrens 1987) in bed 121d. Some specimens (Fig. 7e), which are constricted for a considerable diameter (at least 100 mm), clearly belong to the genus *Lobosphinctes*. They resemble closely to the specimens figured by Torrens (1987) as *Lobosphinctes* gr. *insertus* from the Convergens Subzone; they do not resemble, however, to other specimens figured in the literature as *Lobosphinctes insertus* (Sturani 1966) with very marked constrictions. *Lobosphinctes costulatosus* is more involute and more closely ribbed than the reported specimens and *Lobosphinctes tmetolobus* is coarser and less densely ribbed. The reported *Lobosphinctes* specimens are associated with *Planisphinctes* cf. *tenuissimus.* We tentatively placed the Bajocian/Bathonian boundary in bed 121.

We also calculated the relative percentages of major ammonoid families per stratigraphic unit. Twenty two percent of the Lower Bajocian ammonites belong to the Phylloceratidae and the Lytoceratidae, documenting a faunal exchange with Tethyan oceanic waters. The upper Bajocian ammonites are dominated by nannolytoceratids (42% vs. 25% of Phylloceratidae and 33% of Ammonitina).

Conclusions

According to this study, the Calcaires à *Zoophycos* can be subdivided into three members:

1) A lower marly member (from bed 01 to bed 24), with ammonites of the Late Aalenian Concavum Zone succession found at its base;
2) an intermediate, more calcareous, member (from bed 24 to bed 109), with clear *Zoophycos*, which age spans the interval from the Early Bajocian Laeviuscula Zone to the top of the Humphriesianum Zone;
3) an upper member (bed 109 to bed 122), with ammonites of the upper Bajocian Parkinsonia to lower Bathonian Zigzag Zones.

The presence of the Upper Aalenian Concavum Zone, all Lower Bajocian Zones (Discites Zone, Laeviuscula Zone including Ovale Subzone, Humpriesianum Zone), one upper Bajocian Zone (Parkinsoni Zone) and probably one lower Bathonian Zone (Zigzag Zone) was shown herein. A major gap of both the Niortense Zone and the Garantiana Zone was detected at the boundary between members 2 and 3. In fact, member 3, which contains ammonites of the Parkinsoni Zone (*Parkinsonia* cf. *rarecostata*, *Parkinsonia* cf. *parkinsoni* and *Parkinsonia* cf. *bomfordi*), directly overlies the top of member 2, ascribed to the top of the Humphriesianum Zone on the basis of the occurrence of *Teloceras* cf. *blagdeni* (bed 109) and *Normannites* (bed 108b). The undulated hard ground on top of bed 109 also coincides with a change in sedimentary regime and disappearance of the trace fossil *Zoophycos*. Further research could investigate the nature of this gap, which has not been described before in the literature.

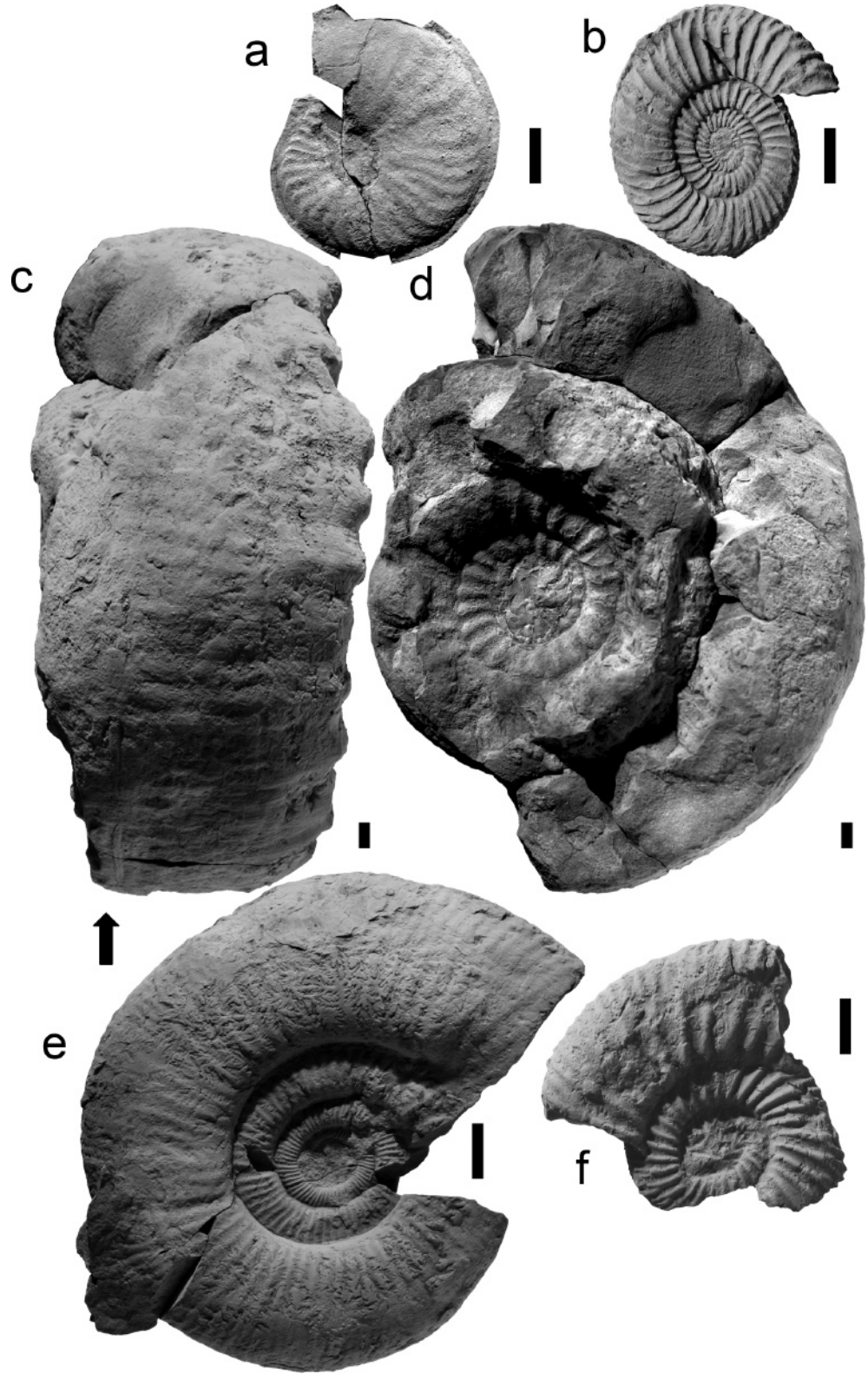

Fig. 7. Humpriesianum (Upper Bajocian) to Convergens Zone (Lower Bathonian) ammonites from La Baume section. a) *Dorsetensia* sp., specimen 77/2, Humpriesianum Zone; internal mold of the phragmocone. b) *Parkinsonia* cf. *rarecostata*, specimen 114/1. Parkinsoni Zone; internal mold of the phragmocone. c, d) *Teloceras* cf. *blagdeni*, specimen 109/1, Humpriesianum Zone; internal mold of the phragmocone. Note the position of the siphuncle (arrow). e) *Lobosphinctes* cf. *insertus* (sensu Torrens 1987), specimen 121d/2, Convergens Subzone; internal mold of the phragmocone. f) *Parkinsonia* cf. *bomfordi*, specimen 119/1, Parkinsoni Zone; internal mold of the phragmocone. Scale bars: 10 mm.

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