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Early Devonian eurypterids with Bohemian affinities from Catalonia (NE Spain)

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ABSTRACT - The sequence of early Lower Devonian (Lochkovian) strata with dominant anchimetamorphic shales of the Olorda Formation yielded numerous remains of eurypterids. These belong to the Family Pterygotidae and are represented by dominant species of *Acutiramus* (closely related or identical with the Bohemian species *Acutiramus bohemicus* and *A. perneri*), and rare finds of *Pterygotus* cf. *barrandei*. The eurypterids are typical components of a purely marine assemblage of the offshore, probably open shelf environment of Benthic Assemblage 4 to 5. The clearly expressed Bohemian affinity points to open migration routes along the northern Gondwana shelves between Bohemia and Catalonia during the early Devonian, particularly Lochkovian time.

RESUMEN - Las pizarras de la Formación Olorda del Devónico Inferior (Lochkoviense) contienen numerosos restos de euriptéridos. Dichos fósiles pertenecen a la Familia Pterygotidae y corresponden en su mayor parte a especies de *Acutiramus*, mientras son más escasos los hallazgos de *Pterygotus* cf. *barrandei*. Los restos de *Acutiramus* son identificados como próximos o idénticos a las especies de Bohemia, *Acutiramus bohemicus* and *A. perneri*. Los euriptéridos proceden de una asociación marina alejada de la costa, probablemente de un ambiente de plataforma abierta de la Asociación Bentónica 4 a 5. La marcada afinidad bohémica de las especies determinadas refuerza la presencia de rutas abiertas de migración a lo largo de las plataformas septentrionales del norte de Gondwana, entre Bohemia y Cataluña, durante el Lochkoviense.

INTRODUCTION

The first palaeontological data from the Catalonian Coastal Ranges near Barcelona were published by Barrois (1893) and Almera (1898) who reported also spines of probable *Pterygotus*. During the recent years, E. Ferrer, J. Magrans and R. Mañé have had the opportunity to collect graptolites, trilobites, brachiopods (Racheboeuf et al. 1993) and discover rather numerous remains of eurypterids in the

shale succession of the earliest Devonian (Lochkovian). As the finds of eurypterids in expressive marine strata of early Devonian age are generally rare, these finds deserve a special interest. The closest and comparable eurypterid faunas are known from Bohemia where the Lochkovian eurypterids developed from their Silurian ancestors in full marine conditions. A similar situation seems to be also in Catalonia, where however, Silurian eurypterids are purely known and so far represented by indeterminable remains. The majority of the new finds were made in the area of Bruguers-Gavà, namely in an area of rounded low hills and gullies, situated below the Triassic mountains of the Aramprunyà castle. A preliminary report on eurypterid finds from this area was presented by Ferrer, Magrans and Mañé (1989). The reference material is deposited in the collections of the Geologic Museum of Seminari of Barcelona. The terminology of the eurypterid exoskeletal parts is adopted according to Tollerton(1989).

Note to drawings: The full lines in drawings indicate the actual limits of eurypterid remains, dotted lines indicate secondary limits caused by damages (broken surfaces, limits of rock samples, etc.).

GEOLOGICAL SETTING

New finds of eurypterids are derived from the outcrops of Palaeozoic rocks of the Bruguers-Gavà, about 20 km to the southeast of Barcelona city. The localities are placed on the eastern part of the Garraf Massif, central sector of Catalonian Coastal Ranges. These mountains trend parallel to the Mediterranean coast and consist of uplifted faulted blocks forming two ranges separated by a Neogene graben, trending in the same direction.

A synoptic stratigraphic section of the Catalonian Coastal Ranges was elaborated by Julivert *et al.* (1987) and Julivert and Durán (1990). However, no detailed stratigraphic study was made in the Bruguers-Gava, succession which yielded the eurypterid remains. The stratigraphical situation is here obscured by Hercynian deformation and development of anchimetamorphism. There exist two coaxial fold systems with axes trending NW-SE, the first facing the south and the second facing the southwest. Apart from these deformations, two phases of thrusting were later developed according to Camprubí *et al.* (1994).

POSITION OF FAUNAS IN THE STRATIGRAPHIC SUCCESSION

The formal stratigraphic units of the Silurian-Lower Devonian of the Catalonian Coastal Ranges were defined by Julivert *et al.* (1985, 1987) in the quarries at Santa Creu d'Olorda, near Barcelona. These authors established three units, namely the Silurian black shales, the La Creu Formation and the Olorda Formation. The La Creu Fm. consists of nodular limestones, mudstones and wackestones with orthoceratids. The lowest limestones belong to the *Saetograptus leintwardinensis* graptolite Zone (Greiling and Punschmann, 1965) or the upper part of the *ploeckensis* conodont Zone (Sanz, 1995). The uppermost beds of the La Creu Fm. yielded conodonts regarded by García-López *et al.* (1990) as corresponding to the *delta* conodont Zone of Lochkovian

age. These authors located the base of the Devonian about 10 meters below the upper boundary of the La Creu Fm., in limestones with *Scyphocrinites* sp. The Olorda Fm. was informally subdivided into several members (A to E, upper Lochkovian to Upper Emsian). The A Mb. overlies the limestones of the La Creu Fm. It is formed by black and pink shales (2-3 m) with nodules of iron oxides, cherts, layers of siltstones or fine-grained sandstones. This unit, as the lower part of the next member, yielded Lochkovian graptolites *Monograptus hercynicus*, *Linograptus posthumus* and *Abiesgraptus* sp. (Greiling and Puschmann, 1965; Julivert *et al.*, 1985). The B Mb. of the Olorda Fm. (5-8 m) is characterised by red and green shales with limestone beds rich in dacryoconarid tentaculites. The base of the B Mb. contains the tentaculite *Homoctenowakia bohemica* after García-López *et al.* (1990). The first carbonate beds yielded conodonts of the *delta* Zone, in particular of the *transitans* interval after Valenzuela and García-López (1996). The uppermost part of the B Mb. may indicate the *pesavis* Zone and include the base of Pragian with *Nowakia acuaria* just under the uppermost occurrence of *Ancyrodelloides trigonicus* (García-López *et al*., 1990). Some spines probably of *Pterygotus* quoted by Almera (1898) were collected in the B Mb. Too, a coxa of eurypterid was found by Antoni Abad in Sta. Creu d'Olorda.

The stratigraphical succession, as described at Santa Creu, may be applied to the Bruguers-Gavà outcrops. However, some tectonic units show a thicker development of the A Mb. of the Olorda Fm, where we collected the eurypterids remains.

The Beds with *Scyphocrinites* are represented by more than 5.5 m thick sequence of black shales with pyrite nodules. The shales become white and pink when are weathered. Individual beds of centimetric to decimetric thickness show laminations, oxides-enriched surfaces of hardgrounds and accumulations of *Scyphocrinites*, *Platyceras*, bivalves, brachiopods, bryozoans, cephalopods, phyllocarids and conodonts of the genus *Oulodus*. Remains of eurypterids are rare and grouped as level 10. Graptolites determined by Dr. Hermann Jaeger include *Monograptus uniformis* and *Linograptus posthumus* demonstrating the earliest *Devonian Monograptus uniformis* Zone. Graptolites of this zone were found even at other localities of the Catalonian Coastal Ranges: *Monograptus uniformis angustidens* was reported at Can Castany (Cervelló) and *M. uniformis uniformis* at Serra de Miramar (Julivert *et al.*, 1985).

Above the described shales, the white and pink shales dominate reaching the thickness of 11 m. They contain scarce ferruginous and decalcified carbonate nodules and horizons of condensed sedimentation intercalated by thin (mm to cm) beds of siltstones and cherts. These beds include layers with abundant remains of eurypterids described in our report as 31A and 31B. Graptolites, determined by Dr. H. Jaeger, include *Monograptus praehercynicus*, *M. microdon*, *Linograptus posthumus* and *Abiesgraptus* sp. which point to the *Monograptus praehercynicus* Zone of the upper Lochkovian.

Upwards, the white shales show an increasing amount of chert nodules. The horizon has 8.5 m thick and its central part contains of yellowish or green shales with scarce carbonate nodules. A block with eurypterids 29A can come from this beds.

The upper 10 m of the A Mb. is composed by white shales that grade to marls of

colour green and red (9.5 m). The fauna is represented by dacryoconarid tentaculites, brachiopods, trilobites, hyolithids, bryozoans, bivalves, solitary rugose corals, cephalopods, gastropods, phyllocarids and eurypterids (levels 4C, 28, 32). Among graptolites, *Monograptus hercynicus* demonstrates the upper Lochkovian age. A eurypterid coxa associated with *Monograptus hercynicus* has also been found near the village of Cervelló. Higher in the sequence, there are a new transition between whitish shales and marls. The green an red marls contain carbonate beds with brachiopods, bivalves, etc., corresponding to the B Mb of the Olorda Fm. Brachiopods with *Plectodonta mimica* (Barr.) still point to the Lochkovian (Racheboeuf *et al.* 1993), whilst the discovery of *Nowakia acuaria* in their proximity indicates the transition into the lower Pragian.

The preservation of eurypterid remains from the studied localities is far from ideal. All specimens are completely flattened in shale and affected by linear deformations. Consequently, the primary features can be reconstructed only with difficulties and data on dimensions are of limited value. As the colour differences between the host rock and the eurypterid remains are frequently obscure or effaced by weathering processes, the recognition of primary shape and outlines of eurypterid remains can be deciphered with difficulties in many cases. Another difficulty lies in the fact that the euryterid remains are frequently accumulated on the same bedding planes. Overlapping remains of different individuals are often found together and just this mode of preservation makes true outlines of individual exoskeletal parts difficult to decipher. All these circumstances make the determination of species hardly possible and almost all finds are left in the open nomenclature. The exception are two chelicerae referred to *Acutiramus perneri* Chlupá_. However, the material is good enough to recognize the relationships and similarities with some species known from Bohemia.

SYSTEMATIC PALAEONTOLOGY

Order Eurypterida Burmeister, 1843
Suborder Pterygotina Caster et Kjelleswig-Waering, 1964
Family Pterygotidae Clarke et Ruedemann, 1912
Genus *Acutiramus* Ruedemann, 1935
Type species: *Pterygotus cummingsi* Grote et Pitt, 1875 (synonyme of *Pterygotus buffaloensis* Pohlman, 1881)

Acutiramus sp.

Pl. I, figs. 1-3, pl. II, figs. 2-4, pl. III, figs. 1-2, text-figs. 3-6

Material: chelicerae, coxae, walking legs, swimming legs, pretelson and telson.
Remarks: The majority of eurypterid remains collected at Bruguers-Gavà localities evidently belong to the genus Acutiramus as diagnosed particularly by Waterston (1961). This is evidenced especially by configuration of chelicerae which teeth in distal part of both cheliceral rami are oriented anteriorly and the larger teeth are serrated. Tips of both cheliceral rami, as far as are preserved in few cases, are angulate. Another evidence of generic assignment is the paddle-shaped telson with serrated margins and terminated by a short spine.

Among individual finds of chelicerae, the following are worth to be mentioned: The chelicera 59610 (text-fig. 3b) exhibits posteriorly directed teeth in distal part of the fixed ramus and the markedly serrated principal tooth D5. The preserved part of the free ramus bears mostly vertically directed teeth in the middle part of the ramus, the posterior (proximal) part being only incompletely preserved. Distal tips of chelicera are broken off. The chelicera 59623 (pl. I, fig. 3, text-fig. 3a) preserves a substantial part of the fixed ramus with several small teeth in the distal part. Teeth in the proximal part are markedly directed anteriorly, the principal tooth D5 being gently serrated at its posterior margin. The proximally following slender teeth are markedly directed anteriorly and striated longitudinally, their length markedly diminishes posteriorly. The free ramus is preserved only fragmentary and shows no prominent teeth except the most proximal slender tooth subparallel with the longitudinal axis of chelicera and directed anteriorly in a sharper angle than in the case of adjacent teeth of the fixed ramus. The chelicera 59612 (pl. I, fig. 2) belongs to a smaller specimen (preserved length 146 mm). It shows slender but characteristically anteriorly directed teeth on the fixed ramus. The free ramus is more completely preserved and is marked by vertically directed but strongly damaged teeth in most part of the gnathal part. The distal tips is angulate and prolonged resembling thus the specimens of *Acutiramus bohemicus* or A. perneri from Bohemia. The proximal part of the free ramus bears slender and sharp teeth directed anteriorly. The specimen 59619 (text-fig. 3c) represents the isolated fixed cheliceral ramus with anteriorly directed and serrated teeth D4 and a very prominent tooth D5 the length of which exceeds 40 mm. The smaller chelicera 59620 (pl. I, fig. 1) is strongly longitudinally deformed and prolonged. Among the anteriorly directed teeth of the fixed ramus, the prominent teeth D4, D5 and D6 exceed in length the others and show traces of serration. The free ramus exhibits prominent tooth D2 and particularly secondarily broadened tooth D3 of triangular outline. The specimen 59626 (pl. II, fig. 4) is exceptional in preserving the distal tips of both cheliceral rami. These are angulate, resembling the terminations of *Acutiramus bohemicus*. However, this chelicera shows a strong secondary shortening and transversal to oblique deformation marked by approached prominent teeth of the fixed ramus to the distal part of chelicera.

Isolated or partly isolated coxae belong to characteristic remains of eurypterids, though they are less suitable for determination in genus or species. In the material from Bruguers-Gavà, coxae are represented by rather numerous finds from which several deserve a special attention: The specimen 59617 (text-fig. 4e) exhibits a strongly deformed and folded coxa in connection with the proximal part of the walking leg. The gnathal part bears 12 to 13 teeth diminishing posteriorly. Our material contains several finds of approached and partly overlapping coxae which either preserve their primary position or are only gently shifted from it. This is the case of the specimen 4538 in which much smaller and slender teeth of coxa, evidently belonging to a walking leg, are followed by two much larger overlapping coxae with strongly developed teeth. Apart from the first anterior small tooth, the succeeding teeth (11) are strong, diminishing in size posteriorly. Another specimens show approached and/or partly overlapping coxae. These coxae either differ in their denticulation (59621, 59625, 59613, text-figs 4b,d,f) or exhibit teeth of similar dimensions and shape (59622, 59615, text-fig. 4c). The finds of overlapping coxae agree with those reported by Chlupáč (1994) in *Acutiramus bohemicus* from the Bohemian uppermost Silurian: whilst the coxae with slender and narrower teeth belong evidently to anterior walking legs, coxae of the posterior walking and the swimming legs are larger and bear strongly developed and broader teeth.

The walking legs are represented in our material by several finds. The specimen 59614 (text.-figs. 4a, 5a) indicates three articulated longitudinally prolonged segments. Three prolonged slender structures subparallel with the remnants of the probable swimming leg in the specimen 59616 (pl. II, fig. 2) are also interpreted as walking legs from which the third, close to the swimming leg, is composed of three prolonged segments. Distal terminations of two of these segments show small denticles at the connecting lines between segments. Two specimens can be interpreted as remains of swimming legs of *Acutiramus*: the specimen 59616 (pl. II, fig. 2) can correspond to the proximal part of a swimming leg with less distinctly delimited joints, whilst the specimen 59624 (text.-fig. 5b) exhibits the distal part of a swimming leg with well differentiated paddle-like termination of elliptical outline.

The pretelson (59618, text-fig. 6) is preserved as a substantial part of a subquadrate segment. The left lateral margin shows a gentle abaxial curvature, a straight row of impressions in sagittal position indicates the median carina primary accentuated by a row of posteriorly directed short spines. The remnants of scales sculpture found on the pretelson of *Acutiramus bohemicus* from Bohemia. Two finds of telsons (59611, 59627, pl. III, text-fig. 7) have characteristic features of *Acutiramus*: the paddle-shaped outline, terminated posteriorly by a short spine, and the serrated lateral and posterior margins. The median carina is only slightly indicated as lines situated sagittally (the complete flattening in shale effaces the details). The remains of *Acutiramus* from the Bruguers-Gavà localities show closest resemblance to *Acutiramus bohemicus* (Barrande, 1872) from the uppermost Silurian of Bohemia, or to *Acutiramus perneri* Chlupáč, 1994 from the early Lower Devonian (Lochkovian) of the same area. The preservation does not allow to establish exactly the identity of the species and, therefore, the open nomenclature is applied in these specimens.

Occurrence: Levels 4C, 10, 28, 29A, 29B, 31A, 31B in the Bruguers-Gavà area, lower part of the Olorda Fm., Lochkovian (*M. uniformis-M. hercynicus* zones).

Acutiramus perneri Chlupáč, 1994

Pl. II, fig. 1, text-fig. 8.

Material: Two incomplete chelicerae.
Remarks: Two specimens of incomplete chelicerae with preserved distal terminations are distinguished by slender acute tips which are typical of the Bohemian species *Acutiramus perneri* occurring in the Barrandian area in strata of Lochkovian age, i.e. in beds coeval with eurypterid-bearing beds from the Bruguers-Gavà region. The specimen 59629 (pl. II, fig. 1) represents an incomplete fixed (?) cheliceral ramus which distal termination is strongly prolonged anteriorly. The mightily developed terminal tooth D1 is markedly directed posteriorly which is the case also in other proximally succeeding teeth preserved on the ramus. The length of the incomplete ramus is 92.5 mm.

The specimen 59628 (text-fig. 8) represents the distal part of a chelicera with fixed and free rami in connection. The characteristically prolonged and sharply terminated distal tips of both cheliceral rami are typical. Apart from the strong posteriorly

directed terminal teeth on the both cheliceral rami, the denticulation is imperfectly preserved and obscured by its complete flattening in shale. The remnants of smaller teeth in the distal part of the fixed cheliceral ramus are directed posteriorly. The preserved length of the free ramus is 41 mm.

Occurrence: Levels 29 and 31A in the Bruguers-Gavà area, lower part of the Olorda Fm., *M. praehercynicus* Zone.

Genus *Pterygotus* Agassiz, 1844
Type species: *Pterygotus anglicus* Agassiz, 1844

Pterygotus cf. *barrandei* Semper, 1898
Text-fig. 9

Material: Chelicera with connected fixed and free rami.
Remarks: The chelicera 59630 (text-fig. 9) shows the typical features of *Pterygotus*, namely the free ramus terminated by a prominent tooth rounded distally. The specimen exhibits the closest similarity with *Pterygotus barrandei* Semper, as described and figured by Seemann (1906, pl. 4, fig. 1), Prant and Přibyl (1948, text-fig. 4, pl. 1, fig. 1) and Chlupáč (1994, text-fig. 2, pl. 6, figs. 5, 6). The specimen 59630 is strongly transversally deformed which results in secondary shortening of the whole chelicera. The most characteristic free ramus bears the long and curved terminal tooth broadly rounded anteriorly. The terminal tooth is followed proximally by teeth of strongly unequal size and length. Generally, the teeth alternate in size and length and the fourth principal tooth exceeds in length the other teeth. This is slender, overlapping up into the fixed ramus of chelicera, lacking any traces of serrated margins. Among the proximally following teeth, the fifth main tooth is prominent but somewhat obscured by the overlap with the fixed ramus of the chelicera. The fixed ramus of chelicera shows the moderately developed, rather short terminal tooth and curved distal margin. Teeth on the fixed ramus are strongly different in size, but certain alternation of larger and smaller teeth is observable. All teeth on both rami of chelicera exhibit a fine longitudinal striation. The primary inclination of teeth is modified by secondary compression, but the slight anterior inclination of teeth on the free ramus and posterior inclination of teeth on the fixed ramus are indicated, being comparable with those in *Pterygotus barrandei*. The North American rare species *Pterygotus cobbi* Hall, 1859, as described and figured by Clarke and Ruedemann (1912, p. 371-374, pl. 77, fig. 6) has a shorter terminal tooth and also other teeth on the free ramus of chelicera seem to be shorter. The type species *Pterygotus anglicus* Agassiz, 1844 is distinguished by shorter, stouter and broader teeth on both rami of chelicera (comp. Woodward 1866, pl. 7, Waterston 1964, text-fig, 4).

Stratigraphical note: All known specimens of *Pterygotus barrandei* from Bohemia are derived from the uppermost Silurian strata of Přídolian age. In contrast, the specimen designated as *Pterygotus* cf. *barrandei* from Catalonia come from younger, namely Lochkovian strata, which may indicate the overlap of the *Pterygotus barrandei* lineage from the Silurian into the Lower Devonian (Lochkovian) without marked changes.

Measurements: The length of the preserved incomplete chelicera is 108.5 mm, the

length of the longest tooth on the fixed ramus is 34 mm.

Occurrence: Level 31A in the Bruguers-Gavà area, lower part of the Olorda Fm., Lochkovian (Monograptus *praehercynicus* Zone).

CONCLUSIONS

The eurypterid fauna from the Bruguers-Gavà area in Catalonia comes from a sequence of purely marine deposits which contain rather common representatives of graptolites, dacryoconarid tentaculites, brachiopods, trilobites, crinoids and other typically marine groups of animals. The rather common occurrence of pterygotids in association with these faunas agrees with conclusion of Kjelleswig-Waering (1961, 1964) on the marine life habit of pterygotids, confirmed even in other regions (the Barrandian area of Bohemia as a typical example). Concerning the lithology and faunal content, the shales with eurypterids from the Bruguers-Gavà area may be ranged within the Benthic Assemblages 4 to 5 in the classification of Boucot (1975). The lithology and fossil content points to offshore marine conditions of a probably open shelf area with broad possibilities of migrations and faunal exchanges on large scale. The clearly expressed Bohemian affinities of the eurypterid fauna from the Bruguers-Gavà area can be explained by open migration routes along the shelves of the early Devonian Gondwana to which both regions used to belong. The Bohemian affinity of eurypterids from Catalonia is not surprising, as it is demonstrable e.g. in brachiopods (Racheboeuf *et al.* 1993). The study of other faunal groups will probably prove these relationships still on a larger scale.

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EXPLANATION OF PLATES

Plate I. *Acutiramus* sp.. Fig. 1 - Longitudinally deformed chelicera 59620, level 31A. Fig. 2 - Chelicera 59612, level 10. Fig. 3 - Chelicera 59623, level 31A. Scale bars=1 cm.

Plate II. Fig. 1 - *Acutiramus perneri* Chlupá_, isolated fixed cheliceral ramus 59629, level 31A. Fig. 2 - *Acutiramus* sp., two fragmentary walking legs and the swiming leg 59610, level 29. Fig. 3 - *Acutiramus* sp., incomplete gnathal part of coxa 59635, level 32. Fig. 4 - *Acutiramus* sp., distal part of chelicera 59626, transversely deformed, 31A. Scale bars=1 cm.

Plate III. *Acutiramus* sp. Fig. 1 - Telson 59627, level 31B. Fig. 2 - Telson 59611, level 10. Scale bars=1 cm.

EXPLANATION OF TEXT.-FIGURES

Fig. 1 - Geological sketch of the Catalonian Coastal Ranges.

Fig. 2 - Stratigraphic succession of shales correlated with the A Mb. of Olorda Fm. at Cañón Colorado (left) and Roca Salena (Bruguers area). The highest part represents the transition into the B Mb. The position of level 29A is tentative, because the fossils were collected in a slide of rocks.

Fig. 3 - *Acutiramus* sp. Scale bars=1 cm.
a, chelicera 59623, 31A
b, chelicera 59618, 29A
c, incomplete fixed ramus of chelicera 59619, 29B

Fig. 4 - *Acutiramus* sp. Scale bars=1 cm.
a, incomplete walking leg 59622, 31A
b, overlapping coxae 59613, 28
c, overlapping coxae 59622, 31A
d, overlapping gnathal parts of coxae 59621, 31A
e, coxa 59636, 31ª
f, three overlapping gnathal parts of coxae 59625, 31A
g, strongly deformed coxa and remains of the walking leg 59617.

Fig. 5. *Acutiramus* sp. Scale bars=1 cm.
a, incomplete walking leg 59614, 29A
b, distal part of the swimming legs 59624, 31A

Fig. 6. *Acutiramus* sp., incomplete and deformed pretelson 59618, 29A. Scale bars=1 cm.

Fig. 7. *Acutiramus* sp. Scale bars=1 cm.
a, incomplete flattened telson 59611, 10
b, incomplete deformed telson 59627, 31B

Fig. 8. *Acutiramus perneri* Chlupá_, distal part of chelicera with narrowly angulate

terminations of cheliceral rami (59628), 29A. Scale bar=1 cm.

Fig. 9. *Pterygotus* cf. *barrandei*, deformed chelicera 59630, outcrop 31A. Scale bar = 1 cm.

Fig. 1

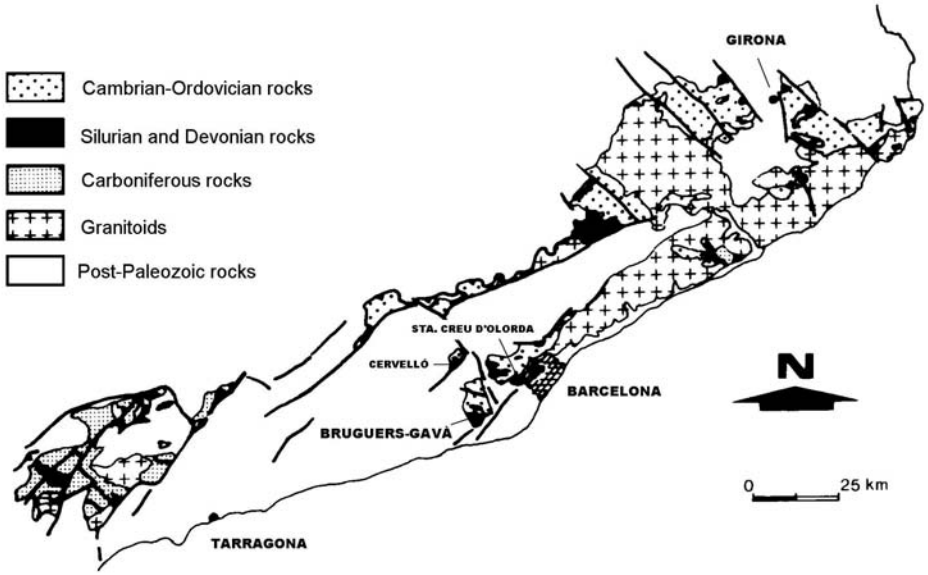


Fig. 2

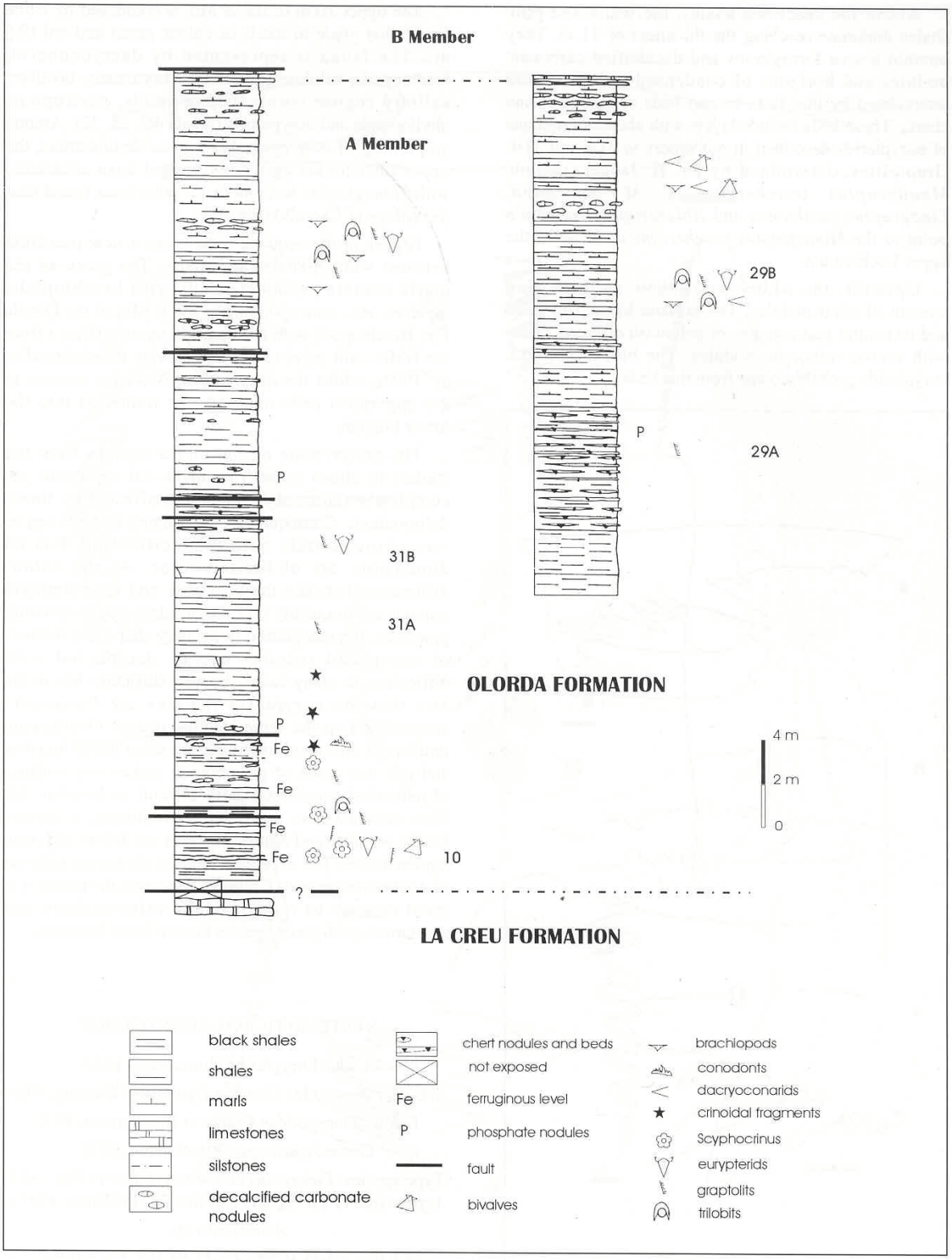

B Member
A Member
29B
29A
P
31B
31A
OLORDA FORMATION
Fe
10
?
LA CREU FORMATION
4 m
2 m
0
black shales
shales
marls
limestones
silstones
decalcified carbonate nodules
chert nodules and beds
not exposed
ferruginous level
phosphate nodules
fault
bivalves
brachiopods
conodonts
dacryoconarids
crinoidal fragments
Scyphocrinus
eurypterids
graptolits
trilobits

Fig. 3

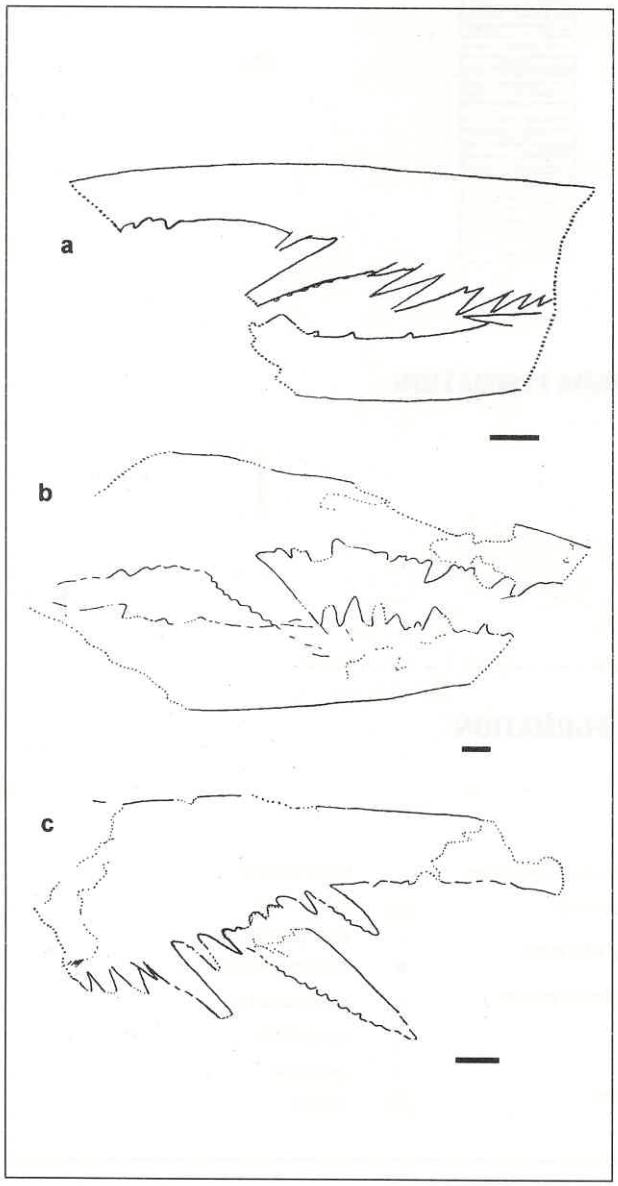


Fig. 4

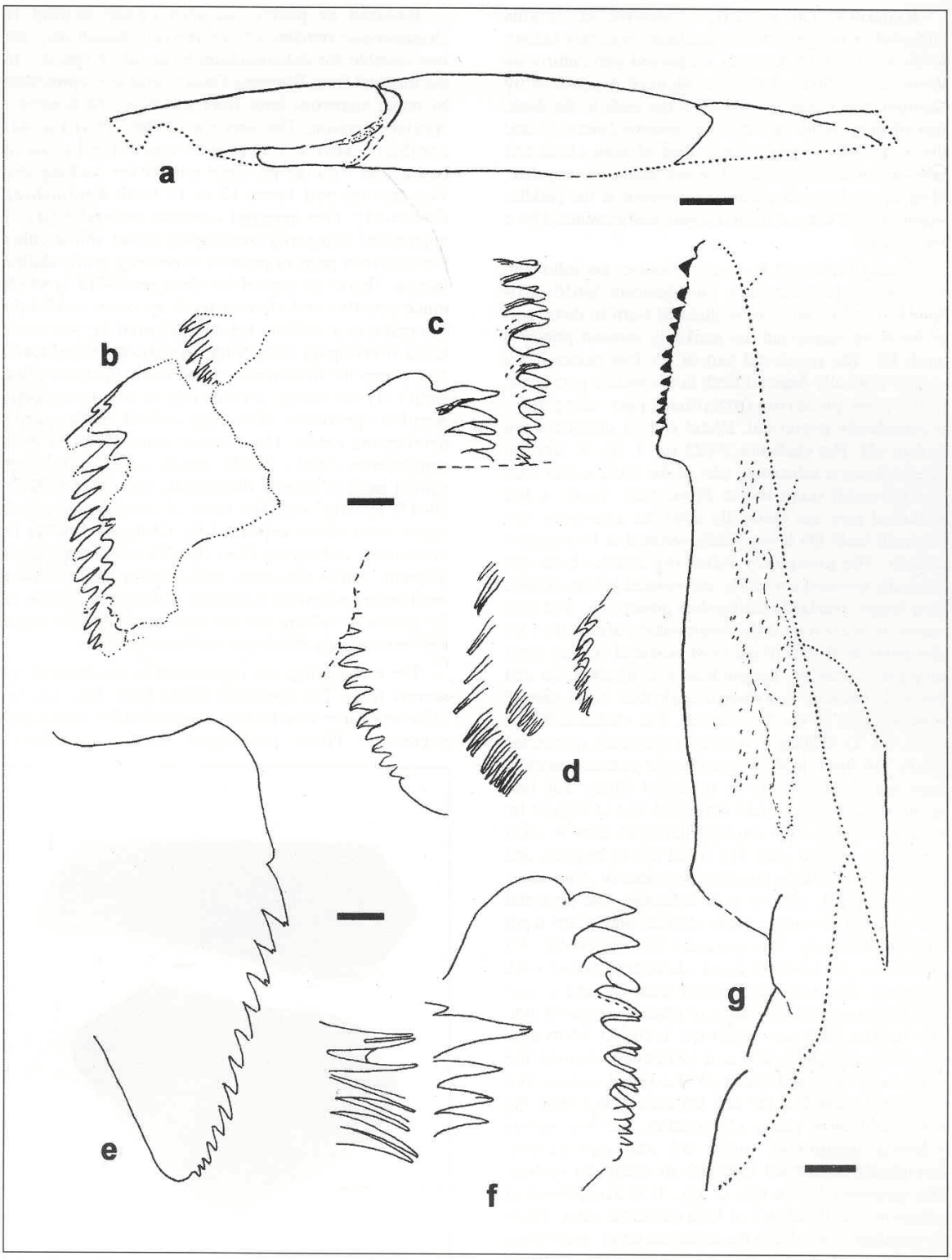


Fig. 5

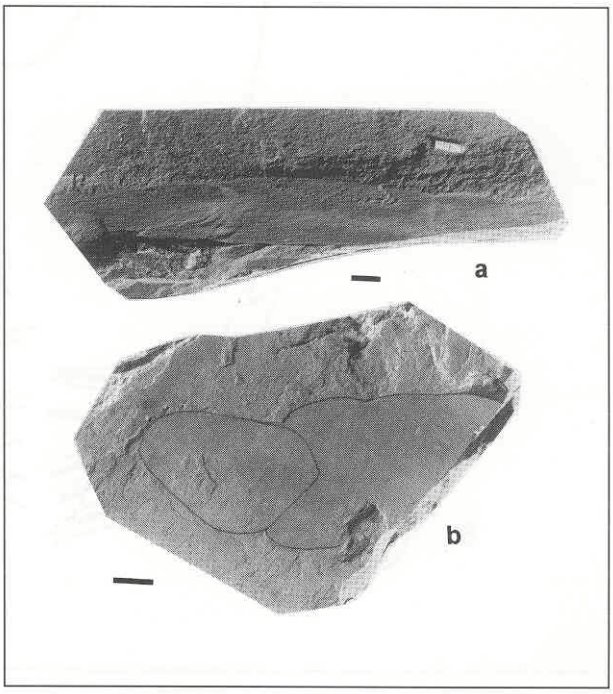


Fig. 6

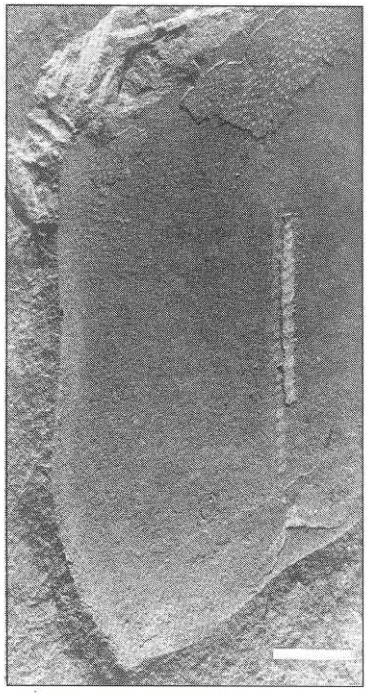


Fig. 7

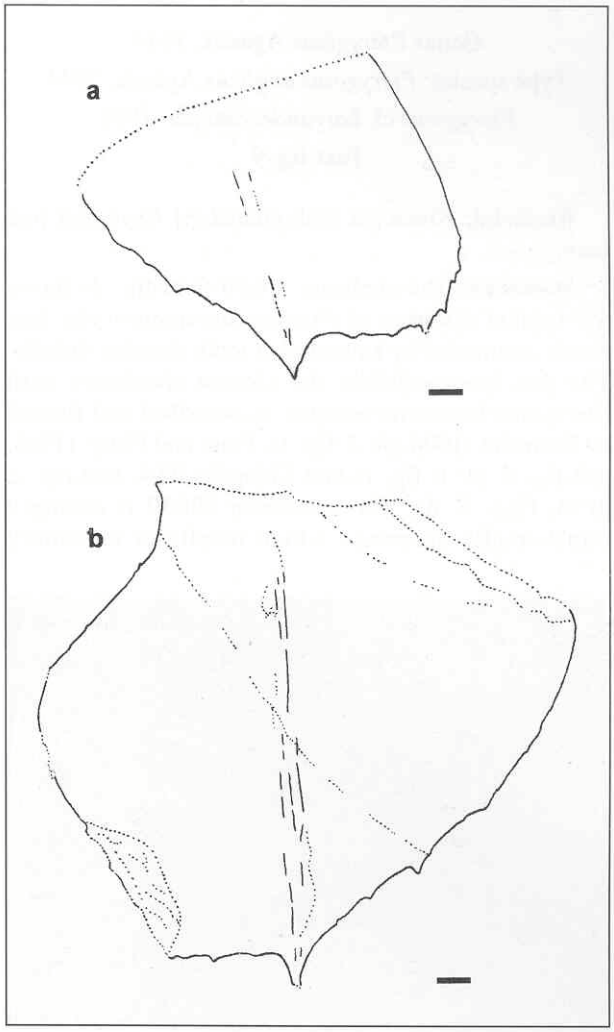


Fig. 8

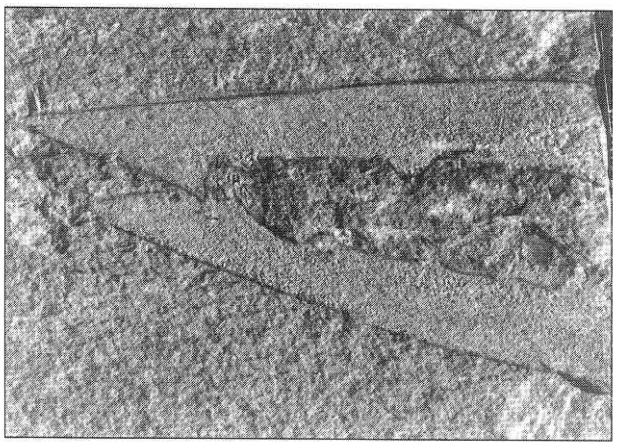


Fig. 9

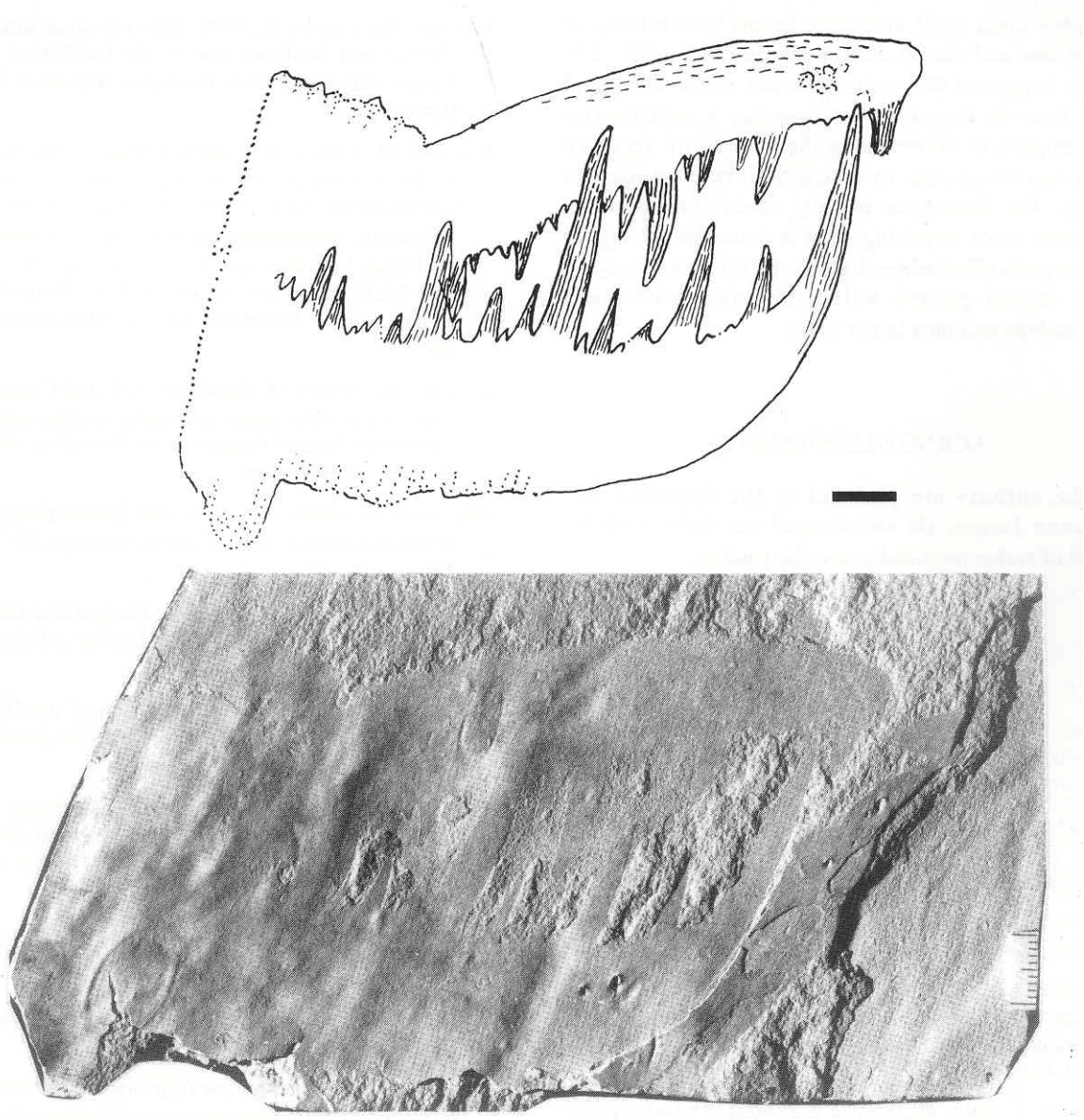
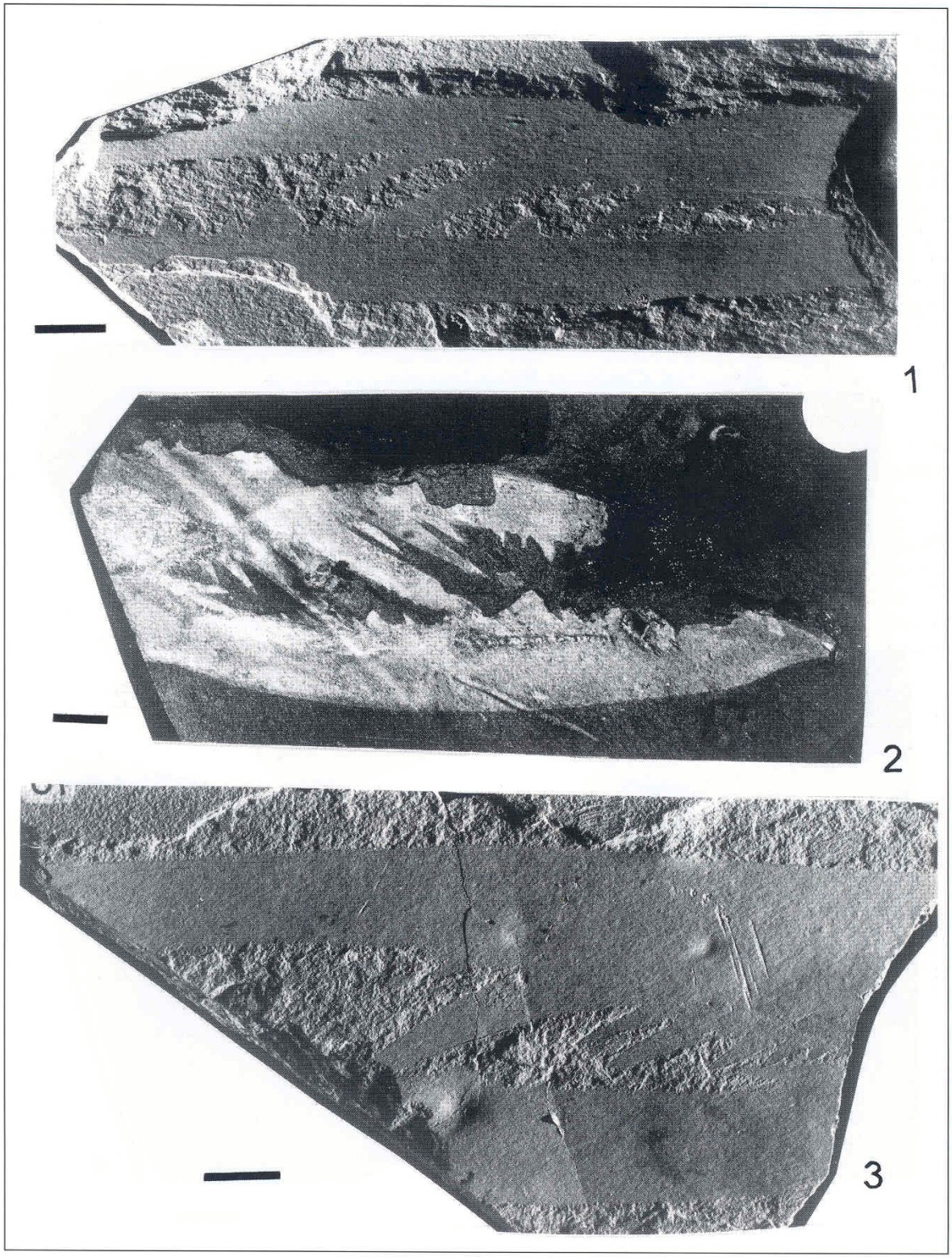


Plate I



I

Plate II

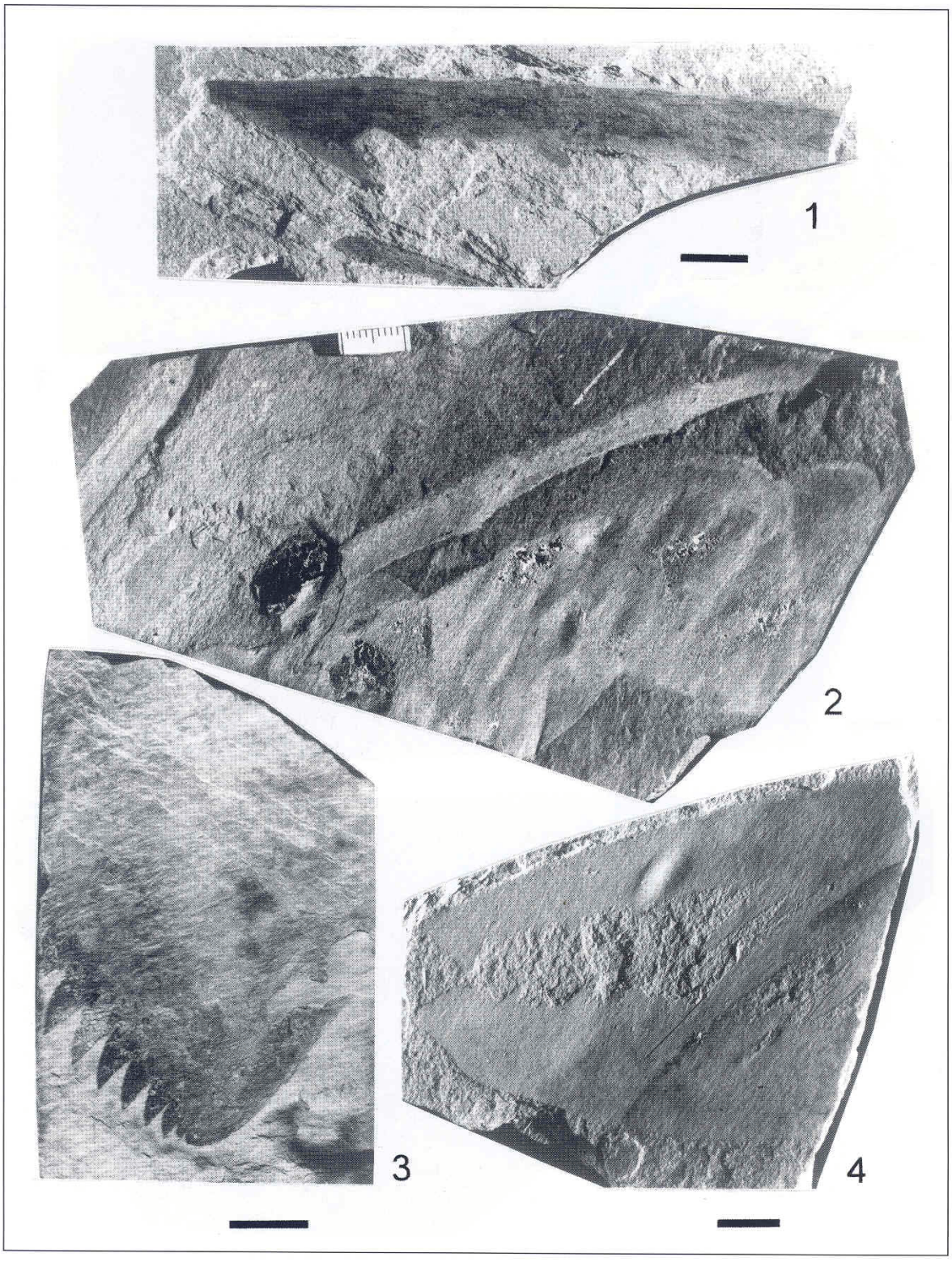


Plate III