First report of *Crumillospongia* (Demospongea) from the Cambrian of Europe (Murero biota, Spain)

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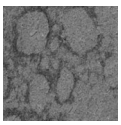

The demosponge genus *Crumillospongia*, originally described from the Burgess Shale (middle Cambrian of Canada), has only been cited from lower and middle Cambrian localities of North America and China. The taxon is now also described from uppermost lower Cambrian rocks of the Murero Lagerstätte (Zaragoza Province, NE Spain). *Crumillospongia mureroensis* sp. nov. is a small to medium sized sack-shaped to elongate demosponge characterized by the presence of densely packed pores of three sizes, considerably larger than those in any other species of the genus. The Spanish material represents a link in the chronostratigraphical gap between the Chinese and North American material.
• Key words: *Crumillospongia*, demosponges, early Cambrian, Lagerstätte, taphonomy, Murero, Spain.

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The Murero Lagerstätte is exposed in the Cadenas Ibéricas, 8 km from Daroca Village, 80 km to the southwest of Zaragoza, in the right margin of the Jiloca River. It cuts the Cadena Ibérica Occidental creating a narrow valley located some 700 m above sea level and parallel to this mountain alignment.

Dry ravines located on the right margin frequently eroded the Tertiary of the Calatayud Basin and allow the study of the subjacent Cambrian materials rich in fossils by means of different outcrops. The better sections in Murero are located at the Rambla de Valdemiedes (Valdemiedes Gully, Fig. 1). A Cambrian monofacial succession 210 m thick is exposed along the Rambla de Valdemiedes. It is composed of lutites and scarce very fine-grained sandstones of grey, green and red-purple colours, which allow to differentiate three formations. There are some interbedded centimetric to decimetric levels of dolostone and dolomitic nodules. Six sections have been studied previously; from a stratigraphic point of view the most complete are the Rambla de Valdemiedes 1 (RV1) and the Rambla de Valdemiedes 2 (RV2) sections (Liñán & Gozalo 1986, Liñán *et al*. 2008), in the west and east banks of the gully, respectively.

Stratigraphically, the Murero site embraces the majority of the Mesones Group (subdivided in ascending order into the Valdemiedes, Mansilla, and Murero formations) and the bottom of the Acón Group (base of the Borobia Formation), with ages ranging from upper Bilbilian (uppermost lower Cambrian) to lower Languedocian (or Cambrian Stage 5 plus Drumian Stage; upper middle Cambrian). The classical "Lower-Middle Cambrian boundary" (approximately coinciding with the limit between Cambrian Series 2 and 3, currently under discussion in the ISCS) is placed at the upper part of the Valdemiedes Formation (Liñán & Gozalo 1986; Liñán *et al*. 1992, 2002, 2008). A total of 15 trilobite zones are recognised in the Cambrian strata of Murero, which are useful both for Spanish and Mediterranean Cambrian stratigraphy and biochronology (Liñán *et al*. 2002, Gozalo *et al*. 2008).

The palaeontological record in the Murero site is composed of many groups, and each formation yields diverse fossils of exceptional preservation (Murero biota), such as complete trilobite carapaces with minute detail, brachiopods with preserved peduncle, bradoriids with articulated valves, complete articulated echinoderms (cinctans,

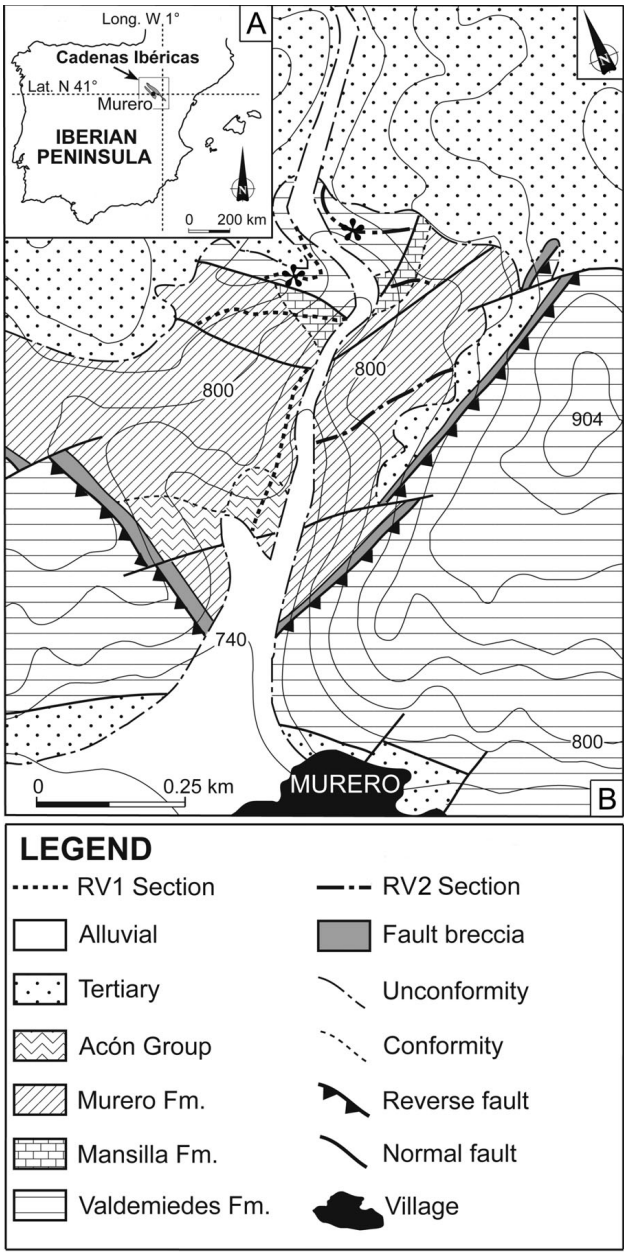


Figure 1. Location map (A) and geological map (B) of the Rambla de Valdemiedes, Murero, Iberian Chains (modified from Gozalo & Liñán 1988). The levels of RV1 and RV2 sections that produced *Crumillospongia mureroensis* sp. nov. are marked by an asterisk.

eocrinoids, and edrioasteroids), sponges, palaeoscolecid and eucephalorhynch worms, xenusian lobopods, and ichnofossils, among others (Liñán *et al*. 2008). The preservation of the Murero biota is due to replication of integuments, skeletons, and some soft tissues in authigenic clay minerals, mainly in the form of chlorite and illite (Zhuravlev *et al*. 2008).

The objective of this work is to describe a new upper Bilbilian (uppermost lower Cambrian) demosponge recorded in the Valdemiedes Formation from RV1 and RV2 sections in Murero (Fig. 2). This will contribute to a better understanding of the Murero biota during the latest early Cambrian, which represents the only window known to study a complete community (skeletal and soft-bodied fossils) of a shallow environment (infralittoral bioma; *sensu* Liñán & Mergl 2001) during this lapse of time in the world (Liñán *et al*. 2008).

Previously, *Crumillospongia* has been recorded in Canada, the United States and South China (Chen 2004, Dornbos *et al*. 2005, Wang *et al*. 2005, and perhaps Johnston *et al*. 2009). The discovery of *Crumillospongia* in Murero extends the palaeobiogeography of the genus to the Acadobaltic province (*sensu* Sdzuy 1972, Sdzuy *et al*. 1999), located in the northwestern margin of Gondwana, yet in slightly higher latitude than the other occurrences. A similar palaeobiogeographical distribution has been observed for the middle Cambrian demosponge *Leptomitus*, also reported in Murero (García-Bellido Capdevila 2003, García-Bellido *et al*. 2007).

Systematic palaeontology

Class Demospongea Sollas, 1883
Order Protomonaxonida Finks & Rigby, 2004
Family Hazeliidae De Laubenfels, 1955

Type genus. – *Hazelia* Walcott, 1920.

List of included genera. – *Lasiocladia* Hinde, 1884, *Hazelia* Walcott, 1920, *Falospongia* Rigby, 1986 and *Crumillospongia* Rigby, 1986.

Genus *Crumillospongia* Rigby, 1986

Type species. – *Crumillospongia frondosa* (Walcott, 1919), middle Cambrian, Burgess Shale, Canada.

Other species. – *Crumillospongia biporosa* Rigby, 1986, also from the Burgess Shale. Various *Crumillospongia* sp. have been cited and figured from the lower Cambrian Chengjiang biota (Chen *et al*. 1996, Chen & Zhou 1997, Chen 2004, Wang *et al*. 2005). There are putative representatives of the genus from the middle Cambrian Wheeler Formation of Utah mentioned and illustrated in the World Wide Web.

Diagnosis. – "Sack-shaped to globular or globose sponges with thin walls of principally vertical, subparallel, monaxial spicules that form tracts around circular canals of at least two sizes; gastral layer a vertical, monaxial thatch that is less perforate; skeleton with weakly developed tufts; marginalia or prostalia absent" (Finks & Rigby 2004, p. 28).

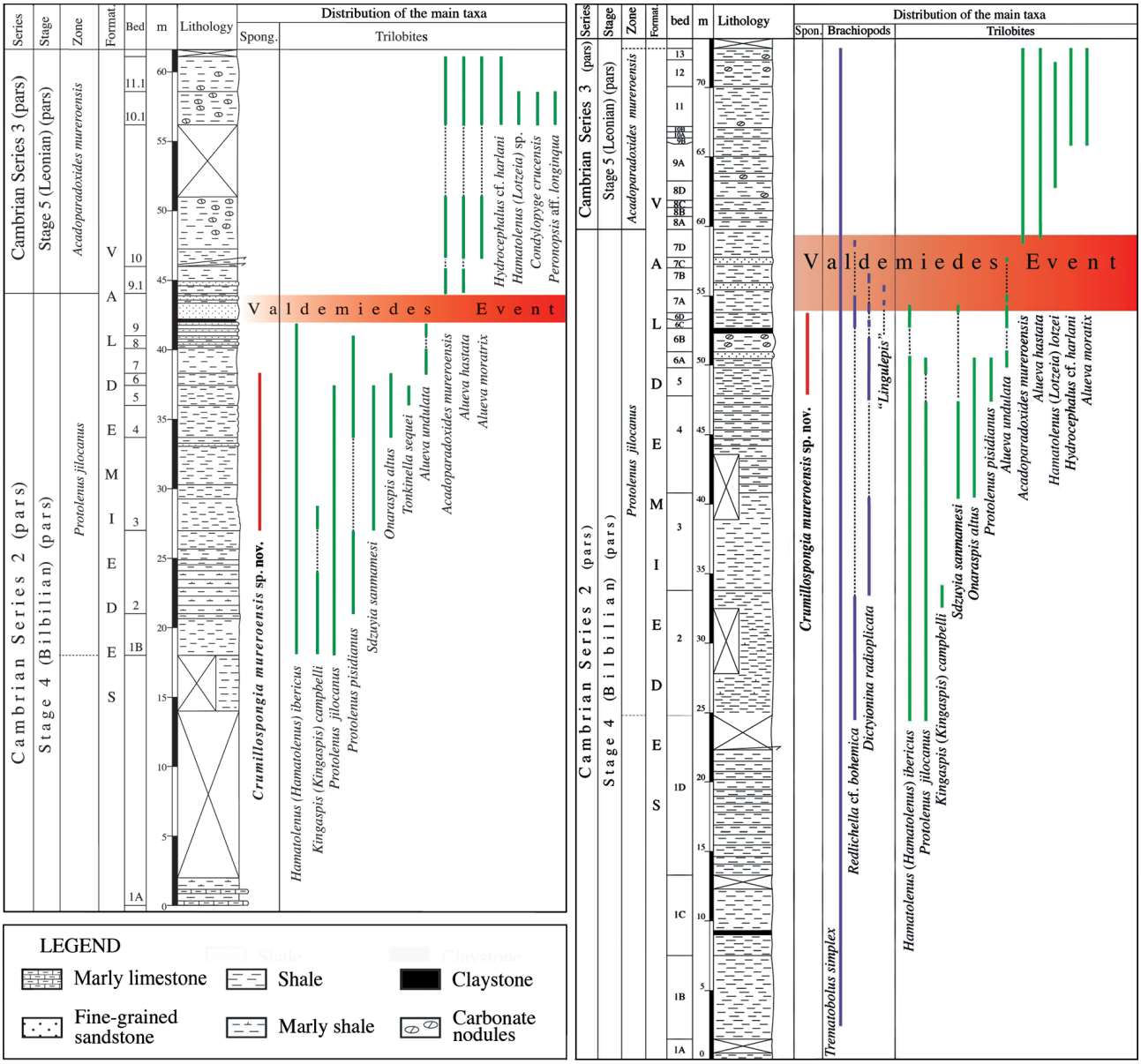


Figure 2. Stratigraphy of the Valdemiedes Formation at the Rambla de Valdemiedes 1 (RV1, left) and 2 (RV2, right) sections, showing the distribution of *Crumillospongia mureroensis* sp. nov. beside that of the main brachiopod and trilobite taxa (modified from Liñán *et al*. 1993).

Crumillospongia mureroensis **sp. nov.**

Figures 3–5

2008 *Crumillospongia biporosa* Rigby, 1986. – Liñán *et al*., fig. 19c.

Types. – All specimens are housed in the collections of the Museo Paleontológico de Zaragoza (MPZ), Spain. Holotype (MPZ 2009/173) and nineteen paratypes (MPZ 2008/158, MPZ 2009/498–MPZ 2009/508, MPZ 2009/510–15, and MPZ 2010/958), most with part and counterpart.

Type horizon and locality. – The levels producing these fossils (RV1/3–6 and RV2/5–6) correspond to the Valdemiedes Formation, Bilbilian Stage, Cambrian Series 2, but the specimens described and figured here were collected in particular from the SE bank of the Rambla de Valdemiedes, in what is known as the RV1 section, some 500 m north of the town of Murero, Province of Zaragoza (NE Spain).

Material. – Twenty-six specimens (MPZ 2008/158, MPZ 2009/175, MPZ 2009/497–MPZ 2009/518, and MPZ 2010/958), most preserved as chlorite carcasses on a beige

Table 1. Dimensions in millimetres of *Crumillospongia frondosa* (Walcott, 1919), *Crumillospongia biporosa* Rigby, 1986 and *Crumillospongia mureroensis* sp. nov. Some values presented as ranges, with exceptional maximum values in parentheses. L = length, Ø = diameter.

	Length	Width	Large pore Ø	Medium pore Ø	Small pore Ø	L pore spacing
C. frondosa (Walcott, 1919)	10–55 (150)	13–80 (130)	2, 2.5 × 3 (3.5)	0.7–1.2	(0.2) 0.3–0.5	3–5
C. biporosa Rigby, 1986	19–20	14–16	0.5–0.8	–	0.2–0.3	0.7
C. mureroensis sp. nov.						
MPZ 2008/158a, b	32	17	1.2 × 2.8–1.5 × 3.5	0.8 × 1.5–1.2 × 2	0.2–0.5, 0.5 × 1–0.6 × 1.2	2.5–3.5
MPZ 2009/173a, b	28	18	(1 × 1.5) 1 × 2–1.5 × 3	1 × 1.5–1 × 2	0.1–0.5, 0.5 × 1	1.8–2
MPZ 2009/498	40	11	1 × 2–1.5 × 2.5	0.6 × 1.5	0.3–0.5, 0.4 × 0.8	2
MPZ 2009/499	35	15	1 × 1.8–1 × 2.2	0.5 × 1.1	0.2 × 0.4, 0.3–0.5	2–3
MPZ 2009/500a, b	65	21	1.2 × 3–1.5 × 3.7	0.8 × 1.5	0.1–0.5, 0.5 × 0.8–0.6 × 1.2	1.5–3
MPZ 2009/501	20	10	1.2 × 2.2–1.7 × 2.7	0.7 × 1.4	0.4–0.6	0.7–1.2
MPZ 2009/502	15	11	0.7 × 1.6–1 × 1.5	0.5 × 0.7–0.7 × 1	0.2–0.4	0.5–1.5
MPZ 2009/503	93	25	1.5 × 3.5–2 × 5	0.9 × 1.5–1.2 × 3	0.1–0.5, 0.5 × 1–0.7 × 1.2	2–4 (5)
MPZ 2009/504a, b	20	15	2 × 3	1.1 × 2.6	0.1–0.7	1–3
MPZ 2009/505a, b	21	11	1 × 1.7–1 × 2	0.5 × 1.5, 0.6	0.1–0.4	2–2.5
MPZ 2009/506	18	16	0.7 × 1.7–1 × 2.5	0.5 × 0.8–0.7 × 1.4	0.15 × 0.22–0.28 × 0.48	0.9–2.5
MPZ 2009/507	23	12	1.2 × 1.5–1.2 × 2.5	0.5 × 1.1–0.7 × 1.2	0.3–0.5	1.5–2.5
MPZ 2009/508a, b	25	15	2 × 3–2.5 × 3	0.6 × 1.5–0.8 × 2	0.1–0.5, 0.5 × 1	0.5–1
MPZ 2009/510a, b	27	18	1.5 × 2.5–2 × 3	0.7 × 1.4	0.2–0.8	0.5–1
MPZ 2009/511	35	10	0.6 × 1.2–0.7 × 1.5	0.15 × 0.6–0.25 × 0.75	0.2–0.5	1–1.5
MPZ 2009/512a, b	40	30	1 × 2	1 × 1.5	0.4–0.5	1–1.5
MPZ 2009/513a, b	35	20	1.5 × 3–2 × 3.5	1.2 × 2.2	–	1.5–2
MPZ 2009/514	23	16	1.45 × 1.8	0.85 × 1.45	0.45	1.45–2.15
MPZ 2009/515	54	13	–	–	–	–
C. cf. *C. mureroensis* sp. nov.						
MPZ 2009/497a, b	80	70	1.5 × 3–2.5 × 4	0.8 × 1.5–1 × 1.8	0.1–0.5	2–3
MPZ 2009/509	75	42	2 × 3–2 × 4.3	0.5 × 1.2–1.5 × 2.5	0.1–0.5, 0.6 × 0.7–0.7 × 0.8	2–3.5

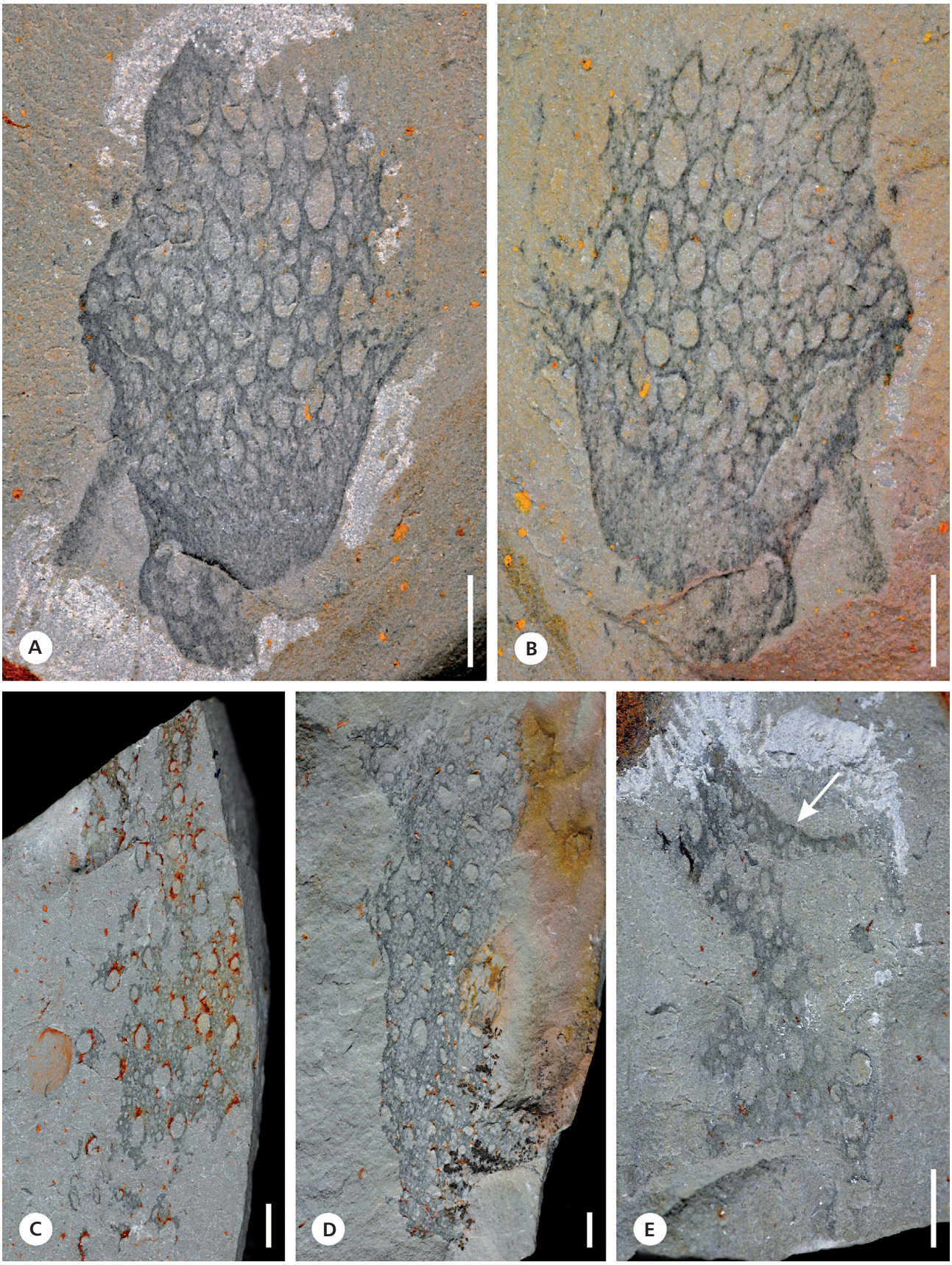
lutitic matrix and a few partially or totally replaced by limonite, with excellent transitional examples. Two other specimens are assigned to the species with doubts, and about a dozen smaller fragments have also been collected, but are not well enough preserved or complete to warrant their measurement.

Etymology. – After the name of the village closest to the outcrop.

Diagnosis. – Small to medium-sized sack-shaped to elongate sponges, with thin walls densely perforated by circular to elliptical pores of three sizes, the largest of which show a largest dimension from 1.2 to 3.7 mm. Large apical osculum. Evidence of gastral layer, tufts, marginalia or prostalia lacking.

Description. – All specimens have suffered compaction and are preserved as two dimensional bodies, but these sponges would have been oval to elongated in life (Figs 3A, B, 4C, 5A). The best preserved specimen (Fig. 3A, B) is 28 mm high and 38 mm wide, with partial specimens ranging from 15 by 10 mm to 65 by 20 mm, and the largest fragments reaching up to 93 by 25 mm. Extrapolation from the largest fragments (Figs 3D, 4A, B), would produce specimens with a maximum of 100 mm high by *ca* 70 mm wide. The outline and detail of these sponges comes from their preserved organic framework, since spicules can

Figure 3. *Crumillospongia mureroensis* sp. nov., from the late early Cambrian Valdemiedes Formation, Murero, Iberian Chains, Spain. • A, B – holotype, almost complete specimen showing the globose shape of the sponge with a lateral outgrowth (possibly a root tuft), immersed in water, part (A) and counterpart (B), MPZ 2009/173a, b (RV1/4C/1a, b). • C – paratype, partial specimen, dry, MPZ 2009/500b (RV1/4C/5"b). • D – paratype, largest specimen in the collection, incomplete on the right side due to break in the rock, dry, MPZ 2009/503a (RV1/4R/203a). • E – paratype, partial specimen preserving the osculum (arrow), dry, MPZ 2008/158b (RV1/4R/208b). All specimens are from Rambla de Valdemiedes Section 1, and are housed in the collections of the Museo Paleontológico de Zaragoza. Scale bars: 5 mm.


A
B
C
D
E

no longer be recognized. Circular to elliptical pores densely perforate the thin dermal wall. Although pores are generally smaller at the base than at the top of the sponge (Fig. 3A, B), there are tree distinct pore sizes in all the specimens. Largest pores are generally 2 by 5 mm, intermediate pores are 1 by 2 mm and small pores are 0.1 to 0.5 mm in diameter. Spacing between large pores ranges between 1 and 4 mm, while spacing between medium pores is 0.85 to 1.15 mm. The most complete specimen shows general increase in large pore size towards the top of the sponge. This specimen also shows a lateral outgrowth (7 mm long and 2 mm wide), which probably corresponds to a root tuft and could have been used to stabilize the sponge on the sea floor. Nevertheless, no such structure has been described until now in *Crumillospongia*, and, although apparently continuous with the sponge body, it may correspond to chance superposition. One of the specimens (Fig. 3E) seems to preserve the oscular margin. The oscular diameter appears to be more than half of that of the sponge. Two specimens (MPZ 2009/497 and MPZ 2009/509) are considerably wider than the other fragments, and despite having pore-sizes within the range of the new species, they have been assigned to it with doubt (Table 1).

Discussion. – The new *Crumillospongia* species is more elongated than the globular *C. biporosa* and *C. frondosa* (Rigby & Collins 2004). It is intermediate in size between the former and the latter, but considerably larger than other *Crumillospongia* specimens, such as those in the lower Cambrian Chengjiang biota (*e.g*. Wang *et al*. 2005) and the middle Cambrian Chancellor Basin, Canada (Johnston *et al*. 2009). The Spanish species has three pore sizes, like *C. frondosa*, but they are more densely packed, with spacing between its large pores generally of 0.5 to 3 mm. However, the pores in the new species are consistently larger than those in any of the other species described to date. Unfortunately, the preservation of the Spanish material does not allow comparison at a spicular level, since no spicules have been recognized. Regarding age, *C. mureroensis* sp. nov. is intermediate between the Chinese and the North American specimens.

Taphonomy

The new *Crumillospongia* specimens show an interesting gradation in preservation showing advancing decay stages. Better-preserved specimens (Figs 3, 4) are more or less complete bodies, where the spicular skeleton has been lost and only the underlying collagenous framework (probably spongin) is preserved, basically in the form of chlorite (Figs 3C–E, 4D, E). However, a few specimens (best represented by Fig. 5A–C) show varying degrees of decomposition of the proteinaceous structure to the stage where they are only recognizable by the somewhat polygonal shape of the decayed pore edges, surrounded by limonite. This limonite would almost surely have been pyrite in origin, formed as the sponge's organic material decomposed and its spicules disolved, precipitating pyrite, which was later fossil-diagenetically transformed to the hydrated iron oxyde.

Biochronology and correlation

The Cambrian was a geological period characterized by important faunal provinciality. This phenomenon is the first time recorded in the Earth history during the Cambrian. This provinciality makes difficult to establish a common biochronological scale; thus, it has been used a different regional stage nomenclatures are commonly employed with the exception of some of them which has been already replaced by the International Subcommission on Cambrian Stratigraphy by official and global names in the last few years (see Babcock & Peng 2007, Babcock *et al*. 2007, Landing *et al*. 2007, Peng *et al*. 2009).

The Spanish regional stages are named Corduban, Ovetian, Marianian and Bilbilian for the lower Cambrian, as well as Leonian, Caesaraugustan and Languedocian for the middle Cambrian; they are frequently used for the Mediterranean region (see Sdzuy *et al*. 1999, Liñán *et al*. 2002).

The Valdemiedes Formation (lower Bilbilian–middle Leonian) contains the classic Lower-Middle Cambrian boundary recorded at the first appearance datum (FAD) of the trilobites *Acadoparadoxides mureroensis* (Fig. 2). This FAD limits the Valdemiedes Extinction Event (VEE), which is concurrent with the disappearance of all but one genera of Protoleninae, Ellipsocephalinae, and Resseropinae trilobites in the Cadenas Ibéricas. Extinct trilobite taxa were replaced by new assemblages at the base of the Cambrian Series 3, including paradoxidids (Liñán *et al*. 1993, 2008; Sdzuy *et al*. 1999; Dies *et al*. 2004; Gozalo *et al*. 2007; Liñán *et al*. 2010).

Crumillospongia mureroensis sp. nov. is recorded in levels 3 to 6 of the RV1 section and also some small fragments in levels 5 and 6 of the RV2. The new poriferan species is associated with trilobites (*Kingaspis campbelli*, *Parasolenopleura* sp., *Hamatolenus (Hamatolenus) ibericus*, *Protolenus jilocanus*, *P. pisidianus*, *Onaraspis altus*, *Tonkinella sequei*, *Sdzuyia sanmamesi* and *Condyolopyge* sp.; see Gozalo *et al*. 2008) of the *Protolenus jilocanus* Zone [former *Hamatolenus* (*H.*) *ibericus* Zone, uppermost Bilbilian; (Fig. 2)]; brachiopods (*Trematobolus simplex*, "*Lingulella*" sp. and *Redlichiella* cf. *bohemica*; see Liñán & Mergl 2001); algae, edrioasteroids, hyoliths, palaeoscolecids worms, xenusian lobopods and several non-trilobitic arthropods are also present in the association (see Liñán *et al*. 2008).

The *Crumillospongia* levels could be correlated by means of their trilobite record with the Australian Ordian

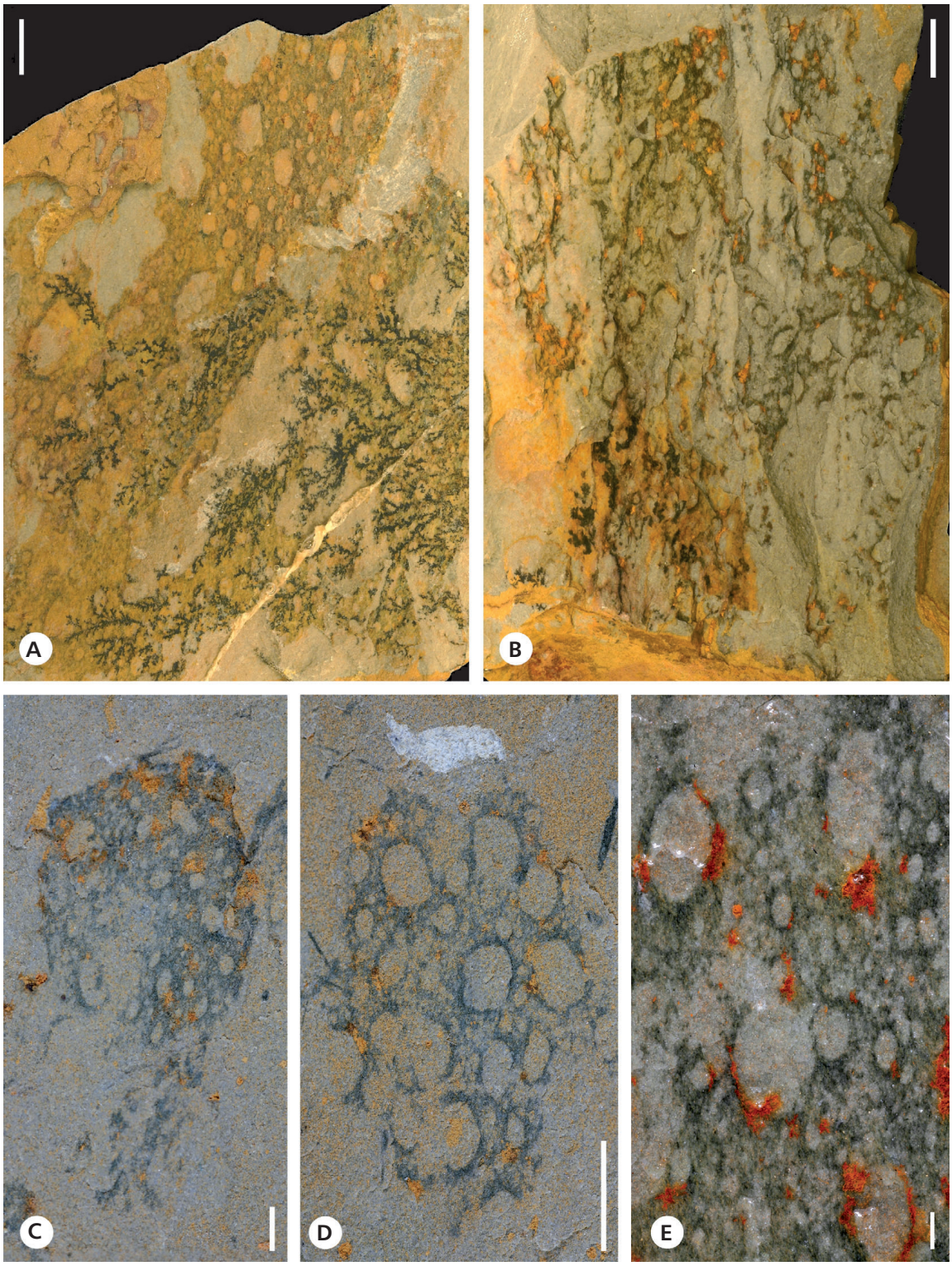


Figure 4. *Crumillospongia* cf. *C. mureroensis* sp. nov. (A, B) and *Crumillospongia mureroensis* sp. nov. (C–E) from the late early Cambrian Valdemiedes Formation, Murero, Iberian Chains, Spain. • A – large specimen, with overlying pyrolusite dendrites, immersed in water, MPZ 2009/497a (RV1/4C/2a). • B – large specimen, immersed in water, MPZ 2009/509 (RV1/5R/1). • C – paratype, almost complete small specimen, dry, MPZ 2009/505b (RV1/4R/204 IIb). • D – paratype, small fragment, dry, MPZ 2009/504b (RV1/4R/204 Ib). • E – paratype, detail of specimen in Fig. 3C showing large, medium and small pores, some pyritic rust can be recognized in the edges of larger pores, immersed in water, MPZ 2009/500b (RV1/4C/5"b). All specimens are from Rambla de Valdemiedes Section 1, and are housed in the collections of the Museo Paleontológico de Zaragoza. Scale bars 5 mm, except E: 1 mm.

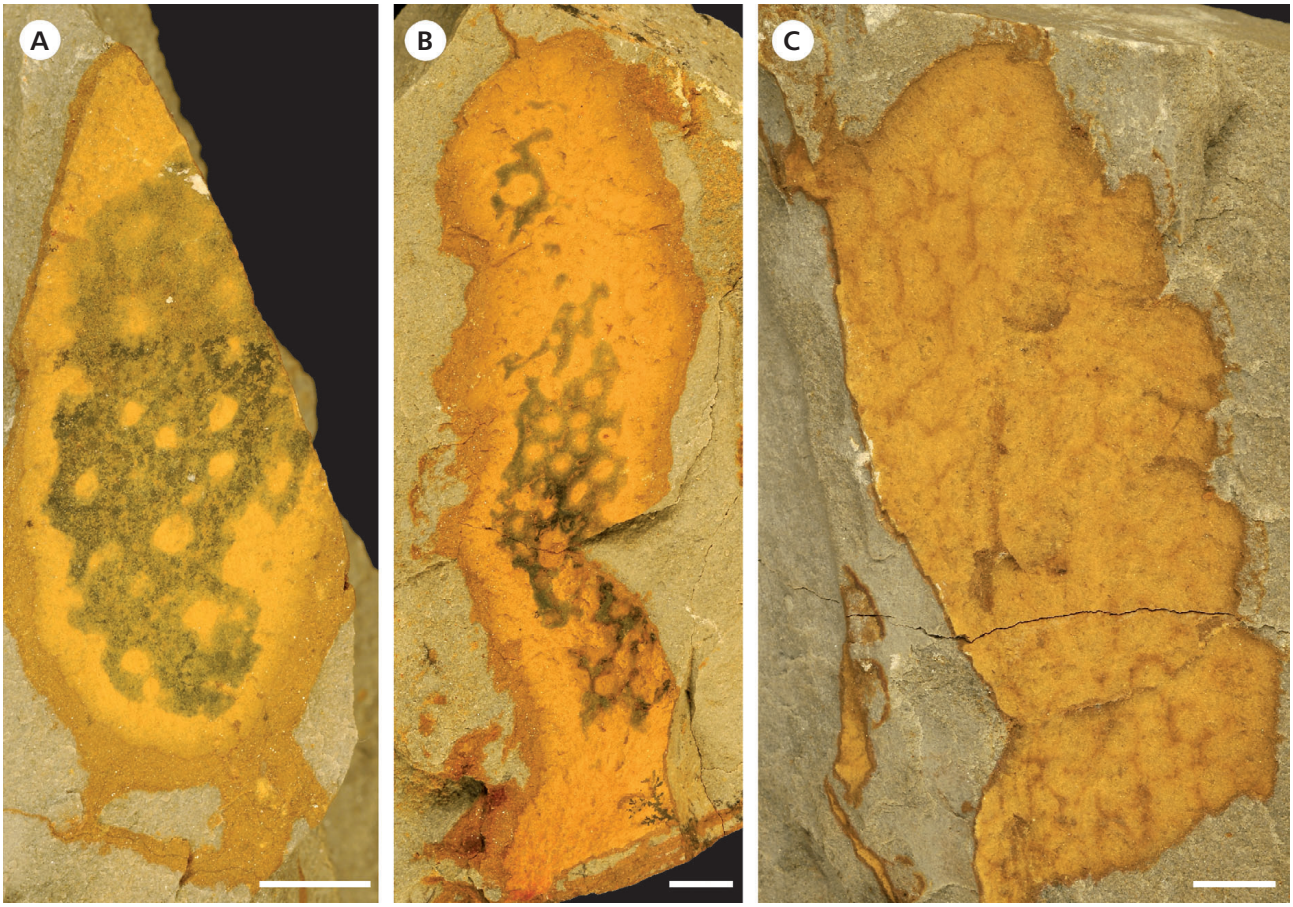


Figure 5. *Crumillospongia mureroensis* sp. nov., from the late early Cambrian Valdemiedes Formation, Murero, Iberian Chains, Spain. • A – paratype, slightly decayed specimen, where outline of the wall with large, medium and some small pores can still be recognized, dry, MPZ 2009/514 (RV1/4F/7). • B – paratype, considerably decayed specimen, where outline is lost and almost only large pores are recognizable, dry, MPZ 2009/515 (RV1/4R/301). • C – paratype, almost completely decayed specimen, where only a polygonal pattern remains from the pores in the sponge wall, dry, MPZ 2010/958 (RV1/4–5). All specimens are from Rambla de Valdemiedes Section 1, and are housed in the collections of the Museo Paleontológico de Zaragoza. Scale bars: 5 mm.

Stage (see Dies Álvarez *et al*. 2007) and the presence of *Kingaspis campbelli* allows a good correlation with the Cambrian of Jordan and Israel (see Liñán *et al*. 2003). Also, the presence of several species of *Protolenus* permits the correlation with Avalonia and Morocco (see Gozalo *et al*. 2007). Furthermore, the FAD of *Acadoparadoxides mureroensis* occurs only 5 m above the last record of the *Crumillospongia* studied herein; this FAD has been roughly correlated with the *Ovatoryctocara granulata* FAD or slightly below of the *Oryctocephalus indicus* FAD, both are considered as candidates marking the base of Cambrian Stage 5 and Cambrian Series 3 (see Gozalo *et al*. 2007). Then the age of the new demosponge species in Murero is uppermost Cambrian Stage 4 and Series 2 in the new proposal of the ISCS, *i.e*. uppermost lower Cambrian in the classical sense.

Crumillospongia mureroensis disappears immediately below the Valdemiedes Event and has not been found in middle Cambrian strata. Later on, during Caesaraugustan times (equivalent to the top of Stage 5 of the Cambrian and part of the Drumian Stage in the new proposals of the ISCS), the demosponge *Leptomitus* is found playing a similar role in the benthic communities of Murero (García-Bellido Capdevila 2003, García-Bellido *et al*. 2007).

Conclusions

The new demosponge species *Crumillospongia mureroensis* is defined from uppermost lower Cambrian rocks in Murero (Cadenas Ibéricas). This is the first reference to the genus in both the Acadobaltic province and Europe. The new species appears at the *Protolenus jilocanus* Zone (uppermost lower Cambrian) and disappears right before the beginning of the Valdemiedes Extinction Event (VEE), which marks the lower/middle Cambrian boundary in the Mediterranean region.

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