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RESEARCH PAPER

Stratigraphy and Biochronostratigraphy of the Lower Pliensbachian (Jurassic) from the Asturian basin (Northern Spain)

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Abstract

A stratigraphic study of the carbonate deposits from the interval between the uppermost Sinemurian and the base of the Upper Pliensbachian is presented herein. For this purpose, four expanded sections of the Asturian Basin, in Northern Spain, were sampled. The sections are located between Rodiles E section (Villaviciosa municipality) and Playa de Vega section (Ribadesella municipality). The ammonites recorded in over 100 successive levels of this sector enabled the substantial improvement of the biochronostratigraphic scale of reference; making it comparable with those defined for other basins of the Iberian Peninsula and other areas of the western Tethys. The lower boundary of the Pliensbachian is indicated by the first appearance of *Gemmellaroceras* aff. *aenigmaticum* (Gemmellaro) below the first appearance of the genus *Apoderoceras*. The upper boundary is defined by the first record of the *Protogrammoceras*. (*Matteiceras*) subgenus which in some levels is associated with *Amaltheus stokesi* (Sowerby). The boundaries between the zones and subzones were able to be established accurately in most cases. The ammonite assemblages are similar to those established for the NW European Province. Some intervals, however, include species typical of the Mediterranean Province. Among these, the Taylori Subchronozone (*Gemmellaroceras*) and the transition between the Jamesoni Subchronozone and the Valdani Subchronozone (*Tropidoceras*) can be highlighted. Additionally, taking into consideration the succession between of ammonite genera and species, 27 horizons were identified, 24 of which correspond to the Lower Pliensbachian, and the other 3 to the uppermost Sinemurian and the lowermost part of the Upper Pliensbachian. Moreover, the identification of 3 of the Lower Pliensbachian horizons were based upon the evolution of the Mediterranean *Tropidoceras*.

Keywords Early Pliensbachian · Ammonites · Ichnofauna · Biochronostratigraphy · Palaeobiogeography

1 Introduction

The Lower Pliensbachian biochronostratigrapy has been established in many sections of Europe i.e. Dean et al. (1961), Mouterde (1967), Mouterde et al. (1983, 2007), Gèczy (1976), Oates (1978), Comas-Rengifo (1982), Braga (1982), Braga et al. (1984, 1985), Phelps (1985), Meister (1986), Dommergues (1987), Dommergues et al. (1997), Blau & Meister (2000), Page (2003), Meister & Friebe (2003), Meister et al. (2006, 2009, 2017) and Fauré & Bohain (2017). However, no studies at high resolution, at chronohorizon or zonula scale, have been performed in Iberia.

The objective of the present study is to establish the highest biochronostratigraphic resolution of the Lower Pliensbachian succession in Northern Spain. For this purpose, a detailed study and sampling of four sections of the Asturian Basin (AB) were completed, (Fig. 1), the Rodiles E (ER) was taken as a reference section where the Lower Pliensbachian deposits are 42.8 m thick. The obtained data were completed with information from other sections, such as

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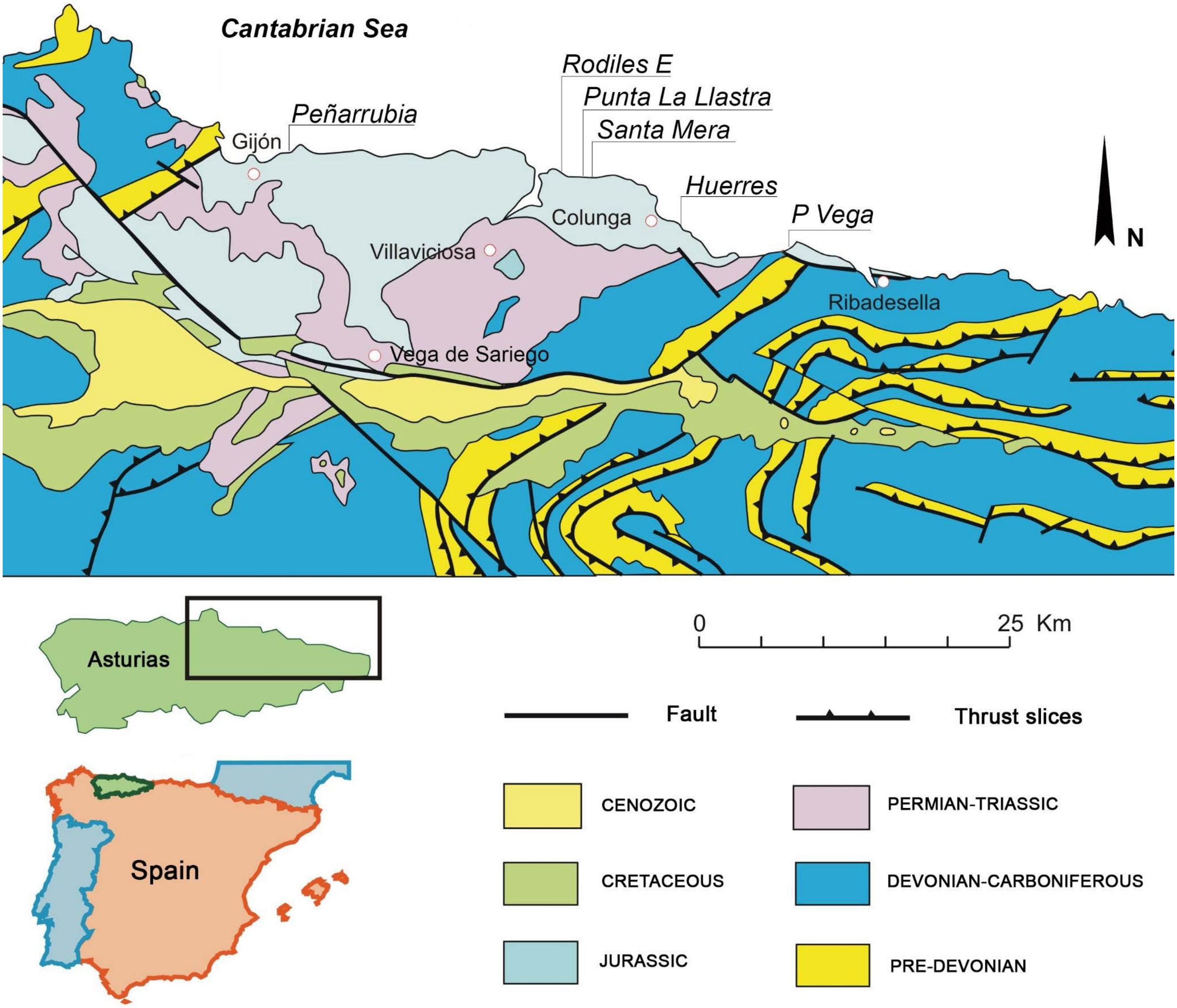


Fig. 1 Geological map of central-eastern area of Asturias (N Spain) modified from García-Ramos & Gutiérrez Claverol (1995) and location of different study sections: Rodiles E, Punta La Llastra and Santa Mera (Villaviciosa), Huerres (Colunga), Playa de Vega (Ribadesella) and Vega de Sariego (Sariego).

those located in Punta La Llastra (LL), Santa Mera (SM) and Playa de Vega (PV).

Analysis of the ammonite succession of the Lower Pliensbachian on the central-western coast of Asturias (North Spain) enabled us to achieve a detailed biostratigraphic and chronostratigraphic study. For this purpose, based on these sections and some local data (i.e., Huerres; Fig. 1), we established the stratigraphic distribution of the identified species, in an attempt to improve the biochronostratigraphic scale of reference obtained by Suárez Vega (1974). A complementary objective involves the correlation of the Asturian Basin (AB) with other basins of the Iberian Peninsula, such as the Basque-Cantabrian Basin (BC), the Pyrenean Basin (PB), the Iberian Basin (IB), the Betic Basin (BB) and the Portuguese Lusitanian Basin (LB), between the uppermost Sinemurian and the base of the Upper Pliensbachian. Other goals of interest are to establish the lower boundary of the Pliensbachian stage between Villaviciosa and Ribadesella, and to determine, with the highest resolution, the boundary between the chronozones and subchronozones of ammonites from the Lower Pliensbachian in an attempt to contribute to a better understanding of the palaeogeography during the Pliensbachian of the Iberian Peninsula.

Previous studies on the biochronostratigraphy of the Pliensbachian in the Asturian Basin were carried out in the second half of the XIX century and at the beginning of the XX century (i.e. Schulz, 1858; Barrois, 1882; Mallada, 1885; Jiménez de Cisneros, 1904 among others, see

Suárez Vega, 1974. Lately, the biostratigraphic distribution of the ammonites and the chronostratigraphy of the Pliensbachian in Asturias were studied by Dubar (1925), Dubar & Mouterde (1957) and Dubar et al. (1972), who studied the Lower Jurassic between Ribadesella and Gijón. These authors indicate that the Lower Pliensbachian shows an increase in thickness (15 to 40 m) between Ribadesella (PV section) and the Playa de Peñarrubia, East of Gijón.

Suárez Vega (1974) attributes a maximum of approximately 42.8 m to the Lower Pliensbachian, providing detailed biostratigraphic information. In the Lower Pliensbachian he characterises the Jamesoni Zone with the Taylori, Polymorphus-Brevispina and Jamesoni horizons, the Ibex Zone with the Maugenesti, Valdani-Ellipticum, Stahli and Beaniceras spp. horizons and the Davoei Zone with the *Oistoceras* spp. horizon in the upper part. He also characterises the Valdani Subzone of the Ibex Zone and the Maculatum Subzone of the Davoei Zone, recognised by different authors from France and England. Some years later Braga et al. (1984) conducted further studies of the ammonite successions, limits and correlations of the Pliensbachian in Spain, making use of the data provided by Suárez Vega to study different aspects of the Lower Pliensbachian in Asturias.

2 Materials and methods

All the sections were studied and sampled bed by bed, and the classified ammonites were collected by the authors of the present paper over the last fifteen years. In the studied sections, the relevant discontinuities identified with the available biochronostratigraphy, always encompass less than one subchronozone.

The specimens collected are from the interval between the Upper Sinemurian (top of the Raricostatum Chronozone) and the base of the Upper Pliensbachian (lowermost Margaritatus Chronozone). In the most complete succession (ER), ammonites from 96 successive levels were collected, 83 of which correspond to the Lower Pliensbachian and the remaining to the Sinemurian and Upper Pliensbachian.

In most cases, the infill of the shells is very similar to the matrix in which they were embedded, indicating thata they are accumulated, and only in some exceptional cases evidence indicating that the ammonites were re-elaborated can be found.

In the ER and PV sections, virtually all the layers were numbered (Fig. 2). In many cases the lowermost part (b) and the topmost part (t) were differentiated and when the thickness was relatively significant, three parts were distinguished: lower: (i), middle (m) and upper (s). In some cases the specimens were labelled with the corresponding level number, followed by the distance in centimetres from the base or top of the limestone layers to the point at which the sample was obtained.

In the SM and LL sections, given the particular features of the outcrops, easily-identifiable limestone layers were established, and the label of each specimen indicated the distance in cm below the base or above the top followed by the reference number of the layer, for example, SM (-15) or LL (+10) respectively.

The collected ammonites have been completed with the review of the Lower Pliensbachian ammonites deposited in the Jurassic Museum of Asturias (MUJA), under the title "Suárez Vega Collection", corresponding to the PhD of this author, along with some specimens of the "Mouterde Collection", studied by Dubar & Mouterde (1957) and subsequently by Suárez Vega (1974). Other Spanish specimens from the "Mouterde Collection" are from the Catholic Faculties of Lyon, and are deposited in the Palaeontology Dept. of the Madrid's Complutense University (DPUCM). Research has also been conducted on the specimens corresponding to the work of Comas-Rengifo et al. (2010), Comas-Rengifo & Goy (2010) and Gómez et al. (2016a, b), as well as the ones from Asturias studied by Rodríguez-Luengo et al. (2012).

3 Stratigraphic succession

3.1 Stratigraphy and sedimentology

The Lower Pliensbachian marine succession cropping out at the Asturian coast is characterized by rhythmic marl-limestone alternations included in the Santa Mera Member of the Rodiles Formation (Valenzuela et al., 1986). These coastal cliffs containing Jurassic rocks run from the localities of Gijón to Ribadesella (Fig. 1). This carbonate succession was deposited in an intrashelf basin displaying an irregular floor controlled by differential subsidence. From a palaeobiogeographic point of view, it represents an intermediate area between the Boreal and the Tethyan domains.

The whole succession likely accumulated in a relatively shallow water environment with a depth of up to 100 m, which most of the time was situated below the fair-weather wave base (Bandel & Knitter, 1986; Bjerrum et al., 2001; French et al., 2014; Leonowicz, 2015). The carbonate content of the limestone beds ranges from 65 to 97%, fluctuating from 8 to 65% in the marl interbeds (Bádenas et al., 2012). TOC values range from 0.75 to 7.32%, with the higher scores found in the laminated black shale intervals (Borrego et al., 1997, updated following biostratigraphic corrections; Gómez et al., 2016a, b; Deconinck et al., 2020).

Prevailing among the invertebrate macrofauna are molluscs such as ammonites, belemnites and bivalves (Fig. 3a and b), although brachiopods (Fig. 3c) and crinoids are also

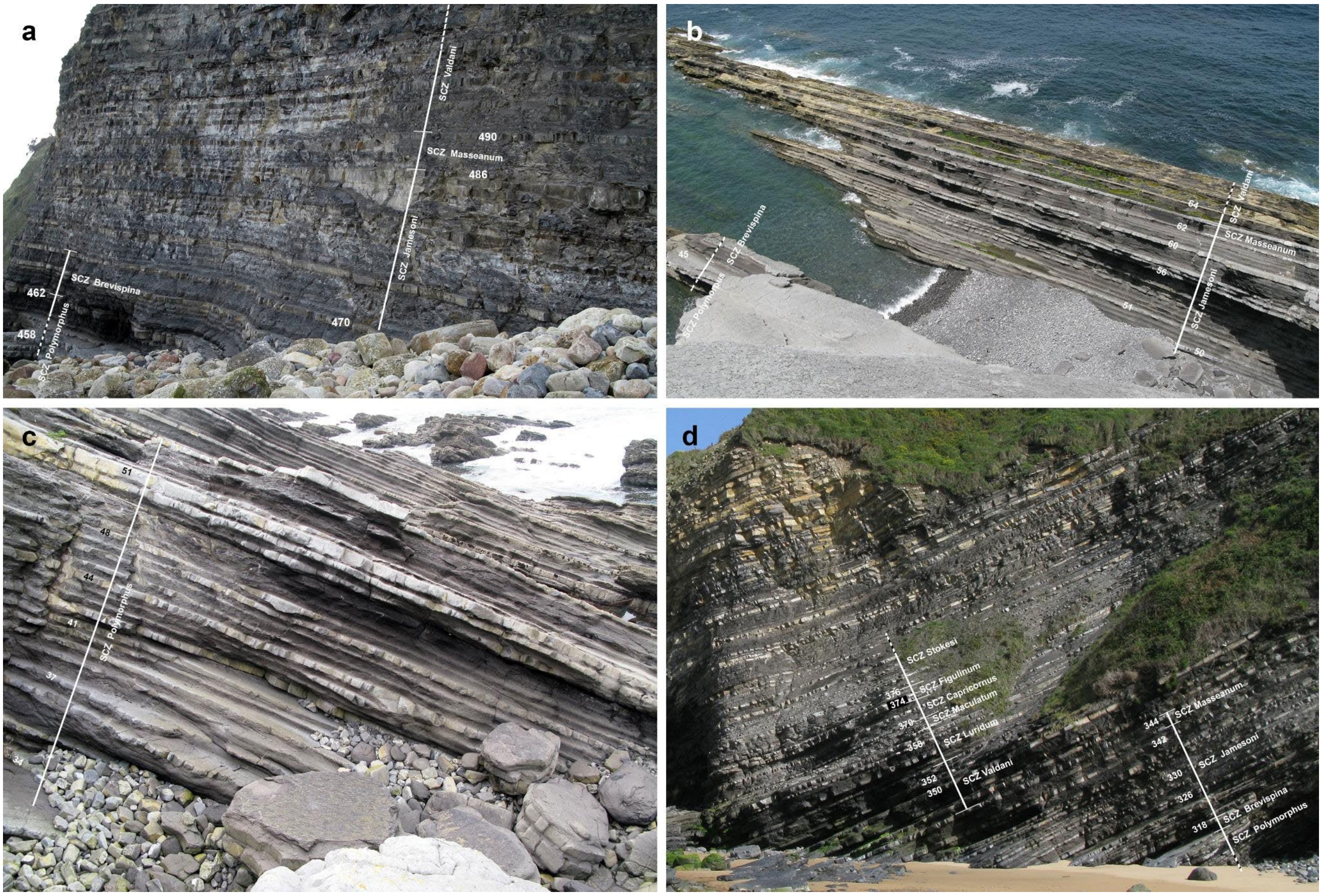


Fig. 2 **a** Rodiles E partial section with Jamesoni Chronozone (Polymorphus, Brevispina and Jamesoni subchronozones) and Ibex Chronozone (Masseanum and Valdani subchronozones). **b** Punta La Llastra partial section with Jamesoni Chronozone (Polymorphus, Brevispina and Jamesoni subchronozones) and Ibex Chronozone (Masseanum and Valdani subchronozones). **c** Santa Mera partial section with Jamesoni Chronozone (Polymorphus Subchronozone). **d** Playa de Vega partial section with Jamesoni Chronozone (Polymorphus, Brevispina and Jamesoni subchronozones), Ibex Chronozone (Masseanum, Valdani and Luridum subchronozones), Davoei Chronozone (Maculatum, Capricornus and Figulinum subchronozones) and Margaritatus Chronozone (Stokesi Subchronozone).

well represented. A characteristic interval of the Taylori Subchronozone black shales includes high concentrations of oil-infilled parautochthonous brachiopods deposited by storm currents and buried alive (Fig. 3c). During a late burial stage, the oil migration filled the porous interior of the empty or drusy calcite-draped specimens.

Likewise, the trace fossils exhibit a relatively high diversity and belong to the *Skolithos*, *Cruziana* and *Glossifungites* ichnofacies. The most representative ichnogenera, (albeit appearing in varying proportions) are: *Arenicolites*, *Asterosoma*, *Bergaueria*, *Chondrites* (Fig. 3e and f), *Conichnus*, *Diplocraterion* (Fig. 3f), *Gyrolithes*, *Kulindrichnus*, *Lockeia* (Fig. 3d), *Multina*, *Oravaichnium Palaeophycus*, *Phycosiphon*, *Phymatoderma* (Fig. 3f and g), *Planolites* (Fig. 3f), *Protovirgularia*, *Ptychoplasma* (Fig. 3d), *Rhizocorallium*, *Skolithos*, *Taenidium*, *Teichichnus*, *Thalassinoides* (Fig. 3f) and *Trichichnus* (García-Ramos et al., 2011).

The vertebrate fauna consists of two partial ichthyosaur skeletons from the Rodiles E (Fernández et al., 2018; Fig. 3h) and Playa de Vega sections, and another incomplete plesiosaur specimen from the Santa Mera section (Bardet et al., 2008); they are all located in the black shale intervals of the Jamesoni Chronozone (Taylori Subchronozone).

3.1.1 Cyclical organization

In the studied rhythmic succession, as a general trend, an increase in both the limestone/marl ratio and the irregularity of the limestone bed surfaces (often by scouring or erosive amalgamation; Fig. 4a) represent shallowing episodes, and vice versa (García-Ramos, 2010; García-Ramos et al. 2011). The marl/limestone couplets are arranged according to the scale considered in two types of cycles: elementary, on one hand, and small transgressive-regressive on the other. The elementary cycles consist of centimetre- to decimetre-thick intervals including a basal bioclastic layer with an erosive base and a fining-upward trend, a middle layer of laminated or massive marl and an upper bioturbated

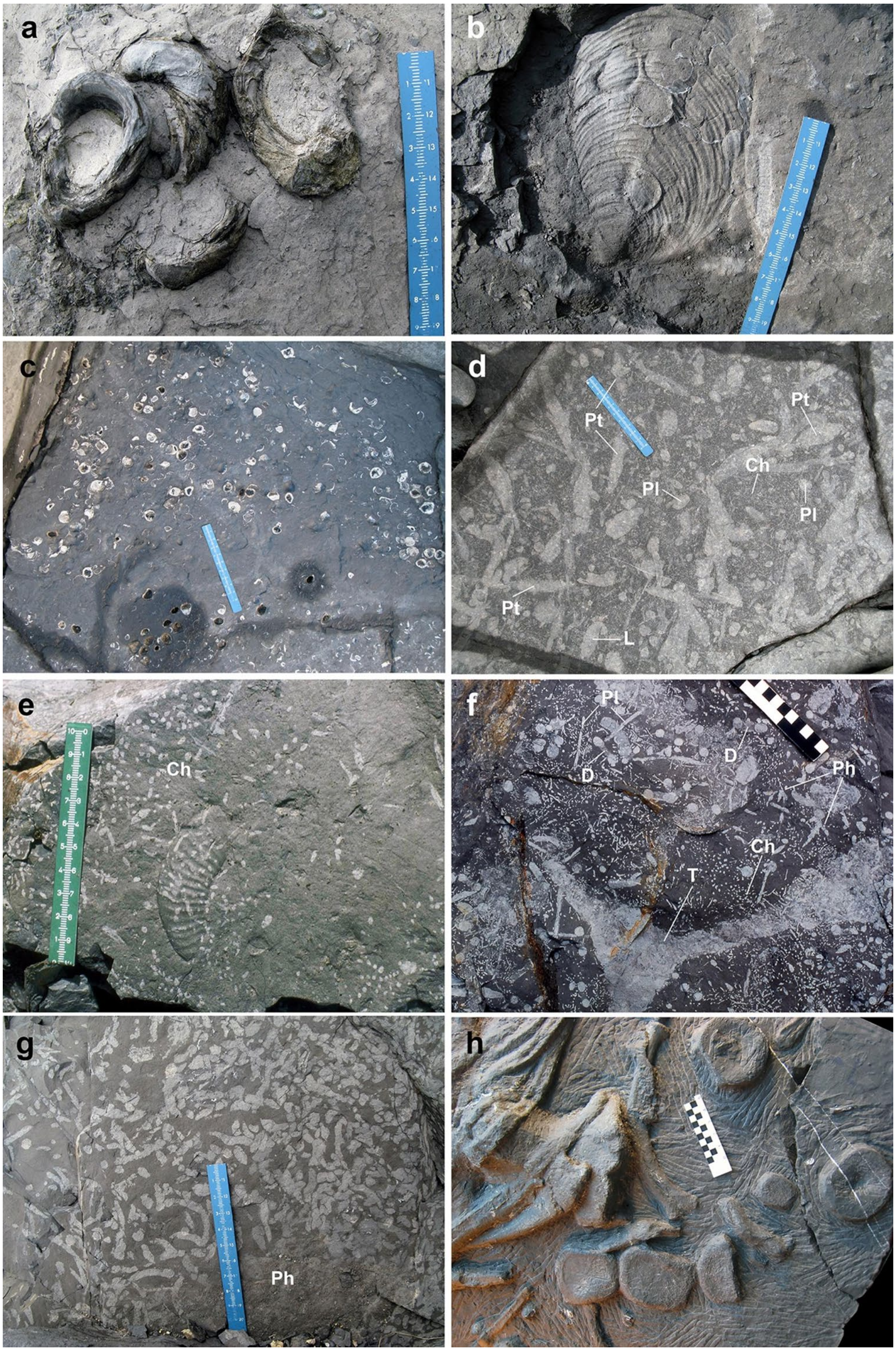


Fig. 3 **a** Concentration by storms of *Gryphaea* specimens in the erosive base (bioclastic layer) of an elementary cycle, Jamesoni Chronozone, Huerres. **b** Inoceramid shell with several oyster encrusters, Jamesoni Chronozone (top of Jamesoni Subchronozone), Punta La Llastra. **c** Brachiopod shellbed, some of them with oil infill, Jamesoni Chronozone (Taylori Subchronozone), Santa Mera. **d** Infaunal bivalve resting (*Lockeia*, L) and locomotion traces (*Ptychoplasma*, Pt) associated to *Chondrites*(Ch) and *Planolites* (Pl), Jamesoni Chronozone, Punta La Llastra. **e** Internal mould of an ammonites traversed by *Chondrites* (Ch) in a marl interbed, Jamesoni Chronozone, Punta La Llastra. **f** Trace fossil association including *Chondrites* (Ch), *Diplocraterion* (D), *Phymatoderma* (Ph), *Planolites* (Pl) and *Thalassinoides* (T) in a marl interbed, Punta La Llastra. **g** *Phymatoderma* (Ph) specimens in a marl interbed, Jamesoni Chronozone (Taylori Subchronozone), Huerres. **h** Skeletal remains of the ichthyosaur *Leptonectes* sp. Jamesoni Chronozone (Taylori Subchronozone), Rodiles E.

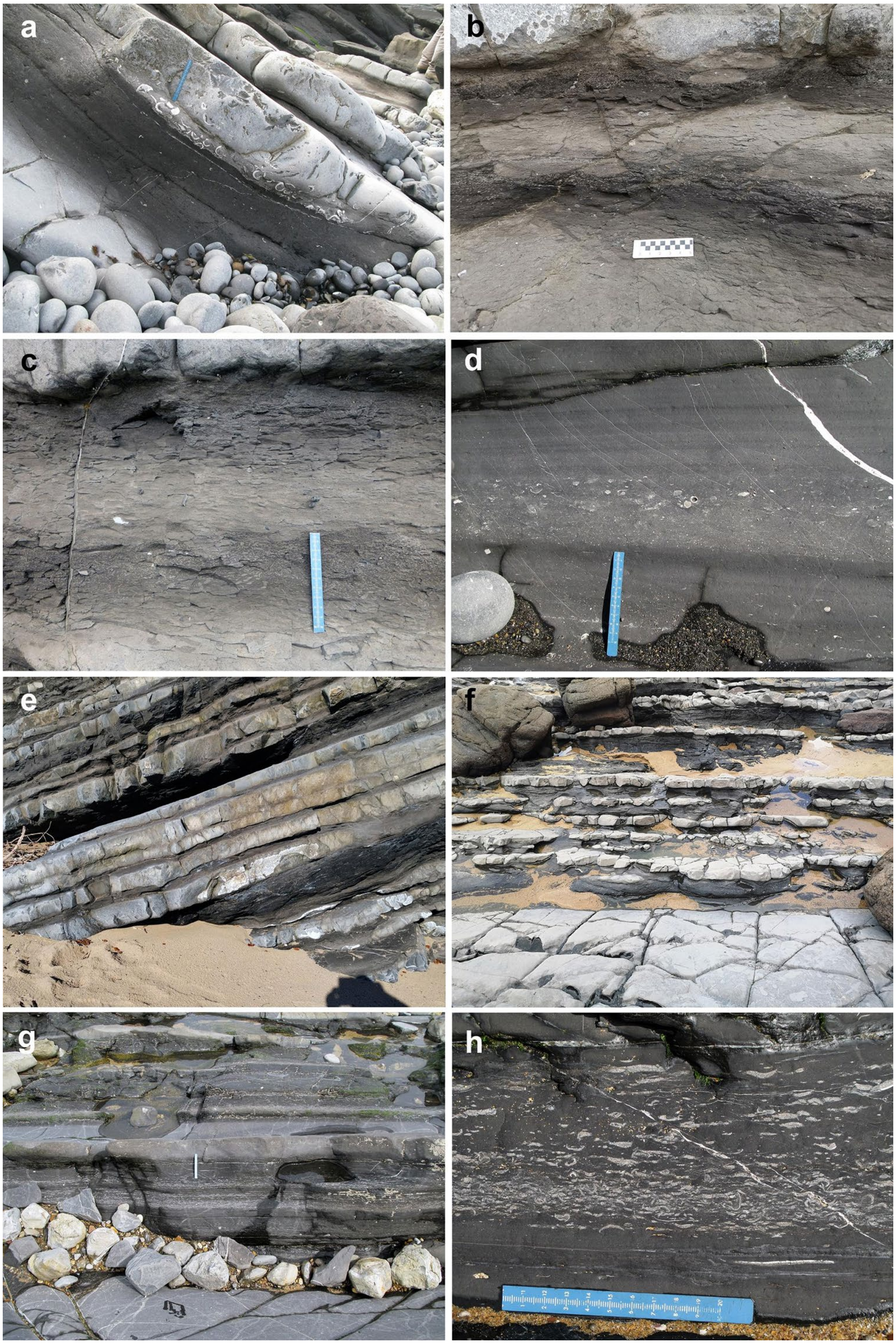


Fig. 4 **a** *Gryphaea* concentrations in the base of a scoured limestone bed excavated by a storm current, Jamesoni Chronozone (Taylori Subchronozone), Santa Mera. **b** Two consecutive elementary cycles, Jamesoni Chronozone (Jamesoni Subchronozone), Playa de Vega. **c** Two consecutive elementary cycles, Jamesoni Chronozone (Jamesoni Subchronozone), Punta La Llastra. **d** The top of scale indicates the base of the bioclastic layer below the laminated layer in an incomplete, at the top, elementary cycle, Jamesoni Chronozone (Jamesoni Subchronozone), Punta La Llastra. **e** Erosive amalgamation of limestone beds interpreted as a sudden shallowing episode, Jamesoni Chronozone (Polymorphus Subchronozone), Playa de Vega. **f** Nodular and discontinuous limestone beds and grey marls including frequent phosphatic faunal fragments reworked by erosion, Davoei Chronozone (Maculatum Subchronozone), Playa de Vega. **g** Laminated black shale interval, Ibex Chronozone (Valdani Subchronozone), Playa de Vega. **h** Detail of **g** with crushed bivalve shell beds.

layer (García-Ramos et al., 2011; Bádenas et al., 2012). These elementary cycles are found throughout the succession (Fig. 4b-d), but it is difficult to detect them in the Ibex Chronozone black shales. The small-scale transgressive-regressive cycles, with a thickness from several tens of centimetres to 1.5 m, include several (up to 6) elementary cycles. Cycle boundaries are characterised by condensed elementary cycles and frequent scouring events, erosive amalgamation processes and burrow mottling with complex tiering (time-averaging effect). These cycle boundaries cannot always be placed at a discrete bed surface and actually represent cycle-boundary zones associated with a general loss of accomodation. Moreover, these bounded zones often exhibit firmgrounds associated with *Glossifungites* ichnofacies and a relatively more diverse assemblages of trace fossils. Herein the limestone/marl ratio is also higher.

On the other hand, these Lower Pliensbachian successions present several sudden shallowing (forced regression) and deepening episodes with apparently sharp lower and upper boundaries. Two of the most representative of these correlatable episodes throughout the Asturian basin outcrops include erosive amalgamated limestone beds 41 to 45 (upper half of the Polymorphus Subchronozone) in the playa de Vega section (Fig. 4e), and beds 360 to 370 (lower half of the Taylori Subchronozone) in the Rodiles E section. Also characteristic of the Playa de Vega section is an interval displaying alternations of nodular or discontinuous limestone beds and grey marls, containing frequent phosphatic faunal fragments, included predominantly in the Maculatum Subchronozone (Davoei Chronozone). This reveals a condensation episode related to a shallowing event, as evidenced also by a relative increase in amalgamated bioclastic deposits (Fig. 4f).

Some of main transgressive surfaces occur around the Sinemurian-Pliensbachian boundary (top of bed 356, base of the Taylori Subchronozone, in the Rodiles E section), at the top of bed 7 (lower half of the Taylori Subchronozone) in the Santa Mera section, and at the top of bed 63 (near the base of the Valdani Subchronozone) in the Punta La Llastra section. The graphic representation and the possible origin of cyclicity are not within the scope of the present paper; this constitutes the objective of a forthcoming publication.

3.1.2 Diagenetic aspects

Rhythmic marl-limestone alternations are usually interpreted as a consequence of periodic oscillations in the orbital parameters of the Earth, even in greenhouse times.

In the present case, the diagenetic modifications are only partially controlled by the primary (sedimentary) processes. Consequently, several orders of cycles and their boundaries do not match exactly with the present lithologic changes between marl interlayers and limestone beds. Specifically, each marl interbed or limestone bed includes several elementary cycles (Fig. 4d-f).

On the other hand, the boundary between both lithologies crosscuts obliquely the time lines, thus merging diachronous deposits into one single limestone or marl layer, a phenomenon previously indicated by Nohl & Munnecke (2019) in the Silurian rhythmic series of Sweden (See also: Biernacka et al., 2005; Gani, 2017; Nohl et al., 2021).

Light to medium-grey massive and/or bioturbated limestone beds are only slightly compacted and generated during a shallow-burial environment (early diagenesis) (Westphal, 2006; Westphal et al., 2010). Within limestone beds, the macrofossils are most frequently undeformed due to early cementation, while in the marls, many of them are crushed with the exception of those possessing a thick calcitic shell. The greatest values of flattening were found in the internal moulds of ammonites preserved in episodes of dark marls and black shales. These differences result from carbonate redistribution, differential compaction and cementation processes between the limestone beds and the marl interbeds. The local presence in the marl interbeds of infilled internal moulds of ammonites traversed by *Chondrites* also suggest an early and shallow subsurfacial aragonite dissolution of the cephalopod shells. On the contrary, the dark grey laminated limestones (frequently marly limestones) occur exclusively within the black shale intervals and are generated after the main compaction phase (later diagenesis), as evidenced by the enclosed crushed both ammonites and the scarce trace fossils.

Another problem arising in the use of limestone-marl couplets for cyclostratigraphic analysis in our case involves the lateral wedging or bifurcation of many limestone beds and the apparently sharp boundaries between both calcareous lithologies controlled by present-day weathering processes in the outcrop. The primary (sedimentary) boundaries are very gradual, as evidenced previously by Ricken (1986), with the highest carbonate content usually located in the middle part of the limestone beds and vice versa in the marl interbeds. Moreover, the frequent incomplete tiering of trace fossils by erosive processes suggests multiple small gaps in the rhythmic succession below the present-day biostratigraphic resolution.

These and other additional diagenetic processes call into question the indiscriminate use of limestone-marl alternations for orbital-related climatic cyclicity and astrochronology. See also: Ricken (1986), Munnecke et al. (2001), Westphal (2006), Westphal et al. (2008, 2010), Bádenas et al. (2009, 2012), García-Ramos (2010), García-Ramos et al. (2010, 2011), Nohl & Munnecke (2019), Nohl et al. (2020), Su et al. (2020).

3.2 Chronostratigraphy

In order to establish the biochronostratigaphy of the Lower Pliensbachian, the ER section has been taken as a reference; because the whole interval considered shows a consistent ammonite record (Suárez Vega,1974; Comas-Rengifo et al., 2010; Gómez et al., 2016a, b). This section is the most complete and representative of the AB (Figs. 2a and 5) and the biochronostratigraphic intervals are commonly more expanded. Nonetheless, it was complemented with the information provided on certain intervals in other sections (Figs. 2b-d and 6), such as LL (Jamesoni Chronozone, Brevispina Subchronozone to Ibex Chronozone, Luridum Subchronozone), SM (Jamesoni Chronozone, Taylori Subchronozone to Jamesoni Subchronozone) and PV (Jamesoni Chronozone, Jamesoni Subchronozone to Margaritatus Chronozone, base of the Stokesi Subchronozone). As has been pointed out, this last section presents less thickness than the other three (Valenzuela et al., 1986; García-Ramos et al., 1992; Comas-Rengifo & Goy, 2010).

For the zonal scales of reference, we compare the obtained results with those previously proposed for the NW European and Mediterranean Provinces. Among others, by Dean et al. (1961), Mouterde (1967), Gèczy (1976), Oates (1978), Comas-Rengifo (1982), Braga (1982), Mouterde et al. (1983, 2007), Braga et al. (1984, 1985), Phelps (1985), Meister (1986), Dommergues (1987), Dommergues et al. (1997), Blau et al. (2000), Page (2003), Meister & Friebe (2003), Meister et al. (2006, 2009, 2017), and Fauré & Bohain (2017).

Figure 7 shows the distribution of the identified species in relationship to the most recently used standard scales (Dommergues et al., 1997; Page, 2003). The succession of these species was used to characterise 26 ammonite horizons in the uppermost Sinemurian and the base of the Upper Pliensbachian interval.

Supplementary Data, Appendix A shows the systematic position of the ammonites and the levels in which the studied specimens were collected in each section; the specimens included in Figs. 8, 9, 10 and 11 are indicated. Appendix B indicates the base of the Horizons (= Zonules) identified, along with their main elements of correlation with the Mediterranean Province.

The Raricostatum Chronozone and the Aplanatum Subchronozone are well represented in ER and PV sections (Comas-Rengifo et al., 2010; Comas-Rengifo & Goy, 2010). In the uppermost part of the Aplanatum Subchronozone we have characterised a Tardecrescens Horizon (Corna et al., 1997). *P. tardecrescens* associated with *Leptechioceras macdonnelli*, at the base, where *Leptonotoceras abnorme*, *Gleviceras* cf. *guibalianum* and *Epideroceras* (?) sp. (= *Villania*, según Howarth, 2013) are also to be found. This assemblage is similar to those found in the N of the Iberian Peninsula (Comas-Rengifo, 1982; Braga et al., 1988; Comas-Rengifo et al., 2010, 2013; Duarte et al., 2014) and in the French-Spanish Pyrenees (Fauré, 2002; Fauré & Teodori, 2019), as well as in some basins in the Euroboreal and NW European areas (Corna et al., 1997; Blau & Meister, 2000; Howarth, 2002; Page, 2003, 2009, etc.).

The succession obtained in the Lower Pliensbachian is similar to the one used in publications that consider the concept of Zonule (= chronohorizon, *sensu* Hedberg, 1976 and in accordance with Meister, 2010). Moreover, in addition to the studies cited above in order to correlate these, we considered the work of the following authors to be of interest: Dommergues (1979), Braga et al. (1982), Dommergues et al. (1983), Meister (1995, 2010), and Dommergues & Meister (2008a, b).

The lower boundary of the Pliensbachian has been situated between the level ER348, which contains the last *P. tardecrescens* recorded, and the level ER357 with *Gemmellaroceras* aff. *aenigmaticum* a species mainly known in the Mediterranean Province and in the southern areas of the NW European Province. Above this level, in sections ER and SM, there are several levels containing *Apoderoceras*. Some correspond to *A. subtriangulare*, and other more recent ones, which are large and badly preserved as a result of marine abrasion, are very close to *A. dunrobinense*. They could be associated with *P. taylori* and they characterise the Taylori Subchronozone. In levels equivalent to intervals ER398-ER418 and SM19-SM24 pyritised fragments of *P.* gr. *taylori* were found. The "*ex situ*" specimens obtained by Suárez Vega (1974, p. 65) might have come from these levels or others located in the vicinity. With the exception of these *Gemmellaroceras*, this succession is similar to the one described by Meister et al. (2006) in Wine Haven, Yorkshire, and very close to the one found in San Pedro de Moel in Portugal (Meister et al., 2012; Duarte et al., 2014).

In the Jamesoni Chronozone, whenever posible the horizons were based on the evolution of Polymorphytinae species, sporadically associated with Phricodoceratidae, Oxynoticeratidae and Coeloceratidae. The Taylori Subchronozone starts with the Horizon aff. Aenigmaticum, which had already been mentioned in the NE of Spain by Comas-Rengifo (1982), followed by the Subtriangulare and Taylori horizons. In the Polymorphus, Brevispina and Jamesoni subchronozones, the horizons were established also considering the evolution of Polymorphytinae species. In the lower part of the Polymorphus Subchronozone, almost no significant ammonites were recorded, and consequently, the lower boundary could not be established. In the upper part, albeit scarce, *Polymorphites trivialis* and *Polymorphites* sp. were found; in ER and SM sections. They are associated with *P. caprarium.* In Vega de Sariego (only in this locality,

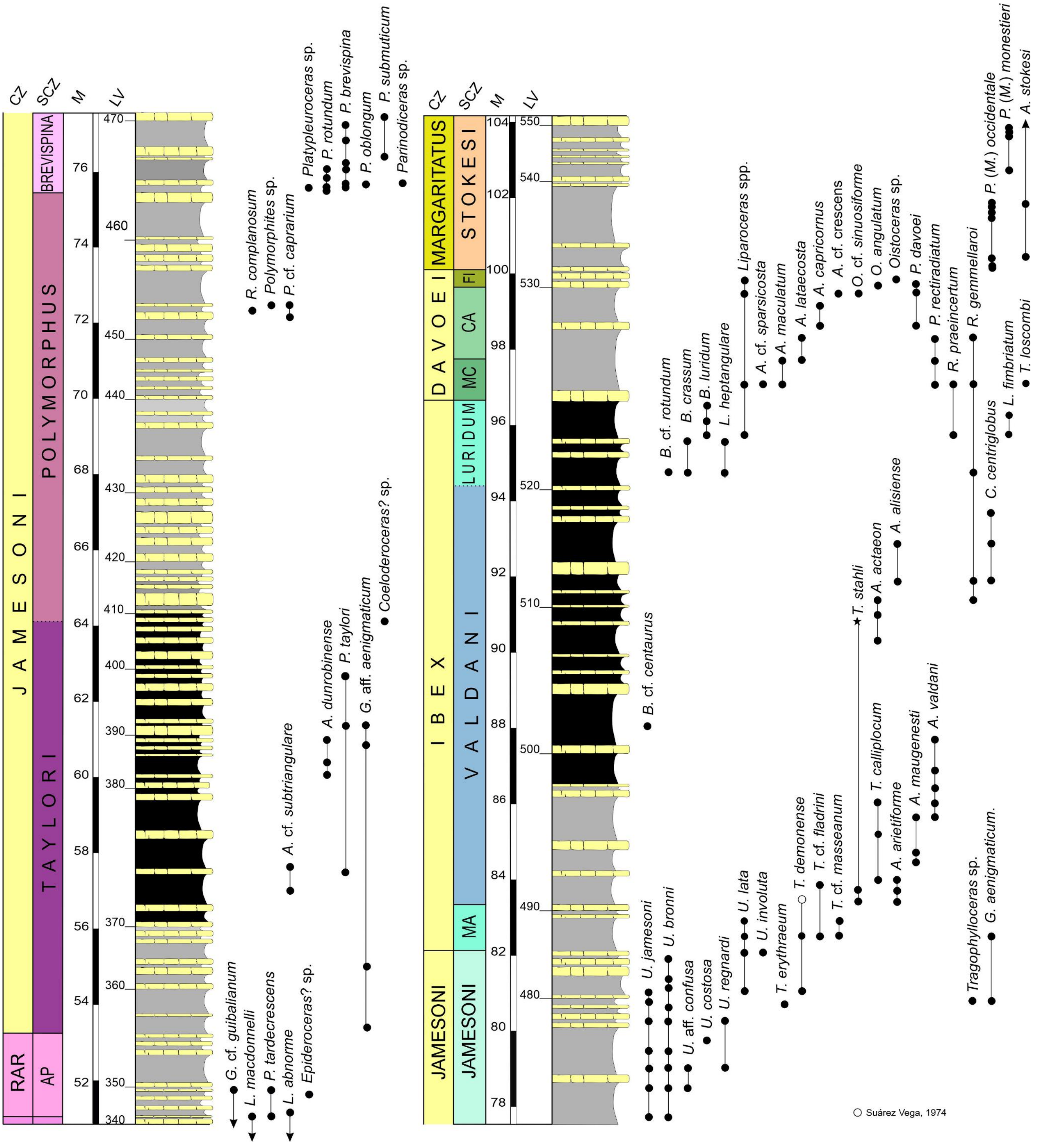


Fig. 5 Lithological section of Rodiles E (ER) with the stratigraphical distributions of the identified species of ammonites (after Comas-Rengifo & Goy, 2010; Gómez et al., 2016a, b). Abbreviations: CZ Chronozone. SCZ Subchronozone. M Meters. LV Level. RAR Raricostatum Chronozone. AP Aplanatum Subchronozone. MA Masseanum Subchronozone. MC Maculatum Subchronozone. CA Capricornus Subchronozone. FI Figulinum Subchronozone.

situated around 12 km to the S of the coast), Suárez Vega (1974) cites the following species in equivalent levels: *P.* gr. *polymorphus* (e.g., *P. mixtus*, *P. costatus, P. polymorphus*) and *P. lineatus*. Additionally, the species *P. caprarium* was cited by some authors in the upper part of the Polymorphus Subchronozone in Germany and Switzerland (Schlatter,

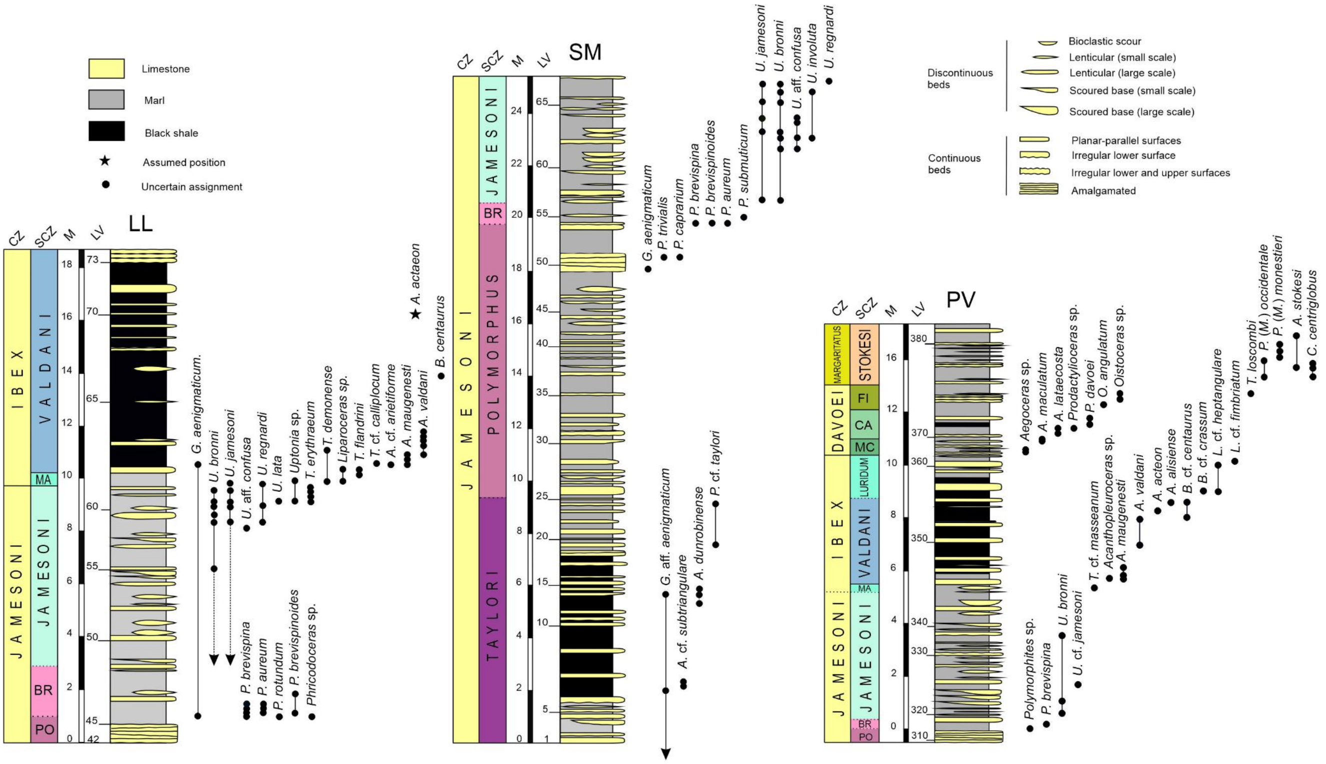


Fig. 6 Lithological section of LLastra (LL), Santa Mera (SM) (after García-Ramos, 2010; García-Ramos et al., 2011) and Playa de Vega (PV) (after Comas-Rengifo & Goy, 2010) sections. Abbreviations: Z Chronozone. SZ Subchronozone. M Meters. LV Level. PO Polymorphus Subchronozone. BR Brevispina Subchronozone. MA Masseanum Subchronozone. MC Maculatum Subchronozone. CA Capricornus Subchronozone. FI Figulinum Subchronozone.

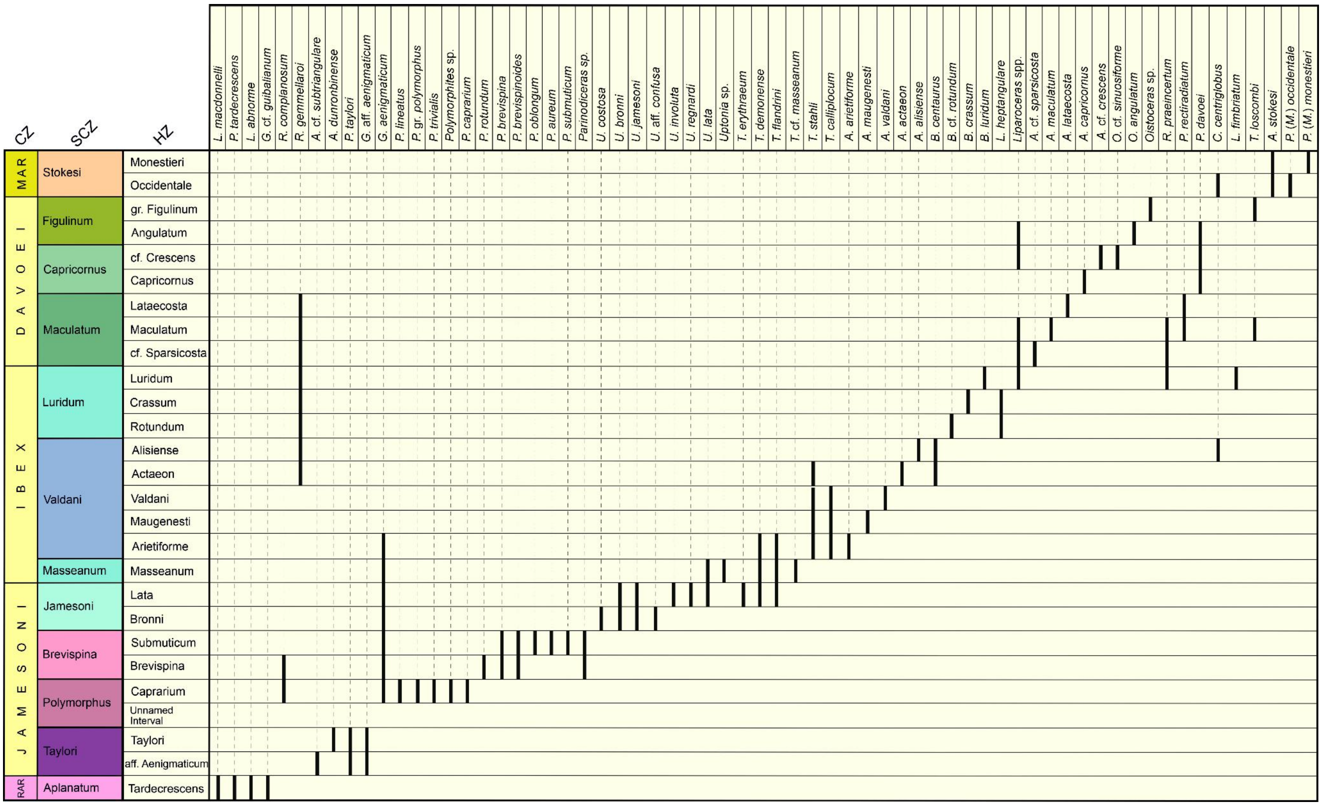


Fig. 7 Stratigraphic distribution of the identified taxa of ammonites. Abbreviations: Z Chronozone. SZ Subchronozone. HZ Horizon. RAR Raricostatum Chronozone. MAR Margaritatus Chronozone.

Fig. 8 Representative ammonites of Jamesoni and Ibex chronozones. **a** *Apoderoceras* cf. *subtriangulare* (Young & Bird) SM7(+33). **b** *Apoderoceras dunrobinense* Spath ER384. **c** *Uptonia jamesoni* (J. de C. Sowerby) LL60T. **d** *Acanthopleuroceras valdani* (d'Orbigny) LL63T. **e** *Acanthopleuroceras maugenesti* (d'Orbigny) LL63(-5). **f** *Uptonia* 66 *regnardi* (d'Orbigny) LL60(-50). **g** *Tropidoceras erythraeum* (Gemmellaro) LL62(-15). **h** *Tropidoceras flandrini* (Dumortier) LL62(-22). **i** *Beaniceras centaurus* (d'Orbigny) 68 LL64(+160). Scale bar = 1 cm, except Fig. c.

1977, 1991; Meister & Loup, 1989; Meister, 1991; Blau et al., 2000), the UK (Oates, 1978; Howarth, 2002), NE of Spain (Comas-Rengifo, 1982), France (Dommergues, 1987; Fauré & Bohain, 2017) and Denmark (Donovan & Surlyk, 2003).

The *Platypleuroceras* are dominant in the Brevispina Subchronozone, which can be associated with *G. aenigmaticum*. However, *Phricodoceras*, *Parinodiceras* and *Metaderoceras* specimens are scarce. One single specimen of the latter genus, *M.* cf. *muticum* D'Orbigny (*sensu* Fauré & Bohain, 2017), has been found in Huerres (Fig. 1), a locality situated between SM and PV. A Brevispina Horizon has been characterised in this subchronozone, followed by a Submuticum Horizon, as occurs in the NW of Europe.

The species of *Uptonia* dominate in the Jamesoni Subchronozone: The Bronni Horizon was characterised with the index species associated with *U. jamesoni* and with scarce *Gemmellaroceras*, along with the Lata Horizon, with the

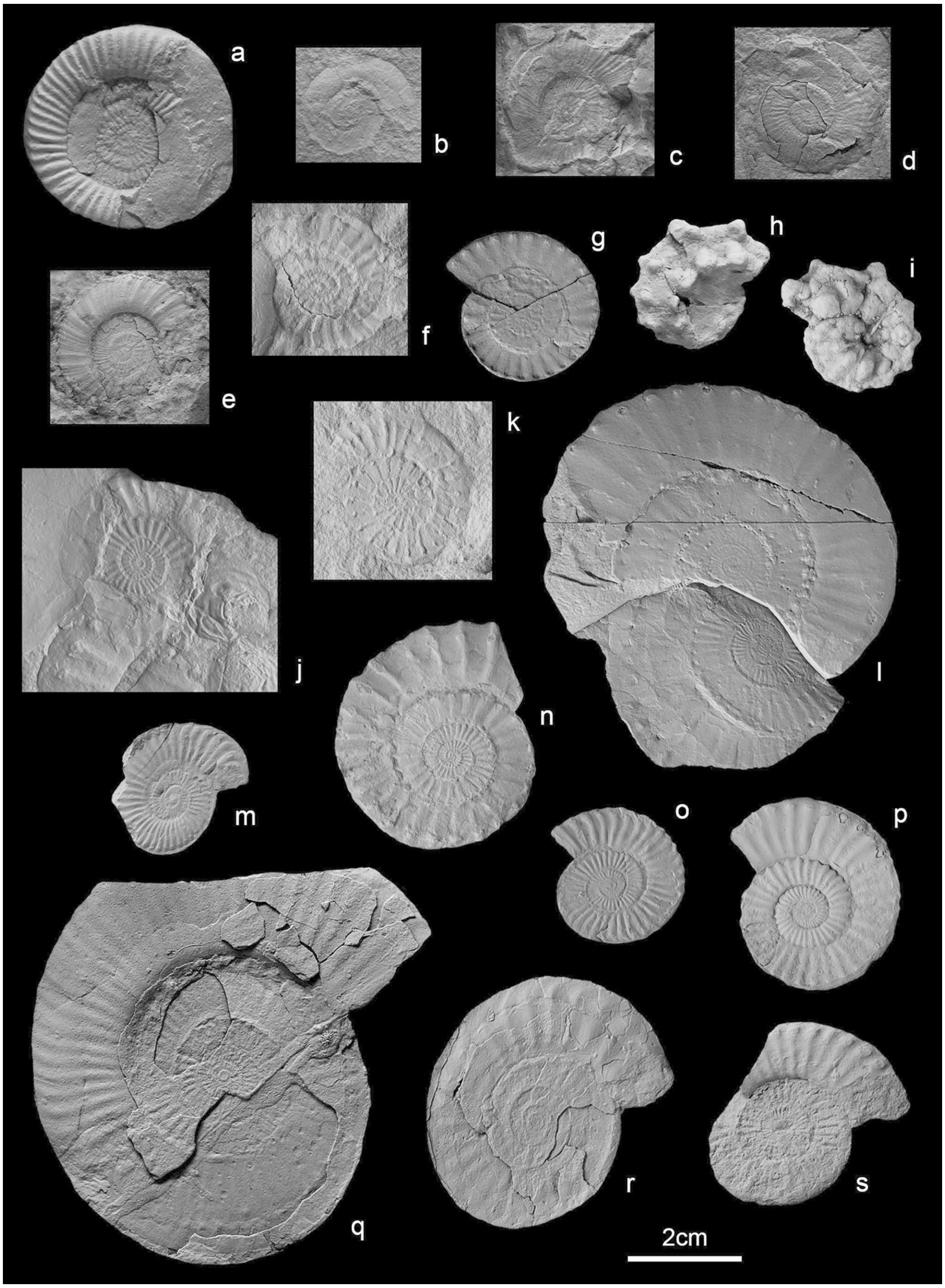


Fig. 9 Representative ammonites of the Raricostatum, Jamesoni and Ibex chronozones. **a** *Paltechioceras tardecrescens* (Hauer) ER342. **b** *Gemmellaroceras* aff. *aenigmaticum* (Gemmellaro) ER387m. **c** *Polymorphites lineatus* (Quenstedt) MUJA2828. **d** *Polymorphites trivialis* (Simpson) SM52. **e** *Polymorphites* gr. *polymorphus* morphotype *mixtus* (Quenstedt) MUJA2027. **f** *Platypleuroceras caprarium* (Quenstedt) SM52. **g** *Platypleuroceras aureum* (Simpson) LL45(+55). **h-i** *Phricodoceras taylori* (J. de C. Sowerby) MUJA2032. **j** *Platypleuroceras rotundum* (Quenstedt) LL45(+30). **k** *Platypleuroceras brevispinoides* (Tutcher & Trueman) LL45(+40). **l** *Platypleuroceras submuticum* (Oppel) SM55. **m** *Uptonia involuta* Meister SM66(+20). MUJA5091a. **n** *Platypleuroceras brevispina* (J. de C. Sowerby) LL45(+30). **o** *Uptonia bronni* (Roemer) ER481(+20). **p** *Uptonia* aff. *confusa* (Quenstedt) SM62(-33). MUJA5114b. **q** *Uptonia lata* (Quenstedt) ER481(+10). **r** *Tropidoceras calliplocum* (Gemmellaro) ER495s. **s** *Uptoniacostosa* (Quenstedt) ER473(+70). All full-size specimens, except Fig. a and Fig. b which are for 1.5. Scale bar = 2 cm.

oldest *Tropidoceras*: *T. erythraeum* (Braga & Rivas, 1985; Page, 2003).

In the uppermost part of the Jamesoni Subchronozone and in the lower part of the Ibex Chronozone (Masseanum Subchronozone), *Tropidoceras* typical of the Mediterranean Province (Linares & Rivas, 1973; Gèczy, 1976; Braga & Rivas, 1985) appear in the Asturian Basin, such as *T. erythraeum*, followed by *T. demonense-flandrini*, and *T.*

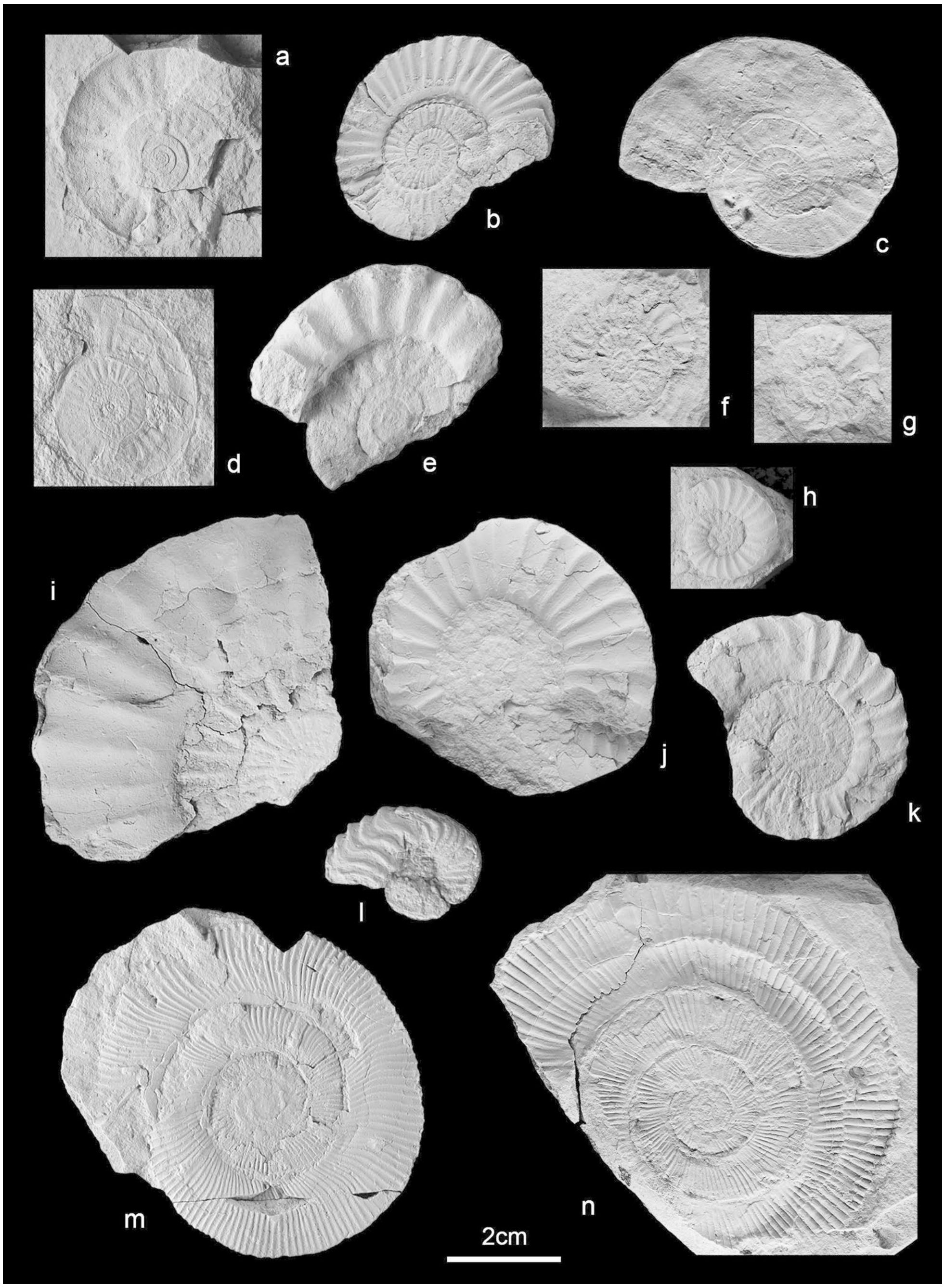


Fig. 10 Representative ammonites of the Ibex y Davoei chronozones. **a** *Tropidoceras demonense* (Gemmellaro) LL62(-15). **b** *Tropidoceras stahli* (Oppel) ER481b. **c** *Acanthopleuroceras alisiense* (Reynès in Haug) PV357T. **d** *Acanthopleuroceras actaeon* (d'Orbigny) ER509. **e** *Acanthopleuroceras arietiforme* (Oppel) LL63(-5). **f** *Beaniceras* cf. *rotundum* Buckman ER521m. **g** *Beaniceras crassum* Buckman ER521m. **h** *Beaniceras luridum* (Simpson) ER525m. **i** *Aegoceras maculatum* (Young & Bird) ER527B. **j** *Aegoceras lataecosta* (J. de C. Sowerby) ER527s. **k** *Aegoceras capricornus* (Schlotheim) ER528. **l** *Oistoceras angulatum* (Quenstedt). ER530i. **m** *Prodactylioceras davoei* (J. Sowerby) PV371s. **n** *Prodactylioceras rectiradiatum* (Wingrave) ER527m. All full-size specimens. Scale bar = 2 cm.

calliplocum-mediterraneum(?), up to the Valdani Subchronozone. Also recorded in this basin were: *T. masseanum* and *T. stahli*, species that are known in the lower-middle part of the Ibex Chronozone in the NW of Europe (Dean et al., 1961; Schlatter, 1977, 1980; Dommergues & Mouterde, 1978; Meister, 1986; Dommergues et al., 1997; Page, 2003; Fauré & Bohain, 2017). The mentioned species were also cited in Submediterranean areas (Kollarova-Andrusova, 1966; Patrulius & Popa, 1971; Popa & Patrulius, 1996; Fauré, 2002; Fauré & Teodori, 2019) and *T. stahli*, previously cited in Asturias by Suárez Vega (1974, pl. 6 A, Fig. 5), is a relatively generalist species from the NW European Province and adjacent areas.

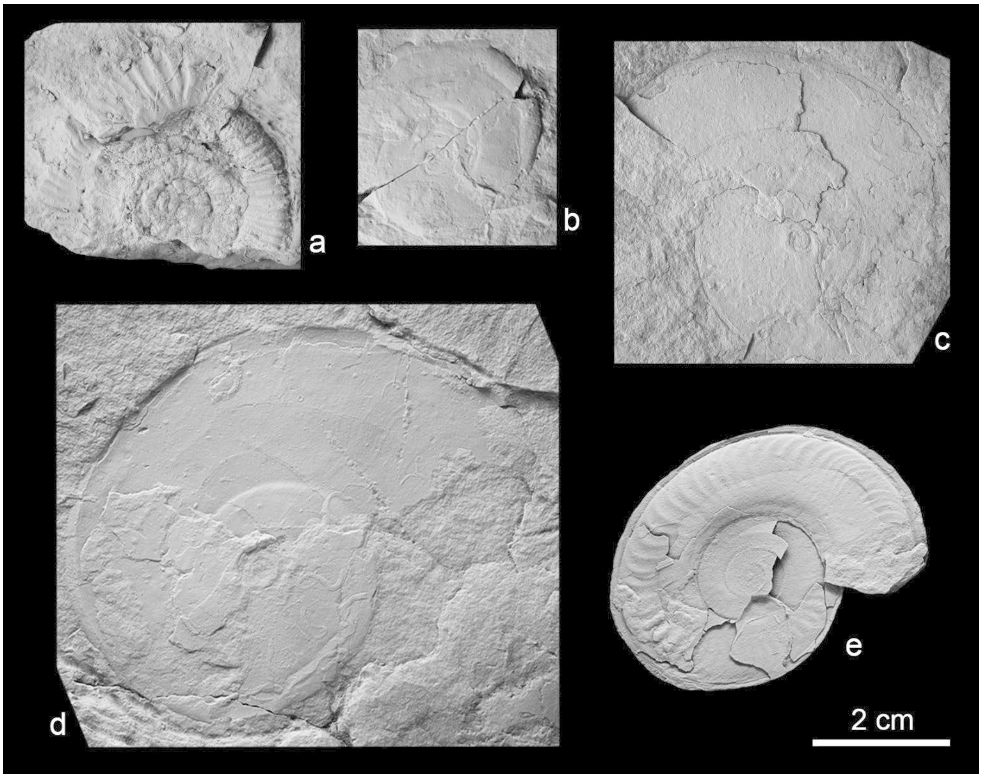


Fig. 11 **a** *Reynesocoeloceras praeincertum* Dommergues & Mouterde ER527i. **b** *Gemmellaroceras aenigmaticum* (Gemmellaro) ER487m. **c** *Radstockiceras gemmellaroi* (Pompeckj) ER513s. **d** *Tragophylloceras loscombi* (J. Sowerby) PV375. **e** *Protogrammoceras* (*Matteiceras*) *occidentale* Dommergues, 1982 ER535m. All full-size specimens. Scale bar = 2 cm.

In the Ibex Chronozone (Masseanum and Valdani subchronozones) the Masseanum Subchronozone includes a Masseanum Horizon, where *Uptonia* persists, and the Valdani Subchronozone comprises five successive horizons based on species of *Acanthopleuroceras*: Arietiforme, Maugenesti, Valdani, Actaeon and Alisiense. In the last two horizons the first *Beaniceras* are recorded (Dommergues & Mouterde, 1978, 1981; Dommergues, 1979; Phelps, 1985; Dommergues et al., 1997; Fauré, 2002, among others). The Liparoceratidae of the genera *Beaniceras*, such as *B. rotundum*, *B. crassum* and *B. luridum*, associated with *L. heptangulare* are common in the Ibex Chronozone, Luridum Subchronozone. We characterised a thin Rotundum Horizon, presenting, a Crassum Horizon that includes *L. heptangulare* and *R. gemmellaroi*, and a Luridum Horizon with the nominal species associated with *R. praeincertum* and *L. fimbriatum*.

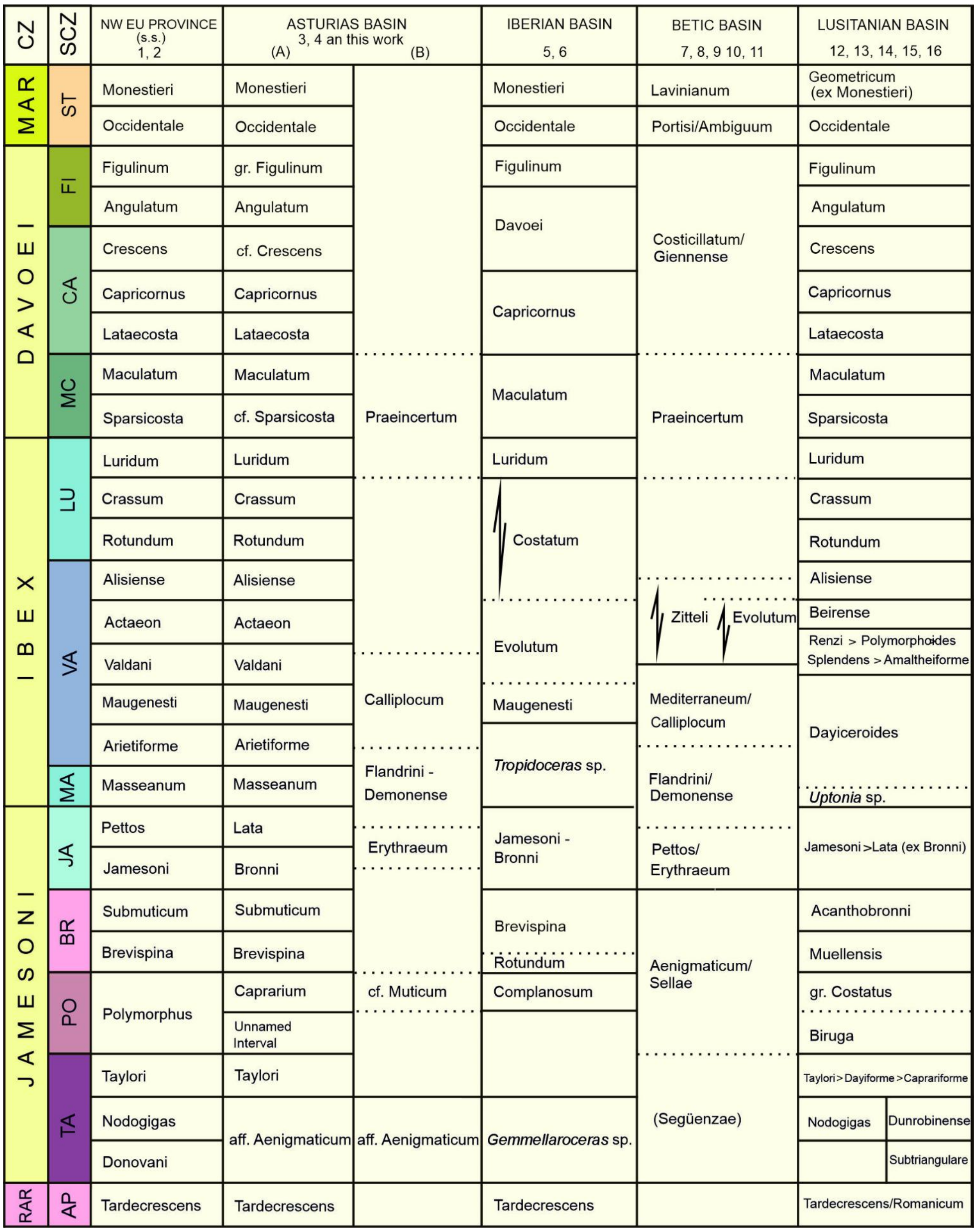
The Davoei Chronozone presents a succession of several species of *Aegoceras*. The presence of *A. sparsicosta* (cited by Trueman, 1919; Spath, 1938; Phelps, 1985; Dommergues & Meister, 1991; Dommergues et al., 1997, 2008a, b; Page, 2003, etc.) is uncertain. Nonetheless, there is a record of *Aegoceras* sp. (close to *A. truemani* Fauré) followed by *A. maculatum*, *A. lataecosta* and *A. capricornus*. In a level equivalent to the Crescens Horizon in the standard scale, we found *A.* cf. *crescens* and *Oistoceras sinuosiforme* (Spath, 1938; Howarth, 2002). Lastly, we also found *O. angulatum* and *O.* sp. gr. *figulinum*. Furthermore, in the Capricornus Subchronozone (lower and middle parts) *Prodactylioceras rectiradiatum* occurs, and between the middle part of the Capricornus Subchronozone and the lower part of the Figulinum Subchronozone, *P. davoei* is relatively frequent.

In the Upper Pliensbachian (Margaritatus Chronozone) the Amaltheidae are frequent and the index species was previously cited in the Stokesi Subchronozone (Suárez Vega, 1974; Comas-Rengifo & Goy, 2010). At the base of the Upper Pliensbachian, some Protogrammoceratinae, such as *Protogrammoceras* (*Matteiceras*) *occidentale* and *P.* (*M.*) *monestieri*, are common associated with *A. stokesi* in some levels of PV and ER sections (Rodríguez-Luengo et al., 2012; Gómez et al., 2016a).

4 Discussion

4.1 Correlation with the chronostratigraphic schemes proposed in other european areas

The succession of the assemblages recognised is very similar to that observed in the basins of NW Europe (Figs. 12



CZ	SCZ	NW EU PROVINCE (s.s.) 1, 2	ASTURIAS BASIN 3, 4 an this work (A)	(B)	IBERIAN BASIN 5, 6	BETIC BASIN 7, 8, 9 10, 11	LUSITANIAN BASIN 12, 13, 14, 15, 16
MAR	ST	Monestieri	Monestieri		Monestieri	Lavinianum	Geometricum (ex Monestieri)
		Occidentale	Occidentale		Occidentale	Portisi/Ambiguum	Occidentale
DAVOEI	FI	Figulinum	gr. Figulinum		Figulinum	Costicillatum/ Giennense	Figulinum
		Angulatum	Angulatum		Davoei		Angulatum
	CA	Crescens	cf. Crescens				Crescens
		Capricornus	Capricornus		Capricornus		Capricornus
		Lataecosta	Lataecosta				Lataecosta
	MC	Maculatum	Maculatum	Praeincertum	Maculatum	Praeincertum	Maculatum
		Sparsicosta	cf. Sparsicosta				Sparsicosta
IBEX	LU	Luridum	Luridum		Luridum		Luridum
		Crassum	Crassum		Costatum		Crassum
		Rotundum	Rotundum				Rotundum
	VA	Alisiense	Alisiense				Alisiense
		Actaeon	Actaeon		Evolutum	Zitteli Evolutum	Beirense
		Valdani	Valdani	Calliplocum			Renzi > Polymorphoides Splendens > Amaltheiforme
		Maugenesti	Maugenesti		Maugenesti	Mediterraneum/ Calliplocum	Dayiceroides
		Arietiforme	Arietiforme	Flandrini - Demonense	*Tropidoceras* sp.	Flandrini/ Demonense	
	MA	Masseanum	Masseanum				*Uptonia* sp.
JAMESONI	JA	Pettos	Lata	Erythraeum	Jamesoni - Bronni	Pettos/ Erythraeum	Jamesoni >Lata (ex Bronni)
		Jamesoni	Bronni				
	BR	Submuticum	Submuticum		Brevispina	Aenigmaticum/ Sellae	Acanthobronni
		Brevispina	Brevispina		Rotundum		Muellensis
	PO	Polymorphus	Caprarium	cf. Muticum	Complanosum		gr. Costatus
			Unnamed Interval				Biruga
	TA	Taylori	Taylori			(Següenzae)	Taylori > Dayiforme > Caprariforme
		Nodogigas	aff. Aenigmaticum	aff. Aenigmaticum	*Gemmellaroceras* sp.		Nodogigas Dunrobinense
		Donovani					Subtriangulare
RAR	AP	Tardecrescens	Tardecrescens		Tardecrescens		Tardecrescens/Romanicum

Fig. 12 Correlation with other basins. **1** Dean et al., 1961. **2** Page, 2003. **3** Gómez et al., 2016a. **4** this work, (A) proposed horizons and (B) position of the Mediterranean elements recorded in Asturias. **5** Braga et al., 1982. **6** Comas-Rengifo, 1982. **7** Braga, 1982. **8** Braga et al., 1982. **9** Braga et al., 1984. **10** Braga & Rivas, 1980. **11** Braga & Rivas, 1985. **12** Mouterde et al., 1983. **13** Mouterde et al., 2007. **14** Dommergues & Mouterde, 1981. **15** Dommergues et al., 2011. **16** Duarte et al., 2013. Abbreviations: RAR Raricostatum Chronozone. AP Aplanatum Subchronozone. TA Taylori Subchronozone. PO Polymorphus Subchronozone. BR Brevispina Subchronozone. JA Jamesoni Subchronozone. MA Masseanum Subchronozone. VA Valdani Subchronozone. LU Luridum Subchronozone. MC Maculatum Subchronozone. CA Capricornus Subchronozone. FI Figulinum Subchronozone. MAR Margaritatus Chronozone. ST Stokesi Subchronozone.

and 13) (Dean et al., 1961; Meister, 1986, 1995, 2010; Corna et al., 1997; Dommergues et al., 1997; Howarth, 2002; Page, 2003, 2009; Meister et al., 2006, 2012; Dommergues et al., 2008b; Fauré & Bohain, 2017), particularly to those described in Dorset (S of England) where the stratigraphy also exhibits some episodes that clearly resemble those in Asturias (Lang et al., 1928; Palmer, 1972; Hesselbo & Jenkyns, 1995; Price et al., 2016; Schöllhorn et al., 2020). There are also numerous elements of correlation with the NE and N of Iberia: IB basin (Braga et al., 1982; Comas-Rengifo, 1982), BC basin (Braga et al., 1984, 1985) and PI basin (Fauré, 2002; Fauré & Téodori, 2019).

In the Portuguese LB, the elements of correlation are remarkable in the Taylori Subchronozone. They are rare between the Polymorphus Subchronozone and the Valdani Subchronozone, and the successions are similar from the

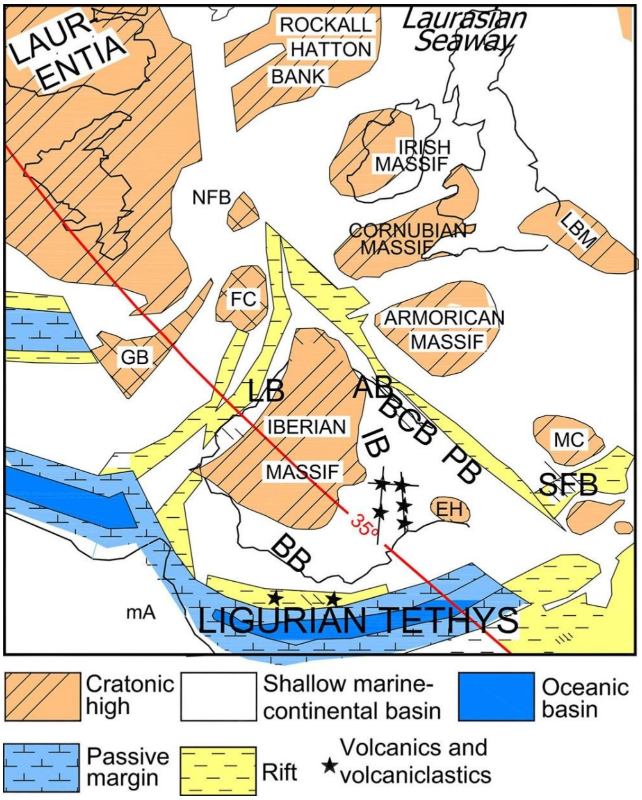


Fig. 13 Palaeogeographical map of Western Tethys and the Proto-Atlantic Ocean for the Pliensbachian-Toarcian (modified after Ziegler, 1990, Vera, 2001, Stampfli & Borel, 2002, 2004, Osete et al., 2011, Gómez & Goy, 2011) showing the position of the basins cited in the text. LB-Lusitanian Basin, AB-Asturian Basin, BB-Betic Basin, BCB-Basque-Cantabrian Basin, PB-Pyrenean Basin, IB-Iberian Basin, SFB-Southern France Basin. Other abbreviations: EH-Ebro High, FC-Flemish Cap, GB-Grand Banks, LBM-London–Brabant Massif, MC-Massif Central High, NFB-East Newfoundland Basin, mA-Middle Atlas.

Luridum Subchronozone up to the end of the Lower Pliensbachian (Mouterde, 1967; Dommergues & Mouterde, 1981; Mouterde et al., 1983, 2007; Dommergues et al., 1983, 1997; Phelps, 1985; Duarte et al., 2014).

On the contrary, the succession obtained only occasionally resembles those described in Southern Spain and in other basins of the Tethys (Supplementary Data). The main elements of correlation consist of the existence of *Gemmellaroceras*, *Tropidoceras* and scarce *Metaderoceras* and *Reynesocoeloceras* typical of Mediterranean basins (Cantaluppi & Montanari, 1971; Gèczy, 1976; Rivas, 1972, 1981; Ferretti, 1975, 1991; Wiedenmayer, 1980; Braga et al., 1984; Braga & Rivas, 1985; Hillebrandt, 1987; Ferretti & Meister, 1994; Venturi & Ferri, 2001; Rakus & Guex, 2002; Gèczy & Meister, 2007; Meister et al., 2011, 2017; Dommergues & Meister, 2017, etc.).

In the Polymorphus Subchronozone in Asturias, as occurs in the IB and the BC (Braga et al., 1982, 1985; Comas-Rengifo, 1982), few ammonites were recorded. They rarely corresponded to the index species which, however, have been cited in other areas of Western Europe (Dean et al., 1961; Schlatter, 1980; Dommergues et al., 1997; Howarth, 2002; Page, 2003; Fauré & Bohain, 2017). Nonetheless, the presence in ER454 and SM52 of *Polymorphites* (*P. trivialis*, *Polymorphites* spp.) and *Platypleuroceras* (*P. caprarium*), in levels previous to the first record of *P. brevispina*, enables the levels cited to be attributed to the upper part of the Polymorphus Subchronozone, as has been justified in Sect. 3.2.

The species of *Platypleuroceras* (*P. rotundum*, *P. brevispina*, *P. brevispinoides* and *P. aureum*, followed by *P. submuticum*) and *Uptonia* (*U. costosa*, *U. confusa*, *U. bronni*, *U. jamesoni*, *U. lata*, among others) dominate in the Jamesoni Subchronozone, similar to what occurs in the NW of Europe and the N of Spain (Schlatter, 1980, 1991; Comas-Rengifo, 1982; Braga et al., 1984; Meister, 1986; Dommergues et al., 1997; Fauré, 2002; Sciau, 2004; Fauré & Bohain, 2017; Fauré & Teodori, 2019) and no different from what can be observed in the LB (Mouterde et al., 1983).

In Asturias (ER, LL, PV), *Tropidoceras* has been recorded in the transition between the Jamesoni and the Ibex chronozones. This fact enables three successive horizons to be characterised: Erythraeum, Demonense-Flandrini and Calliplocum-Mediterraneum, which can be recognised throughout much of the Mediterranean Province (Gèczy, 1976; Braga et al., 1984; Braga & Rivas, 1985; Ferretti, 1991; Meister, 1995, 2010; Page, 2003; Meister et al., 2009, 2011). According to Dommergues et al. (1997, p. 17), these horizons are successively located in the Jamesoni Subchronozone above the Valdani Subchronozone.

In the Valdani Subchronozone, despite the dominance of assemblages presenting elements from the NW of Europe, species typical of the basins of southern Europe arrived to AB. This might have been facilitated by the fact that the interval (Lata Horizon to the Valdani Horizon) corresponds to the transgressive máximum of the T3-R3 cycle described by Quesada et al. (2005) in the BC and shows no significantly effective margins to prevent communication between both areas.

The Valdani Subchronozone is well represented by the succession of several species of *Acanthopleuroceras*, as occurs in other localities in the NW of Europe (Dommerges et al., 1997; Page, 2003) and in basins in the S of France, N of Iberia and the Austroalpine region (Dommergues & Mouterde, 1981; Comas-Rengifo, 1982; Mouterde et al., 1983; Braga et al., 1985, 1988; Meister, 1986; Meister et al., 1994; Fauré, 2002; Meister & Friebe, 2003; Fauré & Téodori, 2019, etc.). In addition, in the Luridum Subchronozone, the succession of *Beaniceras* (*B. rotundum-B.*

crassum-B. luridum) is very similar to that of NW Europe and is also recorded in the IB and the BC (Dommergues et al., 2008b; Fauré & Bohain, 2017; Fauré & Téodori, 2019), and with slight modifications in the LB (Phelps, 1985).

The Davoei Chronozone is not very thick (approx. 4 m. in ER and 2.5 m. in PV sections). It is represented by the succession of seven species of *Aegoceras*-*Oistoceras*, five of which are associated with two successive species of *Prodactylioceras*: *P. rectiradiatum* and *P. davoei*. The transition to the Upper Pliensbachian is well represented in ER and PV. In the uppermost part of the Davoei Chronozone the last *Oistoceras* (*O.* sp.) were recorded; they are situated below the first *P.* (*Matteiceras*) but, unlike what occurs in other basins in the N of Iberia (BV, PB, IB and LB), a typical *O. figulinum* was not found. The basal part of the Margaritatus Chronozone is characterised by the presence of *P. (M.) occidentale* and *P.* (*M.) monestieri*, which are common in the Stokesi Subchronozone and appear sporadically with the nominal species of the subchronozone (Comas-Rengifo & Goy, 2010; Rodríguez-Luengo et al., 2012).

4.2 Black shales

Two main metre-scale episodes of dark grey to black organic-rich marls and laminated shales were identified into the Lower Pliensbachian succession within the Rodiles Formation. The lower interval was deposited during a part of the Taylori Subchronozone (Jamesoni Chronozone). The upper interval was deposited in much of the Valdani and Luridum subchronozones (Ibex Chronozone; Fig. 4 g and h), as previously published by Gómez et al. (2016a, b). Both intervals are associated with episodes of basin deepening that are probably influenced by tectonic pulsations, as evidenced by synsedimentary differential subsidence of the ramp into short-lived swells and troughs. In the most subsident depressions these enhanced episodes of tectonic activity, partially controlled by initial halokinesis (García-Senz et al., 2019), generate several organic-rich deposits like the ones identified in other neighbouring palaeogeographic areas (Basque-Cantabrian and Lusitanian basins; Quesada et al., 2005; Silva & Duarte, 2015; Silva et al., 2021). Consequently, all basins in the northwestern half of the Iberian microplate domain shared a similar tectono-stratigraphic evolution. However, they exhibit a certain degree of diachronism resulting from local or regional tectonics.

Furthermore, the deposition of these organic-rich and black shale facies neither seems to be related to large scale palaeoclimatic oscillations, as deduced from data in Price et al. (2016), Bougeault et al. (2017) and Deconinck et al. (2019, 2020), nor nor seems to be associated with water temperature (Gómez et al., 2016a, b). The most likely drivers involve an irregular bottom topography of the ramp, high rates of differential subsidence and highly variable water circulation.

4.3 Modifications in the ammonite assemblages linked to palaeoenvironmental changes

In the interval studied, several palaeoclimatic and environmental changes took place (Robles et al., 2004; Bádenas et al., 2009; Armendáriz et al., 2012; Gómez et al., 2016a, b), which affected the different ammonite groups recorded in the AB.

In the Sinemurian-Pliensbachian transition, the Echioceratidae became extinct shortly after the end of the R2 regressive episode (Quesada et al., 2005), equivalent to the regressive part of the LJ-2.1 cycle described by Gómez & Goy (2004, 2005); this coincides with the beginning of the T3 transgressive episode described by the same authors. In the lower part of the Taylori Subchronozone, a significant transgressive episode took place, probably at a global scale, coinciding with the first episode of black shales. It is characterised by a clearly negative Carbon ($\delta^{13}C$) excursion that is well recorded in the ER section (Gómez et al., 2016b). Some authors postulate that it might have been caused by volcanic activity and the corresponding hydrothermalism associated with the Central Atlantic Magmatic Province (CAMP) and by the resulting opening up of the Hispanic Corridor (Price et al., 2016; Ruhl et al., 2016). This coincides with the arrival to the Asturian Basin of the Polymorphitinae (*G.* aff. *aenigmaticum*), typical of the southern areas of the western Tethys.

The boundary between the Jamesoni Chronozone and the Ibex Chronozone is situated over a long deepening stage coinciding with the upper part of the mentioned negative $\delta^{13}C$ excursion, before the appearance of the black shale facies present in the Ibex Chronozone. The palaeotemperatures calculated for this boundary can be considered to be normal for this latitude of around 27ºN during the Pliensbachian (Deconinck et al., 2020). Polymorphitinae (*Tropidoceras*), typical from Southern Europe, are registered in the AB in the uppermost part of Jamesoni Subchronozone.

The boundary between the Ibex Chronozone and the Davoei Chronozone, which marks the substitution of *Beaniceras* by *Aegoceras* within the Liparoceratidae family, is located in the upper part of the deepening megasequence that developed during much of the Lower Pliensbachian and it could be linked to a positive $\delta^{13}C$ excursion in a very similar position (Luridum Subchronozone) to that cited by Silva et al. (2015) in the LB (Rabaçal and Peniche sections). The positive peak of $\delta^{13}C$ in belemnites from the upper part of Ibex Chronozone and the beginning of a relatively short-lived warming in the Lower Pliensbachian detected by Gómez et al. (2016a, b) in Rodiles E are clearly marked by a negative excursion in the values of δ^{18}O recorded in belemnite rostra unaffected by the diagenesis. However, only scarce specimens typical from Mediterranean areas, such as *Lytoceras fimbriatum* and *Reynesocoeloceras praeincertum* in the Luridum Subchronozone, *R. praeincertum* in Maculatum Subchronozone and *Tragophylloceras loscombi* in the Figulinum Subchronozone, are registered occasionally in the AB. On the other hand, the absence of *A. sparsicosta* (typical) before the first record of *A. maculatum* could be linked to the existence of a small hiatus in the lower part of the Maculatum Subchronozone.

In the uppermost part of the Davoei Chronozone, the *Aegoceras*-*Oistoceras* became extinct and were substituted, at the base of the Margaritatus Chronozone, by Amaltheidae, such as *A. stokesi*, and by Hildoceratidae, such as *P.* (*M.*) *occidentale*.

4.4 Palaeobiogeographic situation of the Asturian basin

Throughout the Jamesoni Chronozone, the assemblages obtained (Fig. 12) differ slightly from those of the Northwest European Province (Dommergues & Mouterde, 1978, 1981; Dommergues, 1979, 1987, 2003; Dommergues et al., 1997, 2008b; Blau et al., 2000; Howarth, 2002; Page, 2003, 2009; Dommergues & Meister, 2008b; Meister et al., 2012; Fauré & Bohain, 2017, 2022). The most significant difference involves the existence in Asturias of *G.* aff. *aenigmaticum*, in the lower part of the Taylori Subchronozone. In the upper part of this subchronozone the *Gemmellaroceras* are scarce, with large-sized (> 25 cm) more or less generalist species dominating, such as *Phricodoceras* and *Apoderoceras* (*A. dunrobinense*). From the upper part of the Polymorphus Subchronozone, with *Polymorphites trivialis*, *P.* gr. *polymorphus* etc. and *Platypleuroceras caprarium*, to the upper part of the Jamesoni Subchronozone, the assemblages are almost identical to those described in the NW of Europe (UK, France and Germany). Moreover, *G. aenigmaticum* has only been recorded sporadically and, excepcionally, *Metaderoceras*.

As from the Ibex Chronozone, and until the end of the Lower Pliensbachian, the assemblages are similar to those of the Northwest European Province, with few elements typical of the Mediterranean Province, such as *R. praeincertum*, in the Luridum-Maculatum transition. Although up to the Upper Pliensbachian, a Submediterranean Province has not yet been established, according to Page (2003), some areas of the W of Europe, such as Subbriançonais, Australpine, Slovakia, French-Spanish Pyrenees, N Iberia (IB, BC and AB in Spain and LB in Portugal, Fig. 13), show enough elements of correlation to establish the Submediterranean Province (Braga et al., 1982; Comas-Rengifo, 1982; Dommergues et al., 1983, 1990, 1995; Mouterde et al., 1983; Blau & Meister, 1991; Dommergues & Meister, 1991; Meister, 1991, 1995, 2010; Fauré & Téodori, 2019).

They are not very similar to the assemblages recorded in the Mediterranean Province and common genera and species are only recorded in some intervals. The principal elements of correlation are: *Gemmellaroceras* and rare *Metaderoceras* in the Jamesoni Chronozone, *Tropidoceras* in the lower and middle parts of the Ibex Chronozone and *Reynesocoeloceras* in the Ibex-Davoei chronozones transition. In Iberia, in the BB (Subbetic area), species of the four aforementioned genera are to be found (Fig. 12). The succession of *Tropidoceras* enables relatively accurate correlations to be established with different areas of the Mediterranean. The AB contains species of *Tropidoceras*, such as: *T. erythraeum*, *T. demonense* (m) - *flandrini* (M) y *T. calliplocum* (m) that are also recorded in other basins of southern Europe and the N of Africa (Rivas, 1972, 1981; Dommergues, 1979; Braga & Rivas, 1985; Dommergues & Meister, 1990, 2008, 2017; Dommergues et al., 1997; Page, 2003; Gèczy & Meister, 2007; Meister et al., 2011, etc.).

In Italy (Appenines) and Spain (Betic Basin), the *Gemmellaroceras* are present up to the upper part of the Jamesoni Subchronozone. Several species of *Tropidoceras* are particularly frequent between the uppermost part of the Jamesoni Subchronozone and the Valdani Subchronozone (Rivas, 1981; Dommergues et al., 1983, 1994; Braga et al., 1984; Braga & Rivas, 1985; Dommergues & Meister, 1990; Donovan, 1990; Ferretti, 1991; Ferretti & Meister, 1994; Venturi et al., 2005, 2007; Blau & Meister, 2011; Meister & Blau, 2014).

In Hungary (Bakony), at the genus level, the main common elements are: *Leptotonoceras* and *Phricodoceras* in the transition between the Raricostatum and the Jamesoni chronozones, *Platypleuroceras* and *Uptonia* in the Brevispina and Jamesoni subchronozones, respectively, *Tropidoceras* and *Acanthopleuroceras* in the Ibex Chronozone, and *Aegoceras* in the Davoei Chronozone. The most common species are: *P. taylori*, *U. jamesoni*, *T. flandrini*, *T.* cf. *maugenesti*, *R. praeincertum*, *A. maculatum*, *A. capricornus*, *O.* cf. *sinuosiforme* and *P. davoei* (Gèczy, 1976; Dommergues et al., 1983; Dommergues & Gèczy, 1989; Gèczy & Meister, 2007).

In Turkey the ammonite succession exhibits noteworthy differences in relation to Asturias (Bremer, 1965; Alkaya & Meister, 1995), although the Ibex Chronozone is also the interval providing a better correlation.

Correlations with the southern margin of the western Tethys (Morocco, Algeria and Tunisia), are difficult after the uppermost Sinemurian, because there are very few common elements up to the upper part of the Jamesoni Chronozone (Meister, 1995, 2010; El Hariri et al., 1996; Rakus & Guex, 2002; Wilmsen et al., 2002; Fauré et al., 2007; Meister et al., 2011; Dommergues & Meister, 2017).

In the Upper Pliensbachian (Stokesi Subchronozone), the succession obtained corresponds to the Submediterranean Province. The species *A. stokesi* is associated with *P.* (*M.*) *occidentale* and *P.* (*M.*) *monestieri*, and there is a conspicuous absence of *Fuciniceras*, which, albeit scarce, are present in the BC and IB (Braga et al., 1985).

5 Conclusion

The study of the ammonite species from the uppermost Sinemurian to the lowermost Upper Pliensbachian interval in expanded sections of the Asturian Basin between Ribadesella and Villaviciosa provided new data on the biostratigraphy and chronostratigraphy of the Lower Pliensbachian in the western part of the Cantabrian Range. The position of the biosedimentary events have been established accurately. For instance, the precise situation of two specific anoxic episodes and two warming intervals, the latter coinciding with the positive excursion of δ13C in the Upper Sinemurian and the transition between lower and Upper Pliensbachian. Characterisation of over 95 successive levels containing ammonites in the ER section and other sections, such as LL, SM and PV enabled the scale of reference to be improved. It is now more detailed, of much higher resolution and closer to the standard zoning of the NW of Europe.

The succession obtained highlights some particularities typical of the central sector of the Asturian Basin. The lower boundary of the Pliensbachian is marked by the first appearance of *Gemmellaroceras* aff. *aenigmaticum*, first recorded below the first *Apoderoceras* found. The upper boundary is marked by the first record of *Protogrammoceras* (*Matteiceras*), associated in some levels with *Amaltheus stokesi*. With the exception of the lower boundary of the Pliensbachian and of the base of the Polymorphus Chronozone, all the boundaries between chronozones and subchronozones were accurately established. The assemblages recorded are very similar to those established in the Northwest European Province, but in some intervals taxa typical of the Mediterranean Province are recorded. These assemblages only occur at the base of the Jamesoni Chronozone (Taylori Subchronozone) as well as in the transition between the Jamesoni and the Ibex chronozones, which is prolonged until the Valdani Subchronozone. There are also some sporadic levels showing a small number of Mediterranean ammonites, such as *Metaderoceras* in the late Polymorphus Subchronozone and *Reynesocoeloceras* in the transition between the Luridum and Maculatum subchronozones. Additionaly, taxa from the Submediterranean Province have been recorded, e.g. *P.* (*M.*) *occidentale* and *P.* (*M.*) *nitescens* in the Margaritatus Chronozone, Stokesi Subchronozone, from the Upper Pliensbachian.

Moreover, fundamentally based upon the evolution of the species of several families such as Echioceratidae, Phricodoceratidae, Polymorphitidae, Liparoceratidae, Hildoceratidae, twenty-seven ammonoid horizons were characterised for the considered interval: one for the uppermost Sinemurian (Raricostatum Chronozone, Aplanatum Subchronozone), twenty-four for the Lower Pliensbachian and two for the Upper Pliensbachian (Margaritatus Chronozone, Stokesi Subchronozone).

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Statements and declarations

We declare that this manuscript is original, has not been published before and is not currently being considered for publication elsewhere.

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