

Biostratigraphy of the Ribota and Huérmeda formations (Cambrian Series 2) in the Comarca del Aranda (Zaragoza province), Iberian Chains (NE Spain)

Bioestratigrafía de las formaciones Ribota y Huérmeda (Serie 2 del Cámbrico) en la Comarca del Aranda (provincia de Zaragoza), Cadenas Ibéricas (NE de España)

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Abstract: This article presents a detailed biostratigraphic analysis of the Cambrian Series 2 Ribota and Huérmeda formations of four sections of the Iberian Chains (NE Spain), and a systematic study of their trilobite faunas. We identified four major assemblages: two in the middle part of the Ribota Formation, one at the base of the Huérmeda Formation and one at the top of the Huérmeda Formation. The studied species permit the assignment of these formations to the middle and upper Marianiian and probably lower Bilbilian stages in the regional stratigraphic chart for the Iberian Peninsula, which correlates with an interval around the Cambrian Stage 3–4 boundary. The assemblages exhibit a great correlation potential with the presence of *Termierella* and the first figured material of *Andalusiana* from the Iberian Chains, two characteristic taxa of the Marianiian of the Ossa-Morena Zone, having been also recorded from the Central Iberian Zone and Morocco. In addition, specimens tentatively assigned to *Hebediscus* are recorded for the first time from the region, a taxon with a wide geographic distribution which allows a good international correlation in the Cambrian Series 2.

Resumen: Se presenta un análisis bioestratigráfico detallado de las formaciones Ribota y Huérmeda de la Serie 2 del Cámbrico de cuatro secciones de las Cadenas Ibéricas (NE España) y un estudio sistemático de sus faunas de trilobites. Se han reconocido cuatro asociaciones principales: dos en la parte media de la Formación Ribota, una en la base de la Formación Huérmeda y otra en la parte alta de la Formación Huérmeda. Las especies estudiadas permiten asignar estas formaciones al Marianiense medio–superior y, posiblemente, Bilbiliense inferior en la escala regional de pisos para la Península Ibérica, que se correlaciona con un intervalo alrededor del límite entre los pisos 3 y 4 del Cámbrico. Las asociaciones exhiben un gran potencial de correlación con la presencia de *Termierella* y el primer material figurado de *Andalusiana* de las Cadenas Ibéricas, dos taxones característicos del Marianiense de la zona de Ossa-Morena que también se registran en la Zona Centroibérica y en Marruecos. Además, ejemplares asignados tentativamente a *Hebediscus* se registran por primera vez en la región, un taxón con una amplia distribución geográfica que permite una buena correlación internacional en la Serie 2 del Cámbrico.

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INTRODUCTION

Trilobites are a useful tool to establish boundaries between the different chronostratigraphic units in the Cambrian System due to their abundance and global distribution (Babcock *et al.*, 2017; Peng *et al.*, 2020). However, the strongly endemic character of trilobite faunas of the Cambrian Series 2 as well as other factors have prevented the ratification of this Series and Stages 2 to 4 (Palmer, 1998; Geyer & Shergold, 2000). Working toward completing the subdivision of the Cambrian System, the International Subcommittee on Cambrian Stratigraphy (ISCS) encourages to establish regional biostratigraphical schemes which assist in

detailed intercontinental correlations of Cambrian Series 2 successions. Recently, the upper boundary of this series was defined by the ratification of the Miaolingian Series and the Wuliuan Stage (replacing former Middle Cambrian lower strata; see Zhao *et al.*, 2019), and its lower boundary is also under discussion (see Zhang *et al.*, 2017; Peng *et al.*, 2020). Nevertheless, the persistent use of the traditional informal subdivision in lower, middle, and upper Cambrian instead of the 4 series and 10 stages subdivision, adopted less than two decades ago, led Landing *et al.* (2021) to back up and reintroduce the subdivision of this period in three subsystems.

The Cambrian Series 2 have been tentatively correlated to the Ovetian, Marianian and Bilbilian stages in the regional stratigraphic chart for the Iberian Peninsula (Sdzuy, 1971; Liñán *et al.*, 1993; Shergold, 1997; Gozalo *et al.*, 2008; Sundberg *et al.*, 2016; Zhang *et al.*, 2017). In this region, the Iberian Chains show one of the most complete Cambrian record ranging from the Terreneuvian to the Furongian (Liñán *et al.*, 2002, 2004; Gozalo *et al.*, 2008). Still, the works about the Marianian deposits (comprising the Ribota and Huérmeda formations) are preliminary, mainly focusing on stratigraphy and petrology (Schmidt-Thomé, 1973; Gámez *et al.*, 1991; Zamora *et al.*, 1992, 1993; Álvaro *et al.*, 1995; Palacios & Moczyłowska, 1998; Álvaro *et al.*, 2019), and the trilobite biostratigraphy of those formations is yet to be published.

Álvaro *et al.* (2019) studied the trilobite fauna of the first meters of the Huérmeda Formation in various sections of the Mesones tectonostratigraphic unit of the Iberian Chains. In this work, they argued that the Marianian stage would be invalid for correlation throughout the Iberian Peninsula, as none of the different horizons proposed for marking the base and the top of this stage would be recognizable in all regions.

Aiming to improve the knowledge of this stage in the Iberian Chains, this article offers a biostratigraphic analysis of the Ribota and Huérmeda formations for four sections, two of them belonging to the Mesones Unit (Mesones 9, **M9**; Minas Tierga 1, **MT1**), and the other two (Jarque 1, **J1**; Jarque 2, **J2**) to the Badules Unit (Fig. 1), as well as a systematic study of their trilobite faunas. The review and analysis of both the previous data as well as new findings make it possible to establish correlation levels with nearby areas, both in the Iberian Peninsula (Ossa-Morena and Central Iberia Zones) as well as with Morocco and Germany. In addition, the first record of Eodiscina in the lower Cambrian of the Iberian Chains allows new correlations with Series 2 strata in other Cambrian continents.

GEOLOGICAL AND STRATIGRAPHIC SETTING

The Iberian Chains are two NW-SE parallel ranges of Palaeozoic outcrops separated by the Tertiary Calatayud basin whose rocks have suffered major tectonic deformation from both Hercynian and Alpine orogenies. This area constitutes the southernmost prolongation of both the Cantabrian and West Asturian-Leonese Zones (Gozalo & Liñán, 1988; Fig. 1) in the Eastern and Western Iberian Chain respectively, where three tectonostratigraphic units (Badules, Mesones and Herrera Units) have been defined (Lotze, 1929; Carls, 1983; Gozalo & Liñán, 1988).

The lower Cambrian lithostratigraphic units of the Iberian Chains were defined by Lotze (1929, 1958, 1961), and the nomenclature for these units has been modified several times since then (see Liñán *et al.*, 1996b, 2002, 2004, and Gozalo *et al.*, 2008). The

Ribota Formation is a carbonate unit characterized by bedded to massive dolostone with various lutite and marl intercalations. The Huérmeda Formation is a siliciclastic unit mainly composed of lutites and siltstones with minor dolostones intercalations.

The four studied sections are located in the Comarca del Aranda (Zaragoza province, NE Spain). The J1 and J2 sections are located at the Badules Unit (Fig. 1). The J1 section extends parallel to the Aranda River at 0.5 km westwards from the town of Jarque. The upper part of Series 2 and the Miaolingian deposits of this outcrop and their trilobite fauna have been studied extensively (*i.e.*, Dies-Álvarez *et al.*, 2001, 2004; Liñán *et al.*, 2003; Dies-Álvarez, 2004; Chirivella-Martorell *et al.*, 2003, 2009, 2017, 2020; Dies-Álvarez & Gozalo, 2006; Chirivella-Martorell, 2008). Nevertheless, the knowledge on the Marianian stage in this section is limited to the stratigraphy of the Ribota and Huérmeda formations. Moreover, an incomplete trilobite faunal list exists with the ellipsocephalidae species *Strenuaeva incondita* Sdzuy, 1961, *Lusatiops ribotanus* Richter & Richter, 1948 and *Kingaspis* (*Kingaspidoidea*) *velata* Sdzuy, 1961 (Liñán *et al.*, 1996a, 2003, 2008). The to date unpublished J2 section is located at 100 m southward stretching parallel to the J1 section, and its stratigraphy and trilobite fauna is presented herein.

The Ribota Formation in the J1 section is faulted at its base, having a thickness of 84 m characterized by various packages of yellow and grey dolostone and interbedded green marly shale (Fig. 2). The two shale levels in the upper half of the formation have yielded the fauna studied herein along with the first shale levels of the Huérmeda Formation, which is characterized by a 72 m thick succession of green shale and a thick dolostone intercalation in its middle part. The Ribota Formation in the J2 section (Fig. 3) is mainly characterized by a succession of dolostones and shales of 102 m in thickness, with two packages of massive dolostone at the top. The fauna studied herein was collected from two shale levels in the upper half of the Ribota Formation. The base of the Huérmeda Formation is composed of 22 m thick shales with scarce fossils recorded from the top of level 17 and the bottom of level 18.

The M9 and MT1 sections are located in the Mesones Unit (Fig. 1). The area of Mesones de Isuela contains various stratigraphic sections whose upper part of Cambrian Stage 4 and Miaolingian trilobites have been studied in different works (*i.e.*, Valenzuela *et al.*, 1990; Gozalo *et al.*, 1993; Gozalo & Liñán, 1996; Álvaro, 1996; Dies-Álvarez, 2004; Chirivella-Martorell, 2008; Esteve, 2013; Pates *et al.*, 2017). The M9 section (2.5 km westwards from the town of Mesones de Isuela, Zaragoza) records the Ribota and Huérmeda formations and Álvaro *et al.* (2019) studied a nearby section under the name 'Barranco del Judío'. These authors indicated the occurrence of the species *Lusatiops ribotanus*, *Strenuaeva incondita*, *Redlichia* (*Redlichia*) *isuelaensis* Álvaro, Esteve, Gracia &

Zamora, 2019, and the onaraspids *Onaraspis garciae* Álvaro, Esteve, Gracia & Zamora, 2019, *Luciaspis matiasi* Álvaro, Esteve, Gracia & Zamora, 2019, and *Paulaspis tiergaensis* Álvaro, Esteve, Gracia & Zamora, 2019 in the lowest meters of the Huérmeda Formation and presented a schematic stratigraphic profile of the section.

The MT1 section is situated near the Santa Rosa mine, in the vicinity of Tierga. Schmidt-Thomé (1973) published a synthetic stratigraphy of the area. Liñán et al. (2003) reported the species *Kingaspis (Kingaspidoidea)* cf. *velata* Sdzuy, 1961 from the level 23 of the MT1 section, and Sepúlveda et al. (2021a) recorded in three levels

the presence of *Kingaspis (Kingaspidoidea)* *velata*, *Lusatiops ribotanus*, *Strenuaeva incondita*, *Onaraspis garciae*, *Luciaspis matiasi*, *Paulaspis tiergaensis*, *Termierella* sp. and *Redlichia?* sp.

The upper part of the Ribota Formation in the M9 section comprises 30 m of massive dolostone without trilobite remains (Fig. 4). The Huérmeda Formation is characterized by 101 m-thick succession mainly composed by shale with some interbedded dolostone levels. The first shale levels are very fossiliferous, but there are some other shale levels with scarce trilobite remains above the lowest dolostone levels in the half part of the formation, and another level with trilobites

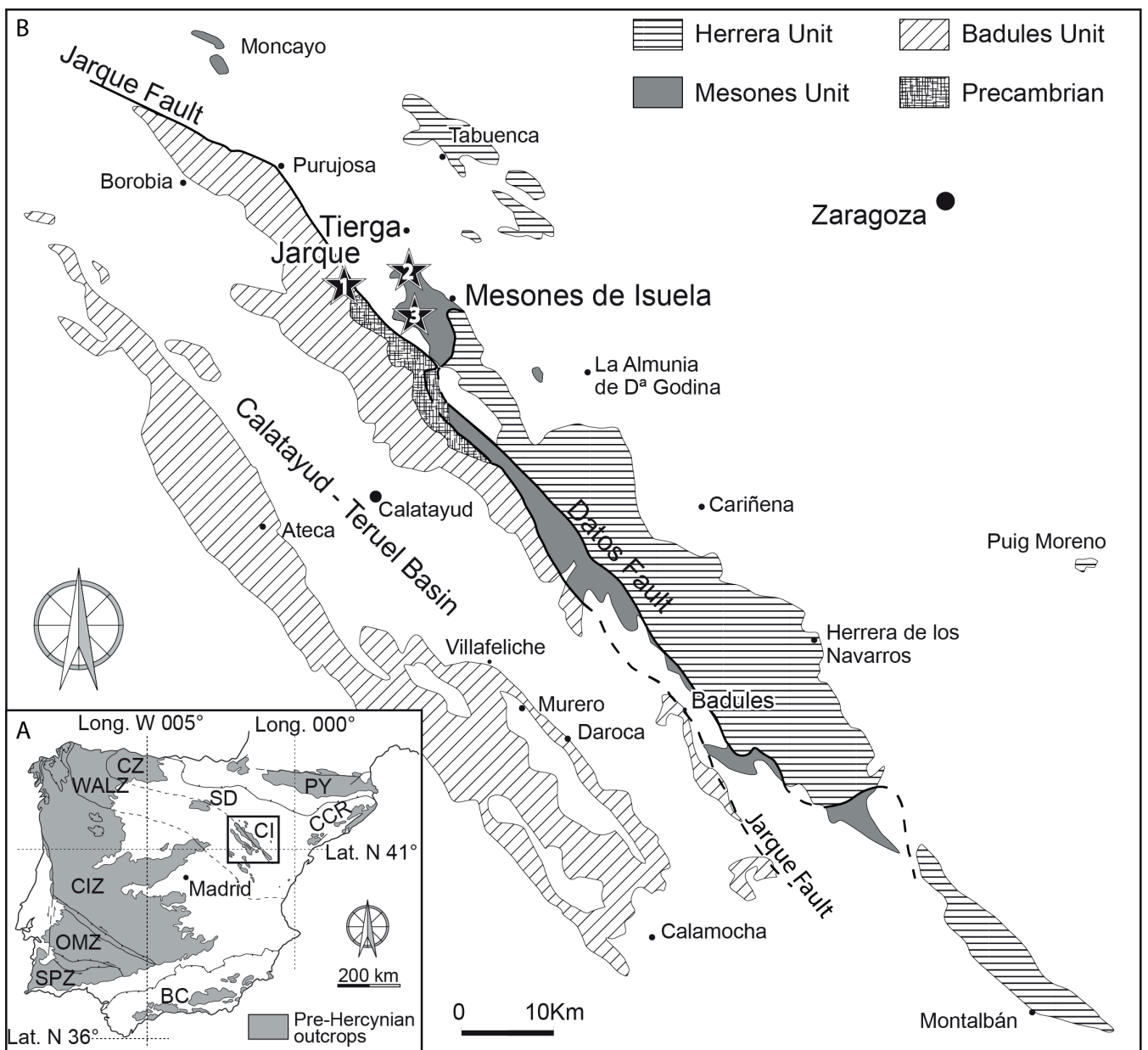


Figure 1. A, Map of the Iberian Peninsula showing pre-Hercynian outcrop areas; B, Location of the studied sections in the Iberian Chains. Modified from Gozalo and Liñán (1988). 1, Jarque 1 and 2 sections; 2, Minas Tierga 1 section; 3, Mesones 9 section; SPZ, South Portuguese Zone; OMZ, Ossa-Morena Zone; CIZ, Central Iberian Zone; WALZ, West Asturian-Leonese Zone; CZ, Cantabrian Zone; SD, Demanda Mountains; CI, Iberian Chains; PY, Pyrenees; CCC, Catalan Coastal Range; BC, Betic Chain.

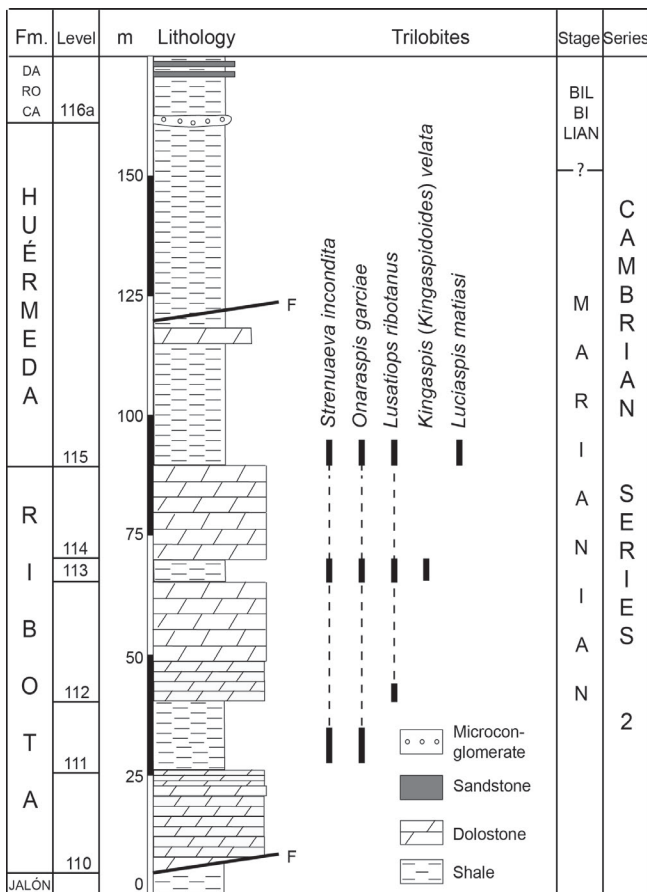


Figure 2. Stratigraphy and distribution of trilobites in the Jarque 1 (J1) section (modified from Liñán et al., 1996a, 2008).

lies above the quartz dyke in the lowest meters of the upper half of the formation.

MT1 is a 250 m thick section (Fig. 5) comprising 150 m strata of the Ribota Formation mainly composed of dolostones and marly dolostones with an intercalation of 10 m thick shales with trilobites. The uppermost 100 m of the section belong to the Huérmeda Formation and contain the other two levels with trilobites studied herein, the former located at the base of the formation and the latter at the top of the formation above dolomitic marlstone and siltstone levels.

In addition, the works for the Geological Map 1:50.000 of Spain in the area comprising the localities discussed in this work cited the presence of the despujolsiid genus *Realaspis* Sdzuy, 1961 in the Huérmeda Formation (Ramírez et al., 1981), the first appearance datum (FAD) of which was used to define the base of the Bilbilian stage in the Iberian Peninsula (see Liñán et al., 1993, 2006).

SYSTEMATIC PALAEOLOGY

The material studied herein is housed in the Museo de Ciencias Naturales de la Universidad de Zaragoza, Spain, formerly the Museo Paleontológico de la Universidad de Zaragoza.

Order EODISCINA Kobayashi, 1939
 Superfamily EODISCOIDEA Raymond, 1913
 Family HEBEDISCIDAE Kobayashi, 1944
 Genus *Hebediscus* Whitehouse, 1936

Type-species. *Ptychoparia attleborensis* Shaler & Foerste in Shaler, 1888 from the Briggus Formation, Massachusetts; by original designation. Cambrian Series 2; United States.

Hebediscus? sp.

Figure 6A–6D

Material and locality. Three cranidia and one pygidium from level 2 of the Huérmeda Formation of the M9 section.

Description. Cranidium subrectangular to subelliptical in outline, with a low curvature of the anterior margin. Glabella subrectangular and slightly tapering forward, with its maximum width at the occipital ring and with anterior margin evenly rounded. Glabellar furrows obsolescent. Semi-circular and narrow occipital ring extending backwards, delimited anteriorly by a shallow occipital furrow. Deep and well-marked axial furrow connected with the anterior border furrow. Anterior border furrow deep and wide (sag. and exsag.), ascending with even slope towards the anterior margin of the glabella and the ocular area, reaching its maximum depth where it coalesces with the anterior border. Anterior border narrow (sag. and exsag.), with low curvature and raised. Fixigena semi-circular and moderately convex, with its most elevated point near the eye. Narrow pre-ocular area. Weakly indicated eye ridge and short (sag.) but relatively wide (tr.) palpebral lobe. Posterior part of the fixigena low and narrow (sag.). Posterior border convex in transverse profile. Thorax unknown. Pygidium subelliptical in outline and convex, with a prominent axis. Pygidial axis subconical and tapering posteriorly, of more than 3/4 of the pygidial length and with a subevenly curved posterior margin almost connected with the pygidial border furrow. Axial ring slightly more inflated than the rest of the axis. Shallow axial furrow and well-marked pygidial border furrow. Lateral and posterior pygidial borders narrow (sag. and exsag.) and strongly elevated, forming a more-or-less uniform curvature at the exterior margin, very similar to the anterior border of the cranidium.

Remarks. The characters of the cranidium are consistent with the diagnosis provided by Jell (1997) and subsequent authors such as Westrop and Landing (2012), with a glabella having almost straight lateral margins and the occipital lobe poorly defined. In any case, both cranidium and pygidium have characters closely similar to *Hebediscus lemdadensis* Geyer, 1988. However, the imperfect preservation of the specimens from the Huérmeda Formation does not permit a confident determination.

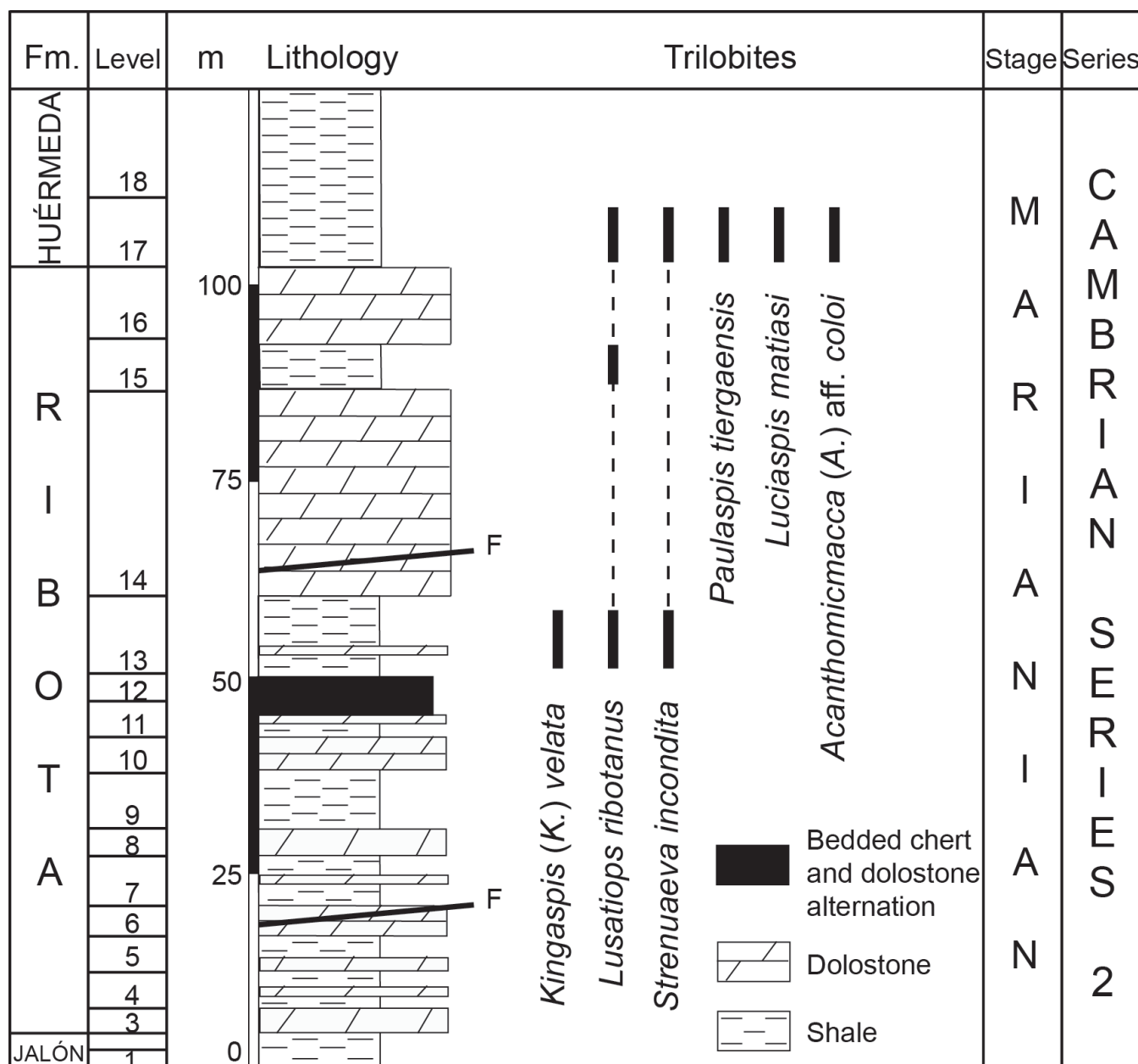


Figure 3. Stratigraphy and distribution of trilobites in the Jarque 2 (J2) section.

Occurrence. Huérmeda Formation, Iberian Chains (Spain).

Age. Upper Marianian (Cambrian Series 2).

Order REDLICHIIIDA Richter, 1932
 Suborder OLENELLINA Walcott, 1890
 Family HOLMIIDAE Hupé, 1953
 Subfamily HOLMIINAE Hupé, 1953
 Genus *Andalusiana* Sdzuy, 1961

Type-species. *Andalusiana cornuta* Sdzuy, 1961 from Guadalcanal FP. 1 (Sevilla province); by original designation. Cambrian Series 2; Spain and Morocco.

Andalusiana cf. cornuta Sdzuy, 1961
 Figure 6E

Material and locality. One cephalon preserved as internal mould collected by Prof. Klaus Sdzuy (1925-2005) in level 23 of the lowermost Huérmeda Formation in the MT1 section (according to the notes presented to Eladio Liñán and field data). This specimen is currently not available (Gerd Geyer, personal communication, 2021).

Remarks. Sdzuy (1971) reported the presence of *Andalusiana* in the lower part of the Huérmeda Formation based on a single incomplete but well-preserved specimen from level 23 of the MT1 section, which he determined as *Andalusiana cf. cornuta* Sdzuy, 1961. This cephalon resembles specimens of *Andalusiana cornuta* Sdzuy, 1961 figured by Sdzuy (1961, 1962) from the Ossa-Morena Zone. The specimen has

subtrapezoidal frontal lobe, a protuberance in front of the eye ridges, a very fine granulation covering the surface of the cephalon, and lacks a facial suture. According to Sdzuy's notes, differences between the specimen from the MT1 section of the Iberian Chains and the previously described material from the Ossa-Morena Zone exist in the more trapezoidal rather than subspherical outline of the frontal lobe, the shallower S2 across the glabella, and the probably broader (sag.) occipital ring. Sdzuy ascribed these differences to differences in the ontogeny since the specimens from the Ossa-Morena Zone are smaller than this specimen. However, the material of *Andalusiana cornuta* Sdzuy, 1961 from Morocco figured by Geyer and Palmer

(1995) includes some specimens with a less rounded frontal lobe slightly tapering backwards just as the here described specimen found by Sdzuy.

Occurrence. Huérmeda Formation, Iberian Chains (Spain).

Age. Upper Marianian (Cambrian Series 2).

Andalusiana? sp.

Figure 6F

Material and locality. Cephalic fragment with the left genal area and genal angle preserved as external

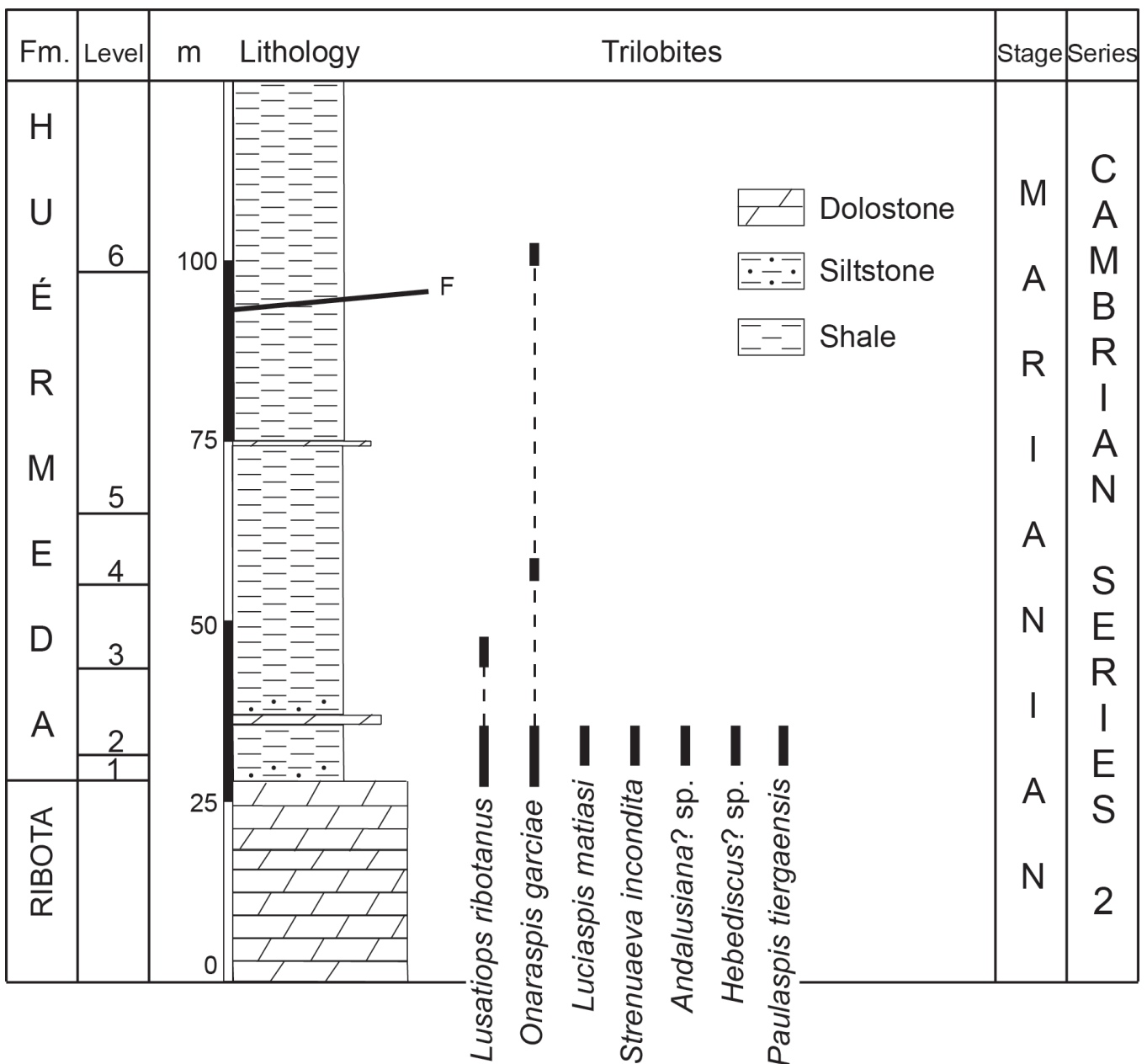


Figure 4. Stratigraphy and distribution of trilobites in the Mesones 9 (M9) section.

mould in yellow-brownish shale from level 2 of the Huérmeda Formation in the M9 section.

Description. Genal area subtriangular in outline, with flat to slightly convex librigenal field. Border furrow absent. Distinction between genal field and lateral border noted only by an increase in convexity in the latter. Lateral border narrow, with an arched lateral margin leading into the genal angle. Posterior margin at the inner part of the genal area straight, progressively bending near the genal angle. Base of the genal spine stout. Surface of the genal area covered with a very fine granulation.

Remarks. Despite the poor preservation of the specimen, the morphology of the genal area is clearly different from those of the co-occurring Redlichiina Richter, 1932 as it lacks facial suture. Also, the other redlichoid trilobites studied herein present a well-marked furrow separating the genal field from the lateral border and a much shorter (tr.) genal field. The presence of *Andalusiana* Sdzuy, 1961 in equivalent levels of the Huérmeda Formation in the MT1 section suggest a tentative assignment of the specimen to this genus.

Occurrence. Huérmeda Formation, Iberian Chains (Spain).

Age. Upper Marianian (Cambrian Series 2).

Suborder REDLICHIIINA Richter, 1932
Family REDLICHIIDAE Poulsen, 1927
Subfamily REDLICHIIINAE Poulsen, 1927
Genus *Redlichia* Cossmann, 1902

Type-species. *Hoeferia noetlingi* Redlich, 1899 from the Lower Cambrian (upper Canglangpuan) of the Salt Range, Pakistan. Cambrian Series 2; Pakistan and Iran.

Redlichia? sp.

Figure 7N

Material and locality. One incomplete thorax with the posterior six thoracic segments attached to an incomplete pygidium; from level 23 of the MT1 section.

Description. Axial ring subrectangular and slightly convex, with a flat-arched posterior margin. Remnants of an axial node. Axial furrow narrow and well-marked. Pleurae flat, slightly shorter (trans.) than the axial ring, and backwards-directed specially in its distal part. Pleural furrow narrow (sag. and exsag.) and shallow, conforming two subtriangular pleural bands. Pleural spines narrow and strongly backwards-directed, increasing in length to the pygidium. Spines of the two posteriormost thoracic segments reach posteriorly beyond the posterior margin of the pygidium. Pygidium small and oval to semi-circular in outline.

Remarks. Despite the imperfect preservation of the specimen described herein (Fig. 7N; MPZ 2021/384), the morphological characters of the thorax resemble that seen in *Redlichia* (*Redlichia*) *isuelaensis* Álvaro, Esteve, Gracia & Zamora, 2019 from the equivalent strata of the Minas Tierga section. The oval shape of the pygidium and the strongly backwards-directed spines that extend beyond the posterior margin of the pygidium distinguish this specimen from those of the co-occurring onaraspids.

Occurrence. Huérmeda Formation, Iberian Chains (Spain).

Age. Upper Marianian (Cambrian Series 2).

Family SAUKIANDIDAE Hupé, 1953
Subfamily ONARASPINAE Álvaro, Esteve, Gracia & Zamora, 2019
Genus *Onaraspis* Öpik, 1968

Type-species. *Onaraspis somniurna* Öpik, 1968 from near Deep Well, Rodinga area, Northern Territory (Australia), locality Rd 10, Ordian; by original designation. Cambrian Series 2; Australia.

Onaraspis garciae Álvaro, Esteve, Gracia & Zamora, 2019

Figure 7A–7H

(?) 2017 Redlichid trilobite; Pates et al., p. 755, fig. 6.
vp. 2018 Neoredlichidae gen. et sp. indet.; Sepúlveda et al., p. 598–560, fig. 4H, 4I, 4K, 4L.
v.* 2019 *Onaraspis garciae* n. sp.; Álvaro et al., p. 12–14, fig. 6.
v. 2021a *Onaraspis garciae* Álvaro et al., 2019; Sepúlveda et al., p. 232–233, fig. 3G, 3H.

Material and locality. 112 cranidia, two articulated specimens, one cephalon, one exuviae, 10 pygidia, one hypostome and 13 librigenae, preserved as internal and external moulds from levels 111, 113 and 115 of the J1 section; levels 18, 23 and 34 of the MT1 section; and levels 1, 2, 4 and 6 of the M9 section.

Remarks. Álvaro et al. (2019) erected the subfamily Onaraspinae Álvaro, Esteve, Gracia & Zamora, 2019 and introduced the species *Onaraspis garciae* Álvaro, Esteve, Gracia & Zamora, 2019, *Luciaspis matiasi* Álvaro, Esteve, Gracia & Zamora, 2019 and *Paulaspis tiergaensis* Álvaro, Esteve, Gracia & Zamora, 2019 from the lowest levels of the Huérmeda Formation. They also place this subfamily under the family Saukiandidae Hupé, 1953 based on the presence of macropleurae and micropleurae and the subsequent subdivision of the thorax into prothorax and opisthothorax. However, they did not mention the proposal to include the *Onaraspis* Öpik, 1968 clade into Bathynotidae Hupé, 1953 by Elicki and Geyer (2013). In addition,

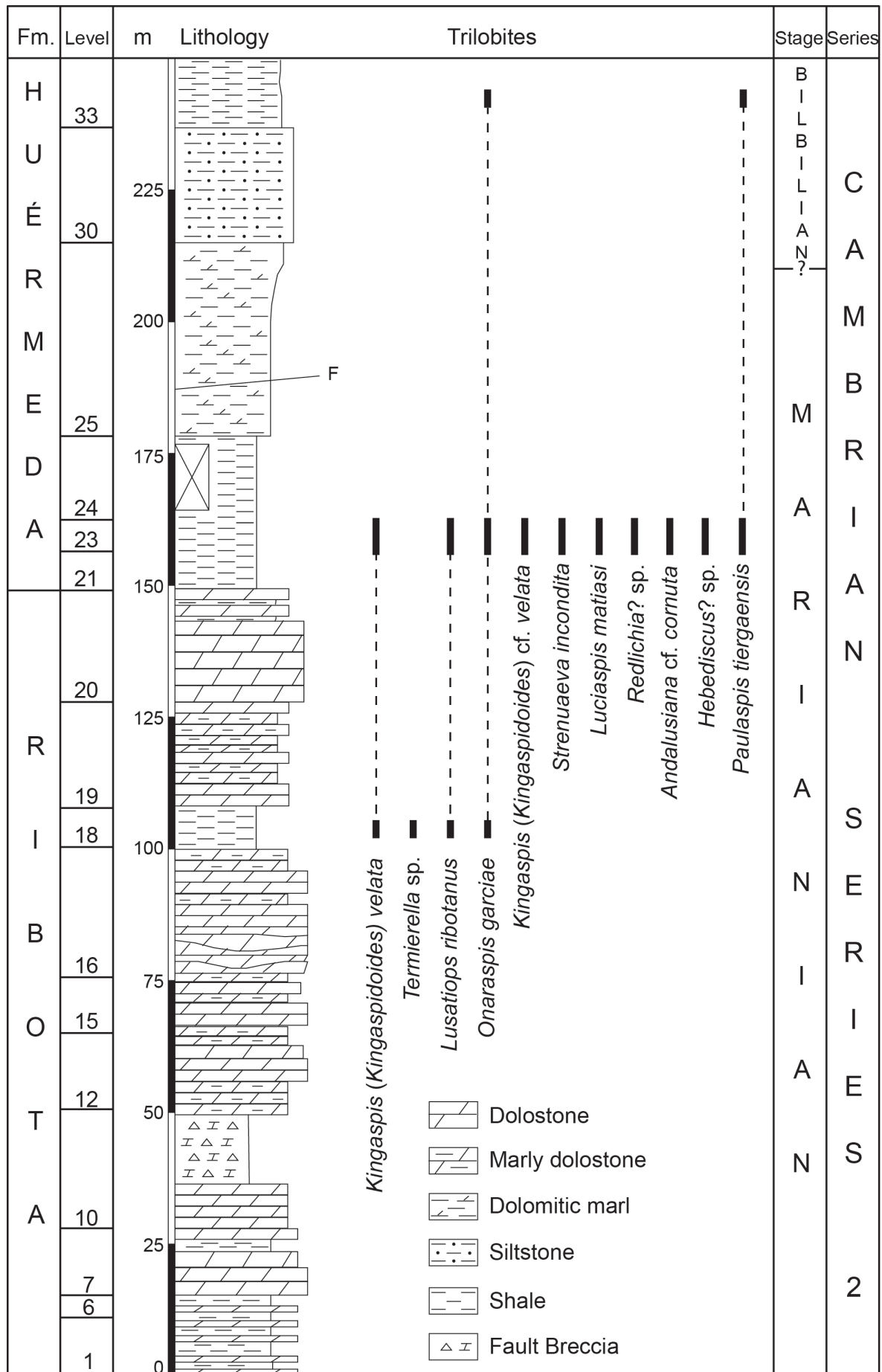


Figure 5. Stratigraphy and distribution of trilobites in the Minas Tiera 1 (MT1) section (modified from Sepúlveda et al., 2021a).

Żylińska and Masiak (2007) indicated the affinities of *Conomicmacca plana* Matthew, 1895 with the genus *Onaraspis* and Geyer (2016) regarded this genus as a junior subjective synonym of *Conomicmacca* Hupé, 1953.

Previously, Quarch (1967) and Ramírez et al. (1981) reported the presence of *Realaspis* Sdzuy, 1961, a genus which is now assigned to the family Despujolsiidae Geyer, 2020, in the Huérmeda Formation of the Borobia section and in the area studied herein. Sdzuy (1961) described *Realaspis strenoides* Sdzuy, 1961 from the Los Cortijos Formation of the Central Iberian Zone, from strata with lower Bilbilian age. However, the distorted specimens figured in Sdzuy (1961) strongly resemble the poorly preserved material of *Onaraspis garciae* from the M-9 section (see Fig. 7C; MPZ 2021/385). Álvaro et al. (2019) did not consider many shared characters between the newly described onaraspids and various despujolsiids, especially with *Realaspis*. The cranidium and the pygidium fit well with *Realaspis* as characterised by Geyer (2020). Moreover, Geyer (2020) cited the presence of a macropleura on the eleventh segment of *Perrektor* Richter & Richter, 1940 and a short, narrow opisthothorax. Thus, the systematic position of this species and of the other onaraspids from the base of the Huérmeda Formation should be considered controversial. Detailed cladistic and morphometric analyses must be carried out to clarify this question.

Occurrence. Ribota and Huérmeda formations, Iberian Chains (Spain).

Age. Middle Marianian to lower Bilbilian (Cambrian Series 2).

Genus *Luciaspis* Álvaro, Esteve, Gracia & Zamora, 2019

Type-species. *Luciaspis matiasi* Álvaro, Esteve, Gracia & Zamora, 2019 from the base of the Huérmeda Formation of the Iberian Chains, Spain; by original designation. Cambrian Series 2; Spain.

Luciaspis matiasi Álvaro, Esteve, Gracia & Zamora, 2019

Figure 7I–7K

vp. 2018 Neoredlichidae gen. et sp. indet.; Sepúlveda et al., p. 598–600, fig. 4J.

v.* 2019 *Luciaspis matiasi* n. sp.; Álvaro et al., p. 16–18, fig. 8.

v. 2021a *Luciaspis matiasi* Álvaro et al., 2019; Sepúlveda et al., p. 232, fig. 3E.

Material and locality. 33 cranidia, three articulated specimens, two hypostomes and one pygidium preserved as internal and external moulds from level 115 of the J1 section; level 17 of the J2 section; level 23 of the MT1 section; and level 2 of the M9 section.

Remarks. Álvaro et al. (2019) described this species from the lower levels of the Huérmeda Formation and assigned it to the newly erected subfamily Onaraspinae. However, the morphology of the cranidium strongly resembles those of some Despujolsiidae as *Perrektor* Richter & Richter, 1940, *Marsaisa* Hupé, 1953 and *Despujolsia* Neltner & Poctey, 1950 (see Geyer, 2020). They all have a broad (sag., exsag.) anterior border and a similar pattern of distinct characters of the cranidium. In addition, the morphology and the attachment of the hypostome in *Perrektor falloti* Hupé, 1953 figured by Geyer (2020) recall those of *Luciaspis matiasi* Álvaro, Esteve, Gracia & Zamora, 2019 figured in Álvaro et al. (2019) and herein (Fig. 7K; MPZ 2021/395).

Occurrence. Huérmeda Formation, Iberian Chains (Spain).

Age. Upper Marianian (Cambrian Series 2).

Genus *Paulaspis* Álvaro, Esteve, Gracia & Zamora, 2019

Type-species. *Paulaspis tiergaensis* Álvaro, Esteve, Gracia & Zamora, 2019 from the base of the Huérmeda Formation of the Iberian Chains, Spain; by original designation. Cambrian Series 2; Spain.

Paulaspis tiergaensis Álvaro, Esteve, Gracia & Zamora, 2019

Figure 7L, 7M

(?) 1961 Cranidium of a species not described in this work; Sdzuy, pl. 6, fig. 15.

v.* 2019 *Paulaspis tiergaensis* n. sp.; Álvaro et al., p. 14–16, fig. 7.

v. 2021a *Paulaspis tiergaensis* Álvaro et al., 2019; Sepúlveda et al., p. 232, fig. 3F.

Material and locality. 16 cranidia preserved as internal and external moulds from level 17 of the J2 section; levels 23 and 34 of the MT1 section; and level 2 of the M9 section.

Remarks. Sdzuy (1961) figured a cranidium (pl. 3, fig. 15) found in the area of Tierga (personal communication to Eladio Liñán and Rodolfo Gozalo, 1986) that strongly resembles those of the onaraspids from the base of the Huérmeda Formation described later in Álvaro et al. (2019). The morphology of the cranidium is probably more similar to *Paulaspis tiergaensis* Álvaro, Esteve, Gracia & Zamora, 2019 than to *Onaraspis garciae* Álvaro, Esteve, Gracia & Zamora, 2019 and *Luciaspis matiasi* Álvaro, Esteve, Gracia & Zamora, 2019. This specimen lacks the wide (sag. and exsag.) and strongly inflated anterior border of *Luciaspis matiasi*, and both the anterior margin and the anterior branch of the facial suture are more straight than those in *Onaraspis garciae*. In addition, the specimen figured by Sdzuy (1961) has a more robust and wider (tr.) glabella than *Onaraspis garciae*.

Occurrence. Huérmeda Formation, Iberian Chains (Spain).

Age. Upper Marianian to lower Bilbilian (Cambrian Series 2).

Family ELLIPSOCEPHALIDAE Matthew, 1887
Genus *Kingaspis* Kobayashi, 1935

Type-species. *Anomocare campbelli* King, 1923 from the Nubian Sandstone of Wadi Zerka Ma'in, Jordan; by original designation. Cambrian Series 2 and Miaolingian; Jordania, South Korea, Morocco and Spain.

Subgenus *Kingaspis* (*Kingaspidooides*) Hupé, 1953

Type-species. *Kingaspis* (*Kingaspidooides*) *armatus* Hupé 1953 [=*Kingaspis* (*Kingaspis*) *brevifons* Hupé, 1953], by original designation. Cambrian Series 2; Morocco.

Kingaspis (*Kingaspidooides*) *velata* Sdzuy, 1961

Figure 6G–6J

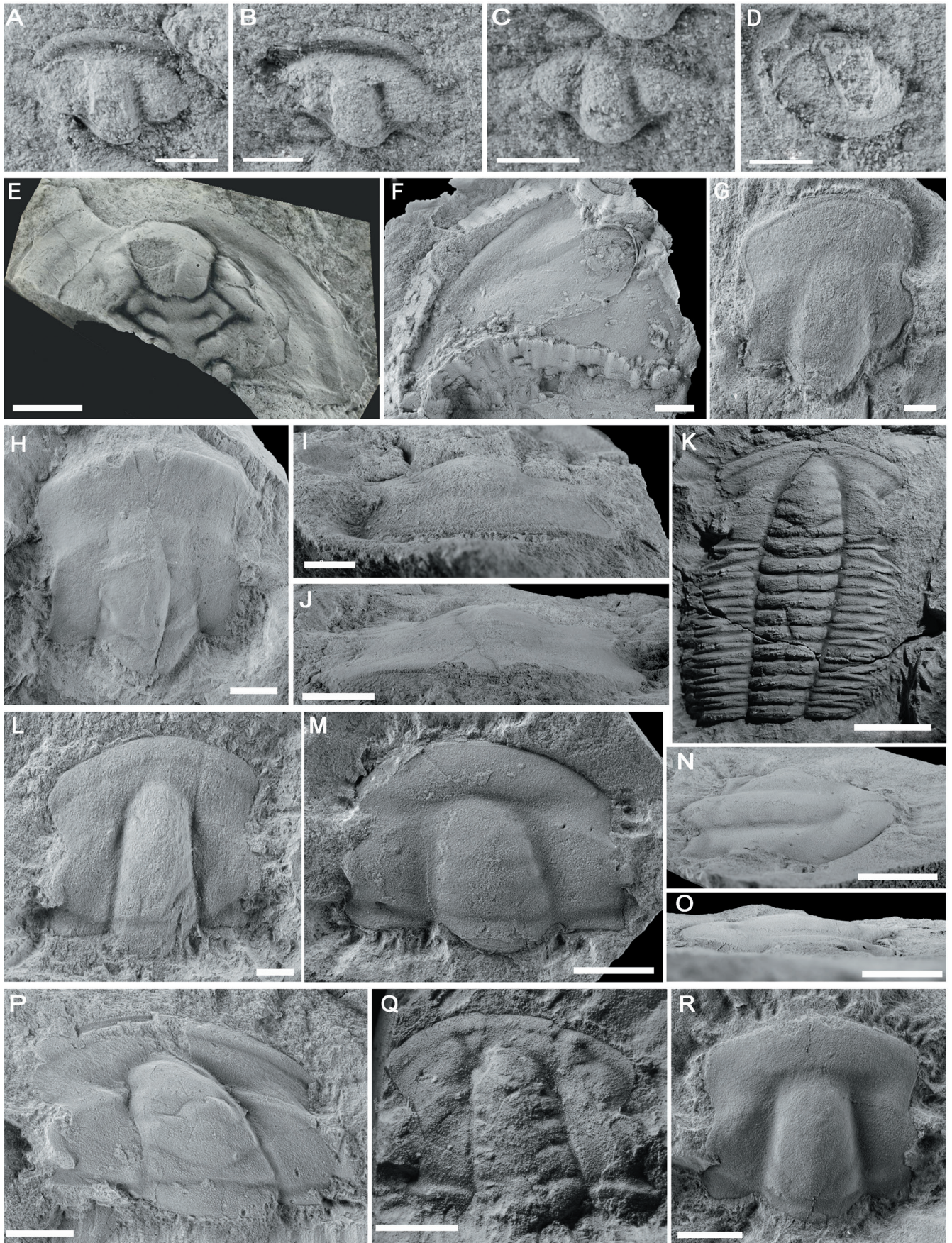
- v.* 1961 *Kingaspis velatus* n. sp.; Sdzuy, p. 308–310, pl. 15, figs. 1–8 (with previous synonymies).
- v. 1996a *Kingaspis velatus*; Liñán et al., fig. 24.
- v. 1996b *Kingaspis velatus*; Liñán et al., fig. 4.
- v. 2003 *Kingaspis* (*Kingaspidooides*) *velata* Sdzuy, 1961; Liñán et al., p. 6, fig. 3a, 3b, 3e.
- v. 2008 *Kingaspis* (*Kingaspidooides*) *velata* Sdzuy, 1961; Gozalo et al., p. 140–141, 143, pl. 1, fig. 2.
- v. 2018 *Kingaspis* (*Kingaspidooides*) *velatus* Sdzuy, 1961; Sepúlveda et al., p. 596–597, fig. 4A.
- v. 2019 *Kingaspis velatus*; Álvaro et al., fig. 3.
- v. 2019 *Kingaspis* (*Kingaspidooides*) *velata*; Zamora et al., p. 40, fig. 23C.
- v. 2021a *Kingaspis* (*Kingaspidooides*) *velata* Sdzuy, 1961; Sepúlveda et al., p. 232, fig. 3.

Material and locality. 26 cranidia preserved as internal and external moulds from level 113 of the J1 section; level 13 of the J2 section; and levels 18 and 23 of the MT1 section.

Discussion. Sdzuy (1961) figured various specimens from the Huérmeda section of the Iberian Chains which were assigned to *Kingaspis velatus* Sdzuy, 1961. On the other hand, he determined poorly preserved material from Los Cortijos de Malagón (Central Iberian Zone) as *Kingaspis* cf. *velatus* Sdzuy, 1961. Later, Dies-Álvarez et al. (1999) reported the presence of *Kingaspis campbelli* King, 1923 in the Valdemedes Formation of the Iberian Chains with a Bilbilian age. Liñán et al. (2003) reviewed the Spanish material of this genus and differentiated two morphologies interpreted as the subgenera *Kingaspidooides* and *Kingaspis* proposed by Hupé (1953), distinguished by the presence of a preocular-preglabellar furrow in the former. They placed the former *Kingaspis velatus* and *Kingaspis* cf. *velatus* in the subgenus *K.* (*Kingaspidooides*) Hupé, 1953 and *Kingaspis campbelli* in *K.* (*Kingaspis*) Kobayashi, 1935. Also, they figured a cranidium from level 23 of the MT1 section which was determined as *Kingaspis* (*Kingaspidooides*) cf. *velata* Sdzuy, 1961, and distinguished between this species and *Kingaspis* (*Kingaspidooides*) *velata* Sdzuy, 1961 by the presence of a moderately marked anterior border furrow and a more convex anterior margin in the former. The material from the J2 section studied in this work contains probably the best-preserved specimens of this subgenus found in the Iberian Chains. One of the specimens (Fig. 6G, 6I; MPZ 2021/371) differs from the other specimens assigned to *Kingaspis* (*Kingaspidooides*) *velata* in a more strongly tapering glabella and by the presence of a narrow and convex edge running across the anterior part of the frontal area and the anterior branch of the facial suture. Liñán et al. (2003) stated that *Kingaspis* (*Kingaspidooides*) cf. *velata* has a preglabellar field three times wider (sag.) than the border, but in the specimen discussed herein the anterior border is distinctly narrower (sag.) than the preglabellar field. Also, none of the specimens of *Kingaspis* (*Kingaspidooides*) cf. *velata* figured in Sdzuy (1961) and Liñán et al. (2003) shows this edge extending to the anterior branch of the facial suture. This specimen has the same convexity of the anterior margin and the cranidium as the rest of the specimens and fits well into the variability of

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Figure 6. A–D, *Hebediscus?* sp. A, cranidium, latex cast of external mould, MPZ 2021/366, from level 2 of the M9 section; B, cranidium, latex cast of external mould, MPZ 2021/367, from level 2 of the M9 section; C, cranidium, latex cast of external mould, MPZ 2021/368, from level 2 of the M9 section; D, pygidium, latex cast of external mould, MPZ 2021/369, from level 2 of the M9 section; E, *Andalusiana* cf. *cornuta*, Sdzuy, 1961, internal mould of incomplete cephalon level 23 of the MT1 section (photograph provided by Prof. Klaus Sdzuy); F, *Andalusiana?* sp., genal area, latex cast of external mould, MPZ 2021/370, from level 2 of the M9 section; G–J, *Kingaspis* (*Kingaspidooides*) *velata* Sdzuy, 1961; G–I, internal mould of a cranidium in dorsal and frontal view, MPZ 2021/371, from level 13 of the J2 section; H–J, internal mould of a cranidium in dorsal and frontal view, MPZ 2021/372, from level 13 of the J2 section; K, L, P, *Lusatiops ribotanus* Richter & Richter, 1948; K, cranidium articulated to thorax, internal mould, MPZ 2017/739 from level 23 of the MT1 section; L, internal mould of a cranidium, MPZ 2021/399, from level 13 of the J2 section; P, internal mould of a cranidium, MPZ 2021/400, from level 13 of the J2 section; M–O, R, *Strenuaeva incondita* Sdzuy, 1961; M–O, internal mould of a cranidium in dorsal, lateral and frontal view; MPZ 2021/379, from level 13 of the J2 section. R, internal mould of a cranidium, MPZ 2021/380, from level 13 of the J2 section; Q, *Termierella* sp., internal mould of a cranidium, MPZ 2020/32, from level 18 of the MT1 section; scale bars = 5 mm (F, H, J, K, M–R); 2 mm (G, I, L); 1 mm (A–D).



the species as dealt with in Liñán et al. (2003). More material is needed to clarify if these differences may be attributed to intraspecific or interspecific variance or to the preservation of the specimen and to resolve the affinities with *Kingaspis* (*Kingaspidoidea*) cf. *velata*.

Occurrence. Ribota and Huérmeda formations, Iberian Chains (Spain).

Age. Middle and upper Marianian (Cambrian Series 2).

Genus *Lusatiops* Richter & Richter, 1941

Type-species. *Protolenus lusaticus* Schwarzbach, 1934 from the *Lusatiops* Member of the Görlitz synclinorium, Germany; by original designation. Cambrian Series 2; Germany.

Lusatiops ribotanus Richter & Richter, 1948

Figure 6K, 6L, 6P

1961 *Lusatiops ribotanus* Richter & Richter, 1948; Sdzuy, p. 566–568 pl. 8, figs. 2–14 (with previous synonymies).

v. 1993 *Lusatiops ribotanus* Richter & Richter; Liñán et al., p. 820.

v. 1996a *Lusatiops ribotanus*; Liñán et al., fig. 24.

v. 1996b *Lusatiops ribotanus*; Liñán et al., fig. 4.

v. 2003 *Lusatiops ribotanus* Richter & Richter; Liñán et al., p. 11, fig. 2.

v. 2008 *Lusatiops ribotanus* Richter & Richter; Gozalo et al., p. 140–141, 143, fig. 1.

v. 2018 *Lusatiops ribotanus* Richter & Richter, 1948; Sepúlveda et al., p. 598, fig. 4E–4G.

2019 *Lusatiops ribotanus* Richter & Richter, 1948; Álvaro et al., p. 8–10, fig. 5.

v. 2019 *Lusatiops ribotanus*; Zamora et al., p. 40, fig. 23D.

v. 2021a *Lusatiops ribotanus* Richter & Richter, 1948; Sepúlveda et al., p. 232, fig. 3D.

Material and locality. 84 cranidia, one articulated dorsal exoskeleton, one cephalon, six librigenae and one exuvia preserved as internal and external moulds

from levels 112, 113 and 115 of the J1 section; levels 13, 15 and 17 of the J2 section; levels 18 and 23 of the MT1 section; and levels 1, 2 and 3 of the M9 section.

Remarks. Richter and Richter (1948) described the species based on the small holotype with a preglabellar field which is wider (sag.) than the anterior border. Álvaro et al. (2019) stated that the wider preglabellar field may be useful to distinguish *L. ribotanus* Richter & Richter, 1948 from the type species, *L. lusaticus* (Schwarzbach, 1934) along with other differences. However, larger specimens figured in the publications of the Richters show an anterior border which is slightly wider (sag.) than the preglabellar field, an ontogenetic pattern than can be also seen in the material figured in Sdzuy (1961), Álvaro et al. (2019) and herein (Fig. 7K and 7L; MPZ 2017/739 and MPZ 2021/399). Geyer and Elicki (1995) figured additional material of *L. lusaticus* with some variability in this character, including some specimens with the preglabellar field as wide as the anterior border. Thus, this character is not valid to distinguish these species and a more detailed study is necessary for the characterization of these two species.

Occurrence. Ribota and Huérmeda formations, Iberian Chains (Spain).

Age. Middle and upper Marianian (Cambrian Series 2).

Genus *Termierella* Hupé 1953

Type-species. *Termierella latifrons* Hupé 1953 from the lower Cambrian of Issafene, Moroccan Anti-Atlas; by original designation. Cambrian Series 2; Morocco.

Termierella sp.

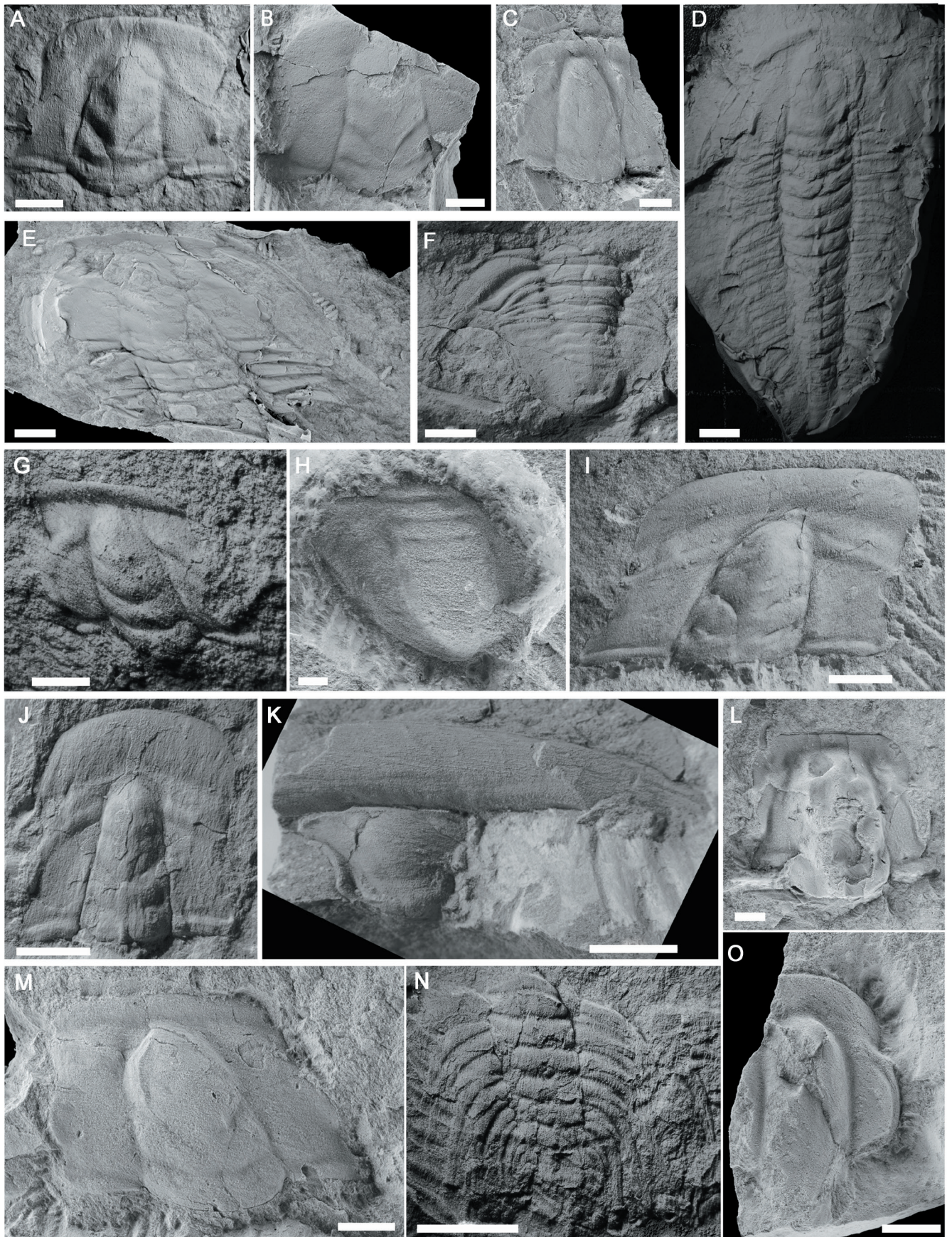
Figure 6Q

v. 2021a *Termierella* sp.; Sepúlveda et al., p. 231–232, fig. 3C.

Material and locality. One cranidium preserved as internal mould, from level 18 of the Ribota Formation in the MT1 section.

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Figure 7. A–H, *Onaraspis garciae* Álvaro, Esteve, Gracia & Zamora, 2019. A, cranidium, latex cast of external mould, MPZ 2020/36, from level 23 of the MT1 section; **B,** internal mould of a cranidium, MPZ 2021/389, from level 113 of the J1 section; **C,** internal mould of a cranidium, MPZ 2021/385, from level 1 of the M9 section; **D,** articulated cephalon, thorax and pygidium, latex cast of an external mould, MPZ 2017/763, from level 23 of the MT1 section; **E,** cephalon articulated to thorax, latex cast of an external mould, MPZ 2021/386, from level 6 of the M9 section; **F,** internal mould of a thorax and pygidium, MPZ 2021/397, from level 23 of the MT1 section; **G,** latex cast of an external mould of a juvenile cranidium, MPZ 2021/398, from level 23 of the MT1 section; **H,** internal mould of a pygidium, MPZ 2021/390, from level 1 of the M9 section; **I–K, *Luciaspis matiasi* Álvaro, Esteve, Gracia & Zamora, 2019; I,** internal mould of a cranidium, MPZ 2017/759, from level 23 of the MT1 section. **J,** internal mould of a juvenile cranidium, MPZ 2017/779, from level 23 of the MT1 section; **K,** internal mould of hypostome and rostrum, MPZ 2021/395, from level 23 of the MT1 section; **L–M, *Paulaspis tiergaensis* Álvaro, Esteve, Gracia & Zamora, 2019; L,** internal mould of a cranidium, MPZ 2021/377, from level 17 of the J2 section; **M,** internal mould of a cranidium, MPZ 2021/391, from level 2 of the M9 section; **N, *Redlichia?* sp.,** internal mould of a thorax and pygidium, MPZ 2021/384, from level 23 of the MT1 section; **O, *Acanthomicmacca* (*Acanthomicmacca*) aff. *coloi* Hupé, 1953,** internal mould of a cranidium, MPZ 2021/375, from level 17 of the J2 section; scale bars = 1 cm (D, E); 5 mm (A–C, F, I–O); 2 mm (G, H).



Description. Cranidium subquadrate to subtrapezoidal in outline of 15 mm long, with a low curvature of the anterior margin. Glabella elongated and slightly tapering anteriorly of 4/5 of the cranidium length, with rounded anterior margin. Three pairs of non-transglabellar furrows deep and well-marked, slightly backwards-directed with its inner tip more backwards-directed. Occipital furrow with subequal depth to glabellar furrows and small occipital ring reaching about 20% of the glabellar length, posterior margin with a low curvature. Axial furrows well-marked, slightly shallower than the glabellar furrows. Eye ridge oblique to axis and progressively increasing in convexity to the palpebral lobe. Palpebral lobe wide (tr.), with its posterior tip more backwards-directed than the anterior part, divided by a shallow but well-marked furrow. Anterior border short (sag. and exsag.) and convex with constant length in its entirety. Anterior border furrow shallow but well-marked and slightly convex. Preocular area three times longer (sag.) than the anterior border. Preglabellar field convex and slightly longer (sag.) than the anterior border. Two oblique, deep and well-marked furrows diverging anterolaterally from the medium part of the frontal lobe. Anterior branch of the facial suture subequal in length (sag.) to the palpebral lobe, conforming an arch to meet the anterior margin. Posterior branch short and backwards-directed. Surface covered with fine granulation.

Remarks. Despite the imperfect preservation of the specimen (Fig. 7Q; MPZ 2020/32), the morphology of the cranidium exhibits some features which suggest an assignment to *Termierella* Hupé 1953. The presence of a medium eye furrow, a wide ocular ring and two oblique furrows diverging from the anterior glabellar lobe, the slightly convex preglabellar field and the curved anterior margin of the glabella are present in *Termierella latifrons* Hupé, 1953 and *Termierella sevillana* Sdzuy, 1961. The great similarity of the specimen with *Lusatiops ribotanus* Richter & Richter, 1948 does not include the presence of the ocular and oblique furrows in the latter. In addition, *L. ribotanus* has smaller (tr.) palpebral lobes and a more pointed anterior margin of the glabella connected to a flatter preglabellar field.

Occurrence. Ribota Formation, Iberian Chains (Spain).

Age. Middle Marianian (Cambrian Series 2).

Genus *Strenuaeva* Richter & Richter 1940

Type-species. *Arionellus primaevus* Brøgger, 1878, from the Lower Cambrian *Holmia* Shale (Zone of *Holmia kjerulfi*) at Tømten, Ringsaker, Norway (*sensu* Ahlberg & Bergström, 1978); by original designation. Cambrian Series 2; Norway and Poland.

Strenuaeva incondita Sdzuy, 1961

Figure 6M–6O, 6R

v.* 1961 *Strenuaeva incondita* n. sp.; Sdzuy, p. 300–301, pl. 12, fig. 6–14, text-fig. 21 (with previous synonymies).

v. 1991 *Strenuaeva incondita* Sdzuy, 1961; Gámez et al., p. 262, 270, fig. 2.

v. 1993 *Strenuaeva incondita* Sdzuy, 1961; Liñán et al., p. 820.

v. 1998 *Strenuaeva incondita* Sdzuy, 1961; Palacios & Moczyłowska, p. 67, 72, 73, figs. 2, 4.

v. 2003 *Strenuaeva incondita* Sdzuy, 1961; Liñán et al., p. 11, fig. 2.

v. 2008 *Strenuaeva incondita* Sdzuy, 1961; Gozalo et al., p. 140–141, 143, pl. 1, fig. 3.

v. 2018 *Strenuaeva incondita* Sdzuy, 1961; Sepúlveda et al., p. 597, fig. 4B–4D.

2019 *Strenuaeva incondita*; Álvaro et al., fig. 3.

v. 2019 *Strenuaeva incondita*; Zamora et al., p. 40, fig. 23E.

v. 2021a *Strenuaeva incondita* Sdzuy, 1961; Sepúlveda et al., p. 232, fig. 3B.

Material and locality. 29 cranidia preserved as internal and external moulds from levels 111, 113 and 115 of the J1 section; levels 13 and 17 of the J2 section; level 23 of the MT1 section; and levels 1 and 2 of the M9 section.

Remarks. The different species of *Strenuaeva* Richter & Richter, 1940 of the Iberian Peninsula are in need of a carefully revision. The specimens attributable to *Strenuaeva* from the Iberian Chains indicate a great variation and suggest the existence of different species. The classical form characterized by an anterior margin with a low to moderate curvature and a strongly inflated frontal area (Fig. 6M–6O; MPZ 2021/379) are relatively distinct from other co-occurring specimens that also fit into the diagnosis of the genus provided by Ahlberg and Bergström (1978). On the other hand, the specimen shown in Figure 6R (MPZ 2021/380) has a deep and well-marked dorsal furrow and a well-defined glabella tapering towards the front. The anterior margin of the glabella is poorly defined and the preglabellar field appears to be more elevated in the medium part. Also, the frontal area and the fixigenae are inflated but much less than specimens of *S. incondita* Sdzuy, 1961 figured in Sdzuy (1961). The specimen in Figure 6R also has a more straight anterior margin with the edge running obliquely to the anterior branch of the facial suture.

Geyer (1990) transferred the species *S. sampelayoi* Richter & Richter, 1940, *S. melendezi* Gil Cid, 1972, *S. orlowinensis* Samsonowicz, 1959 and *S. trifida* Orłowski, 1985 to the newly erected genus *Issafienella* Geyer, 1990. According to this work, *Issafienella* differs from *Strenuaeva* in the absence of a plectrum connecting the anterior margin of the frontal lobe and the preglabellar field, a semicircular anterior margin, a wider (tr.) glabella with a broader frontal lobe and deeper and well-marked glabellar furrows. Later,

Geyer (2016) referred to *S. incondita* Sdzuy, 1961 as *Issafienella incondita*, although no explanation was given. However, according to the differences between *Strenuaeva* and *Issafienella* pointed by Geyer (1990), at least some of the specimens of the Iberian Chains would be more closely related to the former than to the later. The preglabellar field of the specimen in Figure 6R is raised in the medium part as in *Strenuaeva*, while the specimens of *Issafienella* figured in Geyer (1990) (pl. 12; figs. 1–8) show a depressed preglabellar field clearly separated from the frontal lobe. Nevertheless, the two forms assigned herein to *S. incondita* (Fig. 6M–6O, 6R) have a subconical glabella tapering anteriorly in contrast to the species of *Issafienella*, with a more subrectangular glabella in outline. The specimens figured herein and in Sdzuy (1961) (pl. 12, figs. 6–14) have shallow glabellar furrows, while those of *Issafienella* are deeper and well-marked. In the present state of knowledge, we assign the specimens of the Iberian Chains with differing morphologies all to *S. incondita* Sdzuy, 1961.

Occurrence. Ribota and Huérmeda formations, Iberian Chains (Spain).

Age. Middle and upper Marianian (Cambrian Series 2).

Order CORYNEXOCHIDA Kobayashi, 1935
Family CHENGKOUIIDAE Zhu in Zhang et al., 1980
Genus *Acanthomicmacca* Hupé, 1953

Type-species. *Micmacca walcotti* Matthew, 1899 from the Cambrian of Newfoundland, Canada; by original designation. Cambrian Series 2; Canada.

Acanthomicmacca (*Acanthomicmacca*) aff. *coloi*
Hupé, 1953
Figure 7O

1961 *Micmacca* aff. *coloi* Hupé 1953; Sdzuy, p. 305–306, pl. 15, figs. 15, 16, text-fig. 17 (with previous synonymies).

1993 *Micmacca* aff. *coloi*; Liñán et al., p. 820.

2008 *Micmacca* aff. *coloi*; Gozalo et al., p. 140, 143.

2008 *Micmacca* aff. *coloi*; Liñán et al., p. 12, 15.

2016 *Acanthomicmacca* (*Acanthomicmacca*) sp. D; Geyer, p. 368.

Material and locality. Single incomplete cranidium from level 17 of the Huérmeda Formation in the J2 section.

Remarks. The specimen figured herein (Fig. 7O; MPZ 2021/375) only differs from the material described by Sdzuy (1961) in a narrower (tr.) glabella and possibly in a longer (sag.) frontal area. However, these differences may be a result of the considerable deformation of the specimen. Geyer (2016) revised the ‘*Micmacca*’ group and assigned the material of this genus from the Iberian Chains to *Acanthomicmacca* (*Acanthomicmacca*) sp. D. Sdzuy (1961) and Geyer (2016) noted some differences from *Acanthomicmacca*

(*Acanthomicmacca*) *coloi* Hupé 1953 which are present in the single specimen studied herein, such as the poorly defined anterior border, the more curved anterior margin of the frontal lobe and the more oblique to axis eye ridges. However, the material from the Iberian Chains appears to be more closely related to *A. (A.) coloi* rather than to the other species of the genus. These two species have an anterior border with low convexity, a shallow to indistinct anterior border furrow and a relatively narrow (tr.) palpebral lobes and eye ridges with similar length. Therefore, we suggest to maintain the original assignment of this species as the scarce number of samples difficult the study of the affinities of *A. (A.)* aff. *coloi* with other members of the genus.

Occurrence. Huérmeda Formation, Iberian Chains (Spain).

Age. Upper Marianian (Cambrian Series 2).

BIOSTRATIGRAPHY

The study of the Ribota and the Huérmeda formations in the four sections discussed herein led to the recognition of four distinguishable trilobite assemblages. The lower assemblage is found at the middle part of the Ribota Formation and is primarily composed of the ellipsocephalid trilobites *Kingaspis* (*Kingaspidooides*) *velata*, *Lusatiops ribotanus*, and *Strenuaeva incondita*. These species make up 95–100% of the sample collected from the fossiliferous levels at the middle part of the Ribota Formation in the MT1, J1 and J2 sections, suggesting a Marianian age according to the regional stratigraphic units for the Iberian Peninsula (Liñán et al., 1993; Gozalo et al., 2008). The first assemblage also includes *Termierella* sp., a genus characteristic for the middle–upper Marianian in the Ossa-Morena Zone (Liñán et al., 1993, 1997; Álvaro et al., 1998), reported herein for the first time from the Iberian Chains. The second assemblage is found in the shale level above and is composed of *Kingaspis* (*Kingaspidooides*) *velata*, *Lusatiops ribotanus* and *Strenuaeva incondita*. In addition, these two assemblages record the presence of *Onaraspis garciae* in the MT1 and J1 sections. This species also occurs in the middle part of the Huérmeda Formation in the M9 section and at the top of this formation in MT1 (see Sepúlveda et al., 2021a) suggesting a significantly wider stratigraphic range than previously known.

The third assemblage is found at the base of the Huérmeda Formation. This assemblage is composed mainly of the three onaraspid species *Onaraspis garciae*, *Luciaspis matiasi* and *Paulaspis tiergaensis*, which make up the 70–80% of the collection in all four studied sections. These species occur jointly with the ellipsocephalids of the Ribota Formation except for *Termierella*, and with a significant amount of other taxa including *Redlichia?* sp., the holmiids *Andalusiana*

cf. *cornuta*, *Andalusiana* sp., the chengkouiid *Acanthomicmacca* (*Acanthomicmacca*) aff. *coloi*, the eodiscoid *Hebediscus?* sp., and also *Redlichia* (*Redlichia*) *isuelaensis* recorded by [Álvarez *et al.* \(2019\)](#) from this level and *Kingaspis* (*Kingaspidoides*) cf. *velata* ([Liñán *et al.*, 2003](#)). The upper assemblage has been only recognized in the MT1 section and is composed of *Onaraspis garciae* and *Paulaspis tiergaensis*. The position of this assemblage at the top of the Huérmeda Formation suggests a lower Bilbilian age as equivalent strata of the nearby Borobia section with *Protolenus* (*Hupeolenus*) *termierelloides* are indicative for this age ([Palacios & Moczyłowska, 1998](#)).

These assemblages provide a great regional and international potential for correlation despite of a marked endemism of the species studied herein (see Fig. 8). Thus, there are no species which occur in both the Iberian Chains and other regions of the Iberian Peninsula. [Álvarez *et al.* \(2019\)](#) stated that *Strenuaeva incondita* is present in the Ossa-Morena

Zone, but there is no published evidence of this to date. Also, [Gil Cid and Jago \(1989\)](#) reported *Lusatiops* cf. *ribotanus* from the Los Cortijos de Malagón section of the Central Iberian Zone, but the highly distorted material does not allow a confident identification to the species, and their occurrence in lower Bilbilian strata of the Los Cortijos Formation suggests a closer relationship with *Protolenus*, a characteristic taxon of the Bilbilian of the Iberian Chains ([Dies-Álvarez *et al.*, 2001](#); [Gozalo *et al.*, 2008](#)). This condition also applies for *Kingaspis* (*Kingaspidoides*) cf. *velata*, which was reported by [Sdzuy \(1961\)](#) and [Liñán *et al.* \(2003\)](#) from the Los Cortijos Formation based on poorly preserved specimens with a similar lower Bilbilian age as *Kingaspis* (*Kingaspis*) *campbelli* [King, 1923](#) from the Valdemiedes Formation of the Iberian Chains ([Liñán *et al.*, 2003](#)).

Accordingly, the trilobite with the highest significance for correlation between the Iberian Chains and the Ossa-Morena Zone is probably *Andalusiana cornuta*,

ISCS		MOROCCO		IBERIA		IBERIAN CHAINS (this work)
CAMBRIAN SERIES 2	CAMBRIAN STAGE 4	AGDZIAN	<i>Hupeolenus</i>	LOWER BILBILIAN	<i>Protolenus dimarginatus</i>	4th Assemblage
		BANIAN	<i>Sectigena</i>	UPPER MARIANIAN	<i>Realaspis</i> FAD	3rd Assemblage
	MIDDLE MARIANIAN				<i>Serrodiscus</i> FAD	2nd Assemblage
	<i>Andalusiana</i> FAD			1st Assemblage		
CAMBRIAN STAGE 3	<i>Antatlasia guttapluyiae</i>		<i>Strenuaeva + Triangulaspis</i> FAD			

Figure 8. Biochronology of the middle Marianian to lower Bilbilian interval in the Iberian Peninsula and Morocco (modified from [Liñán *et al.*, 2002, 2006](#); [Geyer & Landing, 2004](#); [Sundberg, *et al.*, 2016](#)) and the location of the four trilobite assemblages identified in this work.

as suggested by the specimen from the MT1 section which strongly resembles the specimens from the Ossa-Morena Zone (Sdzuy, 1961, 1962) and from Morocco (Geyer & Palmer, 1995). At genus level, *Andalusiana* occurs along with *Termierella* in the middle and upper Marianian Stage in the Ossa-Morena Zone (see Liñán et al., 1993, 1997), the Central Iberian Zone (Liñán et al., 1993; Sepúlveda et al., 2021b) and the *Sectigena* Zone in the Moroccan Anti-Atlas (Geyer & Palmer, 1995; Sundberg et al., 2016). *Hebediscus* has been also collected from the Ossa-Morena Zone (Liñán, 1984), where *Strenuaeva* has a wide range from the middle to the upper Marianian. The presence of these genera in the Iberian Chains reinforces the correlation between the middle and upper Marianian of the Ossa-Morena and Central Iberian Zones and the Iberian Chains. Moreover, *Lusatiops* is recorded in the Lower Cambrian of Saxony (Germany) where it occurs along with *Acanthomicmacca* and *Serrodiscus silesius* (see Geyer & Elicki, 1995).

Liñán et al. (1993) selected the LAD of olenellids and *Serrodiscus* in the Ossa-Morena Zone to mark the top of the Marianian stage. Although more research is needed, the presence of *Andalusiana* in the Iberian Chains reported herein and in the Central Iberian Zone (Liñán et al., 1993; Sepúlveda et al., 2021b), along with the presence of other shared taxa, could allow the recognition of the top of the Marianian stage in these three regions.

Finally, one of the discussed horizons for defining the base of the Cambrian Stage 4 is the assemblage of the eodiscoid trilobites *Hebediscus*, *Calodiscus*, *Serrodiscus* and *Triangulaspis*, referred as the “HCST band” (Geyer & Shergold, 2000; Geyer, 2005). Another suggested possibility for the definition of this GSSP is the FAD of *Redlichia* (Peng & Babcock, 2011; Peng et al., 2020). The presence of *Redlichia* and specimens tentatively assigned to *Hebediscus* in the Iberian Chains could allow a roughly correlation with the levels discussed to establish the base of the Cambrian Stage 4. However, more research is needed to confirm the presence of *Hebediscus* in the area and to establish the complete biostratigraphy of the Ribota and Húermeda formations of the Iberian Chains.

CONCLUSIONS

A careful study of four sections in the Iberian Chains allows to establish a detailed range chart of the trilobites recorded in the Ribota and the lower part of the Huérmeda formations (middle–upper Marianian; probably uppermost Stage 3 to lower Stage 4 of Cambrian). Four significant trilobite associations have been recognized. The lowest assemblage is distributed in the middle part of the Ribota Formation and is composed of *Lusatiops ribotanus*, *Kingaspis (Kingaspidooides) velata*, *Strenuaeva incondita*, *Termierella* sp. and *Onaraspis garciae*. A second assemblage occurs slightly higher in the Ribota

Formation. It includes *Lusatiops ribotanus*, *Kingaspis (Kingaspidooides) velata*, *Strenuaeva incondita* and *Onaraspis garciae*. A third assemblage is found in the lowermost strata of the Huérmeda Formation and includes *Lusatiops ribotanus*, *Kingaspis (Kingaspidooides) velata*, *Kingaspis (Kingaspidooides) cf. velata*, *Strenuaeva incondita*, *Onaraspis garciae*, *Luciaspis matiasi*, *Paulaspis tiergaensis*, *Redlichia (Redlichia) isuelaensis*, *Redlichia? sp.*, *Andalusiana cf. cornuta*, *Andalusiana sp.*, *Hebediscus? sp.* and *Acanthomicmacca (Acanthomicmacca) aff. coloi*. The highest assemblage is found in the uppermost part of the Huérmeda Formation and consists of *Onaraspis garciae* and *Paulaspis tiergaensis*.

These assemblages clearly indicate that the strata of the Ribota and Huérmeda formations belong into the middle–upper Marianian and probably lowermost Bilbilian, which thus is (in part) equivalent to the Stages 3 and 4 of the Cambrian Series 2. Our first figured report of *Andalusiana* from the Iberian Chains, in addition with the presence of *Termierella* in the region and the presence of other shared taxa as *Strenuaeva* and *Hebediscus*, could allow a relatively precise correlation with coeval strata of the Ossa-Morena Zone. The presence of *Andalusiana* and *Termierella* also provides the base for relatively precise correlations with the strata of the Central Iberian Zone and the Atlas ranges of Morocco.

The presence of *Hebediscus?* (reported herein for the first time) together with *Redlichia* in the Iberian Chains could allow a roughly correlation of the lower boundary of the Cambrian Stage 4 in this region according to two of the levels discussed by the International Subcommission on Cambrian Stratigraphy.

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Authors contributions. All authors collaborated in the field work and preparation of the trilobite specimens. AS, EL and RG studied and discussed the trilobites classification. AS and RG prepared the figures. AS coordinated the work and prepared the first manuscript, which has been revised by all the authors.

Competing Interest. We hereby declare that we have no competing interests.

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