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Specimens of *Eurypterus* (Chelicerata, Eurypterida) in the collections of Museo Geominero (Geological Survey of Spain), Madrid

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ABSTRACT

The non-Spanish, Silurian eurypterids in the collection of Museo Geominero, Madrid, are reviewed. The collection consists of material of *Eurypterus remipes* (three slabs with a total of five specimens) from Herkimer County, New York State, USA and *Eurypterus tetragonophthalmus* (one slab with one complete and three fragmentary specimens) from the Ukraine. The specimens show signs of being exuviae rather than carcases. There are very few ways to unequivocally separate exuviae from carcases, so this is at best a tenuous conclusion based on this material only, but is well-supported in larger collections from these lithologies. One of the American specimens has a type A genital appendage, i.e. it is a female according to the presently favoured interpretation. This is again in line with evidence from larger collections, which suggests that around 90% of specimens of *E. remipes* from Herkimer County had a type A genital appendage. A slab with three specimens shows 'social behaviour' found in certain eurypterid taxa during ecdysis.

Key words: Eurypterids, North America, palaeontological collection, Silurian, Ukraine

Ejemplares de Eurypterus *(Chelicerata, Eurypterida) en la colección del Museo Geominero (Instituto Geológico y Minero de España), Madrid*

RESUMEN

Se revisan los ejemplares de euriptéridos silúricos pertenecientes a las colecciones de Fósiles Extranjeros y de Paleontología Sistemática del Museo Geominero. Se describen tres piezas con un total de cinco ejemplares de Eurypterus remipes*, y una pieza con un ejemplar completo y tres incompletos de* Eurypterus tetragonophthalmus*. Las primeras proceden del famoso yacimiento del condado de Herkimer (Nueva York, EEUU), y la última de Ucrania. Todos los ejemplares parecen corresponder a exuvios articulados, más que a cadáveres, aunque existen pocos criterios para diferenciarlos. Si bien la muestra es insuficiente, la interpretación como exuvios se ajusta al resto de las colecciones descritas en ambos yacimientos. Uno de los ejemplares del condado de Herkimer tiene un apéndice genital del tipo A, como ocurre aproximadamente en el 90% de los ejemplares de* Eurypterus remipes *de este yacimiento, que han sido interpretados como hembras. Otra muestra con tres ejemplares de la misma especie evidencia el "comportamiento social" de ciertos taxones de euriptéridos, que mudan de forma colectiva. También se aportan informaciones generales sobre las dos especies y la procedencia geológica del material del museo.*

Palabras clave: colección paleontológica, Euriptéridos, Norteamérica, Silúrico, Ucrania

Introduction

Eurypterida is an extinct Order of Palaeozoic, predatory chelicerates that dominated certain marginal marine environments in the Silurian and Early Devonian, especially in the palaeocontinents of Laurentia, Baltica, Avalonia and the Rheno-Hercynian Terrane. They are commonly referred to as sea scorpions, although their phylogenetic relationship to extant scorpions is contested; see Dunlop and Braddy (2001) for a summary of this debate. Eurypterida has the highest recorded diversity of any chelicerate order in the Palaeozoic, but they also had a higher preservation potential than for instance the arachnids, that were predominantly terrestrial. 235 species in 62 genera are presently acknowledged, but the

number of valid species is probably around 200 (OET pers. obs.). The eurypterids also represent the largest arthropods known, with specimens commonly approaching 100 cm in most clades (Briggs, 1985) and the derived pterygotids having body lengths of at least 250 cm excluding the frontal pair of claw-like appendages, the chelicerae, and perhaps 350 cm including the chelicerae (M. Poschmann pers. comm., 2002).

The earliest described eurypterid was a specimen of *Eurypterus remipes* from New York State, USA, although in this first description (Mitchill, 1818), it was identified as a catfish of the genus *Silurus* Linné, 1758, with the prosomal appendages mistaken for barbels. It took 7 years, and the discovery of a new specimen for Dekay (1825) to correctly identify the new and Mitchill's fossils as arthropods, although he thought it was a branchiopod crustacean. Dekay (1825) also introduced the name *Eurypterus remipes*. *Eurypterus* means 'broad wing' and this name refers to the prominent swimming legs that protrude like wings laterally to the carapace. *E. remipes* is now known in large numbers, and certainly more than ten thousand specimens have been recovered. This species is the most common eurypterid in the world, although its sister taxon (according to Tetlie, 2006) *E. lacustris* Harlan, 1834, that probably developed directly from *E. remipes* through heterochrony (Tetlie *et al.*, in press) might be catching up in number of recovered specimens.

Although eurypterids are extinct, there are few entirely extinct animal groups which are morphologically better known than eurypterids. The main reason for this knowledge are the exquisitely preserved specimens of *Eurypterus tetragonophthalmus* Fischer de Waldheim, 1839 from the island of Saaremaa, Estonia, but this species was originally described from the south-western Ukraine. However, the Estonian specimens preserve cuticle that is morphologically unaltered from when the animal was alive, although the cuticle composition is altered from chitin in a protein matrix found in extant arthropods into long-chained aliphatic components in the fossil cuticles (Gupta *et al.*, in press). The preservation of cuticle is uncommon in eurypterids. At most localities preserving cuticle, there is some degree of cuticular thermal maturation (Gupta *et al.*, in press), resulting in successive losses of morphological characteristics. It might be only at Saaremaa where eurypterid cuticle is morphologically unscathed by the effects of time and tectonics. It is also fortunate that the Saaremaa fossils are preserved in a relatively pure limestone, while they are more commonly found in dolomitic sedimentary rocks in eastern North America (Ciurca, 1973, 1990) and the Ukraine (Selden and Drygant, 1987). The combination of well-preserved morphology and a lithology that could readily be dissolved in acids in the Estonian specimens was exploited by the Swedish palaeontologist Gerhard Holm, who dissolved large chunks of the Estonian host rocks in the 1890's. He then got almost perfectly preserved cuticular fragments that he mounted onto slides. His milestone paper (Holm, 1898) describing everything from fragments to semi-complete, articulated specimens made minute morphological details known in *E. tetragonophthalmus* that are commonly only known in extant organisms. Subsequent work on the material prepared by Holm has provided much more information about respiratory and reproductive palaeobiology (Wills, 1965; Braddy and Dunlop, 1997) and functional morphology of the prosomal appendages (Selden, 1981; Dunlop and Braddy, 1997). *E. tetragonophthalmus* does not only occur in Estonia and the Ukraine, but also in Norway (Størmer, 1933) and Romania (Văscăutanu, 1932). It is specimens from Estonia and the Ukraine that are most commonly encountered in collections. The Estonian examples are usually from old collections, while new material is still emerging from the Ukraine.

Eurypterids are sexually dimorph animals; there is generally one sex having a long, narrow genital appendage termed type A by Størmer (1934), and one with a shorter appendage termed type B. Our present interpretation (and indeed most previous ones with concurring or conflicting views) of sexual dimorphism in eurypterids is mainly based on the Estonian material of *E. tetragonophthalmus*. Braddy and Dunlop (1997) interpreted the specimens with long narrow appendages as females, based on the presence of blind ending canals termed horn organs in specimens with type A appendages. These canals were interpreted as sperm storage organs by Braddy and Dunlop (1997). In addition, Braddy and Dunlop (1997) found that specimens with type B appendages were associated with modified spines on the third appendage that could be interpreted as claspers, which is typically a male characteristic.

Here, we document four specimens of *E. tetragonophthalmus* and five specimens of *E. remipes* in the collections of Museo Geominero, Madrid, but as expected for such well-known eurypterids, no new information about morphology, sexual dimorphism or phylogenetic position can be ascertained from these specimens. However, it is apparent even from this small sample that most specimens from these horizons represent exuviae rather than carcases, and that the ecdysis was performed in groups that were taxon-specific, and also to a certain degree sorted after size/age of the individuals.

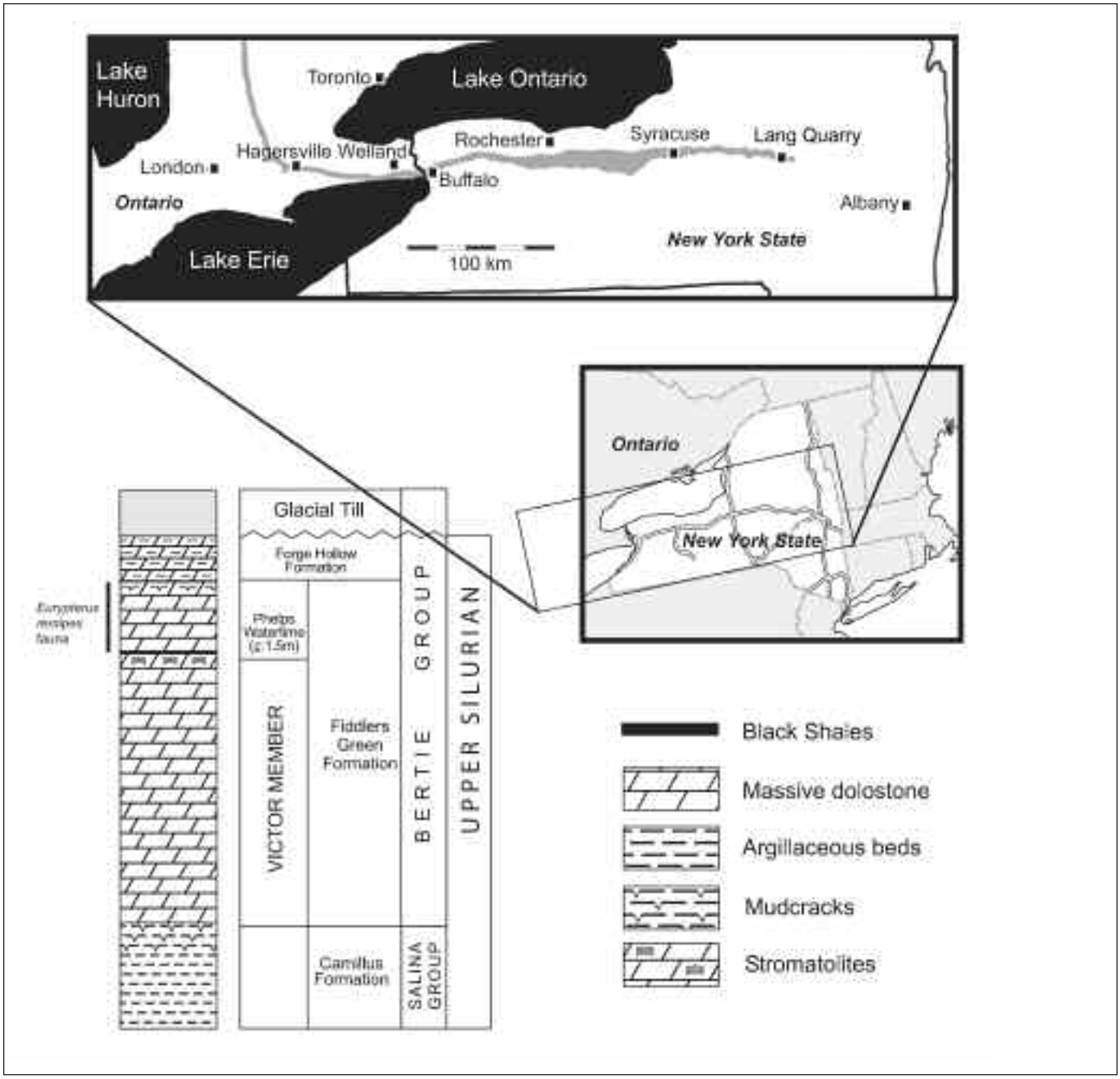

Fig. 1. Map showing area (indicated in grey) where the Bertie Group is outcropping in New York State, USA and Ontario, Canada
Fig. 1. Mapa mostrando los afloramientos del Grupo Bertie (área indicada en gris) en el Estado de Nueva York (EEUU) y su prolongación en Ontario (Canadá)

Geological settings and faunas

Almost all eurypterids from New York State in the United States occur in the Bertie Group, an outcrop belt extending between the city of Buffalo in the west and eastwards approximately to Ilion, east of Syracuse (Fig. 1). From Buffalo, the outcrop belt also extends across the Niagara River and into Ontario, Canada. However, some distance into Canada, the Bertie Group becomes barren in eurypterid fossils. *E. remipes* occur in the Phelps Member of the Fiddlers Green Formation in the Bertie Group. The Phelps Member is a ca. 1.5 m thick dolomitic unit. The entire Bertie Group has a total thickness of ca. 17 m and contains numerous other eurypterid horizons, but the one in the Phelps Member is the best known. Salt

crystal casts (up to 30 cm in diameter) are commonly encountered throughout most of the Bertie Group, indicating elevated salinity in the depositional environment. Desiccation cracks also occur frequently towards the top of the individual units, suggesting the environment periodically dried up completely.

The most productive quarry producing *E. remipes* has been the quarry of Allan Langheinrich (Allan Lang for short – Fig. 2) south of Ilion, Herkimer County, on the easternmost flank of the outcrop belt. *E. remipes* is by far the most common eurypterid at this quarry, making up around 70% of eurypterid specimens (Tetlie *et al.*, in press), but a second species of *Eurypterus*, *Acutiramus macrophthalmus* (Hall, 1859), *Dolichopterus jewetti* Caster and Kjellesvig-Waering, 1956, *Pterygotus cobbi* Hall, 1859, *Clarkeipterus testudineus* (Clarke and Ruedemann, 1912) and a *Buffalopterus* sp. are other eurypterids known from the beds. In addition, primitive scorpions (Dunlop *et al.*, in press), horseshoe crabs, plants, phyllocarids, cephalopods and other rare fossils occur with the eurypterids. It is not known for sure whether the scorpions were terrestrial or aquatic, because terrestrial elements like the early land plant *Cooksonia* also have been found here. Numerous other localities producing eurypterids are also known from the Phelps Member of New York State but the most complete specimens are found in the eastern limb of the outcrop belt, as exemplified by the Lang Quarry. Specimens from localities other than the Lang Quarry are rarely available.

Fig. 2. The oldest part of the Lang eurypterid quarry, Herkimer County, New York State, USA, where the specimens of *Eurypterus remipes* in Museo Geominero probably all originated
Fig. 2. Parte más antigua de la "Cantera Lang" de euriptéridos, situada en el condado de Herkimer (Nueva York, EEUU), probable origen de los ejemplares de Eurypterus remipes *del Museo Geominero*

The Ukrainian slab has a more indeterminate origin. The Ukrainian eurypterids available are usually labelled to be from the area around Kamenets-Podolski, a city in the western Ukraine, close to the borders of Romania and Moldova. Plotnick (1999) listed four eurypterid-bearing horizons in the Ukraine, but one of them (his locality 76) was based on non-eurypterid material (Dunlop and Tetlie, 2006). Gritsenko *et al.* (1999) only noted one eurypterid horizon, the Ustje Member of the Bagovitsa Formation. Since this is the only well-known eurypterid horizon in the Ukraine (see also Selden and Drygant, 1987 and Huff *et al.*, 2000), it is likely, but not certain, that the Ukrainian eurypterid slab originated from the Ustje Member, which is of Wenlock age. The Ustje Member outcrops along the Dniester river south of Kamenets-Podolski (see fig. 1 in Selden and Drygant, 1987), and most of the Ukrainian eurypterid specimens are likely to originate somewhere in this general area. Until a more detailed study of the Ukrainian eurypterid beds are conducted, much remain to be learned about these occurrences.

The Lang Eurypterid Quarry, south of Ilion, Herkimer County, New York

The Lang Quarry is the only operating quarry in the world where the main output is eurypterid fossils. It is operating in the Phelps Member (see above), just a few kilometres west of the easternmost extent of this unit. Allan Langheinrich, who owns the quarry first visited a famous eurypterid locality across the road called Passage Gulf in 1978 on a trip led by Samuel J. Ciurca, Jr. (Ciurca, 1978 is the guidebook for this field trip Allan Lang participated on). Ciurca is another eurypterid enthusiast whose enormous collection has just found a home in the Peabody Museum, Yale University. Passage Gulf has produced a large amount of eurypterids of fantastic quality, and Allan returned several times to Passage Gulf to collect before he decided to lease the land on the other side of the road from Passage Gulf in 1981. In 1985 he bought out his lease, but still lived in New Jersey, ca 400 km away from his newly acquired land.

By balancing his time collecting and restoring the old buildings on the plot, Allan was able to move from New Jersey to the site that would be popularly known as the Lang Quarry, and could start collecting full time. The sedimentary rocks making up the entire Bertie Group are very hard to sample systematically. It is futile to start pounding on a piece of Phelps waterlime without first finding existing

cracks formed naturally along bedding planes that hopefully have fossils on them. Large blocks of Phelps waterlime are excavated from the quarry walls using heavy machinery, and left exposed for natural weathering to occur, so the blocks can be split. It takes many years from when a block is exposed until it has been fully split down. The main advantage with this large scale operation is that much larger bedding planes can be exposed than by regular collecting, increasing the chances of finding accumulations that can provide palaeoecological and behavioural information. Accumulations of eurypterids in the Fiddlers Green Member are commonly seen in two varieties. *In situ* accumulations like the one seen in MGM 5869X (Pl. 1, Fig. B) are probably reflecting groups of animals belonging to the same species moulting together. Several examples are known from the Lang Quarry with up to 20 essentially complete specimens of *E. remipes* on a single slab. Several slabs with multiples of the larger, and much more rare *Acutiramus macrophthalmus* are also known from the Lang Quarry, one with 6 individuals (OET pers. obs., 2003). *A. macrophthalmus* make up around 6% of the total fauna of the site, and chances for this accumulation being accidental is negligible (approximately 1:17,000,000). It is therefore clear that both *E. remipes* and *A. macrophthalmus* occurred in groups, but it is not presently known whether the two *Eurypterus* species intermixed or also were separate. The other type of accumulation is linear accumulations of current-swept material into geographic depressions. These 'windrows', as they have been termed (Ciurca, 1978), of course mainly consist of very fragmentary material due to transportation of fragile exuviae.

Through the years, Allan has found many spectacular specimens, many have found their way to museums all over the world, including Museo Geominero. *Eurypterus remipes* is the most common fossil in the quarry, but a number of other fossils are known (see geological settings and faunas). Isolated parts of spectacularly large pterygotid eurypterids were combined into a monstrous pterygotid that was more than 2 m long. This fantastic specimen was acquired by the Royal Ontario Museum, Toronto, Canada and is on exhibition there.

Allan has now reportedly scaled back the commercial excavations of his quarry and has plans to set up an educational centre with a museum exhibiting some of the most spectacular specimens he has found of *E. remipes*, now the official New York State fossil (Landing, 1987) and other fossils from his quarry.

Are the specimens carcases or exuviae?

Separating eurypterid moults or exuviae from carcases is very difficult, and the problem has occupied eurypterid palaeontologists for almost a century (Ruedemann, 1921). Eurypterid faunas from the Bertie Group of New York have often been interpreted as carcases (e.g Andrews *et al*., 1974), based on the predominance of complete specimens in museum collection. However, a more recent unbiased collection made in New York State by the abovementioned Samuel Ciurca, show that the material found in museum collections is usually considerably biased with much more complete material than what is actually present at the localities. These faunas of the Bertie Group have lately been considered composed largely of exuviae (e.g. Braddy, 2001). This view was mainly based on the lack of evidence of scavenging on the eurypterids, on the frequent crumpling, distortion, superimposing of ventral and dorsal elements, partial telescoping, preservation out of axial alignment and dispersal as disarticulated remains (Braddy, 2001).

Presence of gut structures in eurypterid fossils has earlier been cited as evidence of mortalities (Ruedemann, 1921; Kjellesvig-Waering, 1958; Heubusch, 1962). However, in horseshoe crabs, both the fore- and hindgut are shed (Barnes, 1987). Based on the gut criterion, only the presence of a midgut and/or associated gut content can unequivocally demonstrate that a fossil eurypterid represent a mortality. Selden (1981) considered that all the specimens of *Eurypterus tetragonophthalmus* from Estonia described by Holm (1898) and Selden (1981) probably represented exuviae since all the preserved tissues were of ectodermal origin, including tendonal tissue and Kiemenplatten. Braddy (2001) claimed that in addition to a midgut, only the endodermal muscle tissue and gill tissue could demonstrate the presence of a carcase. However, as pointed out by Gaban and Farley (2002), some of the lung tissue in modern scorpions is actually shed, making the presence of muscle tissue and a midgut the only unequivocal evidence for a mortality. The only certain eurypterid carcases known are therefore those of the Ordovician Soom shale, South Africa (Braddy *et al*., 1995; 1999), and the Devonian Gogo Formation, Australia (Tetlie *et al*., 2004). The following criteria is suggested to aid in identifying eurypterid carcases and exuviae given in order of decreasing predictive power (modified from criteria suggested by Selden, 1981; Braddy, 2001): 1) Presence of muscle tissue (carcase); 2) Presence of a midgut and/or gut content (carcase); 3) Opened sutures on carapace margin and/or ventral plates (exuvium); 4) Recurring pat-

terns of skeletal configurations (carcase and exuvium); 5) Telescoped opisthosomal segments (exuvium); 6) Recurring patterns of displaced or missing skeletal elements (exuvium). However, it is frequently only point 3) that can be employed to separate exuviae and carcases in practice.

In the material from the collection in Madrid, only the smallest of the Ukrainian specimens, an isolated ventral plate with an associated coxa of the swimming leg, suggest this represents a moulted exoskeleton. The ventral plates in *Eurypterus* are paired, i.e. there is one on the left side and one on the right side, and they are joined antero-medially by a suture. This suture opens during exdysis, and the ventral plates often separate from the dorsal carapace when the animal emerges from the discarded exoskeleton. The connection between a ventral plate and the prosomal appendages should be much weaker than between the two ventral plates or the ventral plates and the carapace, unless these two sutures were already opened during ecdysis. Therefore, finding one of the ventral plates that is still associated with parts of the prosomal appendages rather than with the carapace or the second ventral plate is a strong indication that the specimen represents an exuvium. It is not understood why the coxa of the swimming leg often is still associated with the ventral plate on the same side after the sutures have opened. This same association is also commonly seen in the American material of *Eurypterus*. It is not known whether these two elements were attached, but an intimate relationship between them is indicated.

Although not directly seen on the Madrid specimens, because the ventral plates are not exposed in the other specimens, observations by OET on larger collections suggests that the vast majority of specimens of *Eurypterus* from New York State are exuviae, and it is likely that all the *Eurypterus* specimens in the Museo Geominero collection represent exuviae.

History of the Museo Geominero specimens

The specimens in Museo Geominero, Madrid (MGM) are reposited under catalogue numbers MGM 1758X, MGM 2799X, MGM 5868X and MGM 5869X. They were acquired by purchase from fossil dealers; MGM 1758X in 1990, MGM 2799X in 2000 and MGM 5868X and MGM 5869X in 2005. One of the specimens of *E. remipes* (MGM 1758X) is labelled 'Lang's Quarry' on the back of the slab, and it is therefore certain that it originated from the Lang Quarry, south of Ilion, Herkimer County, New York State. The other two specimens are labelled with Herkimer County as place of origin, and since most specimens of *E. remipes* available in the world during the last 20 years have originated from the Lang Quarry, it is likely that all three slabs (five specimens) are from this quarry.

Description of the specimens

MGM 1758X – Pl. 1, Fig. A (*E. remipes*, Lang Quarry, Herkimer County, New York, USA).- A large (around 200 mm if straight) specimen seen in ventral view. It is essentially complete, having the carapace, opisthosoma, telson and most of the prosomal appendages and metastoma. Specimens in ventral view are usually less sought after by collectors than specimens in dorsal view, but they are of more value than a dorsal view from a scientific point of view, since the majority of characters used in reconstructing phylogenetic relationships are present on the ventral side. It is also easiest to separate exuviae and carcases in specimens with a ventral view, since the median suture of the ventral shields can occasionally be seen, but they are not visible on this specimen. The specimen is also the only specimen of the ones in the Museo Geominero collection that has an exposed genital appendage so the sex can be determined. It has a type A appendage, interpreted as a female (see Braddy and Dunlop, 1997).

MGM 2799X – Pl. 1, Fig. D (*E. tetragonophthalmus*, Ukraine).- A small, almost complete juvenile specimen with a complete length of about 90 mm, an isolated swimming leg that might be from the most complete specimen, a smaller specimen preserving a carapace and the anteriormost four opisthosomal segments, and an isolated coxa of a swimming leg with an associated ventral plate. The three most complete specimens have been coated to enhance contrast. In the most complete specimen, parts of the left swimming leg and the entire telson have been painted onto the matrix to increase its commercial value. The association of a coxa with a ventral plate is an indication that the Ukrainian specimens are exuviae.

MGM 5868X – Pl.1, Fig. C (*E. remipes*, Herkimer County, New York, USA).- This is an aesthetically very pleasing specimen seen in dorsal view. It is complete except for the tip of the telson and the prosomal appendages save the two swimming legs. It is ca. 140 mm long, but might have been a cm longer if the telson had been complete. This specimen exhibits well the embayment of the carapace margin laterally to the eyes that separate *E. remipes* from all other species of *Eurypterus* (Tetlie *et al*., in press).

MGM 5869X – Pl. 1, Fig. B (*E. remipes*, Herkimer

Plate 1. Non-Spanish Silurian eurypterid specimens in the collections of Museo Geominero. A-C, *Eurypterus remipes* Dekay, 1825. A, MGM 1758X, Pridoli, Lang Quarry, New York State, USA. B and C, MGM 5869X and MGM 5868X, probably from the same locality as A. D, MGM 2799X, *E. tetragonophthalmus* Fischer, 1839,?Wenlock of western Ukraine. All scale bars: 1 cm.

Lámina 1. Euriptéridos extranjeros de las colecciones del Museo Geominero. A-C, Eurypterus remipes *Dekay, 1825. A, MGM 1758X, de la "Cantera Lang" (Estado de Nueva York, EEUU). B y C, MGM 5869X y MGM 5868X, respectivamente, tal vez de la misma procedencia. D, MGM 2799X,* Eurypterus tetragonophthalmus *Fischer, 1839, probablemente del Wenlock del oeste de Ucrania. Escalas gráficas: 1 cm.*

County, New York, USA).- A slab with three almost complete specimens. All three are showing the critical features of a serrated telson and the notable embayment of the carapace, identifying them as *E. remipes*, not the second species of *Eurypterus* found in the Phelps Mb (Tetlie *et al.*, in press).

Conclusions

The non-Spanish eurypterid specimens in the Museo Geominero belong to two of the most important eurypterid species, *E. remipes*, the earliest described species and the New York State fossil, and *E. tetragonophthalmus*, the morphologically best known eurypterid. In the middle and late Silurian, these two species dominated the enormous shallow inland seas covering large parts of Laurentia and Baltica, respectively. The specimens in MGM support the interpretation that both American and Ukrainian eurypterid faunas are mainly composed of exuviae. They also suggest that *Eurypterus remipes* moulted in groups. The entire clade Eurypteroidea has 7 described genera (*Buffalopterus*, *Dolichopterus*, *Erieopterus*, *Eurypterus*, *Ruedemannipterus*, *Strobilopterus*, *Syntomopterus*), but probably several more unrecognized genera (Tetlie and Cuggy, in press). The genus *Onychopterella* is basal to the remaining swimming forms (Tetlie and Cuggy, in press). The Eurypteroidea is entirely confined to the palaeocontinent of Laurussia (Laurentia, Baltica, Avalonia plus the Rheno-Hercynian Terrane). These basal swimming eurypterids were therefore evidently very well adapted to the hypersaline inland seas where they are found, and maybe even depended on these inhospitable environments for protection from predators during ecdysis (Braddy, 2001). These eurypterids were only able to disperse along coastlines (Tetlie, in review), and therefore unable to reach other continents, for instance Gondwana, where Spain was situated on the northern coast.

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