Biologia Serbica, 2023, 45: 10-18

DOI: 10.5281/zenodo.10402379

Original paper

Arbasus caecus (Simon, 1911): a new member of the ancient family Buemarinoidae (Opiliones, Laniatores) and its relation to the known species

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Accepted: 24 August 2023 \ Published online: 12 September 2023

Summary. *Arbasus caecus* (Simon, 1911) a troglobite from caves of a region in the central Pyrenees in southern France was transferred to Buemarinoidae as the fifth species of this family. Buemarinoidae is an old phyletic lineage of Pangean origin. *Fumontana deprehendor* Shear, 1977, a terricole species from the Appalachian Region of eastern North America, is closely related to *Arbasus caecus.* Their separation occurred before Laurasia broke up into North America and Eurasia. Apart from these, two closely related troglobitic species are known from the west Mediterranean: *Buemarinoa patrizii* Roewer, 1956, from some caves in Sardinia and *Turonychus fadriquei* Derkarabetian, Prieto & Giribet, 2021, from a cave in northeastern Spain. *Flavonuncia pupila* Lawrence, 1959, from Madagascar is also a member of this family.

Keywords: Laurasia, ocular tubercles, Pangea, Pyrenees, troglobite, West Mediterranean.

INTRODUCTION

Arbasus caecus (Simon, 1911) was the first European cave opilionid described, of which still very little is known. It was described as *Phalangodes caecus* Simon, 1911, from the cave Grotte de Pène Blanque in the Arbas massif – the northern slope of central Pyrenees in the southern France (Simon 1911). Roewer (1923) transferred it to the genus *Scotolemon*, and later, in his revision of European Laniatores (Roewer 1935), erected the separate genus *Arbasus*, which is still valid today. By contrast, Rambla and Juberthie (1994) treated this species as representative of the genus *Peltonychia* (in subgenus *Arbasus*), in which they also included some of the Dinaric travuniids. The assignment of this species to families also had its own dynamics. It was originally described in the family Phalangodidae Simon, 1879, and also treated as a phalangodid by Roewer (1923). Later, the same author (Roewer 1935) placed it in the family Travuniidae Absolon & Kratochvíl, 1932, which remained unchanged (Martens 1978; Kury 2007; Kury and Mendes 2007; Kury et al. 2014) until the work of Derkarabetian et al. (2018) who intuitively classified this genus within the family Cladonychiidae Hadži, 1935.

Thanks to the help and support of Dr. Louis Deharveng of Muséum National d'Histoire Naturelle, Paris, I came into possession of a male of this species (Figs 1, 2) and was able to examine it in detail, for which the previously mentioned authors did not have the opportunity to do so. I recognized affiliations of this species to the ancient family Buemarinoidae Karaman, 2019, which is already known from the western Mediterranean with two stenoendemic troglobite species, *Buemarinoa patrizii* Roewer, 1956, from Sardinia and *Turonychus fadriquei* Derkarabetian, Prieto & Giribet, 2021, from

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northeastern Spain. The family Buemarinoidae was recently established by Derkarabetian et al. (2021) by elevating the tribe Buemarinoini Karaman, 2019, within Gondwanan family Triaenonychidae, to family rank.

The family Buemarinoidae has an unusual and highly disjunct distribution (Fig. 3). It consists of five species known so far: *Flavonuncia pupila* Lawrence, 1959, from Madagascar; *Fumontana deprehendor* Shear, 1977, from southern Appalachians of eastern North America, west Mediterranean *Turonychus fadriquei* and *Buemarinoa patrizii* and here presented *Arbasus caecus* from southern France.

In addition to the importance of the statement presented here about the assignment of the species *Arbasus caecus* to the mentioned family, it is even more important to mention that some of the morpho-anatomical characters point to its closer relation to North American *Fumontana deprehendor* than to the two neighboring western Mediterranean species.

MATERIALS AND METHODS

Photographs of habitus morphology were taken using a Leica M205C stereo microscope equipped with a Leica DFC290 HD digital camera. Photographs from the slide were taken using a Zeiss Axio Imager A1 compound microscope equipped with an AxioCam MRc5 digital camera. Final images were taken at different focal planes and combined using Helicon focus stacking software. Drawings were made in Adobe Illustrator CS2 on a Genius EasyPen M610X graphics tablet. Dissected parts were mounted on slides in glycerol. After glycerol, the parts were temporarily mounted on slides in Faure's mounting medium (40 g chloral hydrate, 10 g gum Arabic; 5 g glycerin, 5 g glacial acetic acid, 5 g glucose, and distilled water). The separated body parts were prepared by dehydration through a graded alcohol series before being cleaned in a sonicator. Dried samples mounted on stubs were prepared in a Baltec SCD005 sputter coater. Scanning electron microscopy (SEM) photographs were recorded with a JEOL-JSM-64601v SEM microscope under high vacuum.

RESULTS

***Arbasus caecus* (Simon, 1911)**
(Figs 1-2, 4-6A, 7)

Fig. 1. *Arbasus caecus* male, side view.

Fig. 2. *Arbasus caecus* male, body, dorsal view.

Material examined

1♂, Grotte du Mount, close to "grotte du Cap de Payssas", Arbas massif, central Pyrenees, France, leg. Franck Brehier.

Redescription

Small, blind troglobitic species (male 1.3 mm long) with elongated legs and pedipalps built in the form of a catching basket (Fig. 1). Remains of ocular tubercle (Fig. 4A-B) are situated on the posterior part of the prosoma, at the beginning of the second third of the scute length. Body unpigmented, granulated with small sparse granules of uneven form. They, as well as the rest of the body surface, are covered in narrow scaly outgrowths. Low and wide tubercles are unevenly distributed on the dorsum surface, the most noticeable in a narrowing row from the frontal edge toward the ocular tubercle (Fig. 4A). Chelicerae (Fig. 5C-D) elongated, basal segment slender, almost cylindrical with two setae on dorsal surface, ventrally with one setae; second segment frontally set with seven longer seta on tubercles.

Pedipalps elongated (the femur length is two thirds of the body length) with strong articles (Fig. 5A-B); built in the form of a catching basket, armed with strong elongated spine-like tubercles, each bearing an elongate seta subapically; trochanter ventrally with two strong spine-like tubercles, laterally with five low tubercles bearing small setae; femur covered with numerous simple and spine-like tubercles, proximal part ventrally armed with a row of three strong and two short spine-like tubercles, distally with two medial and one lateral strong spine-like tubercles; patella medially with one strong distal and a short proximal spine-like tubercles, laterally with one short spine-like tubercle distally; tibia armed with two rows of strong spine-like tubercles, four medially and five laterally. Claw elongated.

Sternum narrow (Fig. 6A), terminally very slightly widened (at the level of coxal lobes II); basally widened, with three setae. Coxal lobes II swollen with eight setae each. Coxal lobes III wide and elongated (twice as long as Coxal lobes II).

Legs are elongated with cylindrical segments; coxae, trochanter, femur and patella granulated, with small sparse granules. A stick-like tubercle (Fig. 4C) is present on the dorsal side of coxa II. Each femur with a false articulation basally. Metatarsi I-II divided into shorter astragulus and longer calcaneus. Metatarsi III-IV divided into longer astragulus and shorter calcaneus. Tarsal formula: I-4; II-13; III-4; IV-4. Basitarsi elongated, much longer than individual distitarsal segments. Measurements of legs: I -6.75 mm; II-11.70 mm; III-7.65 mm; IV-10.7 mm.

The tarsal claws of the first and second legs are thin, simple, sickle-shaped; claws of the third and fourth legs (Fig. 4D) with two lateral branches slightly shorter than the median prong. Distal half of claws III and IV, bearing median prong and branches, bent at right angles to the proximal half.

Penis structure (Fig. 7) is similar to other Buemarinoidae, with a short, stout, muscular truncus and elongated glans with two flanking setose arms ventrobasally. Those arms are articulated and are moving independently, so they could not be treated as "deeply bifurcated plate" (Derkarabetian et al. 2021). Glans apically expanded with bifurcated, rigid end of sperm duct which opens terminally and a pair of oval elongated glands laterally. Terminal setae, which are present in other Buemarinoidae, have not been spotted. They may have been broken off as they were exposed outside, due to the specimen's penis being expanded. Each setose arm bears three ventral and two dorsal setae on the base of its apical half. Terminal part in the apical third sharply narrowed and more chitinized.

Remarks

The representatives of the Family Buemarinoidae are characterized by a heterogeneous external morphology, yet possess a unique and very complex structure of the penis, which shows a strong phylogenetic signal. Its structure is the key synapomorphic character of this family and clearly indicates mutual phyletic relationships. Contrary to the expected closeness of *Arbasus caecus* to the two remaining western Mediterranean species (*Buemarinoa patrizii* and *Turonychus fadriquei*), its closest relative is the North American (Apalachian) *Fumontana deprehendor*, despite the huge differences in habitus that make such a claim incoherent at first sight. This close phylogenetic relation is indicated by the similarities in penis structure and the position of the ocular tubercle in these two species. The form of the penis setose arms with wide base and sharply narrowed terminal part, the length and the position of setae (Fig. 7C; fig. 9B in Karaman 2019) indicate that closeness. On the other hand, *B. patrizii* and *T. fadriquei* are close to each other regarding the same characters (fig. 9A in Karaman 2019; fig. 7B in Derkarabetian et al. 2021). The remains of the ocular tubercles in the latter species are located on the frontal edge of the prosoma. Such position must be treated as plesiomorphic. In *Arbasus caecus* and *Fumontana deprehendor* ocular tubercles (only remain in the former) are located on the posterior part of the prosoma.

In addition, there is a clear difference in the coxosternal region between *Buemarinoa patrizii* and *Turonychus*

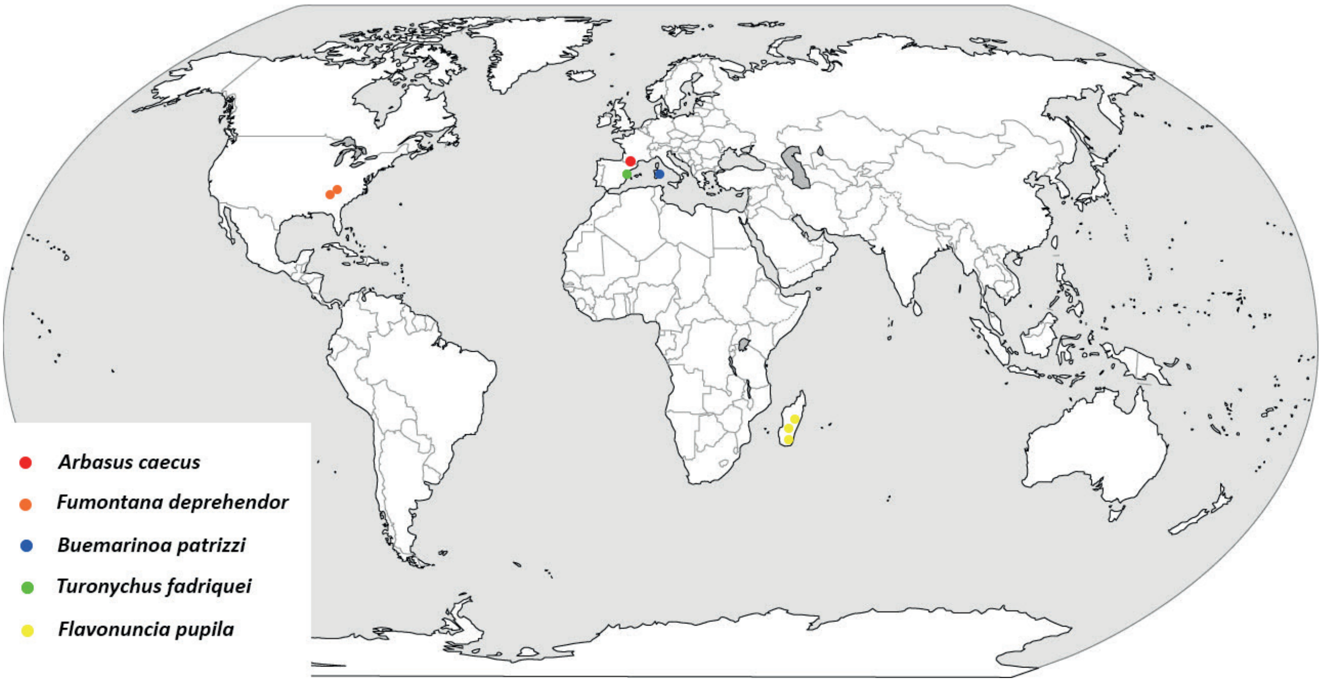

Fig. 3. Geographic distribution of the family Buemarinoidae.

fadriquei on the one hand and *Arbasus caecus* and *Fumontana deprehendor* on the other. Coxal lobii II are more setose in *A. caecus* and *F. deprehendor* and their coxal II endites reach the lobi tips (Fig. 6). In contrast, coxal II endites of *B. patrizii* and *T. fadriquei* do not reach the tips of the lobi (figs 8C, 10C in Derkarabetian et al. 2021).

DISCUSSION

The superfamily Triaenonychoidea includes four families: Triaenonychidae Sørensen, 1886, Synthetonychiidae Forster, 1954, Buemarinoidae and Lomanellidae Mendes & Derkarabetian, 2021, (Derkarabetian et al. 2021). Their representatives almost always appear as relic forms, which emphasizes the great age of this group. Triaenonychoidea are disjunctly distributed in some areas of the subtropics and temperate zones of the Southern Haemisphere (Derkarabetian et al. 2021), whereas the mentioned four species (genera) of the family Buemarinoidae represent an exception. Their connection with the center of the superfamily diversity (Southern Gondwana) dates back to the time of the Pangaea supercontinent. Their ancestor(s) expanded their ranges from the area of North East Gondwana to more northern latitudes, and to the southern part of Laurasia (then in tropical belt) during the early Mesozoic era, before Pangea split up. In an extensive phylogenetic study of Trienonychoidea (Baker et al. 2020), the estimated age of the divergence between Apalachian *Fumontana deprehendor* and Madagascar *Flavonuncia*, is ranged from 234 to 101 Ma. Its upper limit corresponds to the period when Pangaea began to break up.

The separation between *Arbasus caecus* and *Fumontana deprehendor* probably occurred in Jurassic or earlier, before Laurasia broke up into North America and Eurasia. The further fate of the genus *Arbasus* could be linked to the western part of the then-Iberian Massif or, less likely, to the Armorican Massif. Most likely, Mediterranean genera *Buemarinoa* and *Turonychus* were separated from each other by the separation of the Ebro Block from the Sardinia Corsica

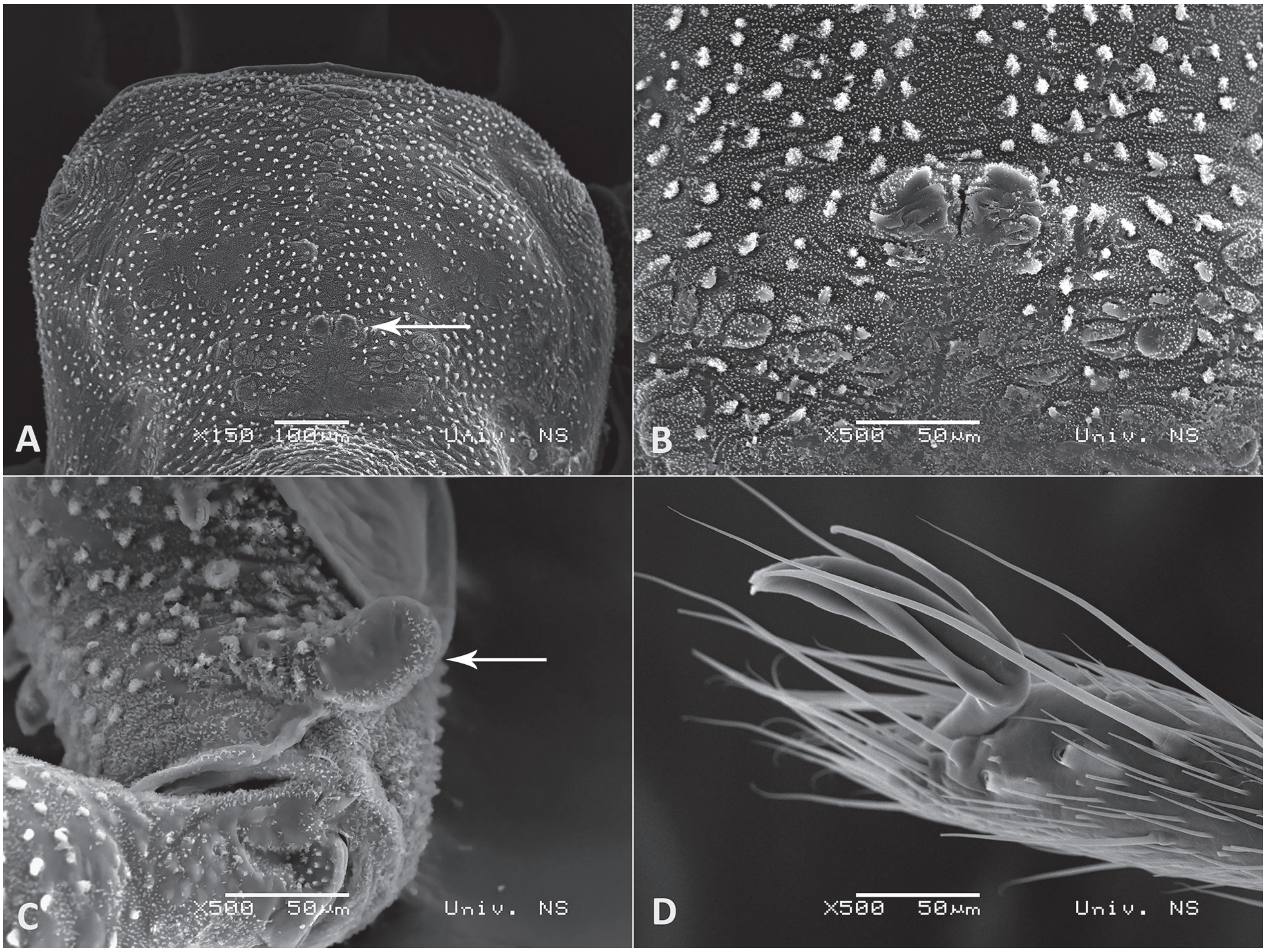

Fig. 4. *Arbasus caecus* male. **A**, dorsum, detail of prosomal part with ocular tubercle (arrow); **B**, ocular tubercle; **C**, stick-like tubercle on coxae II (arrow); **D**, claw of leg IV.

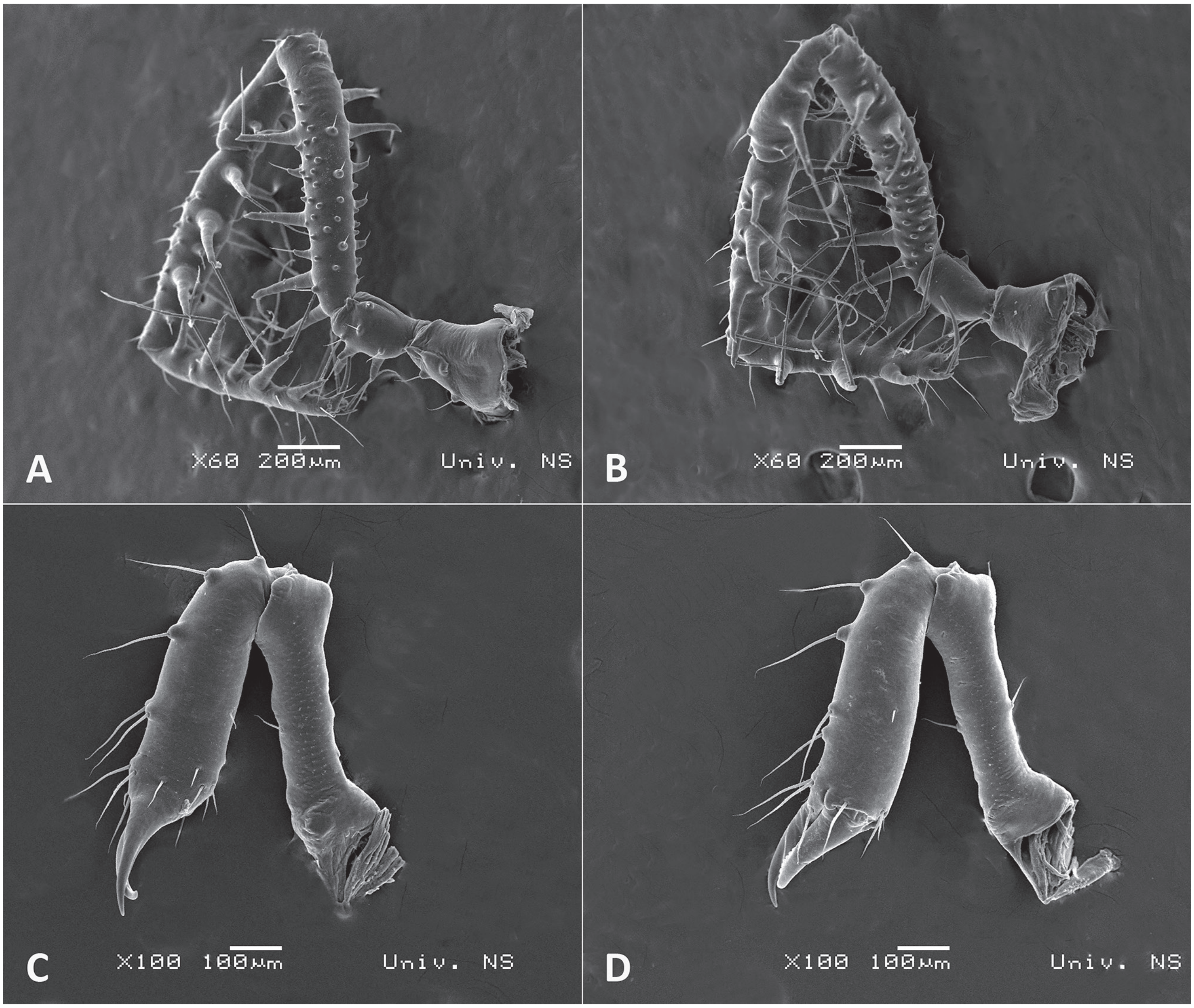

Fig. 5. *Arbasus caecus* male. **A**, left pedipalp, retrolateral view; **B**, right pedipalp, prolateral view; **C**, left chelicera, retrolateral view; **D**, right chelicera, prolateral view.

Block in the late Triassic (Edel et al. 2015) or later. Despite small body dimensions and high microhabitat specificity, the dispersal ability of species in this group, throughout its long history, is evident in the extant distribution of the family.

All known species of Buemarionidae have small body dimensions, 1.2-2.1 mm, and occur in two life forms. The extreme western and the extreme eastern species (*Fumontana deprehendor* and *Flavonuncia pupila,* respectively) are terricole forms, while the three west Mediterranean species known so far are all troglobites. I consider the appearance of the Buemarionidae troglobite forms to be ancestral (Karaman 2019), of course with developed eyes and pigmented body. With the onset of drier climate elongated appendages are lost in epigean conditions (Karaman 2020), as has happened in two terricolous Buemarionidae species. Climbing abilities are crucial for life in underground open habitats where vertical dimensions are dominant. Elongated legs are a prerequisite for climbing abilities, a feature that epigean ancestors must have possessed before settling in underground spaces (Karaman 2020).

Position of ocular tubercles on the anterior margin of the dorsal scutum in *Turonychus fadriquei* and *Buemarinoa patrizii* (also in *Flavonuncia pupila*) is considered plesiomorphic, as are long legs and the structure of pedipalps which function as catching baskets (Karaman 2005, 2019). The latter two characters are also present in *Arbasus caecus*. It is likely that there were epigean buemarinoids in the western Mediterranean area with a different appearance than the species present in that area today, but they have not survived to the present due to dramatic environmental changes to which they could not adapt.

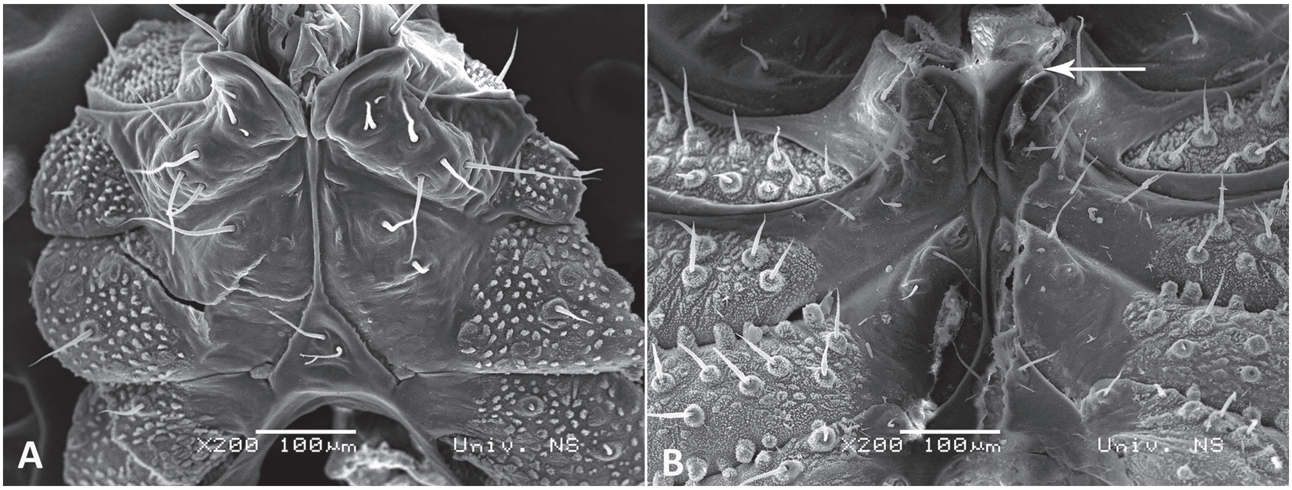

Fig. 6. Medial part of sternal prosomal region. **A**, *Arbasus caecus* male; **B**, *Fumontana deprehendor* male (arrow points to coxal II endite on the lobus tip).

Cave animals are relics representing the former epigean fauna from the near and distant geological past. Significant climate changes during the Pliocene and Pleistocene are most likely the main driver of the settlement in subterranean habitats. In the conditions of a changed, more arid climate, predation and competition from immigrants, some of the members of the old, relict epigean fauna only managed to survive by inhabiting underground habitats. This process took place gradually with the change of climatic conditions and the karstification process. With appropriate predispositions (Karaman 2019), pre-adaptation to the underground environment was not a demanding process. The key factors of subterranean habitats, such as stable humidity and temperature, as well as the absence of competition from immigrants, made these habitats similar to the former habitats and the most favorable remaining alternative. The settlement of underground spaces mainly took place in karstic areas, which are abundant in the wider areas of the Mediterranean, and now representing world hot spots of the subterranean fauna. The richness of the subterranean fauna of the Mediterranean is not only reflected by the large number of subterranean species, but also by the great diversity of this fauna, which is a direct consequence of the very complex palaeogeographic history of this area.

In troglobite dinaric travuniids, there are two medial tubercules on prosoma (fig. 8A in Karaman 2005), an anterior one on the frontal edge and a posterior one behind it, which is the common position of the ocular tubercle in Travunioidea. Both tubercles could possibly be remnants of ocular tubercles. In this case, the basal groups of Laniatores could be real “Tetrophthalmi”. The suborder Tetrophthalmi was established (Garwood et al. 2014) based on the extinct carboniferous harvestman *Hastocularis argus* Garwood et al. 2014, which did not possess two pairs of eyes. In the reconstruction of *H. argus*, the openings of the scent glands (positioned almost frontally as in the mentioned travuniids) are incorrectly interpreted as lateral eyes.

It is fully justified to expect the existence of median and lateral eyes in Opiliones ancestors because they are widely represented visual system in Chelicerates. However, the position of lateral eyes in Opiliones is occupied by scent gland orifices. All Opiliones are characterized by the presence of these unique prosomal exocrine glands. In the same position, the function of the lateral eyes was hindered, so they had to disappear or be relocated. The latter may be the case in the troglobite Dinaric travuniids.

Differences in the position of the ocular tubercles between *Buemarinoa patrizii* and *Turonychus fadriquei* on the one hand and *Arbasus caecus* and *Fumontana deprehendor* on the other hand may be the result of different origins of their ocular tubercles. In *B. patrizii* and *T. fadriquei*, they may originate from the anterior tubercle as present in dinaric travuniids, while in *A. caecus* and *F. deprehendor* they may originate from the posterior one. I see no other explanation for the conspicuous difference in the position of the ocular tubercles among these species. In a recent paper (Karaman 2019), I tried to explain the posterior position of the ocular tubercle in *F. deprehendor* with the necessity for space for the positioning of the large and strong pedipalps. However, in *A. caecus*, this cannot be the reason for relocating the ocular tubercle backwards. The pedipalps of *A. caecus* are somewhat stronger than those of *B. patrizii* and *T. fadriquei*, but not so much that they would require adequate space in the frontal part of the dorsum and the displacement of the ocular tubercle backwards. The posterior position of the ocular tubercle allowed space for the development of strong pedipalps in *F. deprehendor*, but it is apparently not caused by this.

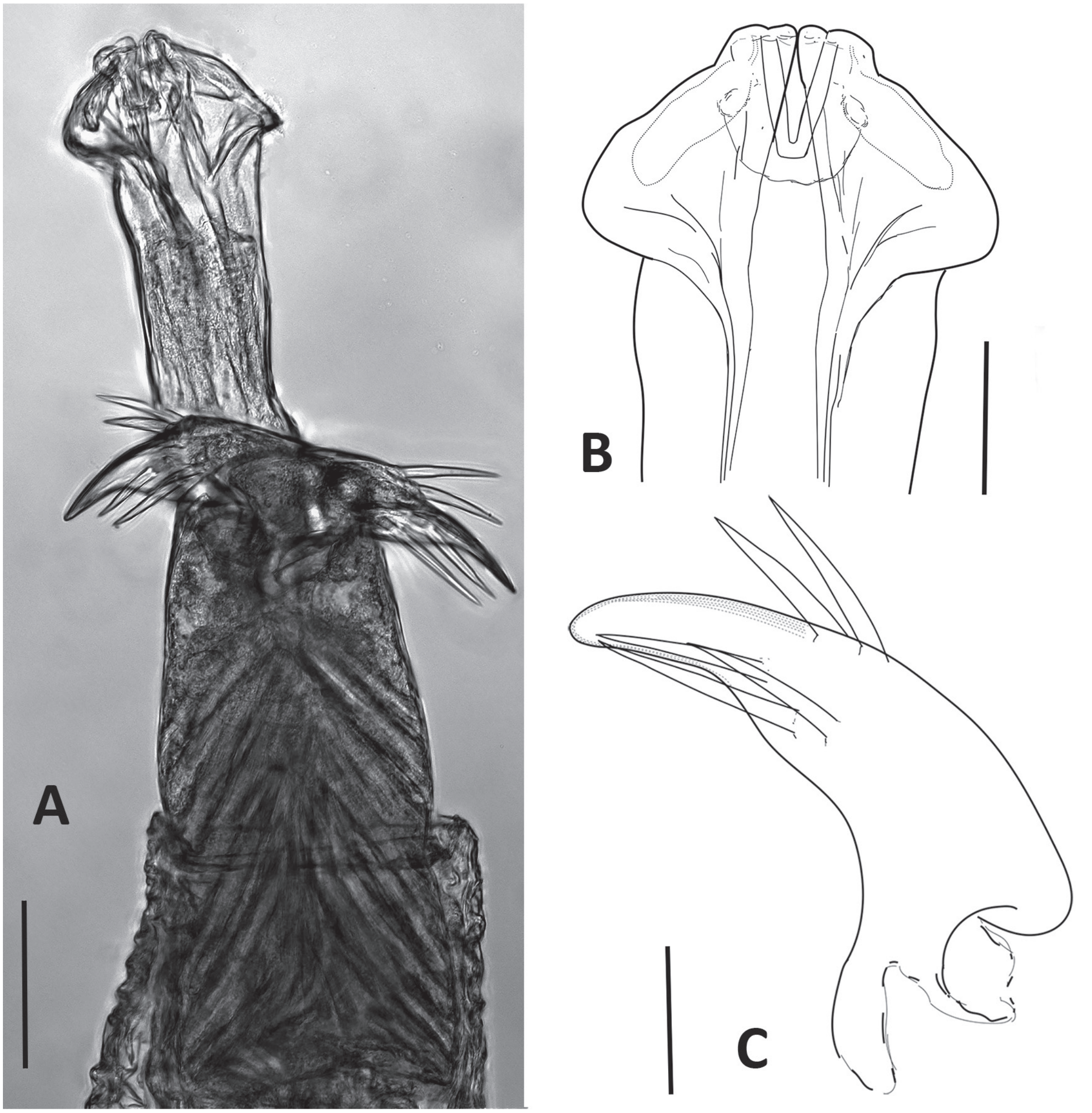

Fig. 7. *Arbasus caecus*, penis. **A**, ventral view; **B**, terminal part (glans), ventral view; **C**, left setose arm. Scale bars : A = 100 μm, B-C = 50 μm.

ACKNOWLEDGMENTS

I am very grateful to Dr. Louis Deharveng and Franck Brehier for providing me the extremely valuable specimen. I am also grateful to Marko Radenković and Miša Bokorov for SEM support. This study was partly supported by the Ministry of Education and Science of the Republic of Serbia, Grant no III43007.

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