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The Cambrian of the Iberian Peninsula: An overview

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ABSTRACT

This work is a brief overview of the Cambrian in the Iberian Peninsula, along with an updated review of lithostratigraphic and biostratigraphic data. A Cambrian correlation chart between the different stratigraphical units that have been established in the Iberian Peninsula is given. We also reappraise the Lower and Middle Cambrian regional stages in the light of new palaeontological data, and the different biozonations proposed with several palaeontological groups.

KEYWORDS | **Cambrian. Iberian Peninsula. Lithostratigraphy. Biostratigraphy. Correlation. Regional stages.**

INTRODUCTION AND GEOLOGICAL SETTING

The Iberian Peninsula has some of the most extensive Cambrian outcrops in Europe (Lotze, 1961), which include a diverse and continuous record of fossils and facies. Consequently, the Iberian Peninsula is a primary information source for increasing biostratigraphic knowledge of the Cambrian System and for the establishment of subsequent intercontinental correlations.

The Cambrian rocks in the Iberian Peninsula crop out within two kinds of major geological settings (Fig. 1): the Iberian Massif (the westernmost exposure of the European Hercynides) and some Alpine ranges where they can be found within the Alpine structures. The Iberian Massif was divided by Lotze (1945) into six geological zones named: Cantabrian, West Asturian-Leonese, Galician-Castilian, East Lusitanian-Alcudian, Ossa-Morena and South Portuguese zones; the latter is the only one without any Cambrian rock exposure. Julivert et al. (1972) defined the Central Iberian Zone which included Lotze's Galician-Castilian and East Lusitanian-Alcudian zones. Recently, three new zones have been recognised in the Western Iberian Peninsula: the Lusitanian-Galician Complexes Zone (Díaz García, 1992), the Badajoz-Córdoba Shear Zone and the Pulo do Lobo Zone (Quesada, 1991). These new zones have no Cambrian fossiliferous materials and the basement is formed by metamorphic rocks. Recently, Sanz-López et al. (2000) reported for the first time the existence of early Lower Cambrian rocks (upper Corduban) from the Catalan Coastal Ranges (NE Spain).

CAMBRIAN LITHOSTRATIGRAPHY

Although the Cambrian rocks crop out over large areas in the Iberian Peninsula, they are mainly spread out in clearly differentiated outcrops that are geographically or tectonically isolated. These different outcrops show frequent facial changes that have led to a profuse stratigraph-

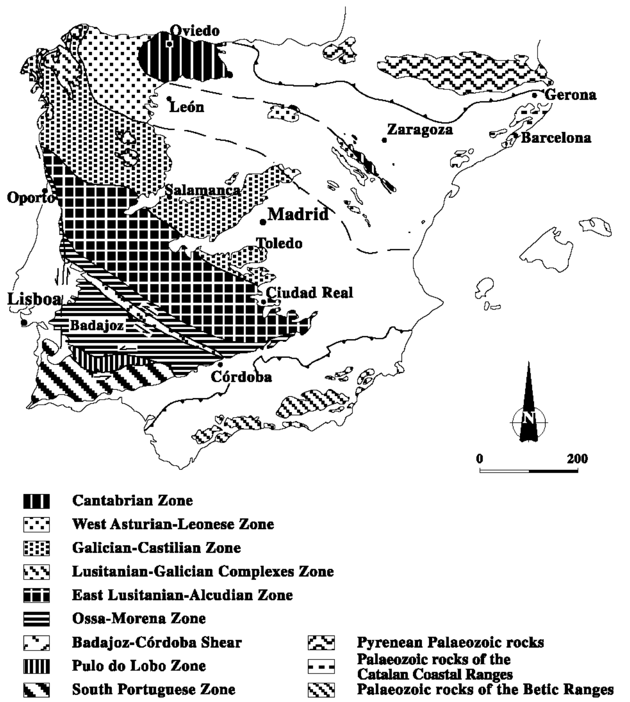

FIGURE 1| **Pre-Mesozoic geological map of Iberia showing the subdivision into tectonostratigraphic zones (after Lotze, 1945; Julivert et al. 1972; Díaz García, 1992; Gozalo and Liñán, 1988; Quesada, 1991).**

ical nomenclature, recently revised by Liñán et al. (1993) for the Lower and Middle Cambrian.

Since Lotze (1961), the general stratigraphic succession of the Iberian Cambrian can be broadly subdivided into three major lithological assemblages with diachronic boundaries, which are in stratigraphical order: Lower Terrigenous, Middle Carbonate and Upper Terrigenous.

The Lower Terrigenous lithological assemblage is Early Cambrian in age; it is represented in the North and South of Spain by a complete megacycle with conglomerates, sandstones and shales in a general stratigraphic order. This megacycle is underlain by Early Cambrian fine clastics in central Spain, which have been divided into different units (see Vidal et al., 1994, and Valladares et al., 2000: Fig. 2).

The Middle Carbonate lithological assemblage is mainly Early Cambrian in age though it may reach the early Middle Cambrian in the Cantabrian and West Asturian-Leonese zones (also including the Sierra de la Demanda and the Cadenas Ibéricas). It includes limestones, dolomites and mixed sequences of terrigenous and carbonates.

Finally, the Upper Terrigenous lithological assemblage is Middle and Late Cambrian in age. It is composed of clastic rocks organised in several sedimentary cycles. Scarce and thin carbonate levels are found within the terrigenous lithological assemblages, e.g. in the Cantabrian region during the Early Cambrian and in the Cadenas Ibéricas and Ossa-Morena Zone during the Late Cambrian.

Using the Iberian regional stages (see below), a provisional correlation chart (Fig. 2) that displays the lithostratigraphic units and thicknesses for the Cambrian rocks in Iberia is shown. Lower and Middle Cambrian are modified from Liñán et al. (1993, 1996b) with new data from Liñán et al. (1997), Liñán and Perejón (1997), Vidal et al. (1994) and Vidal et al. (1999). The column of the western Ossa-Morena Zone (Vila Boim region) is based on Oliveira et al. (1991). The Upper Cambrian lithostratigraphic units and palaeontological data are summarised from Martín Escorza (1976), Palacios (1982, 1997), Shergold et al. (1983), Mergl and Liñán (1986), Pérez Estaún et al. (1990, 1992), Shergold and Sdzuy (1991), Aramburu et al. (1992), Aramburu and García Ramos (1993) and Liñán et al. (1996a).

To sum up, the Lower Cambrian of the Iberian Peninsula is represented by a thick sequence (more than 2000 m) of siliciclastic and carbonate materials, mostly deposited under littoral, recifal and sublittoral conditions. The general trend is transgressive, although interrupted by several regressive events (Fig. 3). The Middle Cambrian of the Iberian Peninsula is represented by a continuous sequence of carbonate and terrigenous rocks 300 to 1000 m thick, deposited under marine, sublittoral conditions in a general transgressive trend which reverses to a regressive trend at the end of the Middle Cambrian. The Upper Cambrian Series is represented by 150 to 600 m (maximun thickness is in the Cadenas Ibéricas) of siliciclastic materials deposited under shallow marine, regressive conditions.

REGIONAL STAGES AND INTERNATIONAL CORRELATION

Using selected trilobite assemblages as chronomarkers, Sdzuy (1971a) defined three regional stages for the Lower Cambrian of the Iberian Peninsula from the base up: Ovetian, Marianian and Bilbilian. Sdzuy (1971b) also proposed three informal Middle Cambrian stages (*Acadoparadoxides*, Solenopleuropsidae and Solenopleuropsidae-free). For beds bearing Cambrian trace fossils that are overlain by rocks containing the first Ovetian fossils assemblages, Liñán (1984) proposed the Corduban stage. These four Lower Cambrian regional stages were revised by Liñán et al. (1993) which offered new stratigraphical and palaeontological data (trilobites, archaeocyaths and trace fossils), and subsequently developed the Middle Cambrian stages. The two first stages were formally named as Leonian and Caesaraugustan. Finally Álvaro and Vizcaïno (1998) defined the latest

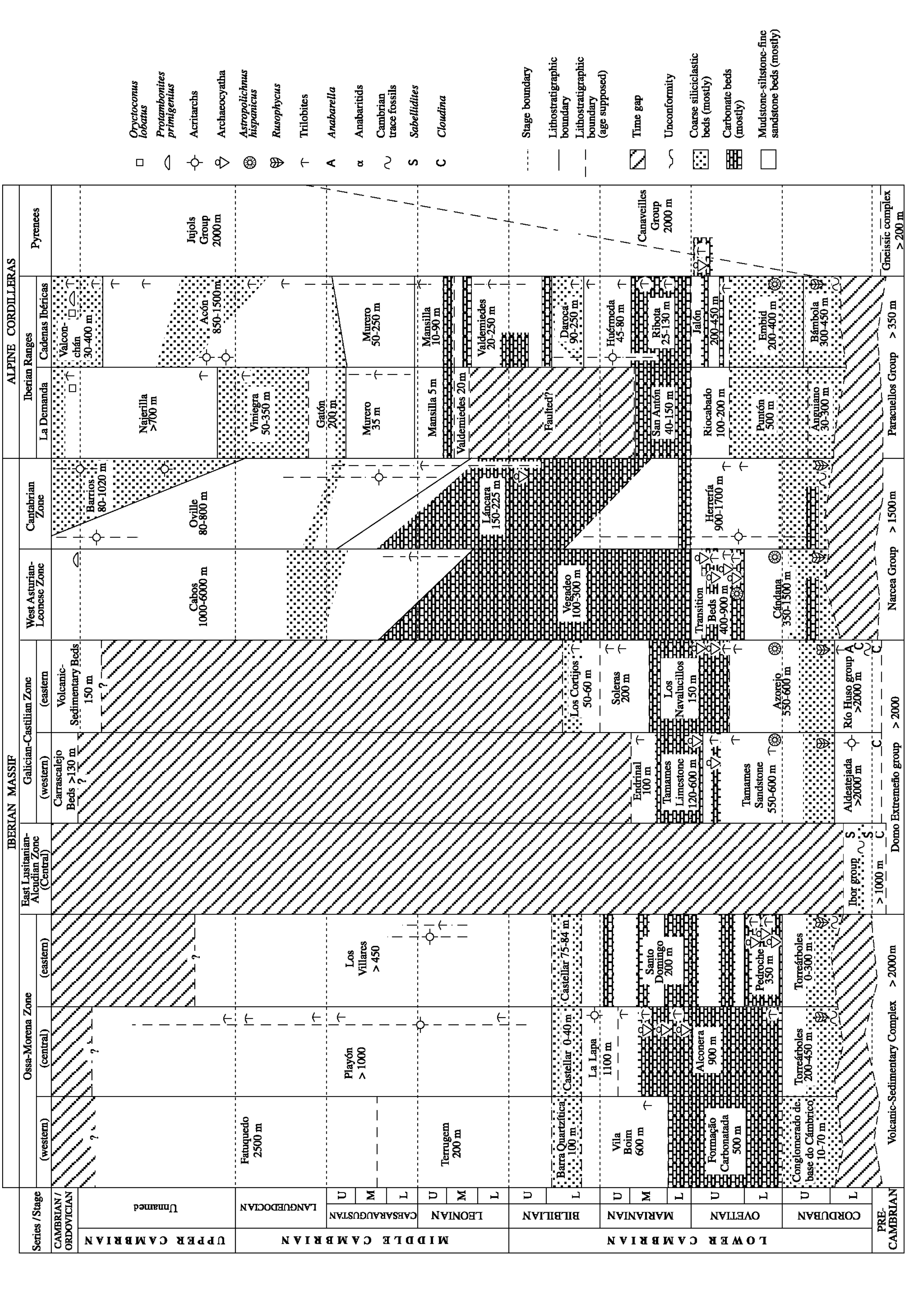

FIGURE 2 **Provisional correlation chart of the Cambrian lithostratigraphic units of the Iberian Peninsula.**

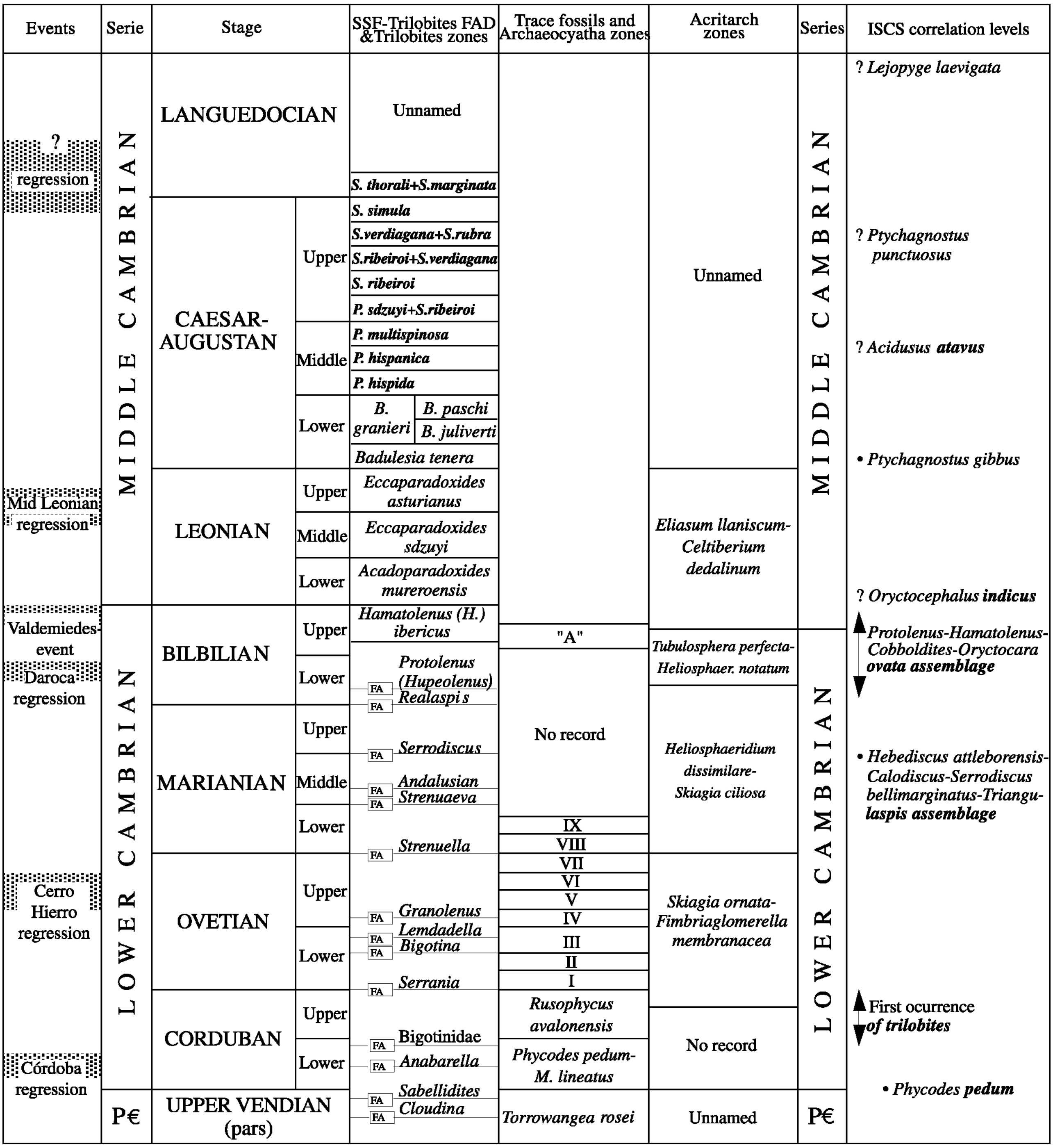

FIGURE 3 | **Lower and Middle Cambrian chrono- and biostratigraphic units in the Iberian Peninsula with the most relevant events and correlation with levels proposed by the Subcommission on Cambrian Stratigraphy (SCS). Legend from the column of Trilobites zones: S., *Solenopleuropsis*; P., *Pardailhania*; B., *Badulesia*.**

Middle Cambrian stage as Languedocian. Recent work on acritarch biochronology provides a more complete characterisation of some of these stages (Gámez et al., 1991; Palacios and Vidal, 1992; Palacios, 1993; Palacios and Moczydlowska, 1998). These chronostratigraphic units have been applied to the Cambrian successions in Germany (Sdzuy, 1971b; Elicki, 1997), Sardinia (Pillola et al., 1995; Loi et al., 1995), Turkey (Dean and Monod, 1997) and France (Álvaro and Vizcaïno, 1998; Álvaro et al., 1998a, 1998b). As a consequence, these stages are now considered as standard for the Mediterranean subprovince.

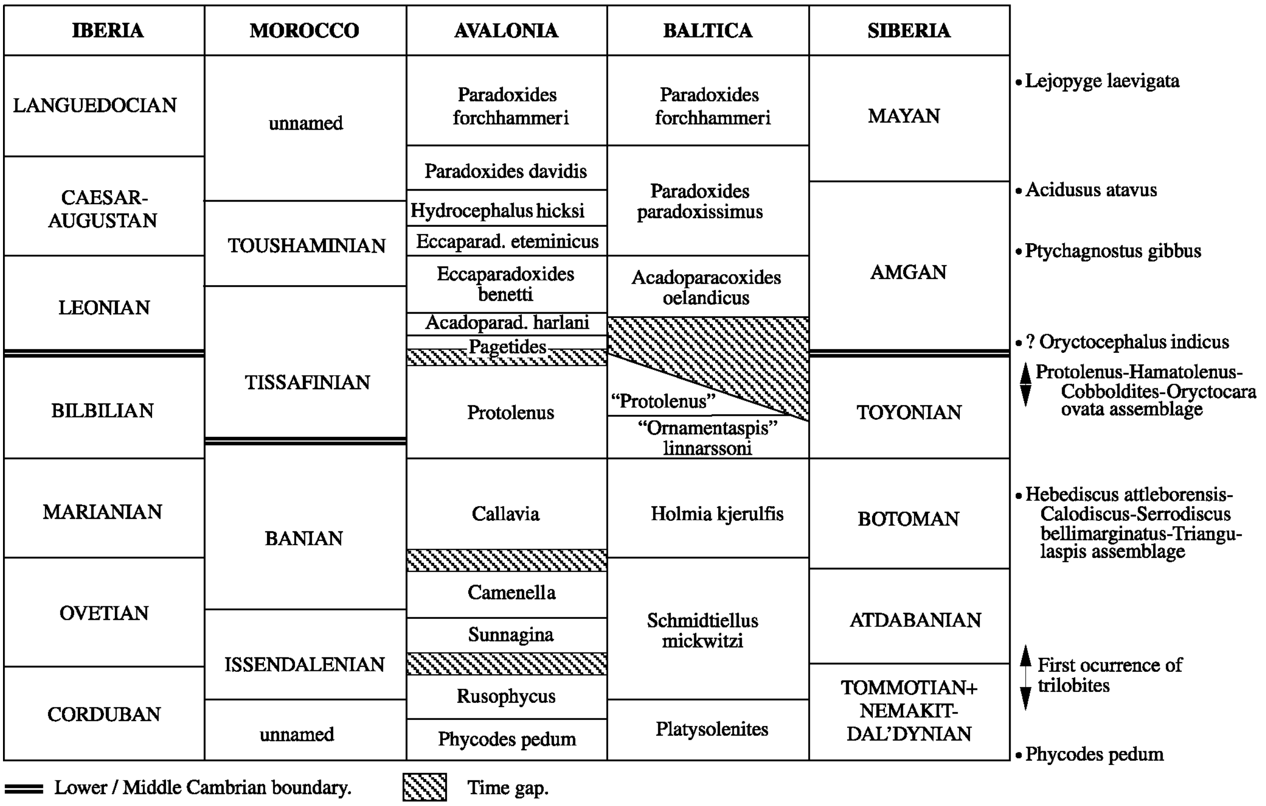

FIGURE 4 **Correlation chart of the Lower and Middle Cambrian of the Acadobaltic Province and Siberia, modified from Sdzuy (1972, 1995), Geyer (1990), Liñán et al. (1993, 1996b), Zhuravlev (1995), Sdzuy et al. (1996, 1999), Álvaro and Vizcaíno (1998) and Geyer and Shergold (2000).**

Corduban stage

This stage (Figs. 2 to 4) is characterised by siliciclastic facies with abundant trace fossils (summarised by Gámez-Vintaned et al., 1995 and Liñán et al., 1996b). The most relevant ichnoevents are the successive first appearances of *Monomorphichnus lineatus*, *Phycodes pedum*, *Treptichnus, Dimorphichnus*, *Diplichnites, Psammmichnites*, *Rusophycus* and *Cruziana*. The lower boundary of the Corduban is defined by the first appearance of *Monomorphichnus* (Liñán et al., 1984, 1993). This event nearly coincides with the first recorded find of *Phycodes pedum* in central Spain (Gámez-Vintaned and Liñán, 1995) which is the index fossil for the Precambrian-Cambrian boundary in the reference stratotype of Eastern Newfoundland. For this reason, Gámez-Vintaned and Liñán (1995) proposed the appearance of the *Monomorphichnus lineatus-Phycodes pedum* assemblage as being the Precambrian-Cambrian boundary in Spain and, consequently, a boundary that corresponds to the beginning of the Corduban. This ichnofossil assemblage may be correlated with many other Precambrian-Cambrian sequences around the world. Upper Corduban strata contain the first records of *Rusophycus* and *Cruziana*. The Corduban has been correlated with the Tommotian regional stage of Siberia (Perejón, 1986).

Recently, Vidal et al. (1995b, 1999) and Palacios et al. (1999) have reported a number of fossil assemblages containing small shelly fossils, trace fossils and trilobites from stratigraphic units spanning the Precambrian/Cambrian boundary in central Spain (Valdelacasa, Ibor, Alcudia and Abenójar-Tirteafuera anticlines). They have interpreted these faunae as Nemakit-Daldynian/Middle Tommotian. In the Valdelacasa anticline (Toledo Mountains), the FAD of *Cloudina* predates the FAD of *Phycodes pedum*. Overlying these FADs, intermediate levels of the Pusa shale (upper part of Río Huso Group) contain *Cloudina*, anabaritids, halkieriids and sponges. The upper part of the Pusa shale yielded an assemblage of small shelly fossils (*Anabarella* sp., aff. *Aldanella*, hyoliths, circothecids, orthothecids, aff. *Mongolitubulus* and chancelloriids) together with Bigotinidae trilobites. In the Ibor anticline (Guadalupe area), shales of the Ibor Group record the FAD of *Sabellidites cambriensis* just above carbonates with *Cloudina* and below beds containing *Phycodes pedum*. According to the regional chronostratigraphic framework, the Cambrian assemblages cited above are regarded as Corduban in age, including the beds containing trilobites. However, in the light of new data and proposed correlations, a re-evaluation of the upper boundary of the Corduban stage is needed.

Ovetian stage

This stage (Figs. 2 to 4) is characterised by mixed facies, chiefly terrigenous in northern Iberia and mostly carbonated in the South. This stage contains the characteristic trilobite genera *Bigotina*, *Lemdadella*, *Serrania*, *Pararedlichia*, *Thoralaspis* and *Granolenus*. Its lower boundary is defined by the archaeocyaths of Zone I of Perejón (1986, 1994) which appear together with *Serrania* trilobites. Using archaeocyaths, a tentative correlation of the Ovetian with the Atdabanian stage of Siberia has been made (Perejón, 1986; Zhuravlev, 1995). This correlation is also supported by the presence of Bigotinidae trilobites in Iberia (Ovetian) and Siberia (reported from the lower Atdabanian by Repina, 1966). However this is not supported by recent data of acritarchs associated with Tommotian archaeocyaths and the trilobite *Pagetiellus* (junior synonym of *Delgadella* sensu Jell, 1997) in eastern Siberia (Vidal et al., 1995a). On the other hand, trilobites provide a good correlation between the Ovetian and the Issendalian stage from Morocco, proposed by Geyer (1990).

Liñán et al. (1993) considered the Herrería Formation from the Los Barrios de Luna section as the Ovetian stratotype in the Cantabrian Mountains. However, Palacios and Vidal (1992) and Vidal et al. (1999) found acritarchs of the *Skiagia ornata-Fimbriaglomerella membranacea* zone and *Skiagia ciliosa-Heliosphaeridium dissimilare* zone in the member I of the Herrería Formation, these zones corresponding to *Schmidtiellus mickwitzi* and *Holmia* trilobites zones from Baltica. Only the *Skiagia ornata-Fimbriaglomerella membranacea* zone is correlated with Ovetian materials elsewhere in Spain (see Fig. 3). As a result of the acritarch data, part of member I of the Herrería Formation and overlying rocks may be of Marianian and Bilbilian ages. This brings to light a discrepancy with data of trilobites *sensu* Sdzuy (1961, 1971a) and Liñán et al. (1993) (see Fig. 2).

To sum up, the Ovetian is widely represented in Iberia where many well exposed sequences can be found in North, South and Central parts of Spain. All these sequences are well characterised by archaeocyaths, ichnofossils (*Astropolichnus hispanicus*) and trilobites. However, at this moment in time the Ovetian lower boundary is only established by means of archaeocyaths. Thus, complementary data on trilobite species and acritarch assemblages are necessary for a global correlation of this boundary.

Marianian stage

This stage (Figs. 2 to 4) comprises mixed carbonate and terrigenous facies in Iberia. The lower boundary is marked by the presence of *Strenuella* trilobites and by the archaeocyathan zones VIII and IX of Perejón (1994). It is clearly characterised by the trilobite genera: *Delgadella, Serrodiscus, Perrector, Eops, Rinconia, Alanisia, Atops, Hicksia, Termierella, Lusatiops, Triangulaspis, Andalusiana, Saukianda* and *Gigantopygus*. These trilobites provide a good correlation with the Banian stage of the Atlas (*sensu* Geyer, 1990). Marianian rocks contain trilobite genera from the Olenellida (Occidental) and Redlichiida (Oriental) palaeobiogeographic realms, as well as the miomeroid cosmopolite trilobites *Delgadella*, *Calodiscus* and *Serrodiscus*, some of which are also present in other Early Cambrian sequences of southeastern Newfoundland, Siberia, Sardinia and Germany (Sdzuy, 1962; Geyer and Elicki, 1995). The presence of these genera provides a good correlation with the Botoman stage (Siberia) and *Callavia* zone (Avalonia). According to Palacios and Moczydlowska (1998), Marianian rocks from the Cadenas Ibéricas contain acritarchs of the *Heliosphaeridium dissimilare-Skagia ciliosa* zone, which is equivalent to the *Holmia kjerulfi* zone in Baltica. The diversity of Marianian faunas and the presence of phytoplankton are among the most useful fossil assemblages for intercontinental correlations in the mid-Lower Cambrian.

Bilbilian stage

This stage (Figs. 2 to 4) was originally defined in mixed facies of terrigenous and carbonates. Its lower boundary is traced to the first record of the trilobites *Realaspis* and *Pseudolenus* (known as the fauna of Los Cortijos de Malagón; Sdzuy, 1961; Gil Cid and Jago, 1989). Furthermore, Bilbilian rocks yield the trilobite genera: *Kingaspis*, *Alueva*, *Hamatolenus*, *Protolenus (Hupeolenus)* (the two latter genera characterise the Tissafinian stage of Morocco *sensu* Geyer, 1990), and *Onaraspis* (an Australian genus, which is characteristic of the Ordian stage; Öpik, 1966). Toyonian archaeocyaths have been found in upper Bilbilian strata (Debrenne and Zamarreño, 1970; Perejón, 1986, 1994). Recently, Sdzuy (1995) correlated the upper part of this stage with the *Hupeolenus* zone of Morocco, the Toyonian stage of Siberia and the *Plagiura-Poliella* zone of Laurentia.

Gámez et al. (1991) and Palacios and Moczydlowska (1998) found several levels with acritarchs in the Cadenas Ibéricas. These levels belong to the top of the *Heliosphaeridium dissimilare-Skagia ciliosa* zone, the *Volkovia dentifera-Liepaina plana* zone and the bottom of the *Eliasum llaniscum-Celtiberium dedalinum* zone *sensu* Palacios and Moczydlowska (1998). Recently, Palacios and Delgado (1999) defined the *Tubulosphera perfecta-Heliosphaeridium notatum* zone as equivalent to the *Volkovia dentifera-Liepaina plana* zone in the Iberian Peninsula. The base of the *Eliasum llaniscum-Celtiberium dedalinum* zone is interpreted by Palacios and Moczydlowska (1998), and Moczydlowska (1999) as marking the Lower-Middle Cambrian boundary; this level is located slightly below the FAD of *Acadoparadoxides* (see Fig. 3).

Leonian stage

This stage (Figs. 2 to 4) was defined within a mixed sequence (carbonates and siliciclastics) of sublittoral facies including the trilobites *Acadoparadoxides, Eccaparadoxides, Hamatolenus (Lotzeia), Protolenus (Hupeolenus), Alueva, Ellipsocephalus, Conocoryphe, Cornucoryphe, Holocephalina?, Acadolenus, Asturiaspis, Maccannaia, Dawsonia, Condylopyge, Peronopsis* and *Peronopsella*. The lower boundary is established by the first recorded find of *Acadoparadoxides mureroensis* (Liñán et al., 1993; Sdzuy et al., 1999), which is also considered as the beginning of the Middle Cambrian by trilobites. This stage includes many continuous and fossiliferous sequences in its type area. This quantity of data makes it possible to draw up accurate correlations by means of trilobites with the *Acadoparadoxides oelandicus* stage of Baltica, the *Glossopleura* and *Albertella* zones of Laurentia, Amga of Siberia, and *Ornamentaspis frequens* and *Cephalopyge* zones of Morocco (Sdzuy, 1971b, 1972, 1995; Gozalo and Liñán, 1995). Sdzuy et al. (1999) have recently revised the biochronology and correlation of this unit.

Caesaraugustan stage

This stage (Figs. 2 to 4) was also defined within an alternance of carbonate and terrigenous facies which were deposited within an outer sublittoral environment. The lower boundary is marked by the first appearance datum of the trilobite *Badulesia tenera* (Sdzuy et al., 1996, 1999) and the upper boundary is located at the base of *Solenopleuropsis thorali* - *Solenopleuropsis marginata* zone. More than 40 trilobite species and other taxa of palaeoscolecids, graptolites, sponges, hyoliths, brachiopods, acritarchs and ichnofossils are present (Sdzuy 1961, 1968; Liñán and Gozalo, 1986; Liñán et al. 1995, 1996a). The Caesaraugustan stage may be correlated with the *Badulesia* and *Pardailhania* zones of Morocco (Geyer and Landing, 1995), and the *Paradoxides paradoxissimus* stage of Baltica (Sdzuy, 1971b, 1972).

Languedocian stage

This stage (Figs. 2 to 4) was also defined within sublittoral shale and sandstone facies. Its lower boundary is marked by the bottom of *Solenopleuropsis thorali* biozone *sensu* Álvaro and Vizcaïno (1998). For the Languedocian biochronology, three substages have been established in France, but they have as yet to be recognised in Spain. Only an upper Languedocian trilobitic level named by Gozalo and Liñán (1999) as *Eccaparadoxides* gr. *macrocercus* gives a good correlation between the Iberian Ranges, Montagne Noire, the Amanos Mountains and possibly Sardinia. The assemblage is made up of *Eccaparadoxides* gr. *macrocercus*, *Chelidocephalus* spp. and *Derikaspis* spp. This assemblage has been correlated with the *Solenopleura brachymetopa* biozone from Baltica.

The Middle-Late Cambrian boundary has not yet been identified in the Iberian Peninsula.

Upper Cambrian

The Upper Cambrian successions from the Iberian Peninsula are mainly siliciclastic and were deposited under shallow marine conditions. Fossiliferous levels are scarce and, for the moment, there are no biostratigraphic units defined. Late Cambrian trilobites have been found in the Iberian Ranges (Sierra de la Demanda and Cadenas Ibéricas; Shergold et al. 1983; Shergold and Sdzuy, 1991). Acritarchs have been found in the Cantabrian Mountains (Fombella, 1978; Fombella et al. 1993), Ossa-Morena Zone (Palacios, 1997) and the Cadenas Ibéricas (Palacios, 1997). Figure 2 shows the position of assemblages near the top of the Cambrian containing *Oryctoconus lobatus*, *Protambonites primigenius* and some trilobites. However their ages are open to dispute as they range from latest Cambrian to earliest Ordovician (see Villas et al., 1995).

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