A NEW CARCINOSOMATID EURYPTERID FROM THE UPPER SILURIAN OF NORTHERN VIETNAM

by SIMON J. BRADDY, PAUL A. SELDEN *and* DOAN NHAT TRUONG

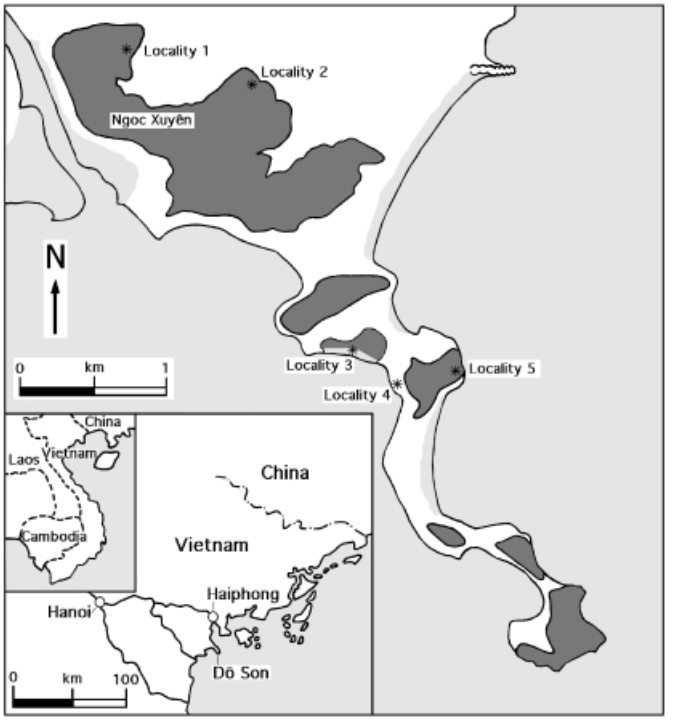
ABSTRACT. A new carcinosomatid eurypterid, *Rhinocarcinosoma dosonensis* sp. nov., and *Hughmilleria* sp., are described from the Dô Son Formation of the Dô Son Peninsula, northern Vietnam. *R. dosonensis* is characterized by podomere 7 of prosomal appendage VI produced into an anterodistal spine, a metastoma with a cordate posterior margin, and an indented opisthosomal differentiation (i.e. preabdomen-postabdomen margin is concave). The Dô Son Formation was originally interpreted as Late Devonian (Givetian/Frasnian) in age but the unit containing the eurypterid assemblage is now considered much older (Late Silurian). A deltaic palaeoenvironmental setting is interpreted from biotic associations and sedimentological evidence.

KEY WORDS: chelicerate, eurypterid, Carsinosomatidae, Silurian, Vietnam, stratigraphy.

THE Dô Son Formation is almost entirely restricted in exposure to the Dô Son Peninsula, a 4-km projection into the Gulf of Bac Bo (Tonkin), around 13 km south-east of Hai Phong in northern Vietnam (Text-fig. 1). It is approximately 400 m thick but its detailed stratigraphy remains debated. Nguyên Dình Hòe (pers. comm. 1991) suggested that it may consist of three members: a 100–200-m-thick lower member of yellow-grey, massive, cross-bedded sandstones, a 100-m-thick middle member of pale red, cross-bedded sandstones interbedded with light grey-green siltstones and clay lenses, and a 150-m-thick upper member of light-green sandstones, siltstones, clays and shales. These siliciclastic deposits generally show a moderate (10–20°) dip to the south-east, but there seem to be local changes in dip direction, possibly due to faults.

Fossils are extremely rare in the Dô Son Formation, hence the problem in assessing an age for its various members. Fishes (the antiarchs *Bothriolepis* sp. and *Vietnamaspis trii*; Janvier *et al*. 1989; Long *et al*. 1990) and plants (the lycophytes *Colpodexylon* and *Lepidodendropsis*; Janvier *et al*. 1989; Tông-Dzuy and Cai 1995) have been discovered in the massive white sandstones, presumably of the lower member, which crop out along the south-eastern coast of the peninsula (localities 3–5, Text-fig. 1). This fossil assemblage is strongly suggestive of a Givetian–Frasnian age. The middle member has yielded some brachiopods (*Lingula* sp. aff. *L. yunnanensis*, *L.* sp. aff. *L. subparallella*), bivalves [*Ptychoparia* (*Actinoptera*) sp. aff. *P. yunnanensis*, *Modiolopsis* sp. aff. *M. yunnanensis*], fish remains (Tông-Dzuy *et al*. 1994), and the eurypterids described herein, which come from the outcrop of Ngoc Xuyên, in the north-western part of the peninsula (locality 1, Text-fig. 1). The upper member only yields *Thalassinoides*-like burrows, presumably of crustaceans.

The relative homogeneity of the Dô Son Formation first suggested that it was entirely Givetian–Frasnian in age, as indicated by the fishes and plants, supposedly from the lower member. However, the excavations made in the eurypterid-bearing locality at Ngoc Xuyên revealed some inconsistencies in this assessment. First, the eurypterid belongs to the genus *Rhinocarcinosoma*, hitherto known exclusively from the Upper Silurian, yet this very rare taxon may well have gone unnoticed and survived until the Late Devonian. Second, the fish remains found in crustacean burrows just above the eurypterid-bearing clay lens do not belong to any of the taxa described by Janvier *et al*. (1989) and Long *et al*. (1990) from the 'lower member'. One of these remains is a strange anterior ventrolateral plate of a placoderm which was said by Tông-Dzuy *et al*. (1994) and Janvier *et al*. (1994) to belong to no known placoderm group, yet sharing some features with the antiarchs. Surprisingly, this plate is strikingly similar to an AVL placoderm



TEXT-FIG. 1. Map of the Dô Son Peninsula showing the outcrop of the Dô Son Formation (dark shading) and the fossil localities. Eurypterid material collected from localities 1 and 2. Associated plant and fish material collected from localities 3–5 (see text for details).

plate found in 1997 in the new Upper Silurian fish locality of My Duc (Quang Binh Province, central Vietnam) and referred to the *incertae sedis* placoderm *Myducosteus anmaensis* (Tông-Dzuy *et al*. 1997). Third, some claystone horizons, presumably of the middle member, yield psilophyte remains, which have been referred to *Cooksonia* and suggested an Early Devonian age (Janvier *et al*. 1987), but this age was doubted soon after (Janvier *et al*. 1989), when *Bothriolepis* and *Colpodexylon* were discovered in the Dô Son Formation. Fourth, palynological samples (mainly triradiate spores) that are diagnostic of a Late Silurian age, have been retrieved from samples obtained from locality 2 (J. Marshall, pers. comm. 1999).

One may thus raise the possibility that the eurypterid-bearing locality of Ngoc Xuyên is Late Silurian in age, thereby implying that the entire Dô Son Formation extends from the Upper Silurian to the Givetian or Frasnian, and that its stratigraphy has to be seriously revised, keeping in mind that the succession may be structurally complex. Another argument may also support this new interpretation: the Kien An hills, about 15 km west of Dô Son, consist of extensively quarried, black Silurian limestone, the top of which passes progressively into calcareous sandstones containing a rich Ludlow-Přídolí fauna dated by, for example, *Retziella weberi*. In the westernmost part of these hills, the *Retziella weberi*-bearing sandstones pass progressively into reddish, azoic sandstones and claystones which are extremely similar to the Dô Son sandstones. This suggests that Upper Silurian or Lower Devonian siliciclastic sediments do exist in this area. Unfortunately, the relationships between the Dô Son Formation and the Silurian of Kien An is unknown, as these two Palaeozoic outcrops are completely surrounded by thick Neogene sediments of the Red River Delta. It is not ruled out that the tectonics of this area are rather complex and that the Dô Son–Kien An outcrops belong to an allochthonous terrane, since the westernmost part of the Kien An hills ends with a major, N–S fault which brings the Silurian sandstones in contact with a small outcrop of massive, black limestone of Eifelian–Famennian age (the Elephant mountain, or Nui Voi). It is difficult to

understand how such a typical carbonate platform limestone could have been only 15 km or so from the deltaic facies of the Dô Son Formation, without showing the slightest trace of siliciclastic episodes.

The locality that has produced most of the eurypterid material (IGMR BT166/1–27) and a fragment of phyllocarid cuticle (IGMR BT166/30) is a small quarry situated just north of the main village on the Dô Son Peninsula, on the hill Ngoc Xuyên (locality 1, Text-fig. 1), in the north-western part of the peninsula. Additional eurypterid fragments (IGMR BT166/28-29) were collected from nearby (locality 2, Text-fig. 1). Bivalves and plant remains were found in smaller nearby quarries. Precise locality details of the Ngoc Xuyên quarry were discussed by Tông-Dzuy *et al.* (1994). All the Ngoc Xuyên material was derived from one particular shaly horizon that occurs in a sequence of interbedded coarse sandstones and shales within the quarry. The sedimentology of these rocks suggests that they represent alluvial sand channels within a deltaic system in a semi-arid environment. The best preserved and most complete material was collected from the base of this bed, although more fragmentary remains occur throughout this unit. This horizon varies in thickness; where the most complete eurypterid material was discovered, it is around twice the thickness of the rest of the bed, suggesting that the eurypterid-bearing clay lens represents a fluvial channel or cut-off pool within a fluvial/deltaic system. The very finely laminated nature, and slightly soapy feel, of the argillaceous lithology which contains the eurypterid remains is suggestive of a slightly evaporitic depositional setting. The material from locality 2 occurs in a lighter brown, sandier lithology, which has derived acritarchs and scolecodonts (J. Marshall, pers. comm. 1999) indicating marine incursions in this part of the sequence.

Only recently have western researchers been able to collect fossils in Vietnam. Fossil fish have been known from northern Vietnam for some time (e.g. Janvier *et al.* 1989; Long *et al.* 1990) but this is the first record of a Vietnamese eurypterid. Recently, some scraps of eurypterid cuticle have been found in the Pragian of Ha Giang Province, northern Vietnam (P. Janvier, pers. comm. 1999). Only a few eurypterids have been recorded from elsewhere in east Asia, all from China (Chang 1957). *Adelophthalmus chinensis* was described by Grabau (1920) from the Lower Permian of Chaokochuang, Kaiping District, Hopeh Province. In 1924 a poorly preserved eurypterid telson was found in the Upper Silurian of eastern Yunnan, but it was not assigned to a genus. Chang (1957) described three new species of *Eurypterus*: *E. yangi*, *E. styliformis* and *E. loi*, as well as a possible *Mixopterus* carapace from Middle Silurian strata near Yang-chiapei, Tzekwei, Hupeh Province. This carapace was described as trapezoid in shape, the width of the anterior margin about one-third that of the posterior margin with the eyes located anterolaterally. This carapace shape is most unlike *Mixopterus* (which has a quadrate carapace) and more suggestive of the genus *Paracarcinosoma*. Apart from this equivocal specimen, carcinosomatid eurypterids are unknown from Asia. Three eurypterid specimens (?*Onychopterella*) lacking appendages have also been collected from the Middle–Upper Ordovician of Shanxi Province, north-west China (Shen Yanbin, pers. comm. 1999), although one is probably an orthocone nautiloid.

Rhinocarcinosoma has previously been described only from the Upper Silurian of New York State, eastern USA (Clarke and Ruedemann 1912) and Somerset Island in the Canadian Arctic (Jones and Kjellesvig-Waering 1985). The discovery of the Vietnamese example represents the first occurrence of *Rhinocarcinosoma* outside North America. The suggestion that the temporal range of the Carcinosomatidae may extend into the Frasnian, based on this material (Selden 1993, fig. 17.1), now needs to be revised, given the evidence (see above) for its greater age.

The Carcinosomatidae, along with the Pterygotidae, were recognised by Kjellesvig-Waering (1961) as representatives of the most marine eurypterid palaeoecological phase. Plotnick (1983) considered that *Carcinosoma*, *Eocarcinosoma* and *Paracarcinosoma* were restricted to inner shelf and marginal marine environments, whereas the ecological range of *Rhinocarcinosoma* extended into non-marine environments. The occurrence of the Vietnamese example from a deltaic setting agrees with the ecological range of this genus.

MATERIAL AND TERMINOLOGY

Thirty specimens were selected for this study from the large amount of material collected, much of which reveals little morphological information. They are housed in the Institute of Geology and Mineral

Resources, Do ng Da, Hanoi, Vietnam (IGMR), under the composite repository number BT166. Each individual specimen is given a separate number thus: BT166/1, BT166/2. A lower case 'a' denotes part, 'b' denotes counterpart.

The holotype (IGMR BT166/1) and several additional fragments (IGMR BT166/2–9) were collected in 1987 by P. Janvier. A further collection of material (IGMR BT166/10–30) was made by SJB and DNT during fieldwork with Janvier and Tông-Dzuy in 1993 (Braddy 1994; Tông-Dzuy *et al.* 1994). Specimen IGMR BT166/1 was broken into three pieces during collection but repaired with clear epoxy resin prior to this study. Specimens IGMR BT166/1–6 were conserved with a surface covering of a clear consolidant. The remaining specimens were originally collected as one piece. Some specimens were prepared, particularly IGMR BT166/18, to reveal more of the fossils.

Morphological descriptions and terminology follow Tollerton (1989). The term 'prosoma' is used in preference to 'cephalothorax'. The term 'carapace' denotes the dorsal shield of the prosoma. Prosomal appendages are denoted by Roman numerals. Individual podomeres are numbered from proximal to distal.

PRESERVATION

IGMR BT166/1–27 and 30 are preserved in a finely laminated, light grey, argillaceous lithology. IGMR BT166/28–29 are preserved in a slightly coarser, light brown sandstone. All of the material consists of external moulds and is preserved as light brown replacements of the original cuticle or shiny, grey to black, thin carbon films. The precise preservational chemistry of these specimens is unknown. Most of the specimens are crushed flat but some show irregular, crumpled surfaces. Only IGMR BT166/18 is three-dimensionally preserved.

Much of the material consists of semi-articulated appendages or opisthosomal tergites, although genital operculae and telsons are also present. Fully articulated specimens are represented only by IGMR BT166/1 and 166/10. Complete articulated eurypterid fossils are generally rare, since most represent exuviae which are easily disarticulated in currents or distorted during burial and compaction.

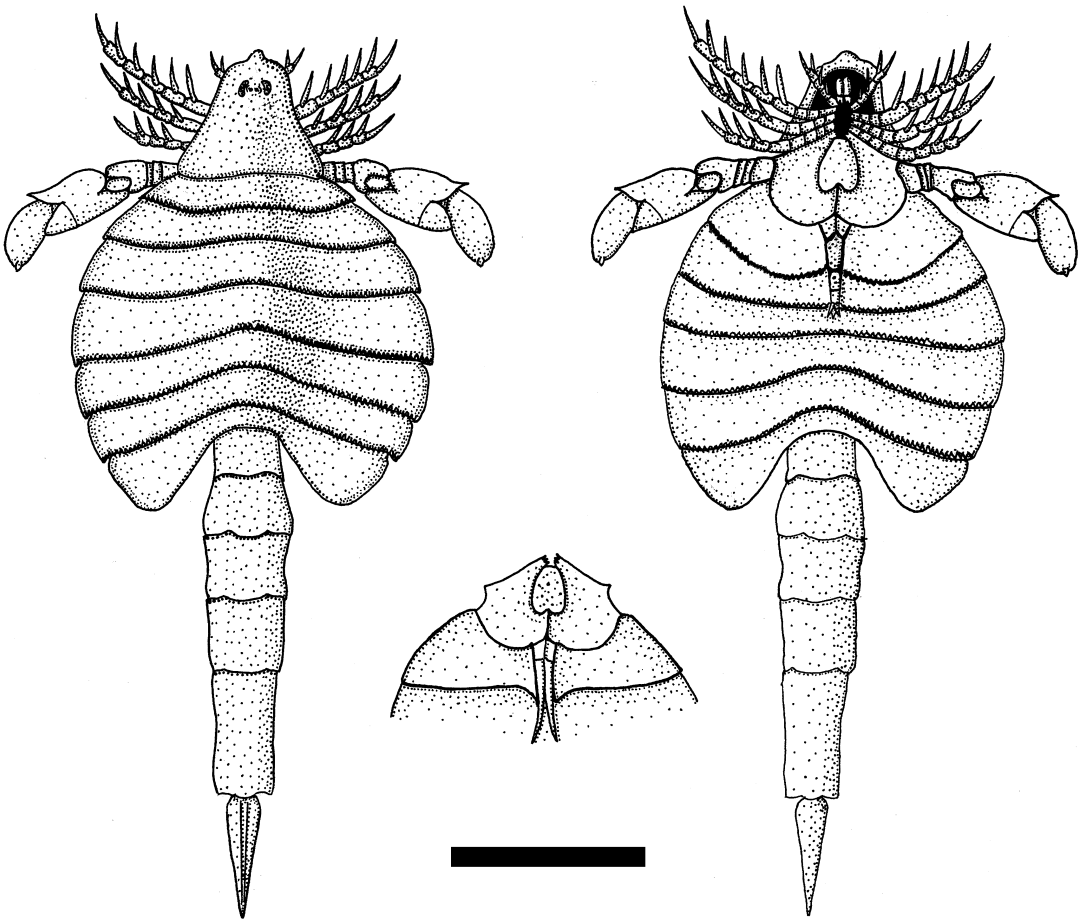
The holotype, IGMR BT166/1, shows portions of the dorsal tergites extending beyond the lateral and posterior edges of the ventral Blattfüsse. The segmentation of the preabdomen may only be distinguished under very low angle illumination owing to the compression of the material. The posterior preabdominal segments are partially telescoped into each other and the first postabdominal segment is telescoped into the preabdomen. The indented opisthosomal differentiation may, therefore, have been exaggerated by this telescoping. Similar opisthosomal indentation was noted in *Rhinocarcinosoma cicerops* by Clarke and Ruedemann (1912, pl. 36, fig. 5), which was also suggested by these authors to be partly due to the mode of preservation. We consider that the indented opisthosomal differentiation displayed in this material is not, however, entirely preservational, but that a true morphological characteristic of this animal has been exaggerated. The medial axis of the holotype is curved slightly to the left. The postabdomen and telson are also turned to the left. This suggests that current activity preserved this specimen out of axial alignment.

There is no evidence (e.g. internal organs such as the endosternite or muscle tissues) that any of this material represents mortalities (i.e. dead carcasses), and it is suggested that all of it represents moulted exuviae. A single eurypterid would have moulted several times during its life, leaving many more moults than carcasses in the fossil record. Carcasses may also be scavenged, lowering their preservation potential. Exuviae may be disarticulated, crumpled, flattened, partially telescoped or distorted, as in much of this material.

MORPHOLOGICAL RECONSTRUCTION

The material available enables a reconstruction of the dorsal and ventral surfaces of the new species to be made (Text-fig. 2). Where features are lacking on the material they are reconstructed from the other species of *Rhinocarcinosoma*, particularly *R. vaningeni*. An animal based on the proportions of the holotype would have been approximately 23 cm long from the front of its carapace to the tip of its telson. The largest material (IGMR BT166/23, podomere 7 of appendage VI) indicates an animal of around 33 cm long.

Based on IGMR BT166/1b (Text-fig. 3C), the posterolateral corner of the carapace is gently curved



TEXT-FIG. 2. *Rhinocarcinosoma dosonensis* sp. nov. Dorsal (left) and ventral (right) reconstruction of a female, bearing a type-A genital appendage. Reconstruction of type-B genital operculum and appendage (centre). Scale bar represents 5 cm.

within a lateral angle of 115 degrees; the lateral margins of the carapace converge anteriorly. The morphology of the anterior carapace is reconstructed as triangular, with a blunt anterior process on the front of the carapace, based on IGMR BT166/10 (Text-figs 5–6) and the other species of *Rhinocarcinosoma*. The lateral eyes are reconstructed as situated submarginally, at the anterior of the carapace. The median ocelli are reconstructed on a prominent ocular mound between the lateral eyes.

The chelicerae are broad and short, based on IGMR BT166/10 (Text-figs 5–6). Appendages II–V are reconstructed as long, slender, terete spiniferous limbs. Appendage VI is based on IGMR BT166/1 (Text-fig. 3A), 166/6b (Pl. 1, fig. 4), 166/21 (Pl. 1, fig. 2) and 166/26 (Pl. 1, fig. 1). The metastoma has a cordate posterior margin, based on IGMR BT166/1a, and tapers anteriorly.

The ala of the type-A genital operculum are large and broadly curved, based on IGMR BT166/1a and 166/5. The type-A genital appendage consists of three segments and short, curved terminal furca, based on IGMR BT166/5. The ala of the type-B genital operculum have a concave anterior margin and are produced into a broad flange near the mid-line, based on IGMR BT166/24 (Pl. 2, fig. 3). These flanges presumably would have assisted in keeping the furca close to the body when the operculum was unflexed

(see Braddy and Dunlop 1997). The type-B genital appendage consists of two long curved furca, based on IGMR BT166/24.

The opisthosoma consists of a broad preabdomen showing an indented, abrupt, first order differentiation with a caudal postabdomen, based on IGMR BT166/1. The segmentation of the preabdomen may be seen with low angle illumination of the specimen. The tergites project out from behind the Blattfüsse in IGMR BT166/1a, allowing a tentative reconstruction of the dorsal aspect, which is considered to have been medially convex with flatter pleural regions, explaining the lateral projection of the tergites beyond the Blattfüsse upon compaction. The ventral aspect was flatter. The indented differentiation of the opisthosoma is interpreted as a true morphological feature of this animal, although it is reconstructed as less severe than in IGMR BT166/1a, as it was probably over-emphasized by the telescoping and compaction (see above). The dorsal medial convexity of the preabdomen is reconstructed as grading into the caudal postabdomen. The postabdomen is based on IGMR BT166/1a. The telson is thin, tapering and slightly curved upwards distally, based on IGMR BT166/9 (Pl. 2, fig. 4).

SYSTEMATIC PALAEONTOLOGY

Order EURYPTERIDA Burmeister, 1843
Suborder EURYPTERINA Burmeister, 1843
Superfamily HUGHMILLEROIDEA Kjellesvig-Waering, 1951
Family CARCINOSOMATIDAE Størmer, 1934

Emended diagnosis. Body scorpion-like, subtriangular carapace with anteriorly positioned lateral eyes, epistoma narrow and short, walking legs strongly developed bearing long spines, swimming legs present (emended after Størmer, 1934).

Remarks. When the holotype was discovered it was provisionally identified as a chasmataspid (Waterston *in* Janvier *et al.* 1989), a group of chelicerates characterised by a preabdomen of three segments, but this interpretation was based solely on photographs from which it was not possible to discern the preabdominal segmentation. Study of the material revealed that it could be referred to Carcinosomatidae (Selden 1993; Braddy 1994).

Caster and Kjellesvig-Waering (1964) recognised four genera within Carcinosomatidae: *Carcinosoma*, *Eocarcinosoma*, *Paracarcinosoma*, and *Rhinocarcinosoma*. Størmer (1934) suggested that a curved telson, anteromedially positioned lateral eyes, and an anteriorly expanded metastoma, were all characteristic of this family, but these features are not present in all genera (as emended above). *Carcinosoma*, containing the majority of species, comprises medium to large forms with a subtriangular carapace, anterolaterally located eyes, appendages II–V strongly developed with long spines orientated anteriorly, appendage VI comprising a large paddle, a dorsoventrally flattened postabdomen, and a short, straight, styliform telson. *Eocarcinosoma*, only known from fragmentary material, is a small form with a broadly triangular carapace, the anterior margin bent downwards, with prominent kidney-shaped eyes located mid-laterally. *Paracarcinosoma* consists of small to medium forms with a triangular carapace, anterolaterally located eyes, appendages II–V weakly developed, orientated downwards, appendage VI much smaller than in *Carcinosoma*, an angular type-A genital operculum, a slender, terete postabdomen, and a curved telson. *Rhinocarcinosoma* consists of small to medium forms, their lateral eyes located intramarginally on a triangular or campanulate carapace that is elongated anteriorly into a linguiform, shovel-like process, indicating a mud-grubbing mode of life. Their prosomal appendages are weakly developed, as in *Paracarcinosoma*, but their type-A genital operculum is broader and rounded.

Genus RHINOCARCINOSOMA Novojilov, 1962

Emended diagnosis. Triangular or campanulate-shaped carapace with an anterior short, blunt process. Lateral eyes located antecentral. Prosomal appendage VI reduced. Type-A genital operculum rounded;

appendage composed of three segments and distal furca. Type-B genital operculum more angular with concave anterior margin; appendage comprised of long furca. Preabdomen broadly rounded, short first segment. Caudal postabdomen. Curved styliform telson (emended after Novojilov 1962).

Remarks. The Vietnamese material is referred to *Rhinocarcinosoma* as appendage VI is reduced (unlike *Carcinosoma*) and the type-A genital operculum is rounded (unlike *Paracarcinosoma*), although the diagnostic features of the carapace are lacking from the holotype. The carapace and anterior appendages are only preserved in IGMR BT166/10 (the juvenile); they show that the carapace was triangular, with a frontal extension, and the anterior appendages were slender, supporting this generic determination. This material enables the postabdomen, telson, and type-B genital operculum and appendage to be included with the morphological features which distinguish this genus.

Rhinocarcinosoma dosonensis sp. nov.

Plates 1–2; Text-figures 3–6

1989 Chasmataspida gen. and sp. indet.; Janvier *et al*., p. 630, fig. 4; pl. 1, fig. 13.
1993 probable carcinosomatid; Selden, p. 301.
1994 *Rhinocarcinosoma* sp.; Tông-Dzuy *et al*., pp. 2–5, fig. 3.
1994 *Rhinocarcinosoma dosonensis* (*nomen nudum*); Braddy, pp. 32–33; figs 1–2.

Derivation of name. Named after the locality, the Dô Son Peninsula of northern Vietnam, where the holotype was discovered in 1987 by Dr Philippe Janvier.

Holotype. IGMR BT166/1a, b: part (in two parts) and counterpart; posterior portion of prosoma, complete appendage VI, complete preabdomen, partial postabdomen and telson.

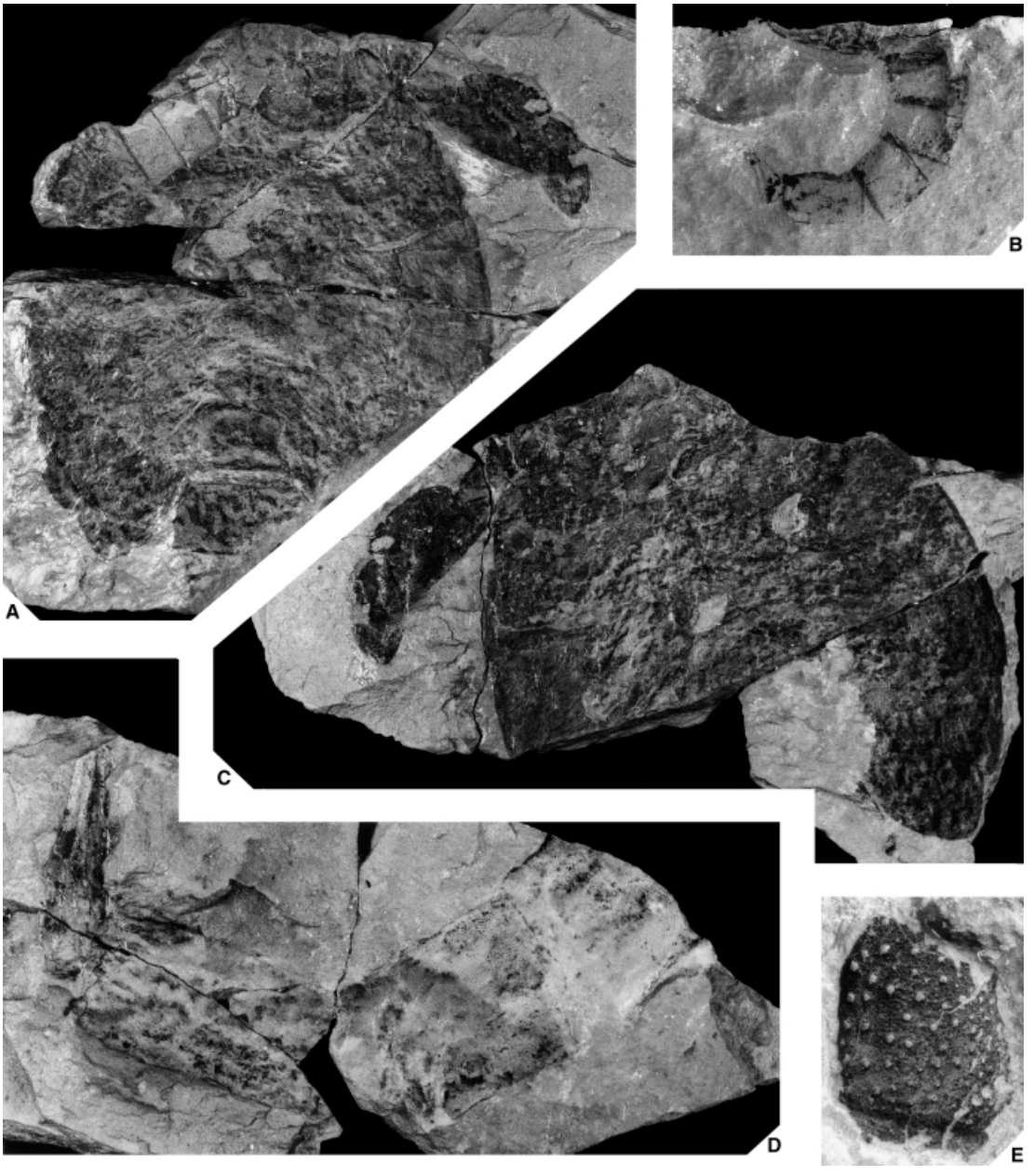
Other material. Paratypes, IGMR BT166/2–10, 14–16, 18–26, 29.

Horizon and locality. Middle Member, Dô Son Formation, Upper Silurian. Locality of IGMR BT166/1–27 is a large quarry in Ngoc Xuyên hill, north of the main village on the Dô Son Peninsula, northern Vietnam (locality 1, Text-fig. 1). IGMR BT166/29 was collected from a nearby locality (locality 2, Text-fig. 1).

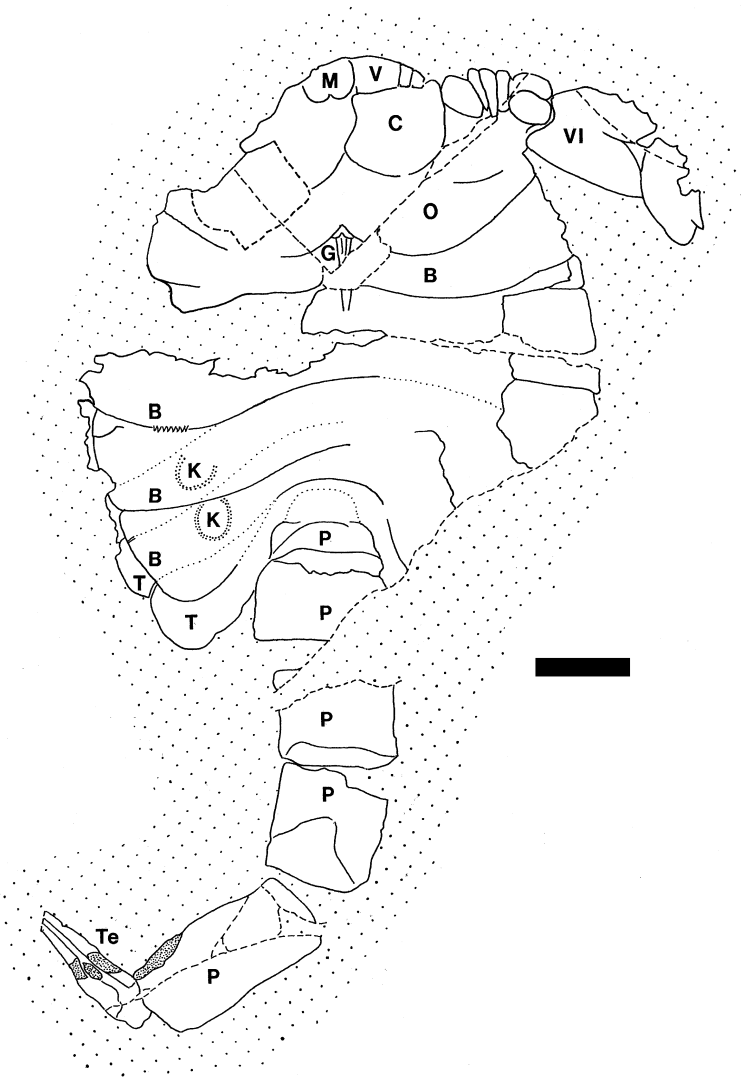
Diagnosis. Podomere 7 of prosomal appendage VI produced into an anterodistal spine. Metastoma with cordate posterior margin, tapering anteriorly. Preabdomen broad, with indented differentiation with a caudal postabdomen.

Description. Holotype IGMR BT166/1. Part consists of posterior edge of carapace, single coxa and proximal podomeres of appendage V, two coxae and distal podomeres of one appendage VI, entire opisthosoma and telson (Text-figs 3A, 4), although most of the postabdomen and telson are preserved on a separate piece (Text-figs 3D, 4). Coxa of appendage V 5·4 mm long. Podomere 2, 4·1 mm long. Podomere 3, 4·4 mm long. Appendage VI entire. Coxa 24 mm long, 16 mm wide, convex posterior margin. Podomere 2 oval, 5·1 mm long, 9·7 mm wide. Podomere 3 narrow, 1·3 mm long, 9·3 mm wide. Podomere 4 narrow, wedge-shaped, anterior length 3·5 mm, width 8·5 mm. Podomere 5 L-shaped, proximal portion 3·4 mm long, 7·4 mm wide, only posterior margin of anterior extension preserved. Podomere 6, oval, 10 mm long, 7·2 mm wide, deeply emarginate with proximal portion of podomere 7, itself subrectangular, 28 mm long, produced proximally and distally into two lobes, although anterior margin not preserved. Podomere 8 oval, 24 mm long, 12 mm wide. Tiny terminal ninth podomere 2·5 mm long, 1·3 mm wide. Posterior portion of metastoma, displaced slightly anteriorly, adjacent to coxa of appendage V, maximum width 14 mm, tapering anteriorly, posterior margin cordate. Width of posterior of prosoma reconstructed as 93 mm, calculated by doubling the distance from the medial margin of the coxa of appendage VI.

Compression has caused opisthosomal segmentation (tergites and Blattfüsse) to become superimposed. Type-A genital operculum, more clearly preserved on right side of specimen, relatively large and rounded medially, each ala 18 mm long, 43 mm wide. Middle portion of type-A genital appendage preserved along mid-line, width 1·6 mm. Anteriorly, two lobate structures may represent distal portion of basal segment. Blattfuss 1 evident on right side of specimen. Blattfuss 2 indistinct due to breakage, yet fine scale-like ornament occurs along portion of posterior margin,



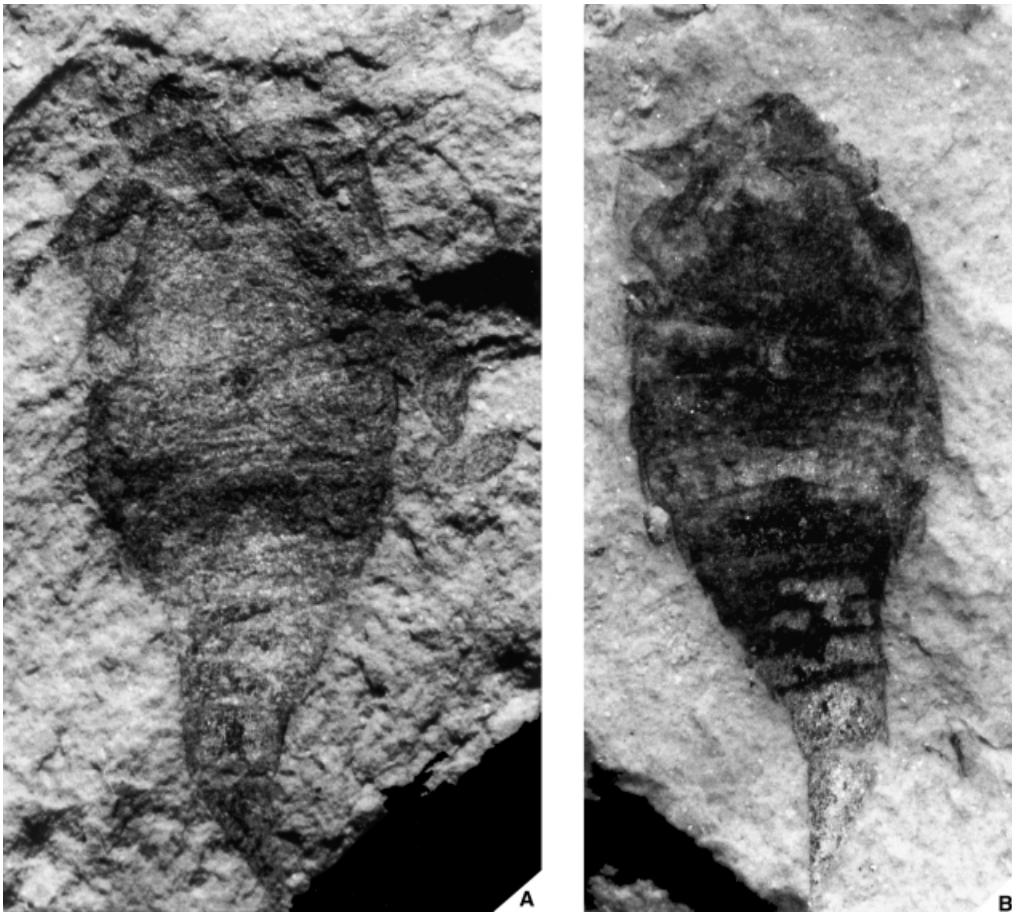
TEXT-FIG. 3. *Rhinocarcinosoma dosonensis* sp. nov., Dô Son Formation, Dô Son Peninsula, northern Vietnam. A, IGMR BT166/1a, holotype; posterior of prosoma, appendage VI, complete preabdomen and partial postabdomen; × 0·6. B, IGMR BT166/7, entire postabdomen and proximal part of telson; × 3·1. C, IGMR BT166/1b, holotype, posterior of prosoma, appendage VI, partial preabdomen; × 0·6. D, IGMR BT166/1a, holotype (separate slab), partial postabdomen and telson; × 1. E, IGMR BT166/8, coarsely ornamented cuticle; × 3.



TEXT-FIG. 4. *Rhinocarcinosoma dosonensis* sp. nov. Camera lucida drawing of the holotype, IGMR BT166/1a. B, Blattfuss; C, coxa of appendage VI; G, middle portion of type-A genital appendage; K, Kiemenplatten; M, metastoma; O, genital operculum; T, tergite; Te, telson; P, postabdominal segments. Scale bar represents 2 cm.

on left side. Blattfuss 3 and 4 evident on left side of specimen. Oval structures on left side of Blattfuss 3 (17 mm long, 10 mm wide, with a 1·2-mm-wide thickened margin) and Blattfuss 4 (11 mm long, 7 mm wide, with a 1-mm-wide thickened margin) are interpreted as Kiemenplatten. Lateral portions of tergites preserved on right side of specimen, their posterolateral corners angular. Lateral margins of tergite 6 and segment 7 extend beyond Blatfuss 4 at lower left side of specimen. Segment 7, partially overlapping Blattfuss 4 laterally, crescent-shaped with two rounded, posterolateral protrusions developed.

Deeply indented, abrupt, first order differentiation separates almost circular preabdomen and slender, caudal postabdomen, although this is made less distinct by the partial telescoping of the first postabdominal segment (8) into the preabdomen. The first two postabdominal segments, and a small corner of the third are preserved on this piece (Text-figs 3A, 4). Segment 8 expands posteriorly. Segment 9, partially preserved, disarticulated from adjacent

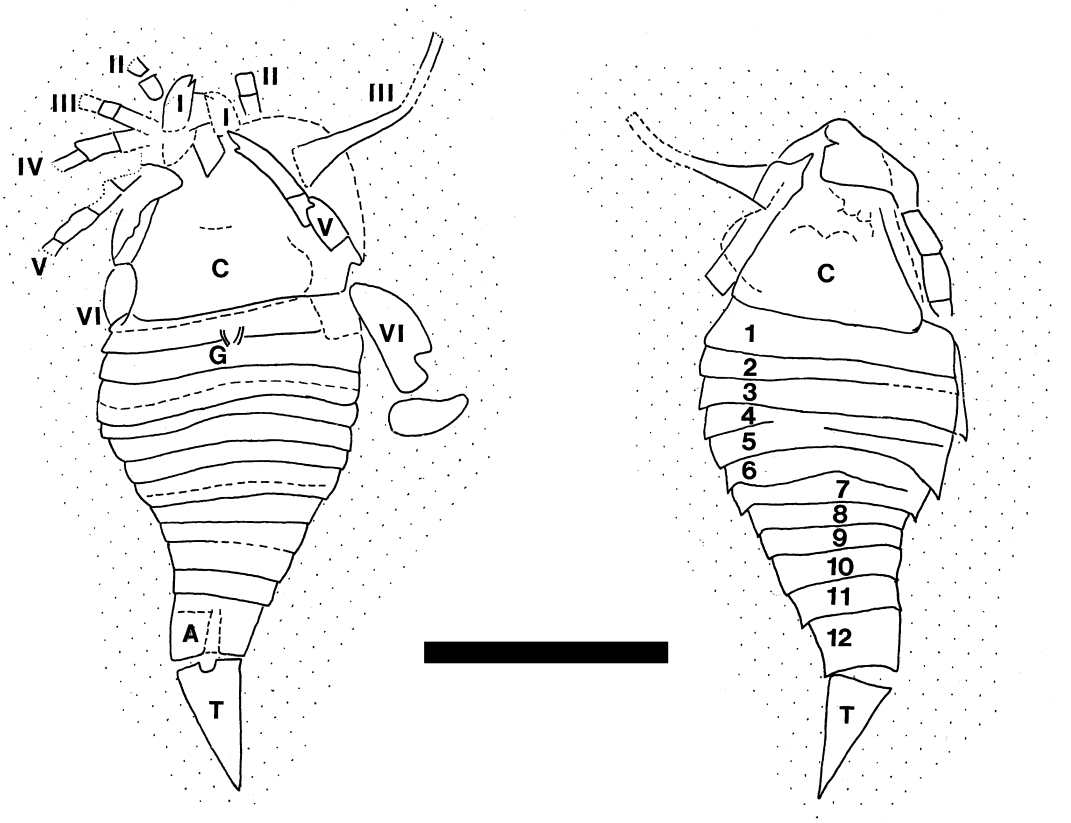


TEXT-FIG. 5. *Rhinocarcinosoma dosonensis* sp. nov., paratype (juvenile), IGMR BT166/10. A, part; B, counterpart; ×7·5.

segments and bearing traces of a fine, scale-like ornament. The postabdomen continues on separate slab, which shows the disarticulated posterior three postabdominal segments and the proximal half of the telson (Text-figs 3D, 4). Much of segment 10 is missing. Segments 10 and 11 have a scattered uniformly-sized, fine, scale-like ornament. Segment 12 (pretelson) partially disarticulated from segment 11. Proximal portion of telson, proximal width 9·7 mm, appears straight (curvature occurs distally in IGMR BT166/9, see below). A medial carina tapers posteriorly, proximal width 4·2 mm. A few small patches of brown cuticle with small lunules are preserved on telson and posterior portion of pretelson (Text-fig. 4).

Counterpart (IGMR BT166/1b) less complete than part, posterior of preabdomen, postabdomen and telson lacking (Text-fig. 3C). Concave posterior margin to carapace evident, curving anteriorly 3 mm in medial region. Lateral angle of carapace 115 degrees. Only podomeres 6–8 of appendage VI are preserved. The segmentation of the opisthosoma is less well-preserved than on the part. An impression of a portion of the genital appendage occurs along the mid-line. Segment 7 is apparent in the lower right corner, extending 3·6 mm beyond the lateral margin of Blattfuss 4.

IGMR BT166/10, another almost complete specimen, consists of part and counterpart of an articulated, very small individual (juvenile), 14·3 mm in total length (Text-figs 5–6). On part, proximal podomeres of prosomal appendages are preserved, partially obscuring outline of carapace. Lateral eyes, median ocelli and metastoma not preserved. Anterior appendages (I–V) best preserved on left side of carapace. Chelicerae large in proportion to such a small animal, length 1·3 mm, width 1·6 mm. Appendage II represented by two disarticulated podomeres on both sides, each 0·3 mm wide, although their position in the limb cannot be determined. Of appendage III, three podomeres are preserved on the left side, each 0·3 mm wide. On the right side, appendage III projects for 2·5 mm then curves



TEXT-FIG. 6. *Rhinocarcinosoma dosonensis* sp. nov. (juvenile). Camera lucida drawing of IGMR BT166/10a (left) and IGMR BT166/10b (right). Tergites numbered 1–12. A, posterior part of alimentary canal; C, carapace; G, proximal portion of genital appendage; T, telson. Scale bar represents 5 mm.

anteriorly for 1·7 mm, although individual podomeres cannot be distinguished. Appendage IV represented by three podomeres on left side, each 0·4 mm wide. Of appendage V, four podomeres are preserved on left side, each 0·4 mm wide. Appendage V also preserved on right side, folded back over carapace; coxa 1·2 mm long, 0·6 mm wide, rest of appendage 2·6 mm long, 0·4 mm wide. Two podomeres (7 and 8) of appendage VI preserved on left side, but they are better preserved on right side of carapace; podomere 7, rectangular, 2·6 mm long, 1 mm wide, podomere 8, disarticulated, oval, length 1·7 mm, width 0·8 mm.

Opisthosoma complete; very short and broad, slightly wider than the posterior margin of carapace. Opisthosomal segments more clearly preserved on counterpart. Faint medial triangular structure, 0·4 mm wide, at anterior of preabdomen, may represent proximal portion of genital appendage. Faint medial lineation, width 0·3 mm, along midline of pretelson, is interpreted as part of the alimentary canal.

Carapace outline more apparent on counterpart (IGMR BT166/10b), as it is less obscured by the appendages (Text-fig. 6); width at base 4 mm, median length 4·2 mm, lateral angle 115 degrees, tapering anteriorly, lateral margins slightly concave, giving carapace a slightly campanulate shape. Bluntly rounded process occurs at anterior edge of carapace. Appendage III preserved to left of carapace. Appendage VI preserved on both sides; on left side various indistinguishable podomeres, total length 3·5 mm, width 0·5 mm. On the right side, possible coxa, displaced forwards, and various other podomeres are preserved.

Tergites well preserved on counterpart, although in places they are partially telescoped, indicating that this specimen is probably an exuvium. Posterolateral corners of tergites angular, particularly towards posterior of preabdomen. Postabdomen very short and broad, tapering gradually to a short, broad, triangular telson, length 2·8 mm, width at base 1·3 mm, slightly disarticulated from pretelson.

The remaining material consists of fragmentary specimens. Appendage VI is represented by eight specimens. IGMR BT166/2, part only, consists of distal portion of podomere 7, and podomere 8, of appendage VI. Podomere 7, 13 mm wide. Podomere 8, oval, length 23 mm, width 10 mm. Small serrations occur along anterior and posterior edges of podomeres 7 and 8. Along posterior edge of podomere eight serrations are 0·4 mm wide, and are smaller and more angular than on the anterior edge, where they comprise more crenate, bluntly rounded protrusions. IGMR BT166/4 consists of distal podomeres of appendage VI. Proximal podomeres crushed so cannot be distinguished individually. Podomere 6, oval, 7·4 mm long, 6·4 mm wide. Podomere 7, 21 mm long, deeply emarginate distally with podomere 8, itself oval, 24 mm long, 10 mm wide. Ninth podomere not preserved. IGMR BT166/6 consists of part and counterpart (Pl. 1, fig. 4) of proximal podomeres of appendage VI. Podomere 2, rectangular, slightly disarticulated from coxa at edge of specimen. Podomeres 3 and 4, narrow, tapering posteriorly. Podomere 5 divided into two sections; a proximal rectangular portion and an anterior oval extension. Podomere 6 oval, deeply emarginate with anterior extension of podomere 5. Only proximal portion of podomere 7 preserved. IGMR BT166/20 consists of podomeres 7 and 8 of appendage VI (Pl. 1, fig. 5). IGMR BT166/21 consists of a partial podomere 6, and podomeres 7 and 8, of appendage VI (Pl. 1, fig. 2). The anterodistal corner of podomere 7 is produced into a broad spine, 2·3 mm long, a characteristic of this new species. Podomere 7a is apparent beneath the proximal part of podomere 8, where the cuticle has broken away. The terminal ninth podomere is not preserved. IGMR BT166/23 consists of the distal portion of a large podomere 7 of appendage VI (Pl. 1, fig. 3), showing the deeply emarginate articulation, comprising a deep notch, with a thickened margin of cuticle. IGMR BT166/26 consists of an almost complete appendage VI, including coxa and gnathobase (Pl. 1, fig. 1). Coxa produced into curved projection with small serrate teeth (i.e. gnathobase). Proximal podomeres crumpled. Podomere 7 includes podomere 7a. IGMR BT166/29 consists of partial proximal podomeres (2–5) of appendage VI. Podomeres 3 and 4 are narrow and wedge-shaped, both anterior length 1·8 mm. Only the proximal portion of podomere 5 is evident, length 7·8 mm. The distal podomeres are lacking.

The genital operculum is represented by two specimens. IGMR BT166/5 consists of a type-A genital operculum and appendage (Pl. 2, fig. 1). Ala large, oval, rounded laterally and medially, although anterior margin is lacking. Type-A appendage joined to operculum via an inverted Y-shaped articulation, 19 mm long (including furca), divided into three segments and distal furca. Basal segment, length 7·8 mm, width 3·9 mm, has a triangular proximal margin. Middle segment 3·9 mm long and 3·6 mm wide. Distal segment 2·8 mm long and 3·6 mm wide, expanding slightly distally. One furca preserved at end of appendage, 4·6 mm long, proximal width 1·4 mm, curving outwards and tapering to a blunt point. IGMR BT166/24 consists of the type-B genital operculum and a proximal portion of the type-B appendage (Pl. 2, fig. 3). The ala is 49 mm wide and overlain by a fragment of indeterminate cuticle. The anterior margin of ala is concave, presumably to accommodate coxa of appendage VI. Upon the ala is a small, curved, chain-like structure, length 14 mm, width 0·6 mm, composed of about ten 'segments'. The affinities of this structure remain obscure; the 'segments' are possibly the site of sensory setae. The posteromedial corner of the ala is produced into a broad, triangular protrusion, medial length 11 mm, width at base 8·6 mm. A contrast in cuticular ornament is apparent between the ala and protrusion; the ala bears many broad lunules, whereas the protrusion is unornamented. The proximal portion of the type-B genital appendage (furca) is present, width 1·6 mm.

The opisthosoma is represented by eight specimens. IGMR BT166/3 consists of an isolated postabdominal segment (probably 10), 20 mm wide at anterior but medially constricted to a width of 17 mm. IGMR BT166/7 consists of the posterior left portion of a crumpled preabdomen, postabdomen and the anterior portion of the telson, of a small individual (Text-fig. 3B). Segments 4–8 are crumpled so their proportions cannot be assessed. Segment 9, 2·6 mm long, 3·3 mm wide. Segment 10, 2·6 mm long, 3·7 mm wide. Segment 11, 2·8 mm long, 3·1 mm wide. Segment 12, 3·8 mm long, 2·5 mm wide. Proximal part of telson preserved, width at base 1·6 mm, with a faint tapering medial carina. IGMR BT166/15 consists of a partial, crumpled, pretelson, width 17 mm, displaying in places, a fine scale-like ornament on the surface. IGMR BT166/16 consists of the lateral portion of a tergite, length 15 mm, with a posterior doublure, 1·9 mm long, of fine striations running parallel to the posterior margin. IGMR BT166/18 consists of the lateral portion of a three-dimensionally preserved tergite, length 16 mm. Lateral margin slopes considerably; posterolateral corner angular, several millimetres lower than medial portion. IGMR BT166/22 consists of the lateral portion of a crumpled tergite, length 18 mm, with a narrow anterior doublure, length 0·9 mm, and a wider posterior doublure, length 1·9 mm. IGMR BT166/25 consists of a partial tergite, length 18 mm, with a posterior doublure, length 5·4 mm, with fine

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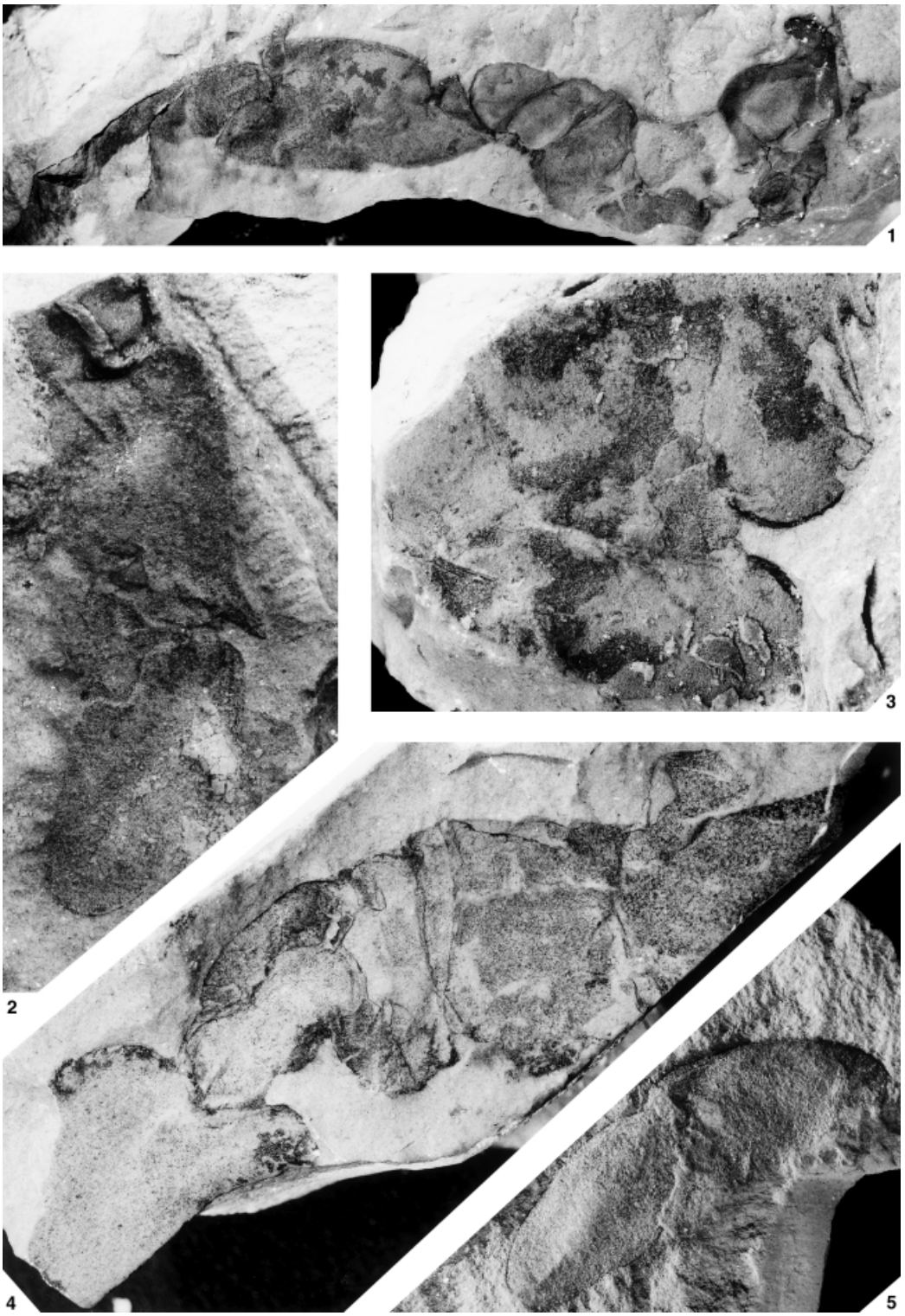
EXPLANATION OF PLATE 1

Figs 1–5. *Rhinocarcinosoma dosonensis* sp. nov. 1, IGMR BT166/26, complete prosomal appendage VI; × 2. 2, IGMR BT166/21, distal three podomeres of appendage VI; × 3·4. 3, IGMR BT166/23, distal articulation of podomere 7, appendage VI; × 3·3. 4, IGMR BT166/6b, partial prosomal appendage VI; × 2·8. 5, IGMR BT166/20, podomeres 7 and 8 of appendage VI; × 2·5.



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striations running parallel to the posterior margin. IGMR BT166/9 consists of part and counterpart (Pl. 2, fig. 4) of an almost complete telson preserved on its side, proximal portion and distal tip lacking, 9·2 mm wide proximally, tapering to 3·1 mm distally. The telson is straight proximally but two-thirds along its length it begins to curve, suggesting that it would have continued to curve towards the tip.

The cuticular ornament is shown in three specimens. IGMR BT166/8 consists of a indeterminate fragment of cuticle displaying a coarse tuberculate ornament (Text-fig. 3E); larger tubercles circular, 0·4 mm in diameter. The size of the tubercules suggests that this cuticle came from an adult animal. IGMR BT166/14 consists of a small fragment of cuticle displaying a coarse ornament of large circular pustules 0·3 mm in diameter (Pl. 2, fig. 2). IGMR BT166/19 consists of a fragment of cuticle displaying in places a fine polygonal ornament composed of 0·5 to 1-mm-wide, squarish structures. The function of this ornament is uncertain; perhaps associated with sites of sensory structures.

Remarks. Although the holotype is incomplete, the anterior portion of the carapace and anterior prosomal appendages lacking, this material represents the most completely known rhinocarcinosomatid eurypterid. Two species of *Rhinocarcinosoma* are currently known, both from New York State.

R. vaningeni, from the Upper Silurian Salina Beds (equivalent to the Pittsford Shale) of Oriskany Creek, near Clinton, was found in shales interbedded with dolomites, in association with lingulid and orbiculoid brachiopods, indicative of shallow brackish waters (Clarke and Ruedemann 1912). This species, known from fragmentary material, has a subtriangular carapace (the lateral margins slightly concave in the posterior half and gently convex in the anterior half), the anterior margin produced into a large linguiform process, about one-fifth the length of the carapace. The lateral eyes are relatively small, submarginal and situated just at the base of the process, a prominent ocular mound located between the posterior extent of eyes. Appendage VI is relatively small and the preabdomen is broad and short.

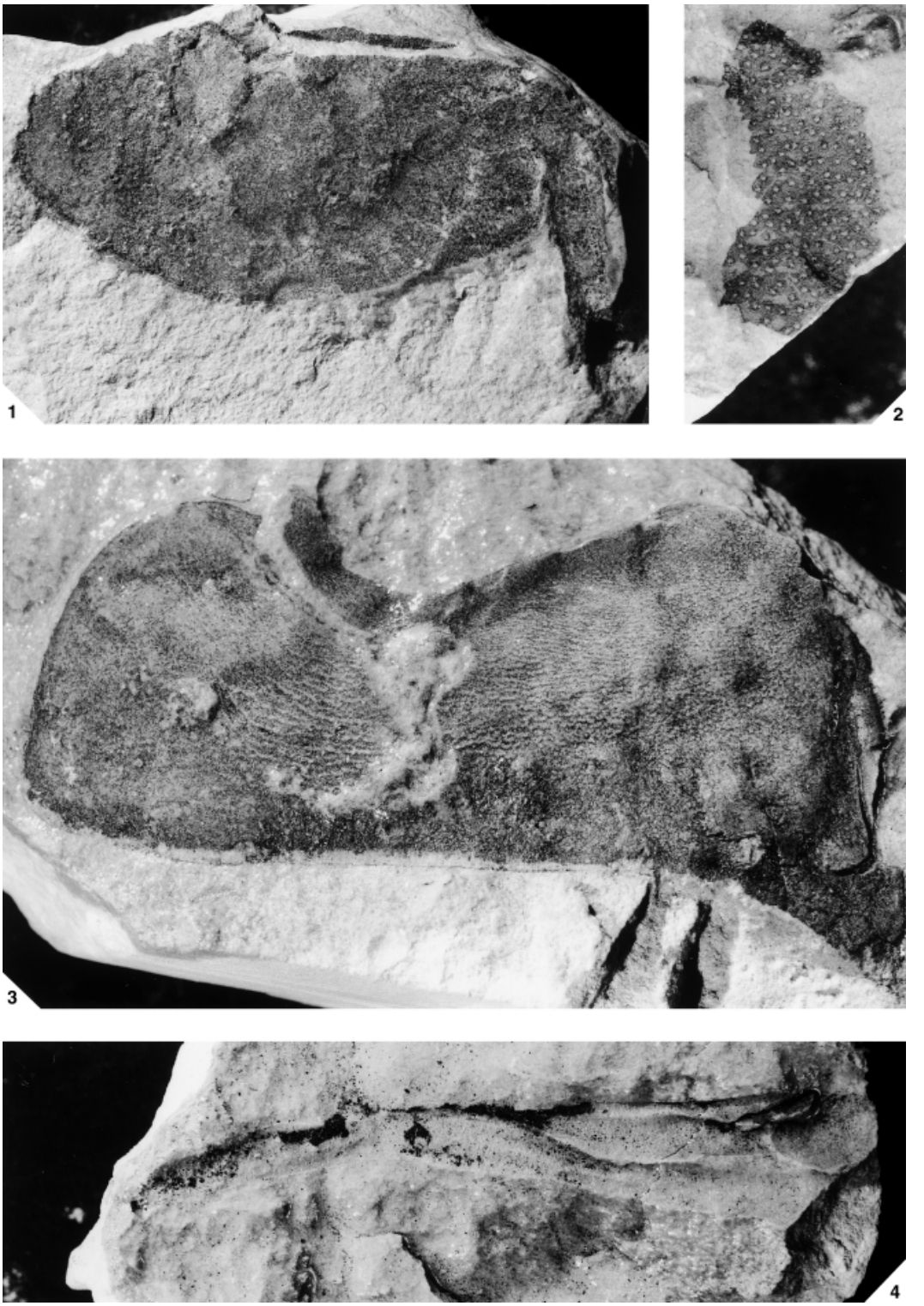
R. cicerops, from the Upper Silurian Shawangunk Grit of Otisville, Orange County (Clarke 1907; Clarke and Ruedemann 1912), known mainly from its carapace, the longest only 7 mm long, has a broadly triangular carapace with acute posterolateral angles and a bluntly rounded anterior process. Its lateral eyes are prominent, and have an arcuate visual surface. Only one specimen shows the mesosoma, the curvature of the tergites suggesting that this form had an indented opisthosomal differentiation, although the postabdomen is not preserved. No appendages are known. Clarke and Ruedemann (1912) suggested that this form may be a juvenile *R. vaningeni*, but did not synonymize them.

The Vietnamese material differs from both *R. vaningeni* and *R. cicerops*, and is consequently referred to the new species *Rhinocarcinosoma dosonensis* sp. nov. The carapace shape in IGMR BT166/10 is unlike *R. cicerops*, yet both are about the same size. The metastoma of *R. vaningeni* expands anteriorly, yet in *R. dosonensis* it has a cordate posterior margin and the lateral margins converge anteriorly. While the proportions of podomeres in the prosomal appendages are susceptible to ontogenetic variation, the distal margin of podomere 7 in appendage VI is produced into an anterodistal spine, a characteristic of this new species. The shape of the posterior part of the preabdomen and the indented differentiation of the opisthosoma, while possibly exaggerated by post-mortem deformation (see above), is also a characteristic of this new species. This new species was mentioned by Braddy (1994) but because no diagnosis was provided this citation may be regarded as a *nomen nudum*. This species is diagnosed, and formally named, for the first time here.

Most of the associated material is sufficiently similar to features on the holotype that they can be referred to this taxon. IGMR BT166/10, the juvenile, however, shows an uncharacteristic opisthosoma (the opisthosomal indentation and caudal constriction of the postabdomen is not expressed), although the carapace shape and long appendage III indicates that this specimen is related. Little is known about carcinosomatid ontogeny, given the lack of material, but based on this material (i.e. length/width of pretelson is 0·8 in BT166/10, 1·5 in BT166/7, and 2·8 in BT166/1), the scorpioniform opisthosoma (i.e.

EXPLANATION OF PLATE 2

Figs 1–4. *Rhinocarcinosoma dosonensis* sp. nov. 1, IGMR BT166/5, genital operculum and type-A appendage; × 2. 2, IGMR BT166/14, coarsely ornamented cuticular fragment; × 3·5. 3, IGMR BT166/24, genital operculum and partial type-B appendage; × 2·7. 4, IGMR BT166/9b, telson; × 2·3.



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caudal postabdomen) developed rapidly in the early ontogeny of the animal, enabling a more effective offensive capability of the telson. It is interesting to note that *Carcinosoma*, a less specialised carcinosomatid, also has a less caudal postabdomen, implying peramorphosis in carcinosomatid evolution.

Family HUGHMILLERIIDAE Kjellesvig-Waering, 1951

Genus HUGHMILLERIA Sarle, 1903

Hughmilleria sp.

Plate 3, figures 1–3, 5–9

Material. IGMR BT166/11–13, 17, 27–28.

Horizon and locality. Middle Member, Dô Son Formation, Upper Silurian. Locality of IGMR BT166/11–13, 17 and 27 is a large quarry in Ngoc Xuyên hill, north of the main village on the Dô Son Peninsula, northern Vietnam (locality 1, Text-fig. 1). IGMR BT166/28 was collected from a nearby locality (locality 2, Text-fig. 1).

Description. IGMR BT166/11 consists of an almost complete, articulated, small individual (?juvenile), although most appendages are lacking. Part, length 12 mm, consists of a complete carapace, partial appendage VI and 11 opithosomal segments, although the last two are partial (Pl. 3, fig. 2). Carapace quadrate, almost parabolic, 4·3 mm long, 4·9 mm posterior width, lateral angle of 92 degrees. One oval-shaped lateral eye occurs at right centrilateral margin of carapace, length 0·9 mm, width 0·6 mm. Median ocelli and metastoma not preserved. Two proximal podomeres (undetermined) of appendage VI preserved to left of carapace; most proximal, 1 mm long, 0·5 mm wide, distal, 0·3 mm long, 0·3 mm wide. Opisthosoma almost complete, long and lanceolate-shaped. Tergite 1, 0·5 mm long, 4·9 mm wide. Tergite 2, 0·8 mm long, 4·9 mm wide. Tergite 3, 0·6 mm long, 4·8 mm wide. Tergite 4, 0·5 mm long (although partially telescoped into preceding segment), 4·5 mm wide. Tergite 5, 0·7 mm long, 4·3 mm wide. Tergite 6, 0·8 mm long, 4 mm wide. Tergite 7, 0·7 mm long, 3·6 mm wide. Tergite 8, 0·8 mm long, 3 mm wide. Tergite 9, 0·8 mm long, 2·7 mm wide. The last three tergites partially preserved; their proportions more apparent on counterpart.

Counterpart (IGMR BT166/11b) consists of partial carapace, single partial undetermined prosomal appendage, partial preabdomen, complete postabdomen and proximal portion of the telson (Pl. 3, fig. 3). Prosomal appendage disarticulated from carapace; most proximal podomere, 1 mm long, 0·6 mm wide; next, 0·7 mm long, 0·6 mm wide; next, 1 mm long, 0·5 mm wide; distalmost is twisted backwards, 0·8 mm long, 0·3 mm wide, and tapers to a blunt point. No spines preserved. Opisthosomal segments 10–12, and proximal portion of telson, well preserved on counterpart. Tergite 10, 0·8 mm long, 2·3 mm wide. Tergite 11, 1·2 mm long, 2·1 mm wide. Tergite 12, 0·9 mm long, 1·8 mm wide. Proximal portion of telson, width 1·3 mm, indicates it was lanceolate-shaped, with a medial carina.

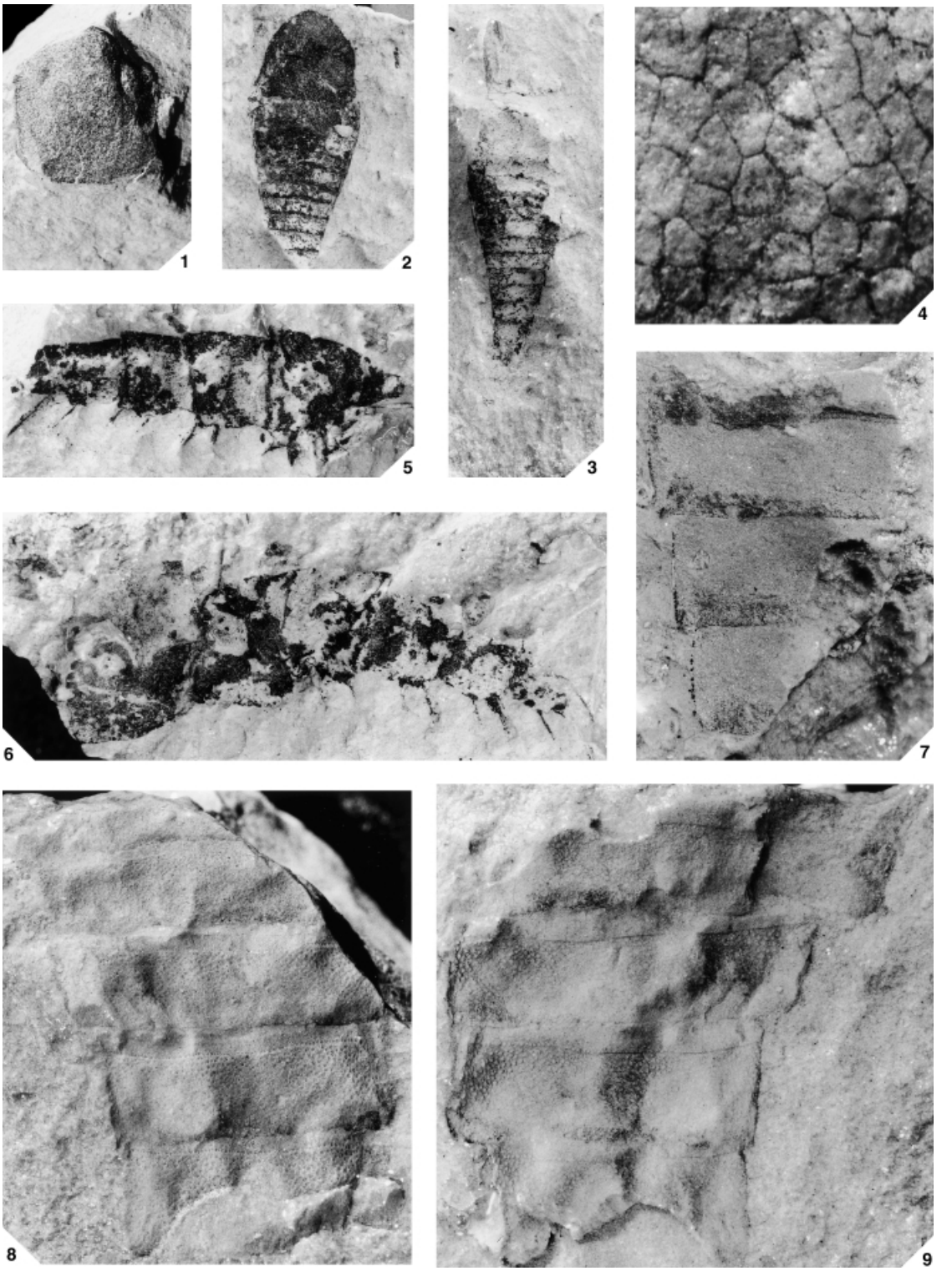
The additional material comprises an isolated carapace, appendage, partial opisthosomal segments and a telson. IGMR BT166/13 consists of an isolated quadrate carapace, length 8 mm, width 6·9 mm, lateral angle 90 degrees, with oval lateral eyes, length 2·2 mm, width 1 mm, situated centrilaterally (Pl. 3, fig. 1). IGMR BT166/12 consists of part (Pl. 3, fig. 6) and counterpart (Pl. 3, fig. 5) of a laterally preserved prosomal appendage with paired ventrodistal spines projecting from each podomere (i.e. *Hughmilleria*-type; Tollerton 1989). Part more complete, but spinosity better preserved on counterpart. Coxa, 7·7 mm long, 9·9 mm wide. Podomere 2, 3·5 mm long, 7·3 mm wide. Podomere 3, 4·5 mm long, 6·1 mm wide, with two short spines, both 1·8 mm long, projecting ventrally. Podomere 4, 3·9 mm long, 4·8 mm wide, the two short spines both 1·8 mm long. Podomere 5, 3·6 mm long, 4·3 mm wide, with two spines, both 1·1 mm long. Podomere 6, 2·7 mm long, 3 mm wide, with two spines; length 2 mm and 3·4 mm respectively. Small portion of podomere 7 is preserved; width 2·3 mm, although no spines are preserved.

EXPLANATION OF PLATE 3

Figs 1–3. *Hughmilleria* sp. 1, IGMR BT166/13, carapace; × 3·1. 2, IGMR BT166/11a, articulated carapace and partial opisthosoma; × 2·2. 3, IGMR BT166/11b, partial appendage, carapace and opisthosoma; × 3·1.

Fig. 4. Phyllocarida indet., IGMR BT166/30, fragment of cuticle with polygonal ornament; × 7.

Figs 5–9. *Hughmilleria* sp. 5, IGMR BT166/12b, spinose prosomal appendage; × 3·1. 6, IGMR BT166/12a, spinose prosomal appendage; × 3. 7, IGMR BT166/27, four opithosomal segments; × 3·7. 8, IGMR BT166/17a, opisthosomal segments 6–10; × 2·6. 9, IGMR BT166/17b, opisthosomal segments 6–10; × 2·8.



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The opisthosoma is represented by three specimens. IGMR BT166/17 consists of part (Pl. 3, fig. 8) and counterpart (Pl. 3, fig. 9) of partially preserved, yet articulated opithosomal tergites 6–10, each covered in a fine, pitted ornament. Tergite 7 has posterolateral corner produced into a short epimera. Tergite 7, 5 mm long. Tergite 8, 5 mm long, 20 mm wide. Tergite 9, 6·1 mm long. Tergite 10 incomplete. IGMR BT166/27 consists of four partial, yet articulated opithosomal tergites (undetermined), each with a thickened (darker) posterior margin (Pl. 3, fig. 7). First incomplete, second 4·1 mm long, third and fourth each 4·6 mm long. IGMR BT166/28 consists of proximal portion of telson, with a thickened margin, 3·7 mm wide, divided into two sections; an outer, paler, smoother cuticle, 2·2 mm wide, and an inner, darker, raised strip of cuticle, 1·5 mm wide, and ornamented with fine scales. Interior cuticle of telson has coarsely pitted ornament, each pit 0·3 mm in diameter.

Remarks. It is clear that another eurypterid, apart from *R. dosonensis*, occurs in this assemblage because these specimens cannot be referred to the Carcinosomatidae. According to IGMR BT166/12 (spinose appendage), this material is assigned to the Hughmilleridae. According to IGMR BT166/11a (juvenile) and IGMR BT166/13 (isolated carapace), this material may be referred to *Hughmilleria* sp. as the lateral eyes of this form were oval and situated marginally, not centrally, as in *Nanahughmilleria* and *Parahughmilleria* (Kjellesvig-Waering 1961). Given the incompleteness of this material, and the fact that hughmillerid taxonomy requires a detailed review, it is unwise to formally classify this material further.

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