Atherfieldastacus rapax (Harbort, 1905) (Glypheidae, Mecochiridae) from the Lower Cretaceous of the Maestrat Basin (NE Spain)

Oscar González-León*[1]; Àlex Ossó[2]; Telm Bover-Arnal[3]; Josep Anton Moreno-Bedmar[4]; Gianluca Frijia[5]; Francisco J. Vega[4]

1: Posgrado en Ciencias de la Tierra, Universidad Nacional Autónoma de México, México CdMx. 04510, México and Facultad de Estudios Superiores Iztacala, UNAM, Tlalnepantla, Estado de México, 54070, Mexico; e-mail: oscar.gonzalez@unam.mx

2: Josep V. Foix, 12-H, 1er-1a 43007, Tarragona, Catalonia; e-mail: aosso@comt.cat

3: Departament de Mineralogia, Petrologia i Geologia Aplicada, Facultat de Ciències de la Terra, Universitat de Barcelona, Martí i Franquès s/n, 08028, Barcelona, Spain; e-mail: telm.boverarnal@ub.edu

4: Instituto de Geología, Universidad Nacional Autónoma de México, Ciudad Universitaria, Coyoacán, CdMx. 04510, Mexico; e-mails: josepamb@geologia.unam.mx, vegver@unam.mx

5: Department of Earth Sciences, Sultan Qaboos University, Al-Khod, 123 Muscat, Oman; e-mail: gfrijia@squ.edu.om

*Corresponding author. Tel.: +52 56231265, E-mail address: oscar.gonzalez@unam.mx

ABSTRACT

Three specimens of the lobster *Meyeria rapax*, which represent the first record of this species in Spain were collected in the Artoles Formation cropping out in the surroundings

of the town of Ares del Maestrat in the Maestrat Basin. Microfacies and paleontological analyses of the sedimentary succession containing the fossil lobsters allow us to infer a near-coastal depositional setting. Numerical ages derived from Sr-isotope analyses combined with previous chronostratigraphic studies of the Artoles Formation suggest an Early Barremian age for the stratigraphic interval, which is located around the middle part of the formation, with lobsters studied. The study of the morphological features observed in the record of the *Meyeria rapax* specimens from Spain supports the ascription of the species to the new genus *Atherfieldastacus* proposed recently for the Mecochiridae family.

Keywords: Mecochiridae; Lobsters; *Meyeria*; *Atherfieldastacus*; Strontium-isotope stratigraphy; Lower Cretaceous; Spain.

1. INTRODUCTION

Glypheidean lobsters (Decapoda, Glypheidea) belong to a particularly specialized group of decapod crustaceans, which are highly diversified in the fossil record (Charbonnier et al., 2015), despite their low preservation potential when compared to other marine invertebrates (Kidwell and Flessa, 1995). In particular, the Mecochiridae family (Van Straelen, 1925) has been the subject of many studies in recent times (Neto de Carvalho et al., 2003; Amati et al., 2004; Neto de Carvalho et al., 2007; Feldmann et al., 2007; Vega et al., 2008; Garassino et al., 2009; López-Horgue, 2009; De Grave et al., 2009; Schweitzer et al., 2010; Astrop, 2011; González-León et al., 2014, 2015; Charbonnier et al., 2015; Breton et al., 2015; González-León et al., 2016; Neto de Carvalho, 2016 and Robin et al., 2016). Mecochiridae is considered to have 48 species within 7 genera (Schweitzer et al.,

2010). One of these genera, *Meyeria* M´Coy, 1849, until recently included 10 species: *Meyeria ornata* (Phillips, 1829); *Meyeria magna* M'Coy, 1849; *Meyeria harveyi* (Woodward, 1900); *Meyeria rapax* (Harbort, 1905); *Meyeria schwarzi* (Kitchin, 1908); *Meyeria bolivari* (Van Straelen, 1927); *Meyeria gracilis* (Glaessner, 1932); *Meyeria mexicana* (Rathbun, 1935); *Meyeria houdardi* (Van Straelen, 1936) and *Meyeria crofti* (Ball, 1960). Nevertheless, in a recent work, Robin et al. (2016) proposed to include a new genus within the family Mecochiridae, (*Atherfieldastacus* Simpson *in* Robin et al., 2016) based on some particular characteristics which are absent or modified in *Meyeria* and *Mecochirus*. Due to these morphological differences, these authors proposed that some species of the former *Meyeria* must be attributed to the new genus *Atherfieldastacus*: *Atherfieldastacus magnus* (M´Coy, 1849); *Atherfieldastacus mexicanus* (Rathbun, 1935); *Atherfieldastacus rapax* (Harbort, 1905) and *Atherfieldastacus schwartzi* (Kitchin, 1908).

The current work is the first report of *Meyeria rapax* in Spain and analyzes the inclusion of the species *M. rapax* under the genus *Atherfieldastacus*. This species has a wide distribution, despite not occurring abundantly in the geological record. *M. rapax* has been known from the early Valanginian of Germany (Harbort, 1905; Glaessner, 1932); Hauterivian, Speeton Clay and Tealby Clay, England (Woods, 1928); and the late Valanginian-early Hauterivian from the Neuquén Basin in Argentina (Aguirre-Urreta, 1985, 1989 and 2003). In addition, the ocurrence of this species has been reported in the lower Barremian of Lusitanian Basin, Portugal (Neto de Carvalho et al., 2003, 2007 and Neto de Carvalho, 2016). The herein studied specimens of *A. rapax* were collected in the Lower Cretaceous of the Artoles Formation, Maestrat Basin, in a sedimentary succession outcropping in the municipal district of Ares del Maestrat (Comarca of l´Alt Maestrat), northeast Spain (Fig. 1). In order to establish a proper stratigraphic and chronostratigraphic

framework of the first Spanish record of *A. rapax* we describe the stratigraphic section that contains this lobster record and we analyse the microfacies, and the micro and macropalaeontological record. Any macro or micro-fossils identified in the studied section do not have a precise bioestratigraphic value. For this reason, we collected oyster shells in order to obtain an age-calibration by means of strontium-isotope stratigraphy.

2. GEOLOGICAL SETTING

The Maestrat Basin developed in the eastern margin of the Iberian plate due to tectonic extension of terminal Oxfordian (Late Jurassic)-early Late Albian (Early Cretaceous) age (Salas and Casas, 1993; Salas et al., 2001, 2010). This rifting episode resulted from the opening and spreading of the Neotethys towards the west, and the opening of the Central Atlantic Ocean and the Bay of Biscay (Salas and Casas, 1993; Salas et al., 2001, 2010). Along this rifting event, the Maestrat Basin was compartmentalized into seven sub-basins: Aliaga, El Perelló, Morella, Oliete, Galve, Penyagolosa and La Salzedella (Salas and Guimerà, 1996; Fig. 1B). Later on, and owing to the Alpine contraction, the Maestrat Basin was inverted and gave rise to the eastern part of the Iberian Chain during the Late Eocene-Early Miocene (Salas et al., 2001; Nebot and Guimerà, 2016; Fig. 1A).

The fossil lobster specimens studied here were sampled in La Salzedella sub-basin (Fig. 1B), in a cut of the road CV-15, which goes from Vilafranca to Ares del Maestrat (Fig. 1C). The stratigraphic succession examined belongs to the Artoles Formation defined by Salas (1987). This lithostratigraphic unit mainly corresponds to marine shallow-water marls, sandy limestones and limestones rich in oysters (Salas, 1987; Bover-Arnal et al., 2016). The Artoles Formation has been classically attributed to the Barremian Stage (Salas, 1987; Salas et al., 2001; Bover-Arnal et al., 2016), although a latest Hauterivian age for its

lowermost part in the depocenter of the basin, such as La Salzedella sub-basin (Fig. 1B), is not discarded (Esnaola and Canérot, 1972; Canérot and Pignatelli García, 1977; Salas et al., 2001). See Salas et al. (2001) and Bover-Arnal et al. (2016) for detailed chronostratigraphic charts of the Early Cretaceous of the Maestrat Basin.

3. SEDIMENTOLOGY AND PALEONTOLOGICAL CONTENT OF THE SUCCESSION

The sedimentary record studied corresponds to a 20.35 m thick alternation of marls, marly limestones and limestones (Figs. 2 and 3A). The first 1.8 m of this succession are constituted by two beds of decimeter – to-meter thickness, with a grainstone texture that is capped by a hardground (Fig. 2). These grainstones are poorly sorted and rich in peloids, ooids (Fig. 3B), grapestones, gastropods, fragments of oysters, other bivalves, fragments of echinoids and bryozoans, miliolids, *Choffatella decipiens* Schlumberger, 1905 (Fig. 3C), *Pseudocyclamina*, textularids, encrusting foraminifera, other undetermined benthic foraminifera, and in sections serpulids and dasycladaceans (Fig. 3D). Saddle dolomite and silt-sized quartz grains occur. Above the hardground, there is an 85 cm-thick bed with oysters, other bivalves, gastropods and fragments of echinoids. The texture is mainly floatstone, but in the uppermost part it corresponds to a cm-thick framestone (Fig. 3E) made up of oysters, serpulids (Fig. 3F) and encrusting foraminifera.

From meter 2.65 to meter 11.1 (Fig. 2), the marly limestones and limestones exhibit wackestone, floatstone and rudstone textures with oysters and other bivalves as dominant skeletal components. The marl intervals contain abundant oysters and other undetermined bivalves. *Gastrochaenolites* borings, at times preserving the shell of the lithophagid bivalve (Fig. 3G), are frequent in these bioclasts. Other common components present in this

stratigraphic interval are peloids, gastropods, fragments of echinoids, serpulids, dasycladaceans and bryozoans, *Trocholina* and other benthic foraminifera. At meter 9.35, millimeter-sized rock fragments occur (Fig. 4A). *Thalassinoides*, as well as other burrows, are widespread throughout this lower part of the succession investigated.

At meter 11.1, a 40 cm-thick bed made up of a floatstone to rudstone texture dominated by fragments of oysters, other bivalves and gastropods occurs. This bed also includes specimens of *Atherfieldastacus rapax* (Fig. 2), ooids, coated grains, peloids, fragments of echinoids, crushing teeth of pycnodont, as well as mud nodules. Following a 1.5 m-thick covered outcrop interval (Fig. 2), the succession corresponds to an alternation between marls, marly limestones and limestones with floatstone to rudstone textures (meters 13-16.45; Fig. 2). The components giving rise to these latter textures are fragments and wholly preserved shells of oysters, other bivalves, gastropods and serpulids. Fragments of mollusks are commonly bioeroded. Coated grains, ooids, peloids and fragments of echinoids also occur. Large *Thalassinoides* (Fig. 4B) and other burrows are widespread in this interval.

A 30 cm-thick floatstone to rudstone limestone bed capped by a hardground with encrusting oysters is found at meter 16.45 (Fig. 2). The bed is composed of fragments of oysters, other bivalves, gastropods, echinoids, corals (Fig. 4C), serpulids and rocks, as well as benthic foraminifera and coated grains. Above, marls, and marly limestones and limestones with wackestone, packstone and floatstone textures, alternate. These deposits, which occur between meter 16.45 and meter 19.85 (Fig. 2), are very rich in oysters and show frequent bioturbation by *Thalassinoides* and other burrows. Other common components in the marly limestones and limestones of the upper part of the strata investigated include other bivalves, which are at times bioeroded, gastropod shells,

serpulids, encrusting foraminifera and fragments of dasycladaceans and echinoids. From meter 16.95 to meter 17.3, specimens of *Atherfieldastacus rapax* are also found (Fig. 2). At meter 17.25, a razor shell was identified (Fig. 4D).

The top of the stratigraphic succession investigated is marked by a 50 cm-thick tabular limestone bed with a wackestone to packstone texture dominated by fragments of oysters, other bivalves, gastropods (Fig. 4E) and echinoids. Occasionally, the mollusk shells are bioeroded. Peloids, coated grains, benthic foraminifera, and fragments of bryozoans, serpulids, dasycladaceans and crinoids (Fig. 4F) also occur. The base of this uppermost bed is characterized by the presence of large *Thalassinoides* burrows.

4. SR-ISOTOPE ANALYSIS AND AGE OF THE *ATHERFIELDASTACUS RAPAX* STUDIED

The age of the specimens studied has been constrained by means of Sr-isotope stratigraphy, see Steuber (1999, 2001), McArthur and Howard (2004), Steuber et al. (2005), Frijia and Parente (2008), Bodin et al. (2009), Boix et al. (2011), Frijia et al. (2015) for detailed reviews on this chemostratigraphic method.

The two shells of oysters (V4A and V4B) used for Sr-isotope stratigraphy come from a bed very rich in these bivalves located at 2.65 meters in the sedimentary succession logged (Fig. 2). This bed is approximately 8.45 and 14.35 meters below the two beds with the identified *A. rapax* (Fig. 2).

The preservation of the analysed fossils was evaluated using an accurate diagenetic screening following the procedure described in detail in previous works (Steuber et al., 2005; Boix et al., 2011; Frijia et al., 2015). Trace element analysis (high Sr content versus low Mn and Fe concentrations; Table 1) and petrographic observations show no evidence

of significant diagenetic alteration of the oyster shells, suggesting that they preserve their pristine chemical composition. Furthermore, internal consistency of the Sr-isotope ratios of the two shell fragments reinforces the hypothesis that they preserve the original Sr-isotope signature of seawater (Table 1).

The $^{87}Sr/^{86}Sr$ value of 0.707472 ± 0.000011 obtained from the analysed samples when compared with the $^{87}Sr/^{86}Sr$ reference curve for Cretaceous seawater (McArthur et al. 2001; age derived using the look-up table version 4: 08/04) translates into two possible ages: one of 126.46 Ma (-0.6/+0.74; Table 1) and a second of 130.43 Ma (-1.89/+1.4; Table 1). The first age corresponds to the Late Barremian whereas the second to the latest Hauterivian-Early Barremian time interval (Gradstein et al., 2004).

The existing chronostratigraphic frameworks for the Lower Cretaceous of the Maestrat Basin mainly attribute the Artoles Formation to the Barremian (Salas, 1987; Salas et al., 2001; Bover-Arnal et al., 2016). In addition, in the depocenter of the basin (La Salzedella sub-basin), the lowermost part of the Artoles Formation could be of latest Hauterivian age (Esnaola and Canérot, 1972; Canérot and Pignatelli García, 1977; Salas et al., 2001). Therefore, both preferred ages are possible considering the associated errors (Table 1). However, according to the numerical age dataset presented by Bover-Arnal et al. (2016), the preferred age of 126.46 Ma (-0.6/+0.74) mainly fails into the numerical age domain of the Late Barremian Morella, Cervera del Maestrat and Xert formations, which stratigraphically overlay the Artoles Formation. On the other hand, the associated maximum age of 127.27 Ma (Table 1) would fall into the numerical age domain of the uppermost part of the Artoles Formation (Bover-Arnal et al., 2016). However, given that the succession studied corresponds to a stratigraphic interval located around the middle part of the formation, this possibility seems unlikely.

Accordingly, we favour the preferred age of 130.43 Ma (-1.89/+1.4; Table 1). Nevertheless, given that the rocks investigated are located in the middle Artoles Formation, a latest Hauterivian age for this stratigraphic interval is improbable according to previous studies on the age assignament of the Artoles Formation (Salas, 1987; Salas et al., 2001; Bover-Arnal et al., 2016). Therefore, an Early Barremian age (130-128.54 Ma) is assigned to the oysters analyzed for Sr-isotope stratigraphy and the beds with *A. rapax* examined in this study.

Acronym: MGB: Museu de Geologia – Museu de Ciències Naturals de Barcelona MGB-MCNB (Barcelona, Catalonia).

5. SYSTEMATIC PALEONTOLOGY

Order Decapoda Latreille, 1802

Suborder Pleocyemata Burkenroad, 1963

Infraorder Glypheidea von Zittel, 1885

Superfamily Glypheoidea von Zittel, 1885

Family Mecochiridae Van Straelen, 1925

Genus: *Atherfieldastacus* Simpson *in* Robin et al., 2016

Type species. — *Meyeria magna* M'Coy, 1849.

Included species. — *Atherfieldastacus magnus* (M'Coy, 1849) — *Atherfieldastacus mexicanus* (Rathbun, 1935) — *Atherfieldastacus rapax* (Harbort, 1905) — *Atherfieldastacus schwartzi* (Kitchin, 1908).

5.1 DIAGNOSIS OF THE NEW GENUS *ATHERFIELDASTACUS* SIMPSON *IN* ROBIN ET AL. (2016) — Subcylindrical carapace, laterally compressed, about two-thirds the length and twice the height of pleon; carapace with bevelled, sublanceolate cross section; short pointed rostrum, spineless; branchial region with three lateral branchial ridges broadening the carapace: dorsal branchial ridge (r2) between postcervical and branchiocardiac grooves; medial branchial ridge (r3), curved and parallel to posterior margin; ventral branchial ridge (r1), extending hepatic carina; antennal pterygostomial region with strongly concave ventral margin; cervical groove strongly oblique, ventrally joined to antennal groove, delimiting narrow cephalic region; cephalic region with longitudinal carinae; short gastro-orbital groove originating as a slight inflexion of the cervical groove at level of gastro-orbital carina; postcervical and branchiocardiac grooves parallel, directed toward the posterior margin; postcervical groove joined ventrally to branchiocardiac groove, forming one elongated lobe crossed by dorsal branchial ridge (r2); straight cardiac groove, forward-inclined and joined posteriorly to postcervical groove; cardiac groove joined to dorsal margin; hepatic region with tuberculated longitudinal hepatic carina above hepatic groove, and prolonged by ventral branchial ridge (r1) in branchial region; hepatic groove shallow and curved toward posterior; short inferior groove joined to hepatic groove, and connected to ventral margin; subchelate P1–P2; achelate P3–P5; very elongated P1; uropodal exopod with diaeresis; uropodal endopod with fibrous and flexible distal portion.

Atherfieldastacus rapax (Harbort, 1905)

Figures 5, 6, 7, 8 and 9A

pars 1863 *Astacodus falcifer* Phillips Bell, p. 30, pl. 9, fig. 3 only.

*1905 *Meyeria rapax* Harbort, 1905, p. 11, pl. 1, fig. 12; pl. 2, figs. 1a-c, 2a-b, 3-4.

1928 *Meyeria rapax* Harbort, 1905; Woods, p. 70, pl. 18, figs. 5?, 6, 7?, 8.

1932 *Meyeria rapax* Harbort, 1905; Glaessner, p. 58.

1976 *Mecochirus rapax* Harbort, 1905; Kemper, pl. 11, fig. 1.

1985 *Meyeria rapax* Harbort, 1905; Aguirre-Urreta, pl. 1, figs. D-G.

1989 *Meyerella rapax* Harbort, 1905; Aguirre-Urreta, pl. 59, figs. 5-8; text-fig. 18; text-fig. 19.

2003 *Meyerella rapax* Harbort, 1905; Aguirre-Urreta, fig.1.

2007 *Mecochirus rapax* Harbort, 1905; Neto de Carvalho et al., fig. 2e-g; fig. 3a-b.

2016 *Meyeria rapax* Harbort, 1905; Neto de Carvalho, fig. 2e-g; fig. 3b-c; fig. 6.

5.2 MATERIAL

The three specimens described here as *Atherfieldastacus rapax* consist of a nearly complete carapace preserving only the right side, and morphological features and regions that are well defined. A second nearly complete specimen from the same outcrop allows us to observe details from the carapace, pleon and telson. A third specimen does not present completely the cephalothorax, only part of the branchial region can be observed. The abdomen is incomplete and only five abdominal segments are preserved, however, the telson is relatively well preserved. The specimens are housed in the collection of the

Museu de Geologia – Museu de Ciències Naturals de Barcelona (MGB-MCNB) (Barcelona, Catalonia) with the collection numbers MGB 76814, MGB 76815 and MGB 78616 respectively.

Carapace anatomical abreviations. a = branchiocardiac groove, ac = antennal carina, b = antennal groove, b_1 = hepatic groove = c = post-cervical groove, cd = cardiac groove, e_1e = cervical groove, gc = gastro-orbital carina, hr = hepatic ridge, i = inferior groove, oc = orbital carina. Regions of the carapace (colors): blue = branchial region, green = hepatic region, yellow = pterygostomial region, orange = antennal region, red = gastric region, purple = cardiac region (Fig. 5).

Locality. Ares del Maestrat, Artoles Formation, Maestrat Basin, Northeast Spain.

5.3 DESCRIPTION OF THE SPECIMENS

Regarding the anatomical features and regions of the carapace we follow the terminology published in Charbonnier et al. (2013) for the glypheideans. For the branchial carinae terminology we follow González-León et al. (2014).

Carapace. Laterally compressed and subcylindrical; cephalic region with three longitudinal spiny carinae; orbital, gastro-orbital and antennal carina parallel; very short distance between orbital and gastro-orbital carinae, antennal carina separated four times the distance from the others; cephalic carinae raised, antennal carina and gastro-orbital carina more raised than the orbital carinae. Hepatic region: granules above of a hepatic groove forming a hepatic ridge; between branchiocardiac groove and post-cervical groove there are

granules towards the hepatic region forming the branchial ridge (r2) extending towards hepatic ridge; ventral branchial ridge (r1) not developed; medial branchial ridge (r3) curved and parallel to posterior margin of carapace. Cervical groove deep, in an average height of carapace, inclined 44° toward lower anterion margin, cervical groove ventrally connected to antennal groove; branchiocardiac groove shallow, inclined 18° from upper part of posterior margin to midheight of carapace; post-cervical groove slightly deep and parallel to branchiocardiac groove; hepatic groove slightly deep, convex ventrally at intersection with antennal groove; shallow and undeveloped inferior groove, connected to hepatic groove. Cuticle of the anterior cardiac region with small tubercles; the entire cuticle of the branchial region is covered by tubercles of uniform size, coming together toward the pterygostomial region and the ventral part of the branchial region.

Pleon. Five segments of the abdomen are preserved; abdominal segments with the smallest tubercules are found in the dorsal region, more evident in the pleural region; first abdominal segment not well preserved; second abdominal segment with anterior and lower margin rounded, posterior margin straight; pleura three to five times smaller in size and triangular; telson with tubercules at the basis, uropodal of endopodite and exopodite towards the posterior region; uropodal of exopodite with diaeresis.

Thoracic appendages. Pereiopods are partially preserved and exhibit the first slender and long pereiopods; merus, carpus and propodus evident with two lines of tubercles in the ventral margin.

6. DISCUSSION

We support the inclusion of the *Meyeria rapax* species in the genus *Atherfieldastacus* on the basis of their morphological features which distinguish them from the *Meyeria* genus (see Robin et al., 2016 for more detailed explanations about the morphological differences).

The three specimens analized here from the Ares del Maestrat in the Maestrat Basin (Figs. 6, 7 and 9) have many similarities with those published first by Harbort, 1905, and those published later by Woods, 1928, Aguirre-Urreta, 1989, and recently by Neto de Carvalho et al., 2003 and Neto de Carvalho, 2016.

In figures 6A, C and 7, the specimens of *Atherfieldastacus rapax* present the development of the dorsal branchial rigde (r2), the medial branchial ridge (r3) and the development of the hepatic rigde (hr). Nevertheless *A. rapax* does not present the ventral branchial ridge like other species such as *Atherfieldastacus magnus* and *Atherfieldastacus mexicanus* in which this ridge is connected to the hepatic ridge. The features observed in the herein studied Spanish specimens are the same as the specimens illustrated by Harbort, 1905 pl. 1, fig. 12; Woods, 1928, pl. 18, fig. 8; Aguirre-Urreta, 1989 pl. 59, figs. 5, 7 and 8; Neto de Carvalho et al., 2003 fig. 2b and Neto de Carvalho, 2016 fig. 3c.

In the figure 6A, B the arrangement and number of spines that form the gastro-orbital carinae on both sides of the specimen can be observed, having twelve spines that increase in size towards the anterior part of the rostrum. The orbital carinae consists of small granules forming a parallel line above the gastro-orbital carinae. *Atherfieldastacus rapax* presents a particular arrangement of the rostral carinae; there is a very short distance between orbital and gastro-orbital carinae and the antennal carina is separated from the gastro-orbital carine with almost four times the distance than between the orbital and gastro-orbital carinae (Fig. 6A, C and D). This can also be observed in the specimens

figured by Harbort, 1905 pl. 2 figs. 1a and 4; Woods, 1928 pl. 18, fig. 5-6; Aguirre-Urreta, 1989 pl. 59, fig. 8 and Neto de Carvalho, 2016 fig. 3c. These features are easily distinguishable compared with the other species of the genus (e.g. *Atherfieldastacus magnus* and the only known specimen of the *A. mexicanus* species) in which the distance between the three rostral carinae has a similar separation (Fig. 8).

The length of the pleon in the specimen MGB 76815 from Artoles Formation is 1.5 times longer than that of the cefhalothorax (Fig. 7). For the specimen MGB 78616 the total length of the abdomen cannot be observed, but some details of the ornamentation can be observed in the abdominal pleuras, as well as the uropodal endopodite and exopodite of telson (Fig. 9A-C).

With the objective of confirm the taxonomic features of Spanish specimens, we compared the specimens studied in this work with specimens of the early Valanginian of Sachsenhagen locality in Germany located in a private collection (Appendix 1A-C). Specimens A and B show the short distance between orbital and gastro-orbital carinae. Distance between gastro-orbital and antennal carinae consist of a greater separation. It is also clearly observed that the specimens A-C present the dorsal branchial rigde (r2), the medial branchial ridge (r3) and the hepatic rigde (hr), and like the Spanish specimens they do not present the ventral branchial ridge.

Regarding the species *A. schwartzi*, there is also a very short distance between the orbital and gastro-orbital carinae and almost four times that distance between the antennal carinae and the gastro-orbital carinae. This feature is most similar to the *Atherfieldastacus rapax*, according to the drawing published by Kitchin, 1908 (pl. VIII, fig 22). Aguirre-Urreta previously recognized in 1989 the closeness between *A. rapax* and *A. schwartzi*, asserting similarities in the ornamentation, patterns of the grooves and age. But in *A.*

schwartzi the size is smaller and presents a major compression of the cephalothorax that distinguishes it from *A. rapax*. This closeness could be explained considering different ontogenetic stages, in which *A. schwartzi* could represent a juvenile stage of *A. rapax*.

The features described above are not observed in specimens included within the genus *Meyeria* according to Robin et al. (2016); therefore, it is feasible to include the species aforedescribed as *Meyeria rapax* within the new genus *Atherfieldastacus* and use the new combination *Atherfieldastacus rapax* proposed recently by these authors.

7. ENVIRONMENTAL INTERPRETATION

The alternating marls, marly limestones and limestones including abundant oysters described previously indicate a near-coastal depositional setting. The presence of ooids, or other biotic elements such as dasycladaceans or scleractinians, supports a tropical shallow-marine environment. The packstone, rudstone and grainstone beds mark periods of higher energy than the marl lithology, and the wackestone and floatstone textures. The occurrence of large *Thalassinoides* indicates the possible dwelling of this decapod. This has been suggested based on the evidence of the relationship of *A. rapax* and *Thalassinoides suevicus* recognized in different beds of the Lower Barremian of the Boca do Chapin and Rivera de Ilhas formations in the Lusitanian Basin, Portugal (Neto de Carvalho et al., 2003 and 2007).

The record of this decapod inside of the *Thalassinodes suevicus* burrows in these formations has been interpreted as massive mortality events (Neto de Carvalho et al., 2007 and Neto de Carvalho, 2016). Neto de Carvalho (2016) also found some specimens of *Meyeria rapax* without any apparent relation to the burrows, but these specimens were contemporaries with those preserved in their burrow systems. We did not find the record of

the *Atherfieldastacus rapax* inside the burrows recognized as *Thalassinoides* in the Artoles Formation, but it is highly probable that these fossil traces are related to the infaunal activity of this lobster.

8. CONCLUSIONS

Three specimens of the fossil lobster *Meyeria rapax* are described here and ascribed to the recently proposed genus *Atherfieldastacus*. The fossil material comes from the Artoles Formation, Ares del Maestrat in the Maestrat Basin (NE Spain). This species is reported for the first time in Spain. The sedimentology, micro and macropaleontological analyses of the sedimentary succession containing *Atherfieldastacus rapax* indicate a shallow marine environment. The Sr-isotope results derived from the analysis of oyster shells in combination with previous chronostratigraphic data of the Artoles Formation indicate an Early Barremian age for the strata with the record of the fossil lobster *Atherfieldastacus rapax*. To confirm the taxonomic allocation of the Spanish specimens, we compared the Spanish specimens with those specimens of the early Valanginian of Sachsenhagen locality in Germany.

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FIGURE CAPTIONS

Fig. 1. (A) Geographical situation of the Maestrat Basin in the eastern Iberian Chain (E Iberian Peninsula). (B) Simplified palaeogeographic and structural map of the Maestrat Basin during the Late Jurassic-Early

Cretaceous rifting cycle and location of the study area in La Salzedella sub-basin. Mo: Morella sub-basin, Pe: El Perelló sub-basin, Sa: La Salzedella sub-basin, Ga: Galve sub-basin, Ol: Oliete sub-basin, Al: Aliaga sub-basin, Pg: Penyagolosa sub-basin. Modified after Salas et al. (2001) and Bover-Arnal et al. (2014). (C) Geological map and location of the outcrop logged and sampled for *A. rapax*. Modified after Esnaola and Canérot (1972) and Canérot and Pignatelli García (1977).

Fig. 2. Stratigraphic section of the Lower Barremian sedimentary record containing specimens of *Atherfieldastacus rapax* logged in the surroundings of Ares del Maestrat in the Maestrat Basin (E Iberia). The situation of the two horizons with *A. rapax* recognized, as well as the 26 samples used for microfacies and micropalaeontological analyses and the oysters collected for strontium-isotope stratigraphy, are indicated. See Fig. 1C for location of the sedimentary log.

Fig. 3. Outcrop, components and textures. (A) Outcrop view of the upper part of the sedimentary succession studied in a road cut on CV-15 that goes from the town of Ares del Maestrat to Vilafranca. (B) Photomicrograph of a poorly sorted peloidal-skeletal grainstone located at the base of the succession studied. Note the presence of an ooid (red arrow). Sample V1. (C) Specimen of *Choffatella decipiens* (red arrow) occurring in a poorly sorted grainstone texture found in the lower part of the sedimentary succession analyzed. Sample V2. (D) Detail of a Dasycladacean section found in a skeletal-peloidal grainstone of the lower part of the succession investigated. Sample V2. (E) Detail of a centimeter-thick framestone texture made up of oysters and serpulids (white tubes). Meter 2.65. (F) Photomicrograph of serpulids giving rise to a framestone texture located at meter 2.65. Sample V4. (G) Detail of an oyster exhibiting *Gastrochaenolites* with the shell of the lithophagid bivalve preserved within the boring. Sample V5.

Fig. 4. Components and textures. (A) Floatstone with fragments of rocks (red arrows), mollusks and echinoids. Sample V11. (B) Detail of *Thalassinoides* occurring at the base of a limestone bed in the upper part of the succession investigated. Meter 15.45. (C) Close-up view of a scleractinian fragment within a floatstone texture dominated by shells of mollusks. Sample V19. (D) Razor clam found in the upper part of the section studied. Sample V21. (E) Photomicrograph of a skeletal wackestone to packstone texture from the tabular limestone bed marking the top of the succession examined. Red arrows point to gastropod shells. Sample

V26. (F) Close-up view of a crinoid fragment occurring within a skeletal wackestone to packstone texture around meter 20. Sample V26.

Table 1. Strontium-isotope stratigraphy of the oyster shells analyzed and their elemental composition. In bold the mean value of the Sr-isotope ratio of the sample set. Preferred numerical ages have been derived from the look-up table of McArthur et al. (2001, version4: 08/03), which is calibrated to the Geological Time Scale of Gradstein et al. (2004). The Early Barremian time interval comprised between the underlined preferred age of 130.43 Ma and its associated minimum age of 128.54 Ma corresponds to the assigned favoured age for the *A. rapax* specimens (see text for further details).

Fig. 5. Morphological features and regions of the carapace in *Atherfieldastacus rapax* based on specimen MGB 76814. Anatomical abbreviations: a = branchiocardiac groove, ac = antennal carina, b = antennal groove, b_1 = hepatic groove = c = post-cervical groove, cd = cardiac groove, e_1e = cervical groove, gc = gastro-orbital carina, hr = hepatic ridge, i = inferior groove, oc = orbital carina. Colors: blue = branchial region, green = hepatic region, yellow = pterygostomial region, orange = antennal region, red = gastric region, purple = cardiac region.

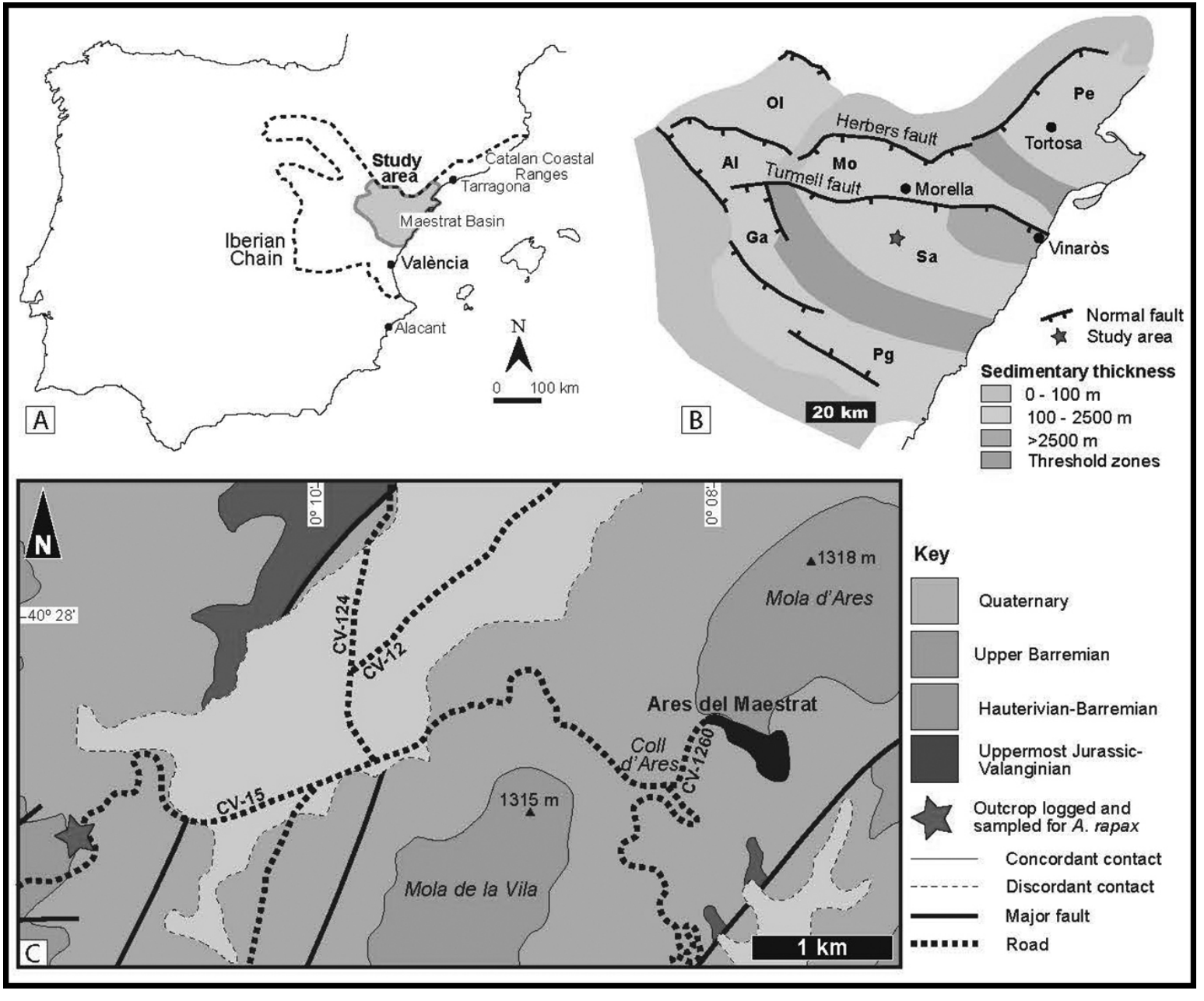
Fig. 6. *Atherfieldastacus rapax*, lateral view of specimen (MGB 76814) from Ares del Maestrat. (A) Close up of the lateral view showing the granules in the cephalotorax (for the anatomical features and regions see Figure 5). (B) Close up of the dorsal view that shows the lateral compression of the cephalotorax. (C) Close up of lateral view, it is possible to observe the orbital, gastro-orbital and antenal carinae. (D) Full view of specimen with a preserved cephalotorax and some incomplete pereiopods and a small part of the abdomen.

Figure 7. *Atherfieldastacus rapax* MGB 76815. (A) Coated with ammonium chloride. (B) Non-coated. The figure shows the morphological features in the cephalothorax; the pleon is separated from the cephalothorax. Some slender pereiopods can be observed disjointed from the body.

Figure 8. Schemes that show the differences between the arrangement of the three rostral carinae in (A) *Atherfieldastacus rapax* and (B) *Atherfieldastacus magnus*. B modified from González-León et al., 2016.

Figure 9. *Atherfieldastacus rapax*. Specimen MGB 78616 (A) Full view of specimen showing part of the branchial region of cephalothorax, five triangular abdominal pleuras incomplete and telson. (B) Close up of the telson showing uropodal endopoite and serrated exopodite with dieresis. (C) Close up of the abdomen showing the granulation and serrated edges of the abdominal pleuras.

Appendix 1. *Meyeria rapax* early Valanginian of Sachsenhagen locality, Germany; specimens located in a private collection (www.starkefossilien.de). A-C) Show some features presents in the Spanish specimens: oc=orbital carinae, gc=gastro-orbital carinae, ac=antennal carinae, hr=hepatic ridge, r2=dorsal branchial ridge and r3=medial branchial ridge. Dimensions: A) 15 cm, B) 16 cm and C) 22 cm.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Key
Quaternary
Upper Barremian
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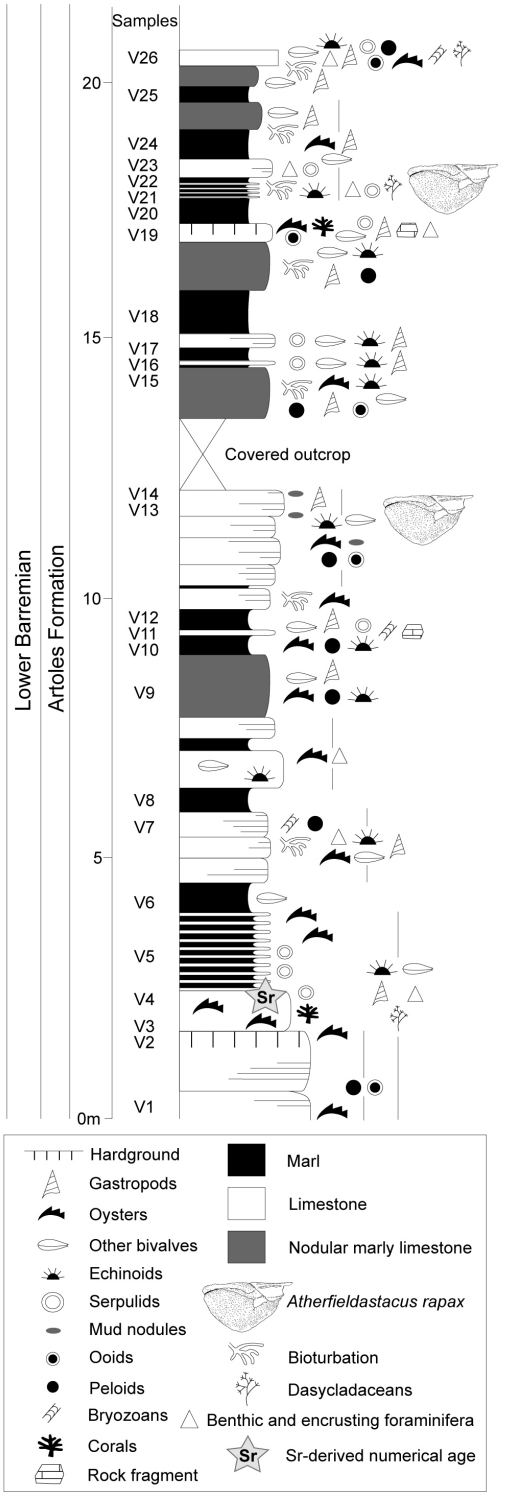
Uppermost Jurassic-Valanginian
Outcrop logged and sampled for A. rapax
Concordant contact
Discordant contact
Major fault
Road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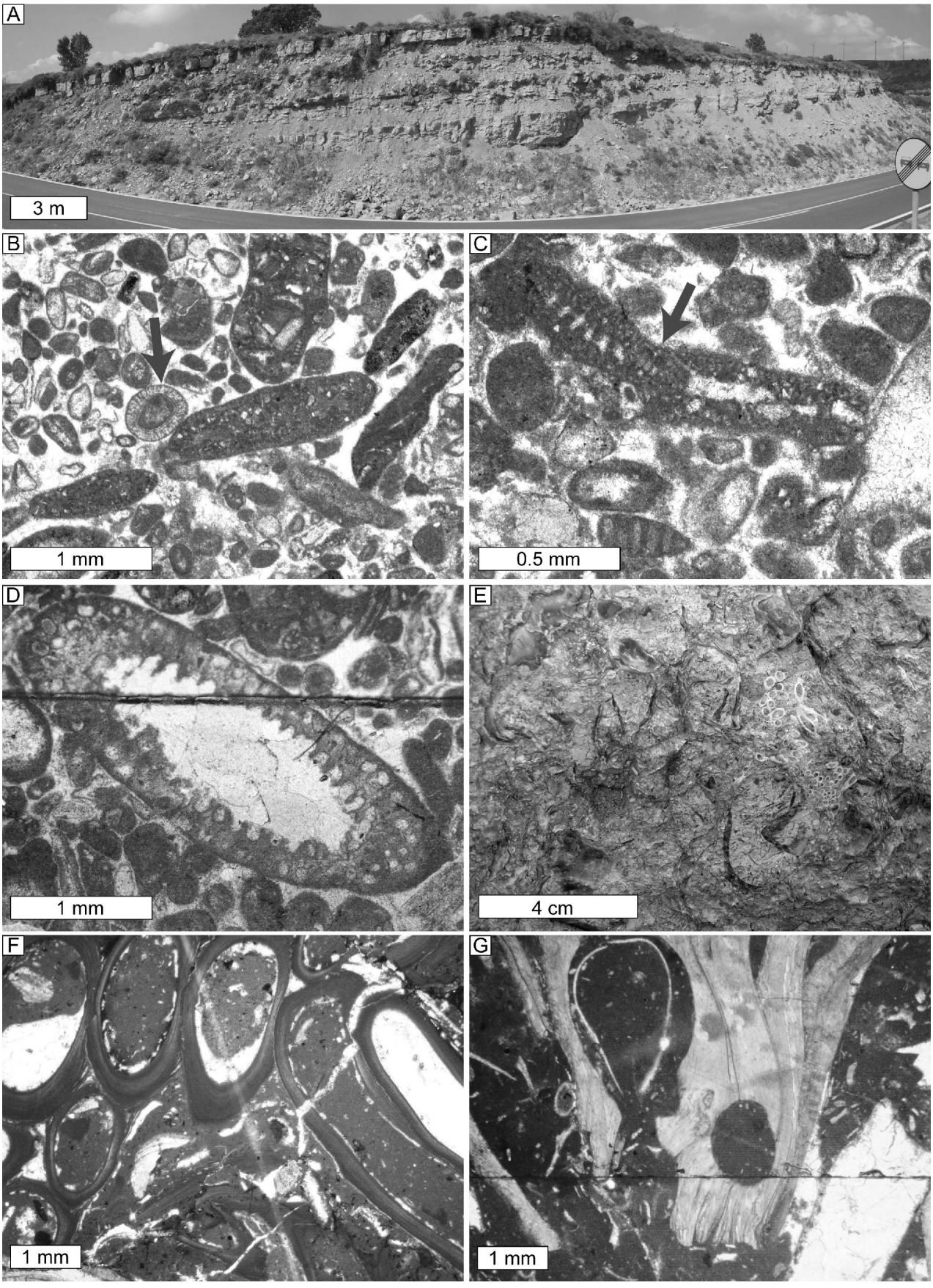
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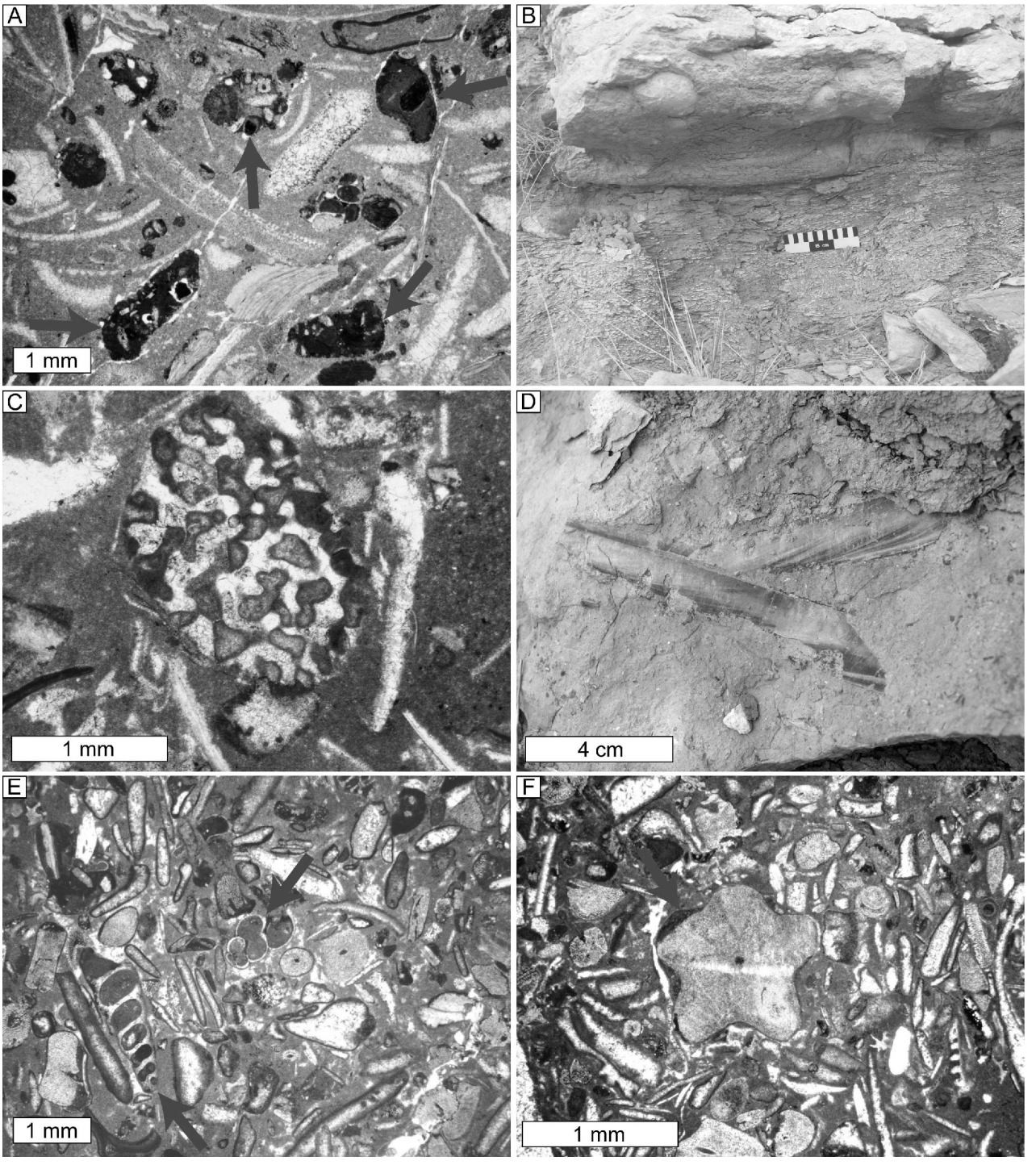
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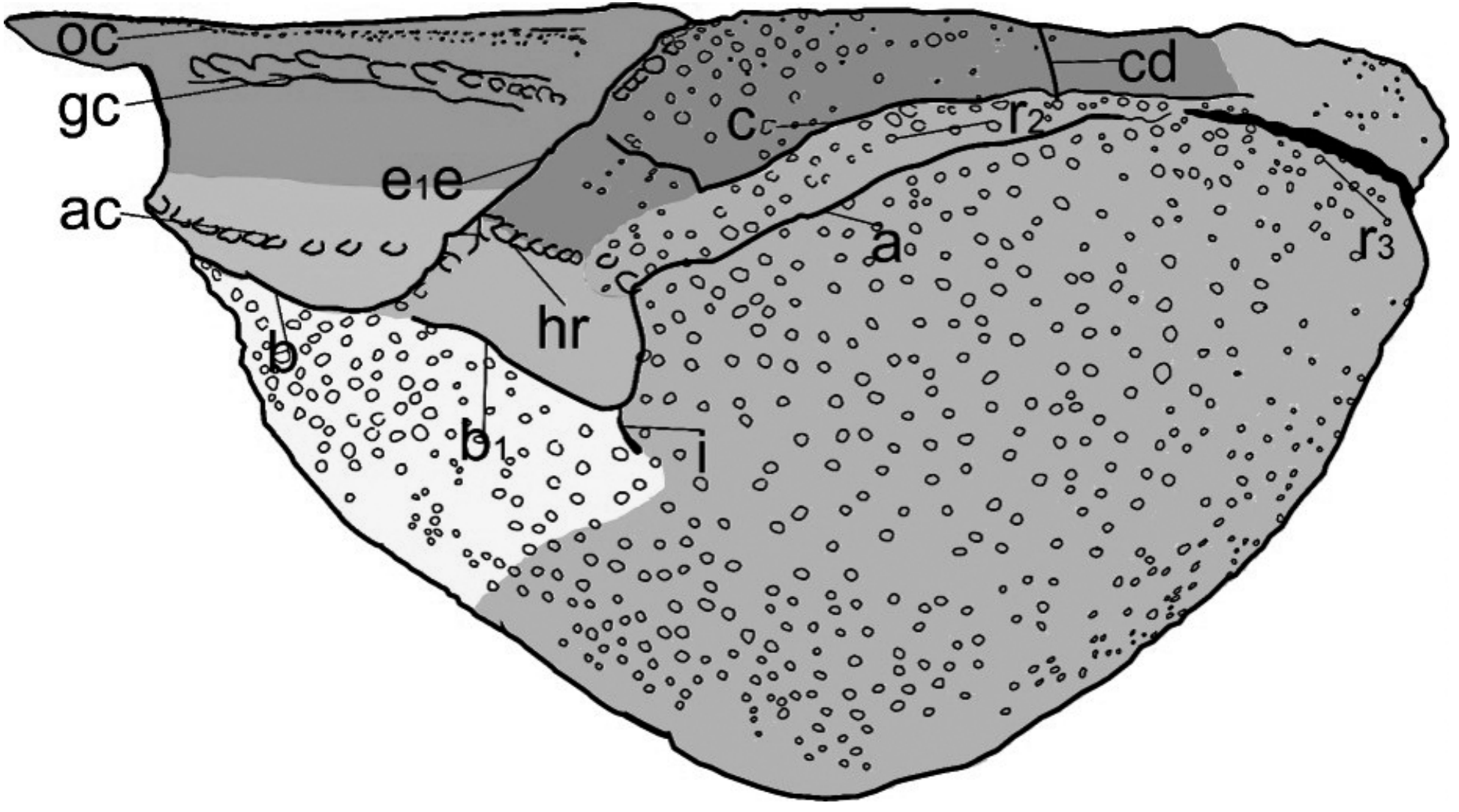
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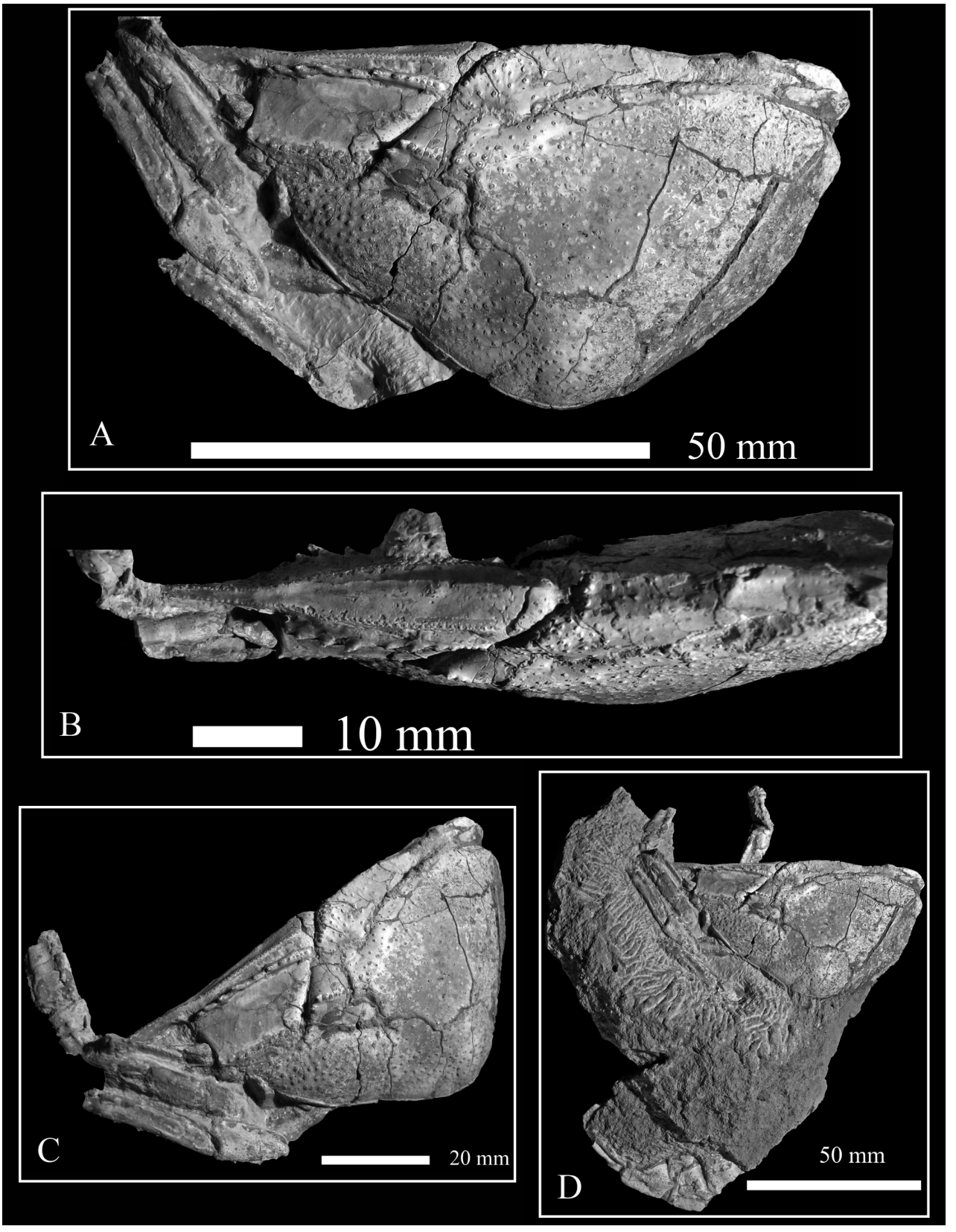
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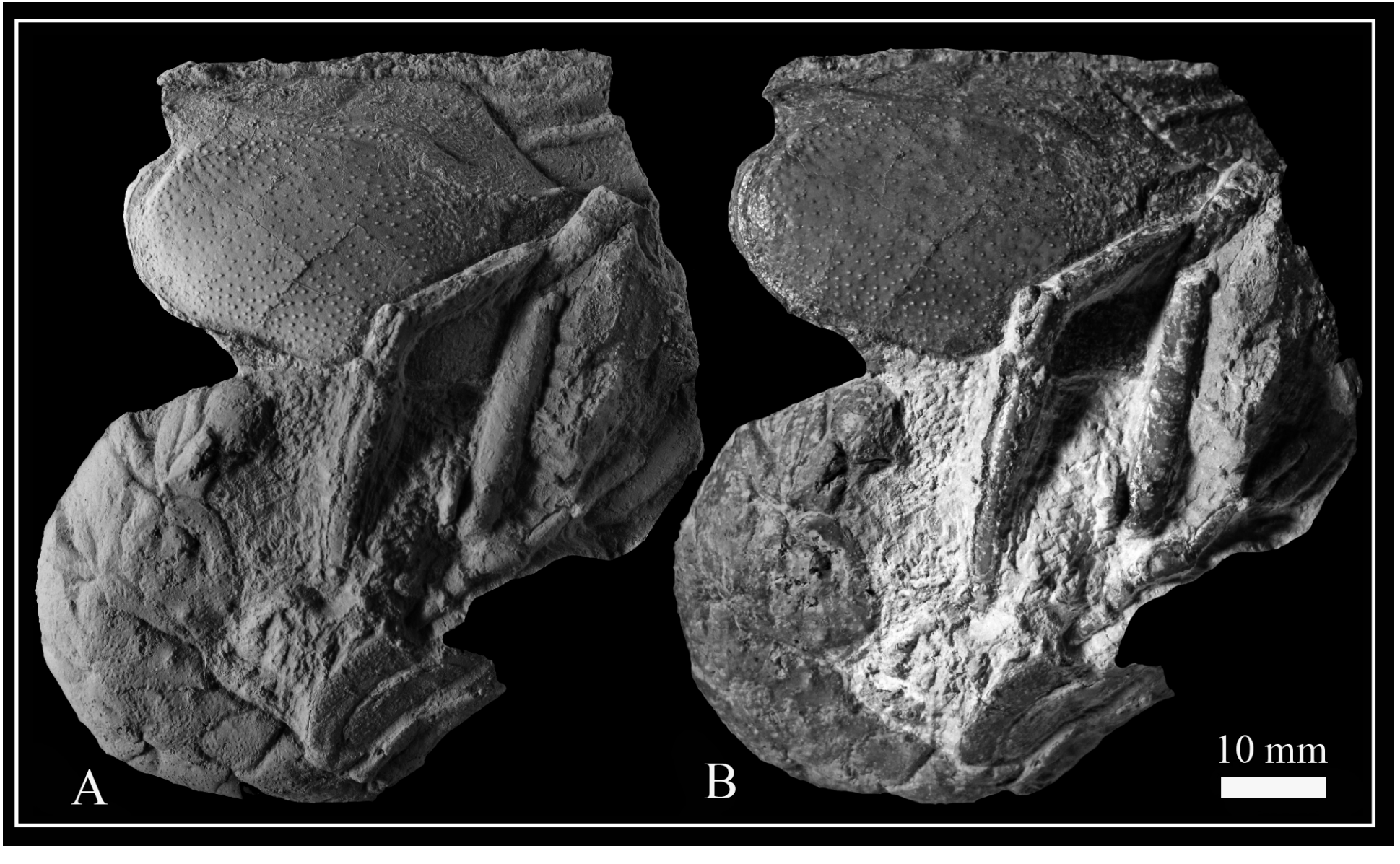
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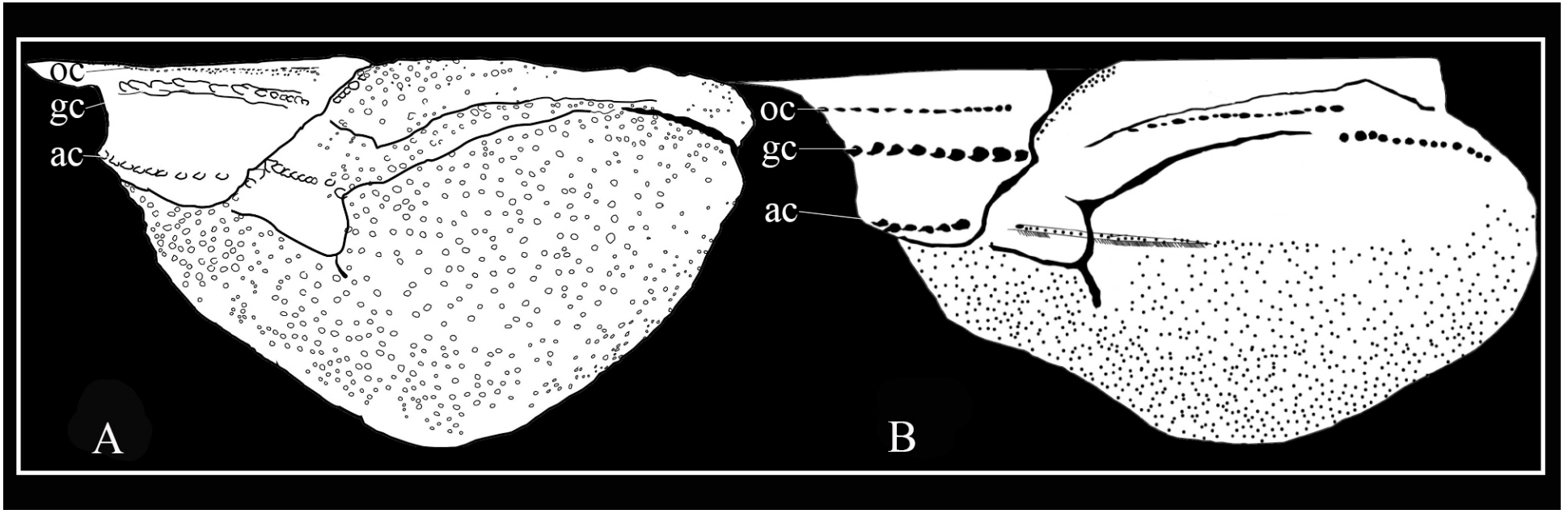
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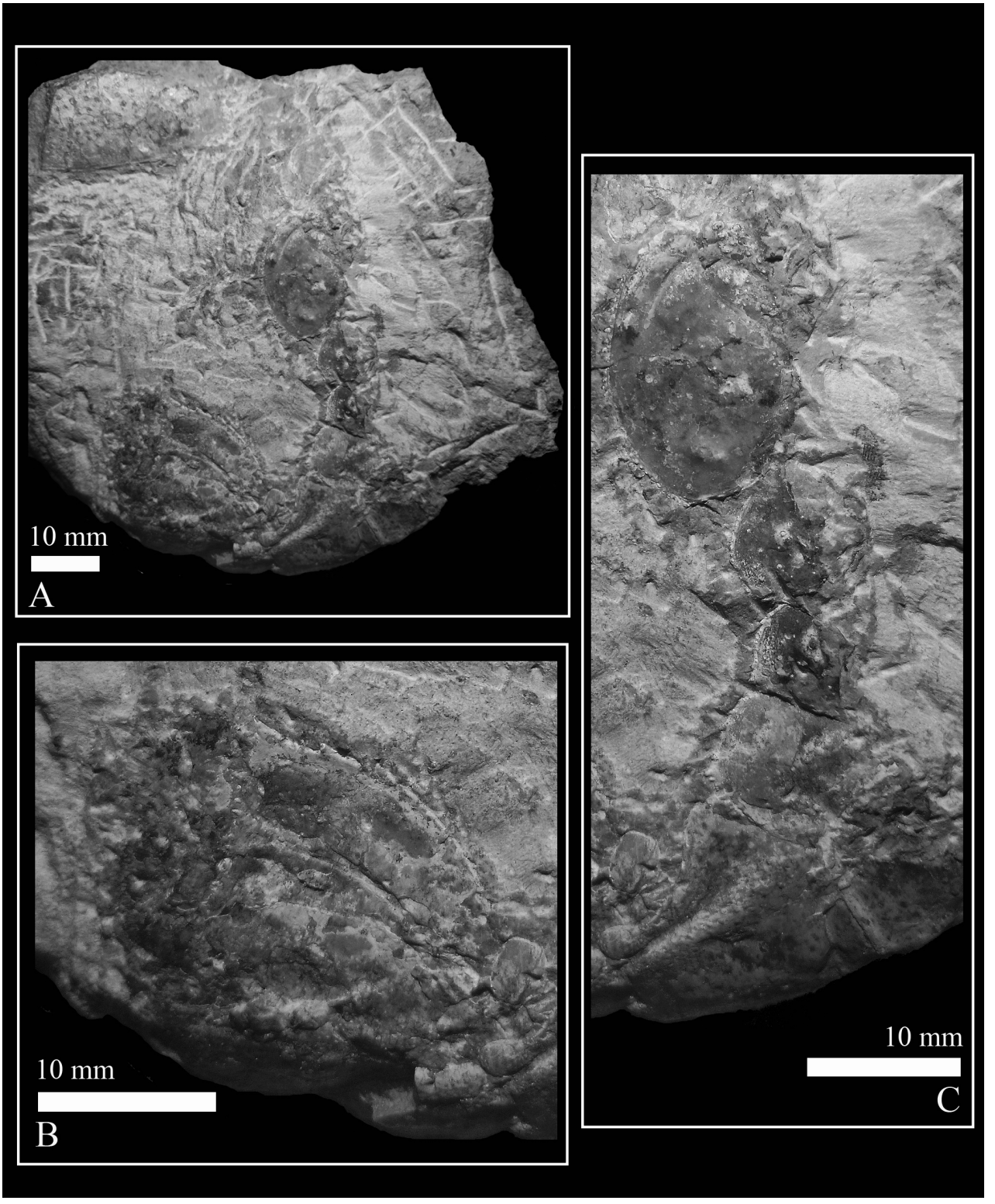
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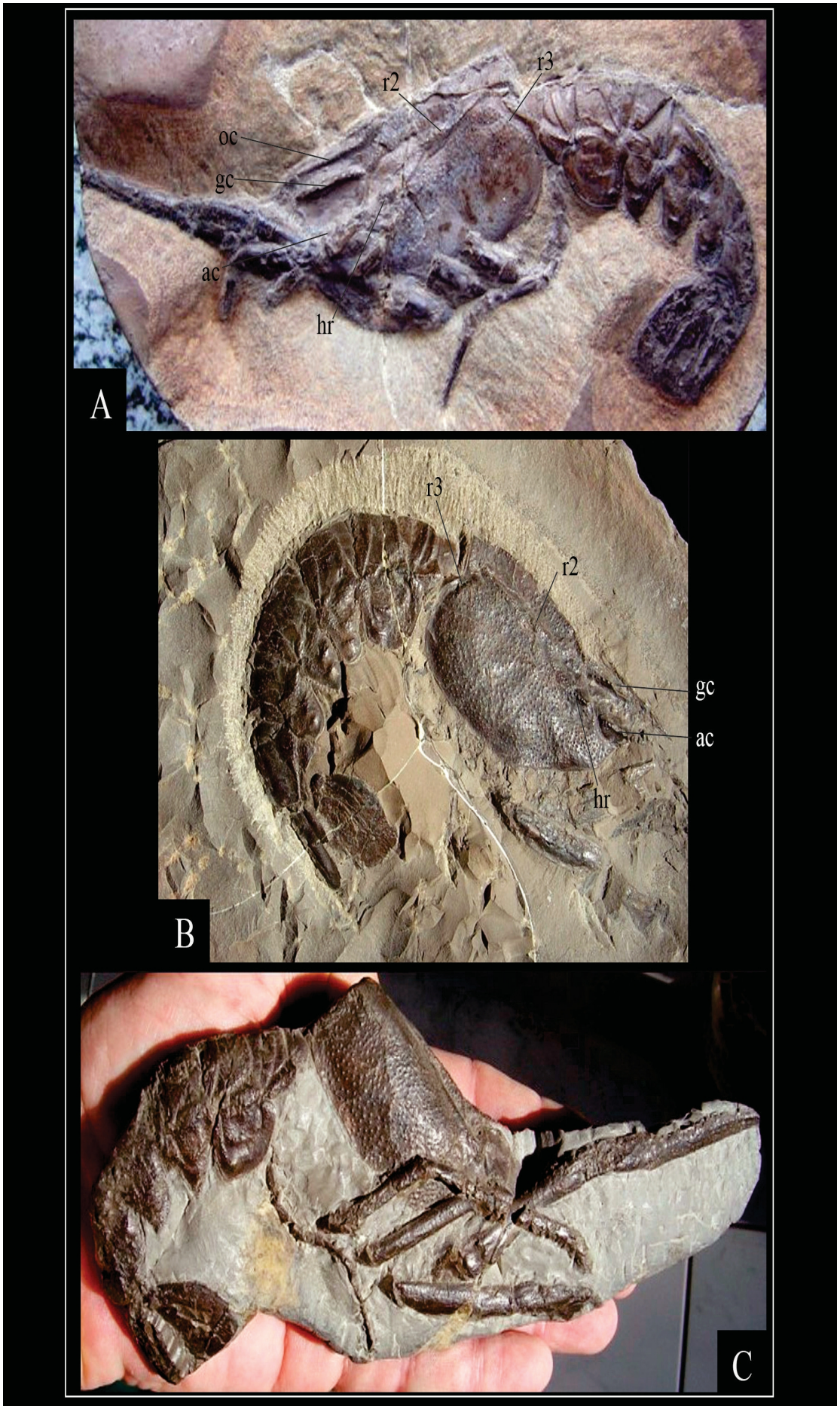
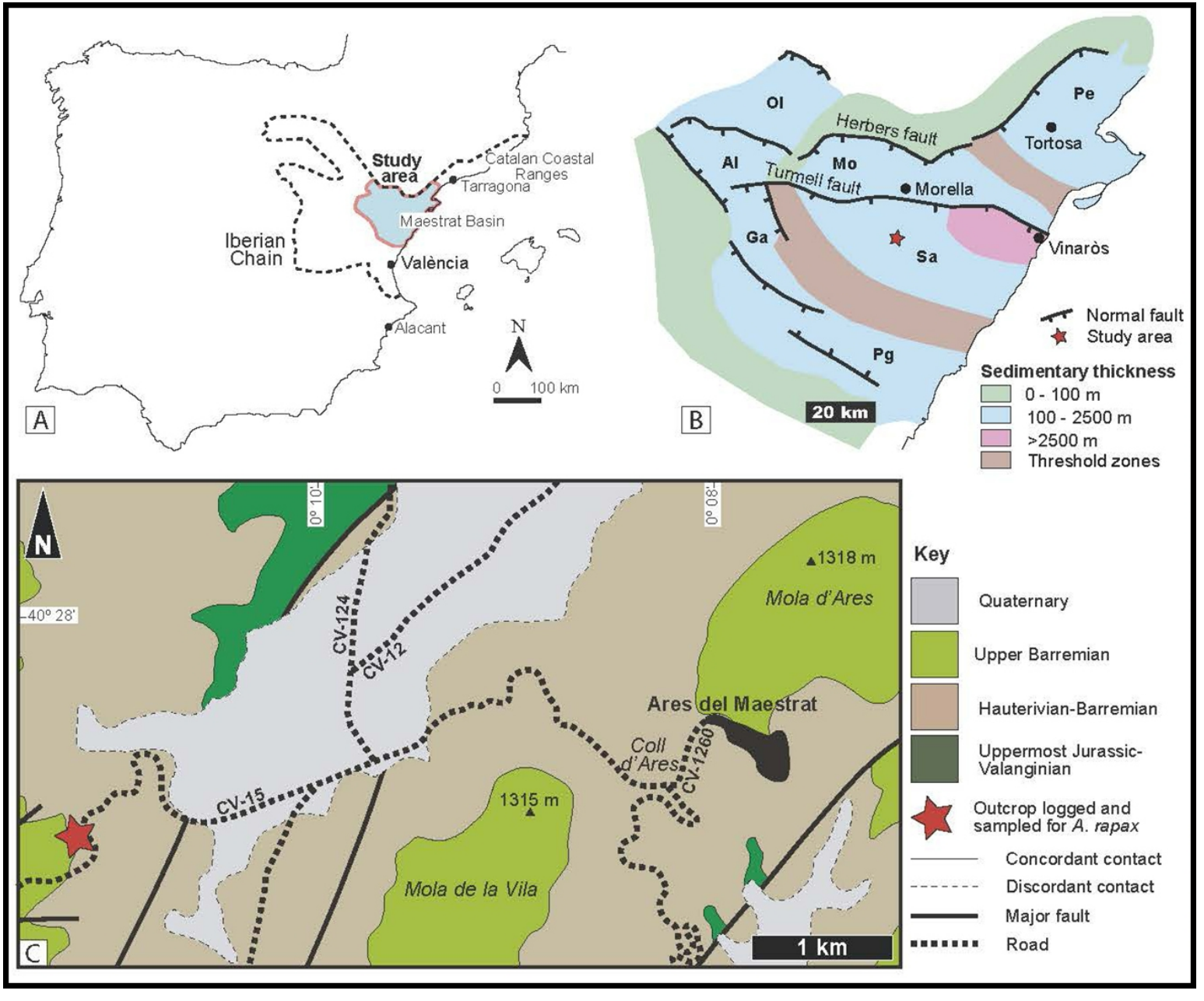
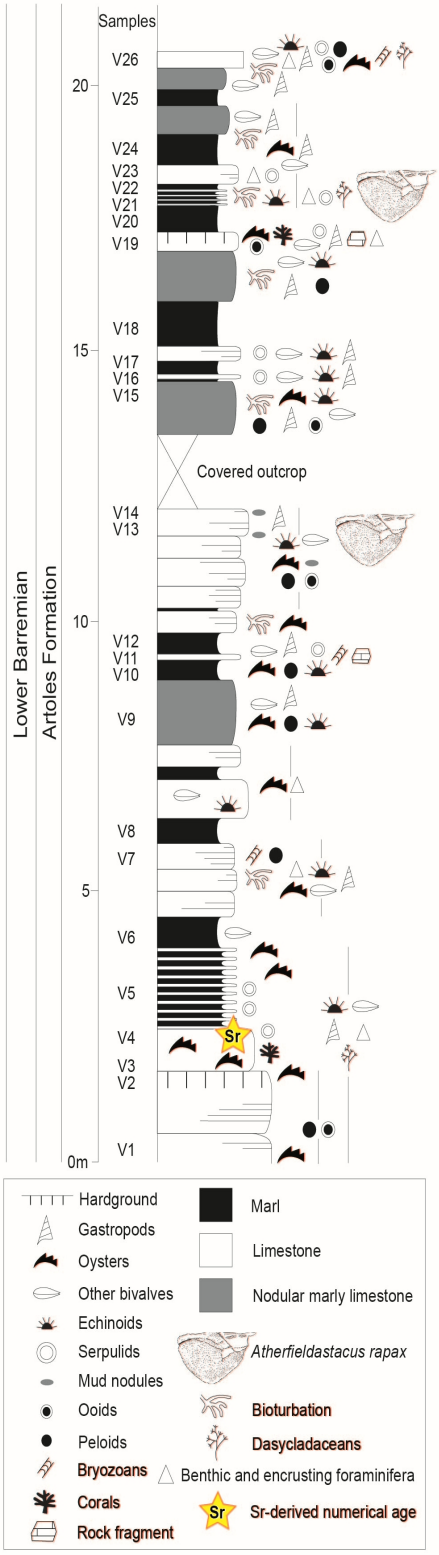
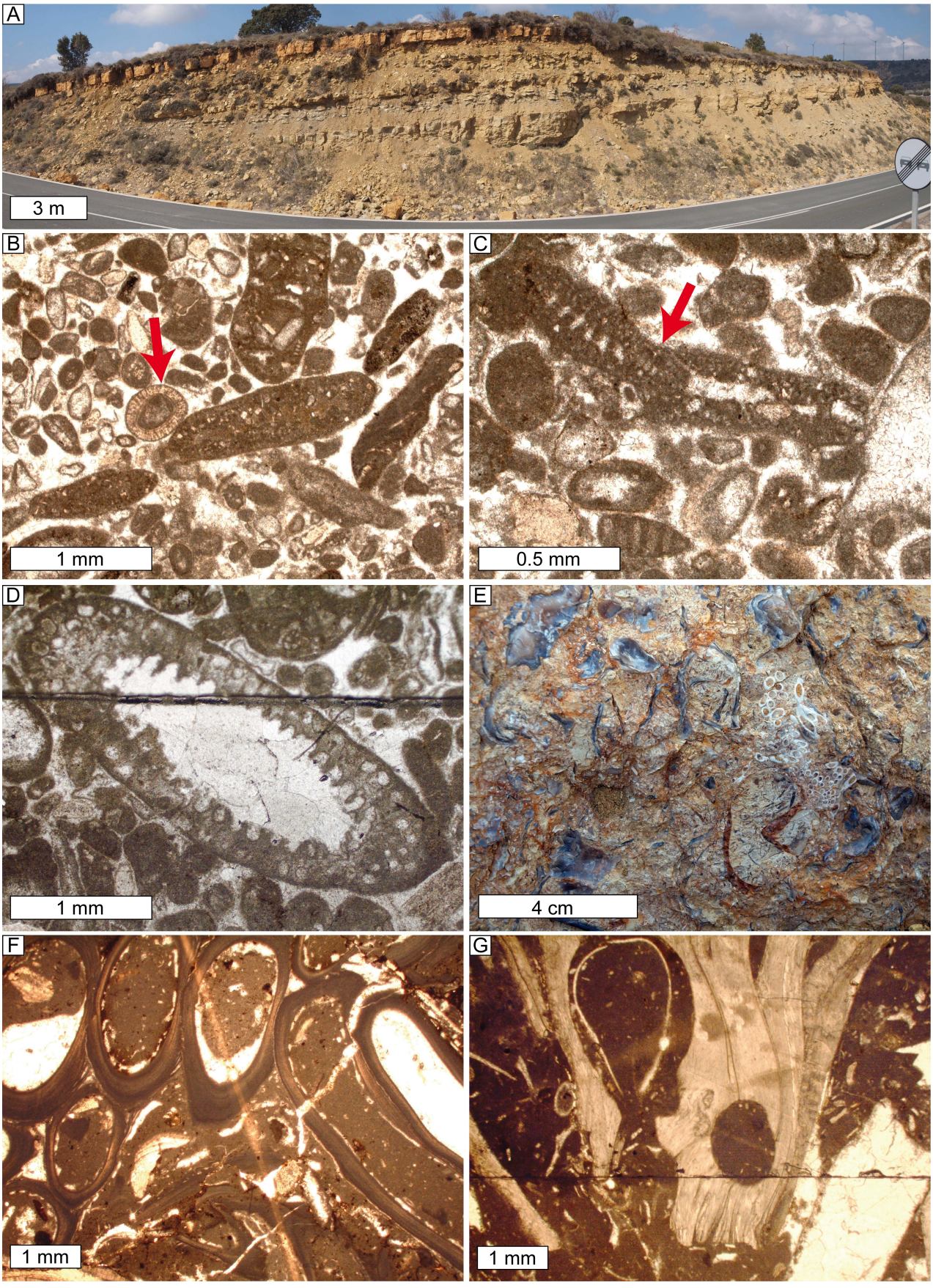
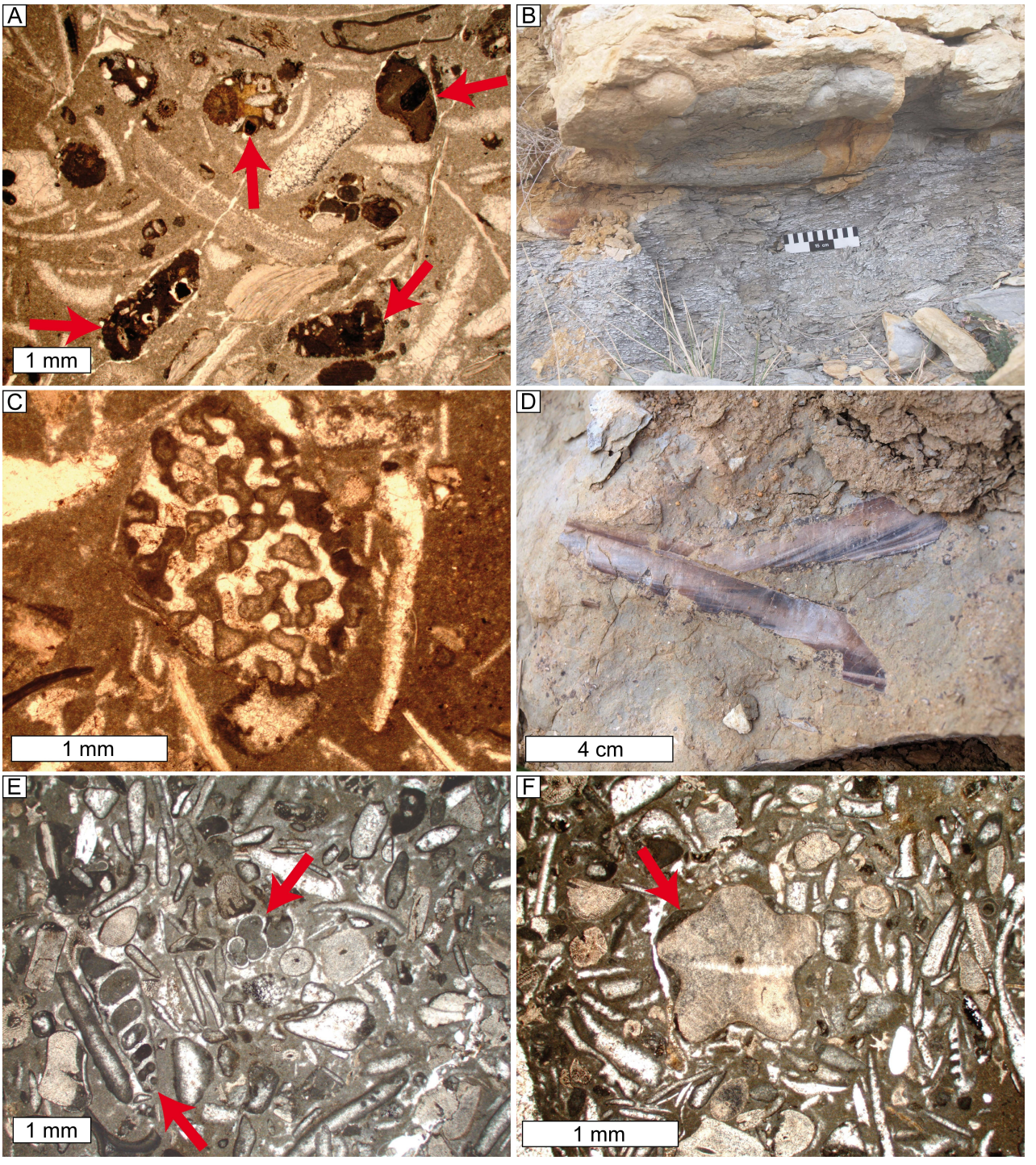
10 mm
C

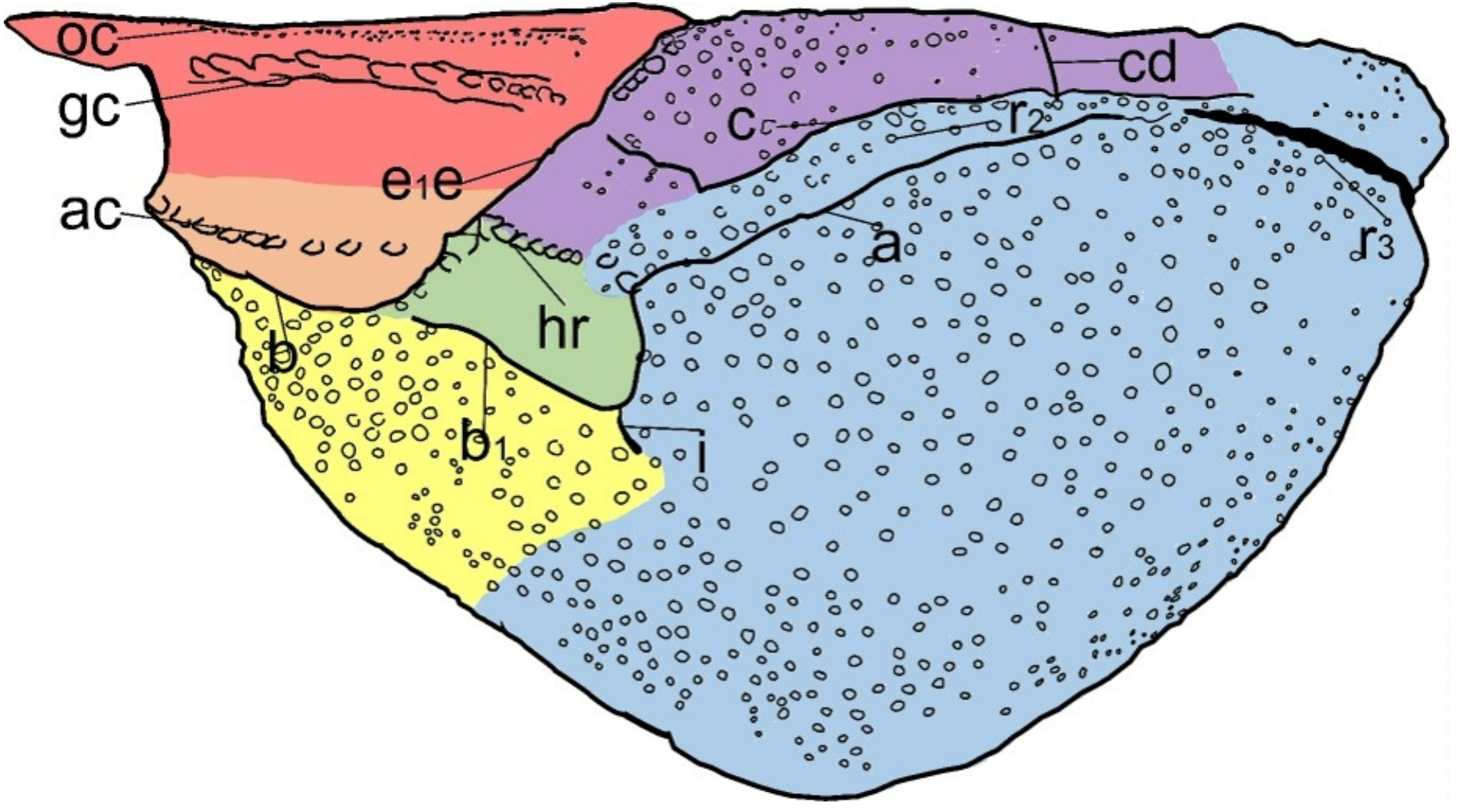

r2
r3
oc
gc
ac
hr
A
r3
r2
gc
ac
hr
B
C

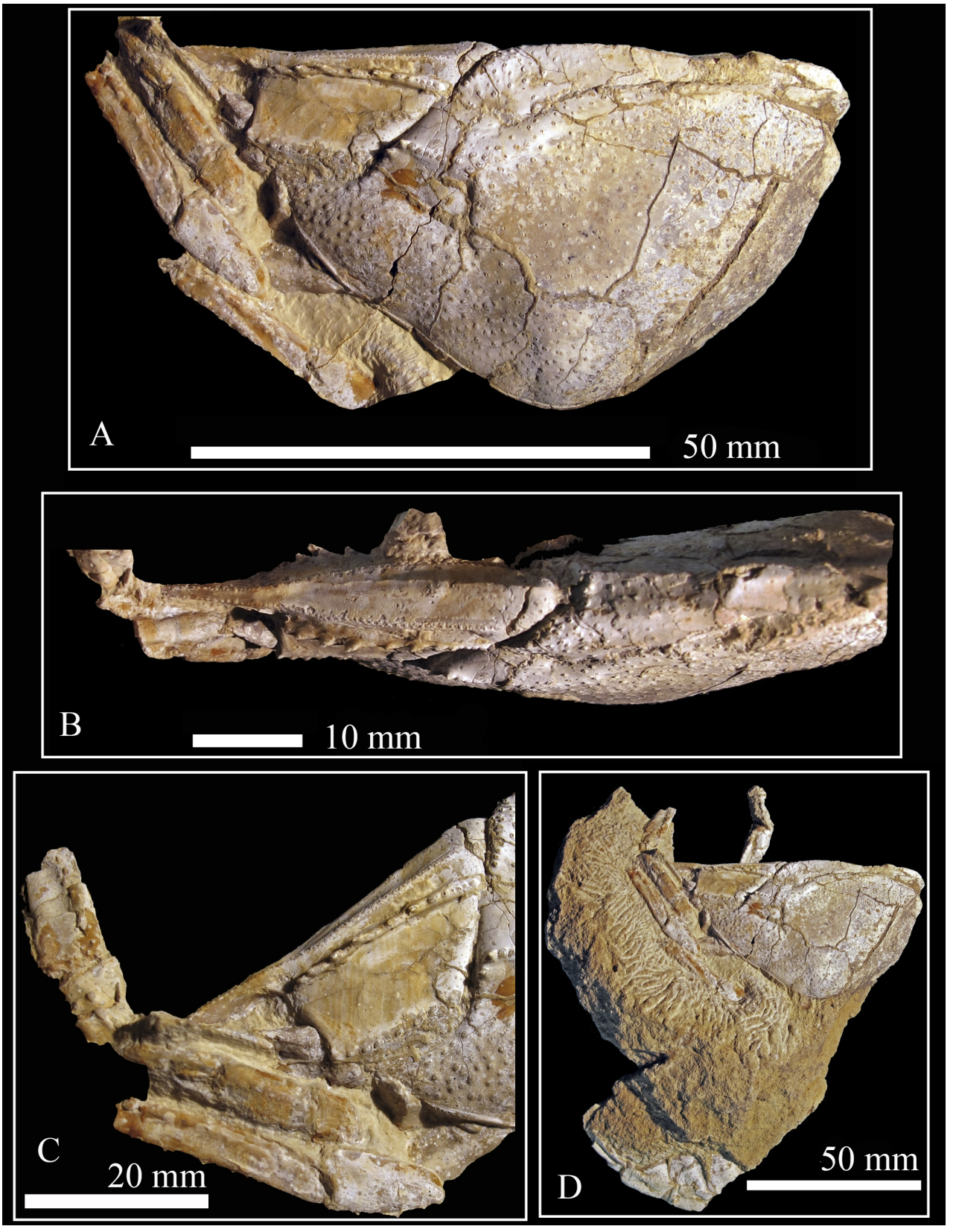

A
Study area
Catalan Coastal Ranges
Tarragona
Maestrat Basin
Iberian Chain
València
Alacant
N
0 100 km
B
Ol
Herbers fault
Pe
Tortosa
Al
Mo
Turmell fault
Morella
Ga
Sa
Vinaròs
Pg
20 km
Normal fault
Study area
Sedimentary thickness
0 - 100 m
100 - 2500 m
>2500 m
Threshold zones
C
N
0º 10'
0º 08'
40º 28'
1318 m
Mola d'Ares
CV-124
CV-12
Ares del Maestrat
Coll d'Ares
CV-1260
CV-15
1315 m
Mola de la Vila
1 km
Key
Quaternary
Upper Barremian
Hauterivian-Barremian
Uppermost Jurassic-Valanginian
Outcrop logged and sampled for A. rapax
Concordant contact
Discordant contact
Major fault
Road

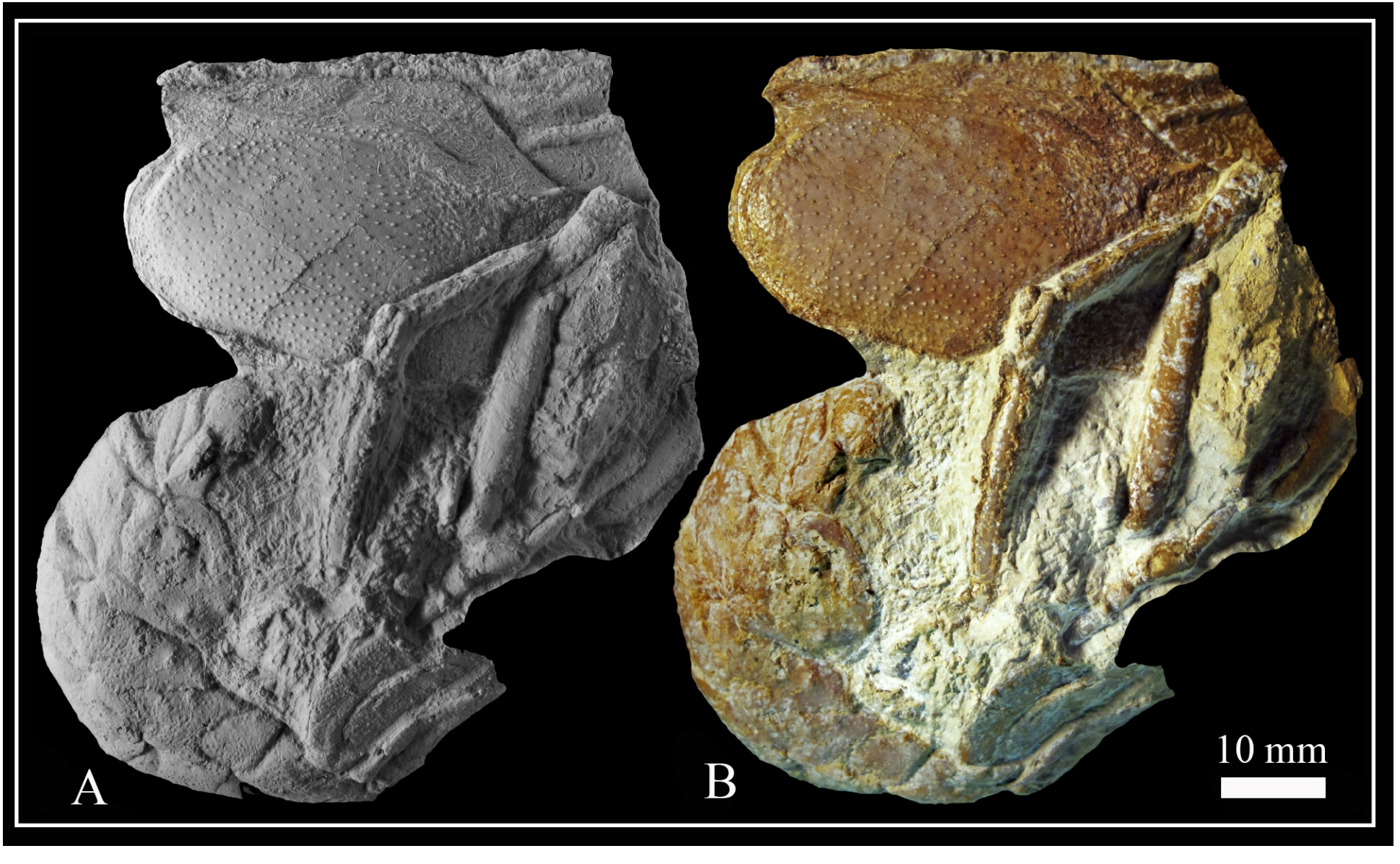

Lower Barremian
Artoles Formation
Samples
V26
V25
V24
V23
V22
V21
V20
V19
V18
V17
V16
V15
Covered outcrop
V14
V13
V12
V11
V10
V9
V8
V7
V6
V5
V4
V3
V2
V1
Sr
20
15
10
5
0m
Hardground
Gastropods
Oysters
Other bivalves
Echinoids
Serpulids
Mud nodules
Ooids
Peloids
Bryozoans
Corals
Rock fragment
Marl
Limestone
Nodular marly limestone
Atherfieldastacus rapax
Bioturbation
Dasycladaceans
Benthic and encrusting foraminifera
Sr-derived numerical age


A
3 m
B
1 mm
C
0.5 mm
D
1 mm
E
4 cm
F
1 mm
G
1 mm


A
1 mm
B
15 cm
C
1 mm
D
4 cm
E
1 mm
F
1 mm


oc
gc
ac
e1e
c
cd
r2
a
r3
hr
b
b1
i


A
50 mm
B
10 mm
C
20 mm
D
50 mm


A
B
10 mm


10 mm
A
10 mm
B
10 mm
C

Sample	Component	$^{87}Sr/^{86}Sr$ measured	± 2 se sample	$^{87}Sr/^{86}Sr$ corrected	± 2 se mean sample values	Ca ppm	Mg ppm	Sr ppm	Fe ppm	Mn ppm	min	Age (Ma)	max	Stage
V4A	Oyster	0,707454	0,000005	0,707468		391480	673	797,5	96,4	21,8				
V4B	Oyster	0,707461	0,000005	0,707475		392500	1050	846,9	83,0	26,3				
			mean	**0,707472**	0,000011						128,54	130,43	131,83	latest Hauterivian / Early Barremian
											125,86	126,46	127,27	Late Barremian

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- The first occurrence of the decapod mecochirid *Atherfieldastacus rapax* (*Meyeria rapax*) of the Artoles Formation NE Spain.

- Microfacies and paleontological analyses of the sedimentary succession containing the fossil lobsters allow us to infer a near-coastal depositional setting.

- Numerical ages derived from Sr-isotope analyses combined with previous chronostratigraphic studies of the Artoles Formation suggest an Early Barremian age for the stratigraphic interval.

- Morphological features in the Spanish specimens allows us included this material in the new genus recently proposed "*Atherfieldastacus*".