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THE CAMBRIAN OF THE CADENAS IBÉRICAS (NE SPAIN) AND ITS TRILOBITES

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INTRODUCTION AND GEOLOGICAL SETTING

The Cadenas Ibéricas (Iberian Chains) are the two strings of Palaeozoic outcrops located in the central part of the Iberian System (NE Spain). The Cadena Ibérica Oriental is separated from the Cadena Ibérica Occidental by the Tertiary Calatayud continental basin. The Cadenas Ibéricas constitute a segment of the Hercynian fold-belt and their rocks are mainly deformed by the superposition of both Alpine and Hercynian orogenies. The Cadenas Ibéricas are separated from the Spanish segment of the Ibero-Armorican arch (i.e. the Iberian Massif) by Mesozoic and Cainozoic materials. Nevertheless, some of the tectono-stratigraphic zones of Lotze (1945) defined for the Iberian Massif may also be traced along the Cadenas Ibéricas. On the basis of tectonic, stratigraphic and palaeontological criteria, Gozalo and Liñán (1988) have suggested the prolongation of both the Cantabrian and West Asturian-Leonese zones trough the Sierra de la Demanda to the Cadenas Ibéricas (Fig. 1).

This structurally complex area has been divided into three geological units, from Southwest to Northeast are: Badules, Mesones and Herrera units (Lotze, 1929; Carls, 1983; Gozalo and Liñán, 1988). They are bounded by of two tectonic structures first order, the Jarque and Datos faults. The Badules unit shows a general sequence from late Neoproterozoic to early Ordovician rocks; these intensively faulted rocks dip primarily to the South. This unit shows a structure in nappes (Lotze, 1961; Liñán and Gozalo, 1986; Álvaro *et al*., 1992; Álvaro, 1994). The Mesones unit contains a folded stratigraphic sequence from late Neoproterozoic to Middle Cambrian rocks with a general dip to the North (Valenzuela *et al*., 1990). Finally, the Herrera unit shows a more complete and basically folded Upper Cambrian-Permian sequence.

STRATIGRAPHY

The Cambrian succession of the Cadenas Ibéricas (Fig. 2) is known through Lotze's work (1929) and was selected by Sdzuy (1971a, 1971b) as the reference section for the Spanish Lower and Middle Cambrian sequences because of their trilobite record. Since Lotze's study (1929), lithostratigraphic

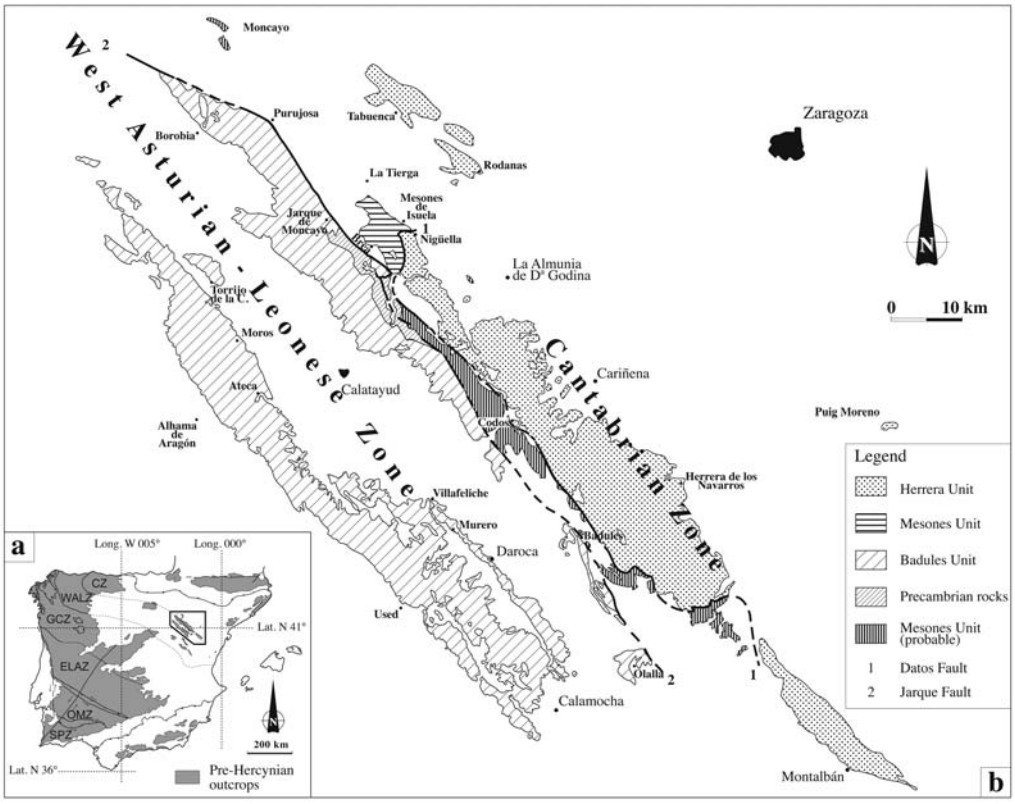

Figure 1. a, Pre-Hercynian outcrops and tectonostratigraphic zones of the Iberian Peninsula. The Iberian Chains are framed. Zones: CZ - Cantabrian, WALZ - West Asturian-Leonese, GCZ - Galician-Castilian, ELAZ - East Lusitanian-Alcudian, OMZ - Ossa-Morena, SPZ - South Portuguese. b, Pre-Hercynian outcrops and tectonostratigraphic zones and units of the Cadenas Ibéricas (from Gámez Vintaned, 2007).

nomenclature for the Precambrian and Cambrian rocks has been modified (Lotze 1958, 1961; Sdzuy, 1971a; Schmitz, 1971; Liñán and Tejero, 1988; Liñán *et al.*, 1992; Álvaro, 1995), and was summarized by Gozalo (1995), Liñán *et al.* (1996a, 1996b, 2002, 2004) and Gozalo *et al.* (2004). The units along the Precambrian-Cambrian sequence are, in an ascending order: the Paracuellos Group, Bámbola Formation, Embid Formation, Jalón Formation, Ribota Formation, Huérmeda Formation, Daroca Formation, Mesones Group and Acón Group. This sequence shows plus 3,000 m thick with important fossiliferous levels consisting mainly of trilobites.

The Cambrian sedimentation of the Cadenas Ibéricas begun with the coarse sandstone and interbedded conglomerates of the Bámbola Fm; this unit lies unconformable on the Precambrian materials of the Paracuellos Gr. The Embid and Jalón Fms lie conformable on the Bámbola Fm; both formations are siliciclastic with sandstones and shales interbedded and the percentage of lutites increases towards the top; the first carbonate levels recorded appear in the Jalón Fm. The three first Cambrian formations were deposited after the Corduban regression, in a transgressive phase during the Corduban and Ovetian stages (see Liñán and Gámez-Vintaned, 1993; Liñán *et al.*, 2006). The fluvially influenced bottom of the Bámbola

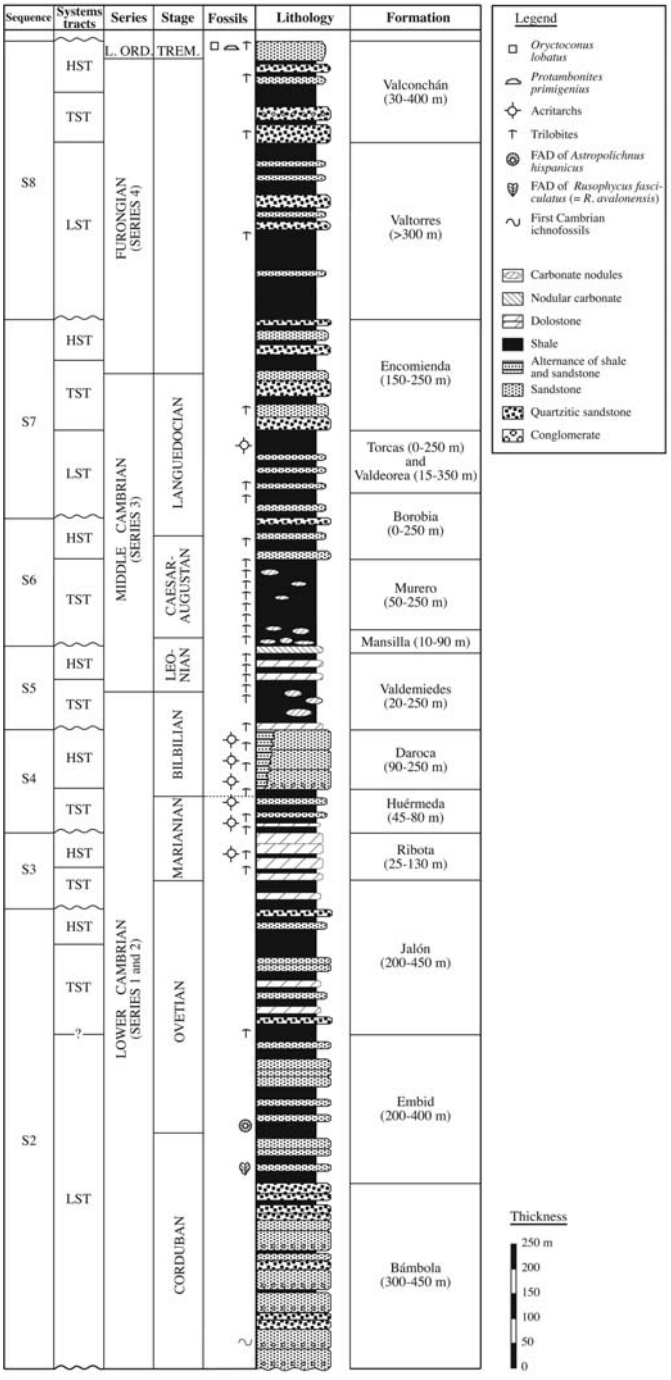

Figure 2. Cambrian stratigraphy of Cadenas Ibéricas and sequences recognised therein. Sequences after Schmitz (2006) and Gámez Vintaned *et al.* (in press).

Fm evolved to shallow sublittoral conditions and, finally, to clearly sublittoral conditions in the base of Jalón Fm. The levels with stromatolites and mud cracks recorded in the upper part of the Jalón Fm indicate a littoral environment and it is considered as the beginning of another regressive pulse, that has been correlated with the Cerro del Hierro regression in the upper Ovetian (see Liñán and Gámez-Vintaned, 1993; Liñán *et al.*, 2006). The Jalón Fm shows red and violet colours and salt pseudomorphs that indicate arid conditions, which, in accordance with Sdzuy and Liñán (1993), were probably extended in the western Mediterranean area. The first trilobites (family Dolerolenidae) have been found in transitional beds between the Embid and Jalón formations indicating an upper Ovetian age (Sdzuy, 1987).

The Ribota Fm is a carbonate unit Marianian in age, which is composed of several metric levels of dolostones and limestones with lutites and marls intercalations. During the sedimentation of this formation, the environment changed from a littoral (sometimes supralittoral) environment in the bottom, with stromatolites and breccias, to a protected sublittoral environment, where invertebrate benthic communities could occasionally be developed (Álvaro *et al.*, 1995). Two successive trilobite assemblages are recorded in the shales; the first one is characterised by *Lusatiops ribotanus* and *Strenuaeva incondita*, and the second one contains *Kingaspis*, *Redlichia* and *Strenuaeva* species (Sdzuy, 1971a).

The overlying Huérmeda and Daroca Fms are siliciclastic. The first is mainly composed of lutites and siltstones, which were deposited in open sublittoral conditions during the upper Marianian times. Two trilobite assemblages have been described in the bottom of the formation. The assemblage of *Micmacca* aff. *coloi*, *Andalusiana*, *Strenuaeva incondita*, *Kingaspis (Kingaspidoides) velata*, *Redlichia* and *Triangulaspis* (Sdzuy, 1961, 1971a) suggests a Marianian age. The assemblage of *Strenuaeva* sp. and Protolenids (Sdzuy, 1971a) documents the disappearance of the Olenellids in Spain and indicates a Bilbilian age. The Daroca Fm (lower Bilbilian) supposed a new entry of coarse siliciclastic material to the basin; this formation shows important facies lateral changes, with coarse siliciclastic material southward and fine siliciclastic material northward (Álvaro and Vennin, 1998). The environmental conditions changed from a littoral with fluvial influences environment in the south to a shallow sublittoral environment in the north. Those shallow deposits marked the regressive phase of the lower Bilbilian named Daroca Regression, which has been correlated with the Hawke Bay Regression (Gámez *et al.*, 1991; Liñán and Gámez-Vintaned, 1993; Liñán *et al.*, 2006). The trilobites recorded in this formation are scarce: *Aragotus attacanus*, *Protolenus* sp., *Lusatiops* sp. and *Realaspis* sp.

The overlying Mesones Group (lower Bilbilian to upper Caesaraugustan/lower Languedocian) is composed of the Valdemiedes, Mansilla and Murero Fms. It is essentially composed of shales with carbonate nodules, dolostones and limestones interbedded, containing a rich assemblage of fossils, including Burgess Shale type fossils. These materials were mainly deposited in sublittoral environments (Sdzuy and Liñán, 1993). The middle part of the Valdemiedes Fm records the Valdemiedes Extinction Event (Liñán *et al.*, 1993a, 2002, 2006; Gozalo *et al.*, 1993b, 2007; Álvaro *et al.*, 1993). This global event is marked by a geochemical anomaly expressed in a pronounced $\delta^{13}C_{org}$ excursion, probably, coeval with the ROECE (Liñán *et al.*, in press). The first paradoxididis are recorded just above this event; they mark the base of Leonian stage (middle Cambrian) and the beginning of a new transgressive pulse. The top of Valdemiedes Fm and the bottom of Mansilla Fm coincide with the upper Leonian regression (Sdzuy *et al.*, 1999; Liñán *et al.*, 2002); the base of Mansilla Fm shows griotte facies, which were deposited in very shallow marine conditions and developped in perireefal environments. The Murero Fm shows a uniform sequence into a continue transgressive pulse, within a deep sublittoral environment, occasionally circalittoral. The trilobite biodiversity of the three formations is abundant in genera and species (see trilobite list).

The Acón Group (uppermost Caesaraugustan to Furongian) is characterized by a thick and conformable succession of siliciclastic rocks (Álvaro *et al*., 2007). The Acón Group conformably overlies the regionally diachronous top of the shaly green Murero Fm (Liñán *et al*., 2002, 2004), which marks the beginning of a new regressive pulse in the uppermost Caesaraugustan and lower Languedocian. Álvaro (1995) subdivided this group into five formations: Borobia, Valdeorea, Torcas, Encomienda and Valtorres formations. Shergold and Sdzuy (1991) summarized the biostratigraphic data and recognised six different assemblages, ranging from uppermost Languedocian to Furongian (former Upper Cambrian).

The Valconchán Fm consists mainly of quartzite with interbeds of mudstone deposited in littoral or shallow sublittoral environments. Trilobite and brachiopod faunas appear n the lower part of the formation and were considered Upper Cambrian in age by Shergold and Sdzuy (1991). At the top of this formation, there is another assemblage of trilobites, brachiopods and echinoderms which has been considered as either Upper Cambrian (Shergold and Sdzuy, 1991) or transitional Cambrian to Ordovician (Wolf, 1980; Villas *et al*., 1995; Álvaro *et al*., 2007).

BIOCHRONOLOGICAL FRAMEWORK

Using selected trilobite assemblages as chronomarkers, Sdzuy (1971a) defined three regional stages (in ascending order: Ovetian, Marianian and Bilbilian) for the Lower Cambrian of the Iberian Peninsula, and Sdzuy (1971b) proposed three informal Middle Cambrian stages (*Acadoparadoxides*, Solenopleuropsidae and Solenopleuropsidae-free stages). Liñán (1984) proposed the Corduban stage for the strata with Cambrian trace fossils that are overlain by rocks containing the first Ovetian fossil assemblages. These four regional stages were revised by Liñán *et al.* (1993b) using new data from trilobites, archaeocyatha and trace fossils. In the same paper, the Middle Cambrian stages were elaborated and the Leonian and Caesaraugustan were defined. Álvaro and Vizcaïno (1998) named the highest Middle Cambrian stage as Languedocian. Recent works on trilobite biochronology permit a more accurate zonation with trilobites (see figure 3).

TRILOBITES LIST

The list of trilobite taxa of the Cadenas Ibéricas has been extracted from several works: Richer and Richter (1948), Sdzuy (1958, 1961, 1971a, 1987), Liñán and Gozalo (1986, 1999, 2001), Valenzuela *et al.* (1990), Shergold and Sdzuy (1991), Gámez *et al.* (1991), Liñán *et al.* (1993a, 1993b, 1996b, 2003, 2004), Gozalo *et al.* (1993a, 1993b, 2003, 2007), Álvaro *et al.* (1993), Gozalo and Liñán (1996), Álvaro (1996), Sdzuy and Liñán (1996), Álvaro and Liñán (1997), Dies *et al.* (2001, 2004, 2007), Chirivella Martorell *et al*. (2003), Dies and Gozalo (2004, 2006). The specific names listed herein meet the last systematic proposals.

Transitional beds between the Embid and Jalón Fms (upper Ovetian)

Dolerolenus? sp. indet., *Anadoxides*? sp. indet., *Thoralaspis* n. sp. A.

Ribota Fm (Marianian)

Lusatiops ribotanus Richter and Richter, 1948, *Strenuaeva incondita* Sdzuy, 1961, *Kingaspis (Kingaspidoides) velata* Sdzuy, 1961 and *Redlichia* sp.

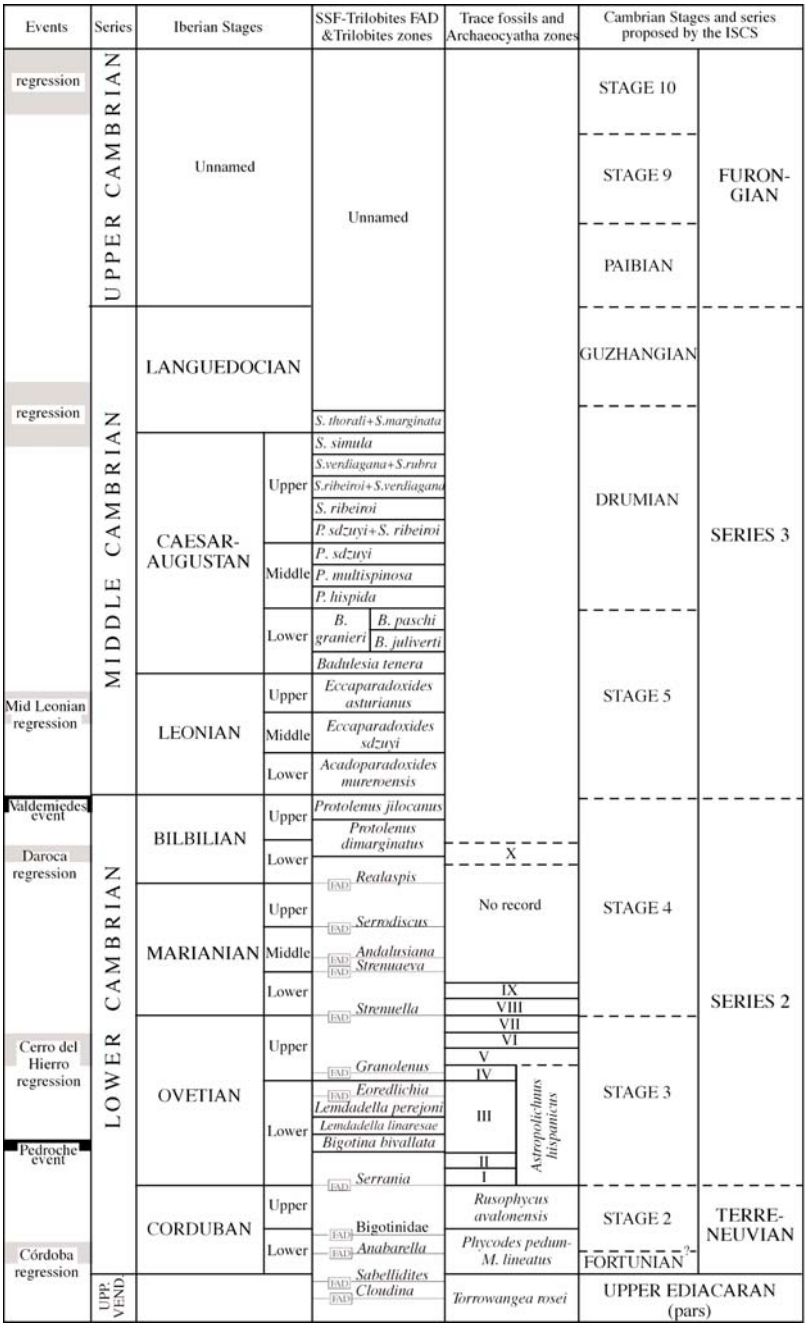

Figure 3. Cambrian chronostratigraphical and biochronological units in the Iberian Peninsula with the most relevant events and correlation with chronostratigraphical units proposed by the International Subcommission on Cambrian Stratigraphy (ISCS). FAD: first appearance datum; *B.*: *Badulesia*; *M.*: *Monomorphichnus*; *P.*: *Pardailhania*; *S.*: *Solenopleuropsis*; SSF: small shelly fossils.

Huérmeda Fm (Marianian)

Micmacca aff. *coloi* Hupé, 1953, *Andalusiana* sp., *Strenuaeva incondita*, *K. (Kingaspidoides) velata*, *Redlichia* sp. and *Triangulaspis* sp.

Huérmeda Fm (lower Bilbilian)

Srenuaeva sp., *Kingaspis (Kingaspidoides)* cf. *velata* and Protolenids.

Daroca Fm (lower Bilbilian)

Protolenus sp., *Realaspis* sp. and *Aragotus attacanus* Liñán and Gozalo, 2001.

Valdemiedes Fm (Bilbilian)

Protolenus termierelloides Geyer, 1990, *P. jilocanus* (Liñán and Gozalo, 1986), *P. dimarginatus* Geyer, 1990, *P. interscriptus* Geyer, 1990, *P. pisidianus* Dean *in* Dean and Özgül, 1994, *Hamatolenus (H.) ibericus* Sdzuy, 1958, *H. (Myopsolenus)* sp. A, *Kingaspis (K.) campbelli* King, 1923, *Alueva undulata* Sdzuy, 1961, *Sdzuyia sanmamesi* Liñán and Gozalo, 1999, *Tonkinella sequei* Liñán and Gozalo, 1999 and *Onaraspis altus* (Liñán and Gozalo, 1986).

Valdemiedes Fm (Leonian)

Acadoparadoxides mureroensis (Sdzuy, 1958), *Hydrocephalus* cf. *harlani*, *Eccaparadoxides sdzuyi* Liñán, 1978, *Hamatolenus (Lotzeia) lotzei* Sdzuy, 1958, *Alueva hastata* (Sdzuy, 1958), *A. moratrix* (Sdzuy, 1958), *Asturiaspis* sp., *Peronopsis* aff. *longinqua*, and *Condylopyge crucensis* Liñán and Gozalo, 1986.

Mansilla Fm (upper Leonian)

Eccaparadoxides asturianus Sdzuy, 1968, *E. sdzuyi*, *E. sulcatus* (Liñán and Gozalo, 1986), *Bailiaspis* aff. *tuberculata*, *Cainatops schirmi* (Sdzuy and Liñán, 1996), *Conocoryphe (Parabailiella) sebarensis* Sdzuy, 1968, *C. (P.) matutina* Sdzuy, 1968, *C. (P.) schmidti* Sdzuy, 1957, *Ctenocephalus* cf. *terranovicus*, *Holocephalina? leve* Liñán and Gozalo, 1996, *Asturiaspis inopinatus* Sdzuy, 1968, *Acadolenus* sp., *Parasolenopleura ouangondiana* (Hartt *in* Dawson, 1868) and *Peronopsella pokrovskajae* Sdzuy, 1968.

Murero Fm (Caesaraugustan)

Peronopsis acadica (Hartt in Dawson, 1868), *P. ferox* (Tullberg, 1880), *Peronopsella westergardi* (Sdzuy, 1968), *Condylopyge rex* (Barrande, 1846), *Corynexochus delagei* Miquel, 1905, *Eccaparadoxides sequeirosi* Liñán and Gozalo, 1986, *E. brachyrhachis* (Linnarsson, 1883), *E. pradoanus* Verneuil and Barrande, 1860, *Acadoparadoxides* sp., *Hydrocephalus donayrei* Liñán and Gozalo, 1986, *Badulesia tenera* (Hartt *in* Dawson, 1868), *B. granieri* (Thoral, 1935), *B. paschi* (Sdzuy, 1958), *Pardailhanica hispida* (Thoral, 1935), *P. multispinosa* Thoral, 1948, *P. sdzuyi* Liñán and Gozalo, 1986, *Solenopleuropsis ribeiroi* (Verneuil and Barrande, 1860), *S. truncata* (Sampelayo, 1935), *S. verdiagana* Sdzuy, 1958, *S. rubra* Sdzuy, 1958, *S. simula* Sdzuy, 1958, *S. marginata* Sdzuy, 1958, *S.* cf. *multigranifera*, *S. jarquensis* Álvaro, 1996, *S. vizcainoi* Álvaro, 1996, *Bailiaspis meridiana* Sdzuy, 1958, *Ctenocephalus antiquus* Thoral, 1946, *Conocoryphe (Parabailiella) languedocensis* Thoral, 1946, *C. (C.) heberti* Munier-Chalmas and Bergeron, 1889, *C. (C.) sdzuyi courtessolei* Liñán and Gozalo, 1986, *Agraulos longicephalus* (Hicks, 1872), *Skreiaspis* aff. *tosali* and *Jincella* sp.

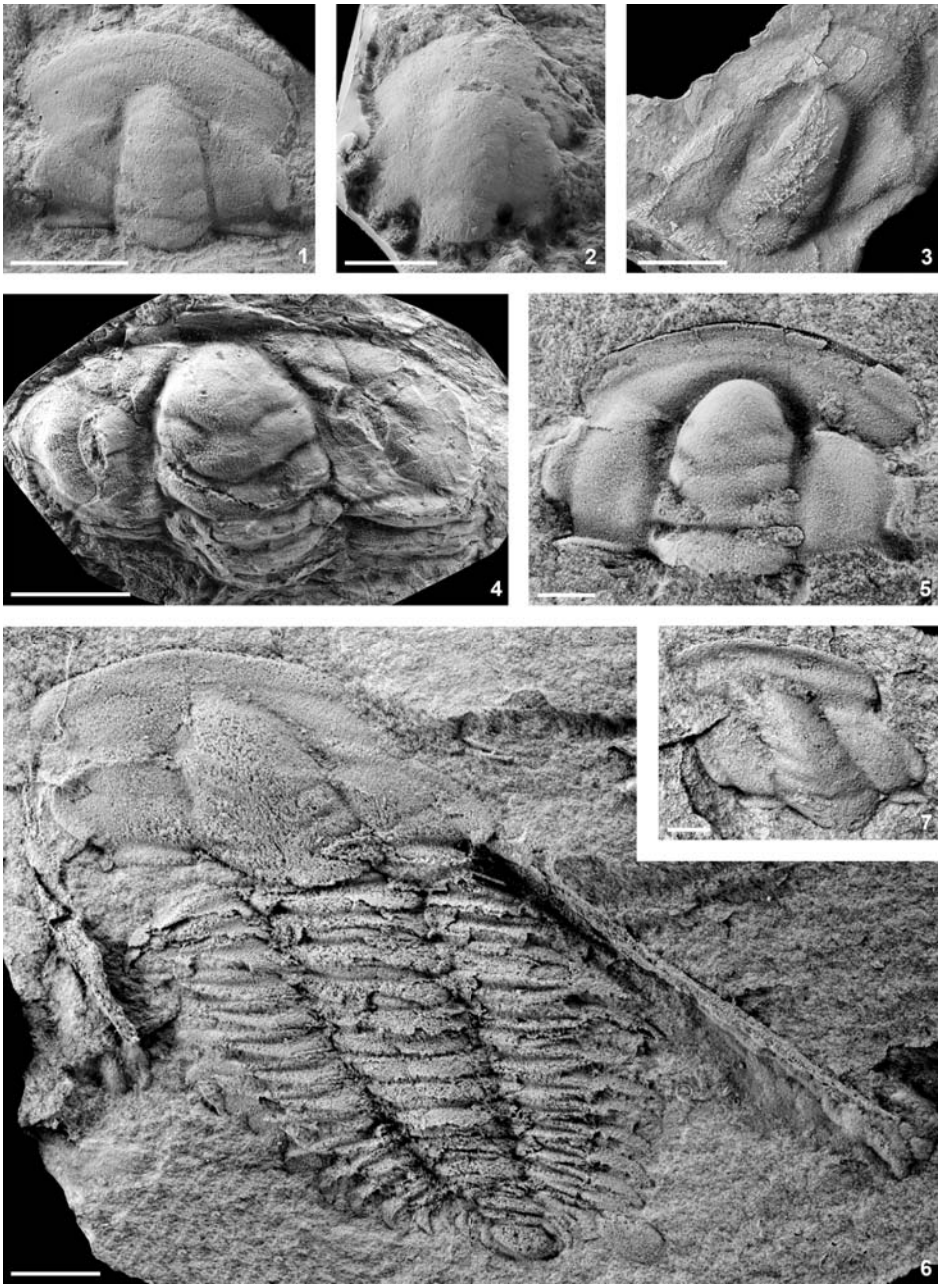

Plate 1. 1, *Lusatiops ribotanus*. Specimen MPZ 2005/91 (Museo Paleontológico de la Universidad de Zaragoza, Spain). Internal mould of cranidium. Scale bar = 5 mm. 2, *Kingaspis (Kingaspidoides) velata*. L 3230 (Lotze Collection, Universität Münster). Holotype. Latex replica of cranidium. Scale bar = 5 mm. 3, *Strenuaeva incondita*. SMF 11692 (Senckenberg Museum, Frankfurt). Holotype. Latex replica of cranidium. Scale bar = 5 mm. 4, *Aragotus attacanus*. MPZ 97/416. Cephalon and first thoracic segment of the holotype. Scale bar = 10 mm. 5, *Protolenus dimarginatus*. MPZ 01/100. Internal mould of cranidium. Scale bar = 2 mm. 6, *Hamatolenus (H.) ibericus*. MPZ 99/184. Complete specimen with the rigth librigena separated. Scale bar = 10 mm. 7, *Alueva undulata*. MPZ99/173. Internal mould of cranidium. Scale bar = 2 mm.

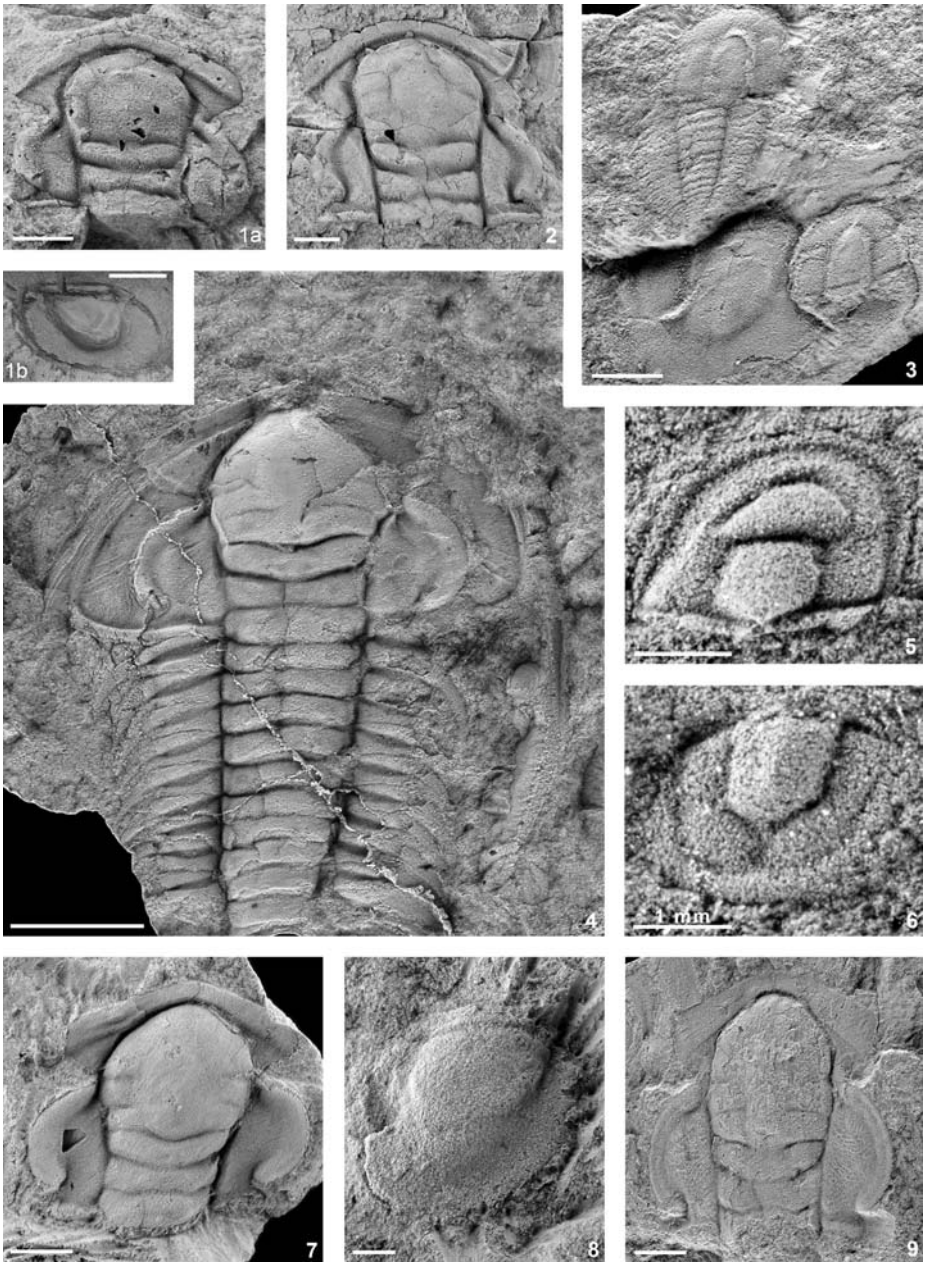

Plate 2. 1, *Acadoparadoxides mureroensis*. Specimen MPZ 2003/797 (Museo Paleontológico de la Universidad de Zaragoza, Spain). Internal moulds. 1a: cranidium; scale bar = 5 mm; 1b: pygidium; scale bar = 10 mm. 2, *Hydrocephalus* cf. *harlani*. MPZ 2004/96. Internal mould of cranidium; scale bar = 5 mm. 3, *Alueva hastata*. Specimens MPZ 2003/431 (upper one), MPZ 2003/432 (lower right) and MPZ 2003/433 (lower left). Internal mould. Scale bar = 5 mm. 4, *Eccaparadoxides asturianus*. MPZ 2007/559. Latex replica of cephalon and ten thoracic segments. Scale bar = 10 mm. 5, *Condylopyge crucensis*. MPZ 7826. Internal mould of cephalon. Scale bar = 1 mm. 6, *Condylopyge crucensis*. MPZ 804. Internal mould of pygidium. Scale bar = 1 mm. 7, *Eccaparadoxides sdzuyi*. MPZ 2007/604. Internal mould of cranidium. Scale bar = 5 mm. 8, *Eccaparadoxides sdzuyi*. MPZ 2007/615. Internal mould of pygidium. Scale bar = 2 mm. 9, *Eccaparadoxides sulcatus*. MPZ 2007/997. Internal mould of cranidium. Scale bar = 5 mm.

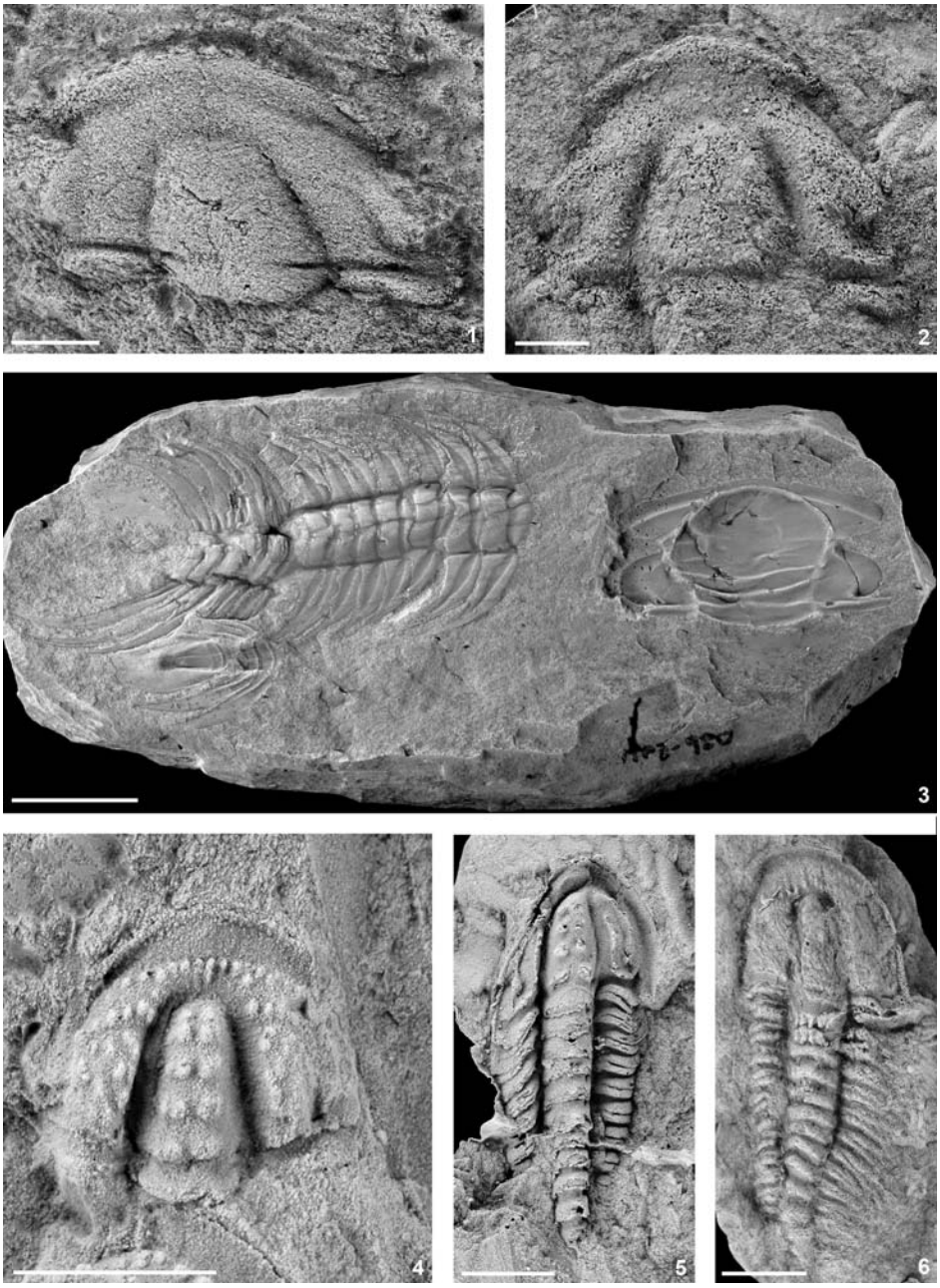

Plate 3. 1, *Asturiaspis inopinatus*. Specimen MPZ 2003/125 (Museo Paleontológico de la Universidad de Zaragoza, Spain). Internal mould of cranidium. Scale bar = 2 mm. 2, *Badulesia tenera*. MPZ 2007/1393. Internal mould of cranidium. Scale bar = 2 mm. 3, *Eccaparadoxides sequeirosi*. MPZ 980. Holotype. Internal mould of a molting specimen. Scale bar = 20 mm. 4, *Pardailhania hispida*. MPZ 3079. Internal mould of cranidium. Scale bar = 5 mm. 5. *Badulesia granieri*. MPZ 3072. Latex replica of a specimen without pygidium. Scale bar = 5 mm. 6, *Solenopleuropsis ribeiroi*. MPZ 2008/153. Internal mould of a specimen without pygidium. Scale bar = 5 mm.

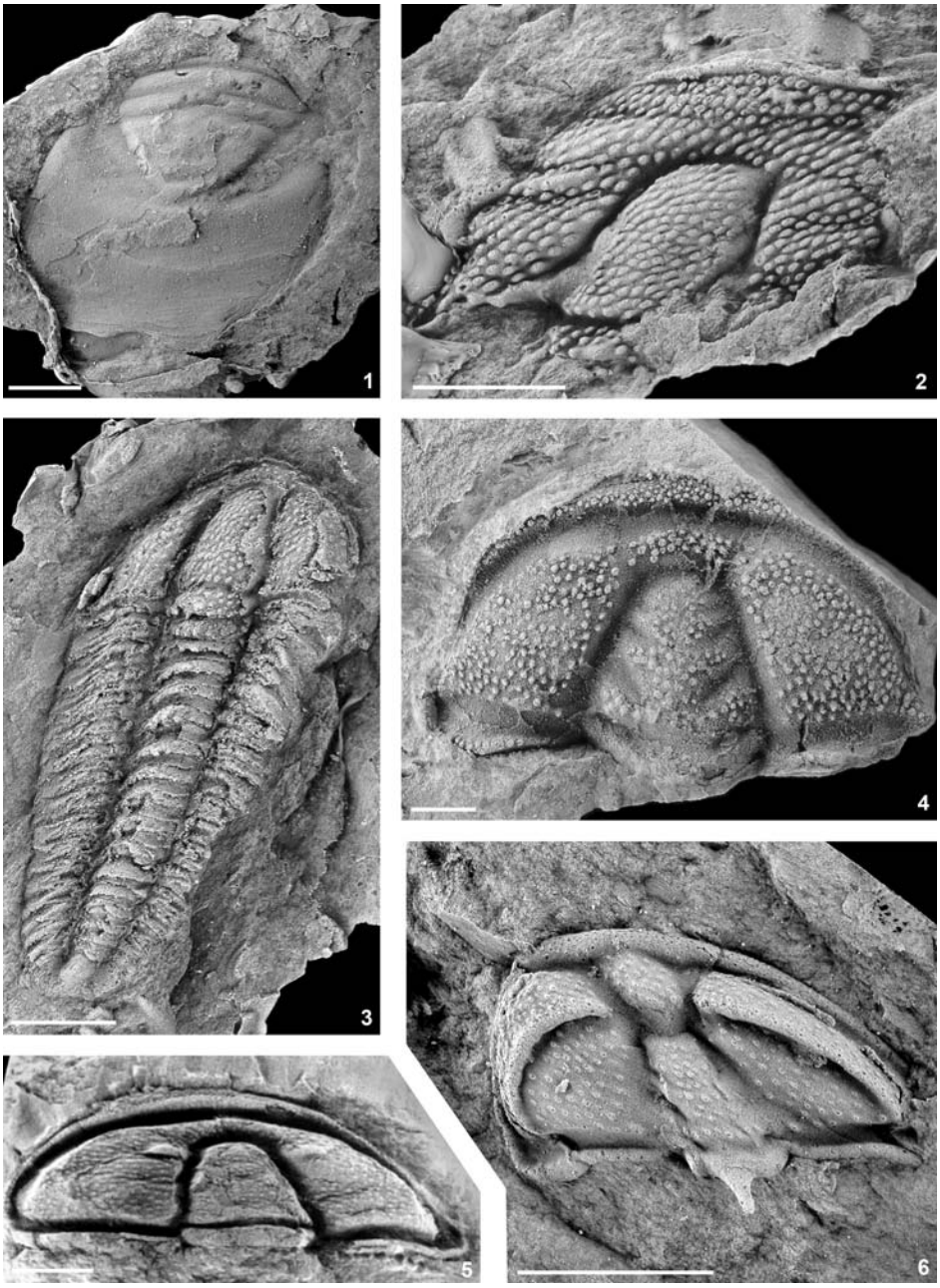

Plate 4. 1, *Eccaparadoxides melaguesensis*. Specimen MPZ 3044 (Museo Paleontológico de la Universidad de Zaragoza, Spain). Latex replica of pygidium. Scale bar = 5 mm. 2, *Solenopleuropsis simula*. MPZ 2008/155. Latex replica of cranidium. Scale bar = 5 mm. 3, *Solenopleuropsis thorali*. MPZ 2008/156. Latex replica of a complete specimen. Scale bar = 5 mm. 4, *Conocoryphe* (*Parabailiella) languedocensis*. MPZ 2008/154. Internal mould of cranidium. Scale bar = 5 mm. 5, *Conocoryphe (C.) sdzuyi courtessolei*. MPZ 3190. Holotype. Internal mould of cranidium. Scale bar = 10 mm. 6, *Ctenocephalus coronatus*. MPZ 2008/152. Latex replica of cranidium. Scale bar = 10 mm.

Acón Gr (Languedocian)

Peronopsis ferox, Eccaparadoxides brachyrhachis, E. melaguesensis Courtessole, 1973, *E. macrocercus* Courtessole, 1967, *Conocoryphe (C.) sdzuyi courtessolei, C. (C.) brevifrons* (Thoral, 1946) *C. (C.) ferralsensis* Courtessole, 1967, *Ctenocephalus* gr. *coronatus, Bailiella barriensis* Sdzuy, 1958, *B. levyi* Munier-Chalmas and Bergeron, 1889, *Solenopleuropsis marginata, S. thorali* Sdzuy, 1958, *Proampyx* sp. indet., *Parasolenopleura* n. sp.?, and *Solenopleura* s.l.

Acón Gr. and Valconchán Fm (Furongian)

Parachangshania? sp. indet., Aphelaspidinae aff. *Aphelaspis rara*, *Punctuaspis*? *schmitzi* Shergold and Sdzuy, 1991, *Valtorresia volkeri* Shergold and Sdzuy, 1991, *Elegantaspis* cf. *beta* and *Pseudagnostus (P.)* sp. indet.

Valconchán Fm (Tremadoc)

Pagodia (Wittekindtia) alarbaensis Shergold and Sdzuy, 1991 and olenid gen. et sp. nov (*Jujuyaspis*? sp. indet. *sensu* Shergold, 2000).

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