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Graptolites and trilobites from the Eusebio Ayala Formation (Hirnantian?–early Llandovery), Paraná Basin, eastern Paraguay

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A low-diversity graptolite fauna from the upper part of the Eusebio Ayala Formation exposed in the intracratonic Paraná Basin of eastern Paraguay is reported herein. The sections studied are composed dominantly of red micaceous mudstones with intercalations of purple sandstones from a series of clay quarries (Santa Elena; Galeano; Western Itauguá) around Itauguá city. The graptolites *Metaclimacograptus* sp., *Normalograptus* cf. *ajjeri* (Legrand), and *Normalograptus* cf. *medius* (Törnquist) indicate an early Llandovery age for the upper Eusebio Ayala unit. Compared to coeval, postglacial successions in southwestern Gondwana, the graptolites studied have their closest affinities with those from the Rhuddanian lower Lipeón (Subandean Ranges, northwestern Argentina) and La Chilca (Precordillera) formations. In addition, a trilobite assemblage dominated by the genus *Mucronaspis* was collected from the Eusebio Ayala Formation type locality near Eusebio Ayala city. The latter represents an isolated small outcrop which seems to be latest Ordovician (Hirnantian) in age.

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1. INTRODUCTION

The Lower Palaeozoic Itacurubí Group (Harrington, 1972) is exposed along the western border of the intracratonic Paraná Basin of eastern Paraguay and comprises, from base to top, the siliciclastic Eusebio Ayala, Vargas Peña, and Cariy formations. This *ca*. 350-m-thick sequence was traditionally assigned to the Llandovery (e.g. Harrington, 1950; Wolfart, 1961; Dyck, 1991; Benedetto *et al*., 1992; Benedetto, 2002; Galeano Inchausti and Poiré, 2006; Uriz *et al*., 2008a, b and references therein) on the basis of its abundant marine fossil record (graptolites, trilobites, brachiopods, bivalves, gastropods, nautiloids, tentaculitids, crinoids, ichnofossils). In addition, Llandovery palynofacies assemblages dominated by acritarchs, chitinozoans and miospores were described by Steemans and Pereira (2002).

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The latest Ordovician–earliest Llandovery represents a time slice with relevant palaeoclimatic and evolutive significance (Cocks, 1985, 2001). The objective of the present contribution is to describe new faunas from the basal Itacurubí Group. Graptolites and trilobites from classic localities of the Eusebio Ayala Formation are reported herein, and their stratigraphic and palaeobiogeographic implications are outlined.

2. GEOLOGICAL SETTING AND STRATIGRAPHY

The South American Paraná Basin extends into eastern Paraguay, the south and southeast of Brazil, central Uruguay and northeastern Argentina. The geological evolution of this intracratonic basin of southwestern Gondwana was affected by compressional stress along an active convergent margin (Milani and de Wit, 2007). During the Late Ordovician–Early Devonian, the basin was filled by continuous and thick siliciclastic sequences. In eastern Paraguay, a major extensive tectonic event controlled by NW-trending faults (‘Asunción rift’) took place during post-Palaeozoic times, developing a conspicuous morphologic graben structure (Ypacaraí Graben) (Figure 1). Distensive structural processes exposed the Palaeozoic sedimentary sequences, and partially their Precambrian basement. The Ypacaraí Graben has a general NW–SE orientation and bears a well-known, rift-related alkaline magmatism.

The pre-Carboniferous units are widely exposed along the south-western edge of the Ypacaraí Graben, constituting a sub-horizontal cratonic sedimentary sequence that overlies Precambrian rocks. The Ordovician *ca*. 700-m-thick Caacupé Group (Harrington, 1972) is the basal sedimentary unit which includes in ascending order, the Paraguarí, Cerro Jhú and Tobatí formations, and is composed of conglomerates and coarse-grained sandstones that culminate with tillite deposits linked to the Late Ordovician glacial event. The Itacurubí Group (Harrington, 1950, 1972), mainly of early Silurian age, overlies these glacial deposits and is composed of the Eusebio Ayala, Vargas Peña, and Cariy formations. It represents a complete transgressive–regressive cycle, in which the sandstones of the Eusebio Ayala Formation mark the base of the series. In the study area, the Itacurubí Group is locally covered by either Cretaceous–Tertiary rocks (Asunción Group) or Quaternary alluvial deposits.

The *ca*. 200-m-thick Eusebio Ayala Formation (Harrington, 1950, 1972) is composed of yellowish, brownish, reddish to purple micaceous sandstones with intercalated mudstone-siltstone beds and ferruginous levels. The sandstones are laminated, and wave cross-stratifications are frequent. Reddish fine-grained sandstone levels bearing fossils have bedding planes with abundant detrital muscovite mica (see petrographic detail in Figure 2). Grains are subrounded, with moderate sorting. Sedimentary rock fragments (microcrystalline chert) are present and secondary hematite cement is widespread, filling available porosity. Mudstones and siltstones show high bioturbation rates and wavy-linsen structures. The Eusebio Ayala Formation contains invertebrate fossils that developed in a shallow marine environment at the beginning of the latest Ordovician–early Silurian flooding event (Milani and de Wit, 2007).

3. FOSSIL LOCALITIES AND FAUNAS

New graptolite levels from the upper part of the Eusebio Ayala Formation were found in a series of clay quarries (Santa Elena, 25°23′27″S–57°18′54″W; Galeano, 25°23′33″S–57°18′22″W; Western Itauguá, 25°22′25″S–57°20′08″W) around Itauguá city, about 60 km east of Asunción, where the ‘Asunción rift’ defines the western border of the Paraná Basin (Figure 1). Figure 3 shows the main field photographs

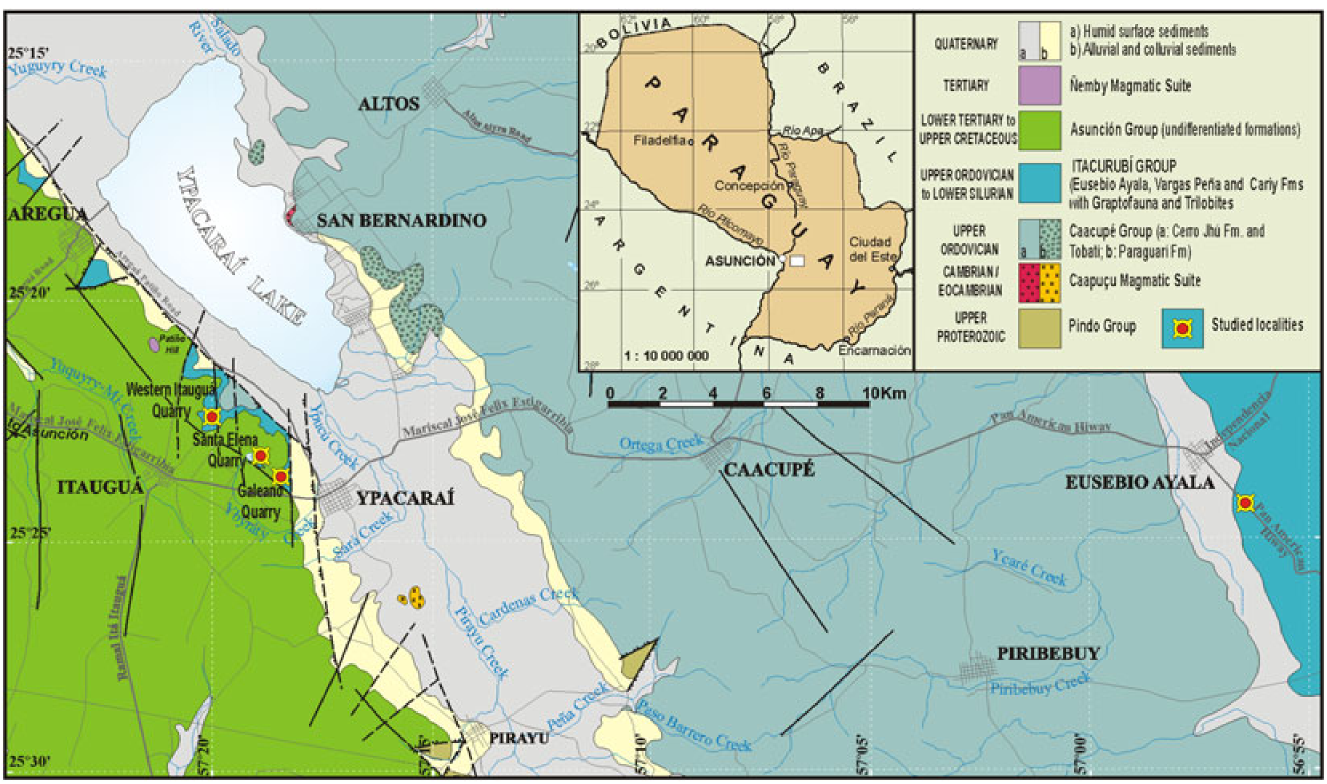

Figure 1. Geological sketch map near Itauguá town based on Dionisi (1999) and location of the quarries in which the fauna was collected. This figure is available in colour online at wileyonlinelibrary.com/journal/gj

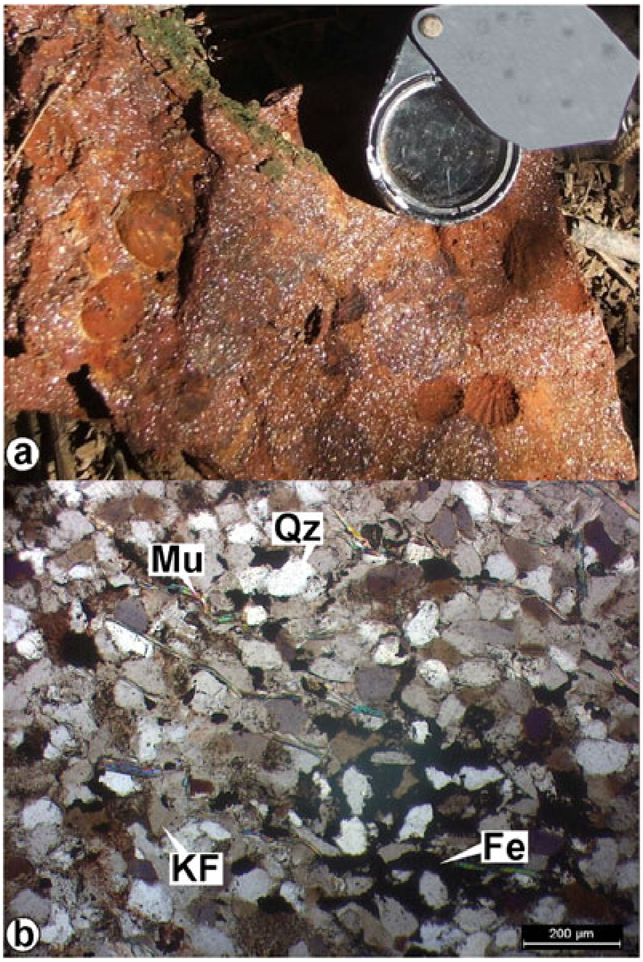

Figure 2. (**a**) Typical rock of the reddish sandstone levels of the Eusebio Ayala Formation bearing shelly fauna (brachiopods). Note that the bedding plane contains abundant detrital white mica. (**b**) Photomicrograph (crossed-nicols) of fine-grained sandstone with presence of Qz (Quartz), KF (K-Feldspar) and sedimentary rock fragments (chert) as sub-rounded grains. Flexured detrital muscovites (Mu) in the matrix and secondary hematite (Fe) are abundant. The sandstone shows moderate sorting. The sample was taken near the San Fernando quarry (25°22′27″S–57°19′47″W). This figure is available in colour online at wileyonlinelibrary.com/journal/gj

and stratigraphic logs of the Eusebio Ayala Formation in the Western Itaugua, Galeano and Santa Elena quarries. The graptolites identified have a low diversity and include *Metaclimacograptus* sp., *Normalograptus* cf. *ajjeri* (Legrand, 1977), and *Normalograptus* cf. *medius* (Törnquist, 1897). General orientations of the strata range from N139° to 145°, dipping 12° to 32°SE. The base of the formation is not exposed in the outcrops studied but diamictite deposits have been reported in drill holes from the Santa Elena area (see below). The upper part of the Eusebio Ayala Formation shows a transgressive surface characterized by the presence of iron-rich levels.

In addition, a trilobite assemblage was collected from the Eusebio Ayala Formation type locality (Harrington, 1972, p. 42). The latter represents a small isolated outcrop near Eusebio Ayala city (Figure 1). The trilobites are scarce and restricted to *Mucronaspis* sp. (Dalmanitidae) and two incomplete and poorly preserved homalonotid pygidia (not figured).

4. SYSTEMATIC PALAEONTOLOGY

The specimens studied are deposited in the Department of Invertebrate Palaeontology at the Museum of La Plata, Argentina (MLP 32916a,b, 32918, 32920, 32924a,b, 32926b, 32928–32929a,b, 32933, 32944, 32947–32949). Graptolites were studied under alcohol or glycerin with a binocular microscope. Trilobites were whitened with magnesium oxide prior to photography.

4.1. Graptolites

Family NORMALOGRAPTIDAE Štorch and Serpagli, 1993
Genus METACLIMACOGRAPTUS Bulman and Rickards, 1968; emended Melchin 1998

Metaclimacograptus sp.
(Figures 4a–h, 5a–d)

Material. Forty-eight well-preserved specimens were collected from the Santa Elena, Galeano and Western Itauguá quarries, upper Eusebio Ayala Formation (Rhuddanian) (samples M7/09, M8/09, M9/09, M11/09 and MSE). Most rhabdosomes are raised and fully or partially replaced by iron oxides, which give them reddish or blackish colours. Specimens replaced by iron oxides retain some fine morphological details. Only two specimens are complete; most colonies are represented only by proximal, median or distal fragments.

Description. The rhabdosome has a total length of 18 to 24.5 mm and a width of 0.8–1.1 mm at the first thecal pair; its width increases to 1.4–1.5 mm (in relief colonies) and 1.9 mm (in flattened specimens) in the initial 5 mm (maximum distal width). The proximal 2TRD is 1.3 mm and the distal 2TRD is 1.9 mm. The sicula is conical, commonly preserved in relief, with a length of 0.5–0.9 mm when measured from the obverse side of the colony. The sicular apex attaining the level of the second thecal pair. The sicular aperture is 0.2 mm across. The descending portion of the first theca is 0.3 mm long; it grows below the sicular aperture and then bends sharply upwards, while the $th1^2$ grows up along its length, giving an asymmetrical appearance to the proximal end of the colony. Early astogeny of pattern H. Apertures occupy one-fourth of the width of the rhabdosome in relief specimens, and one-third in flattened colonies. Thecae

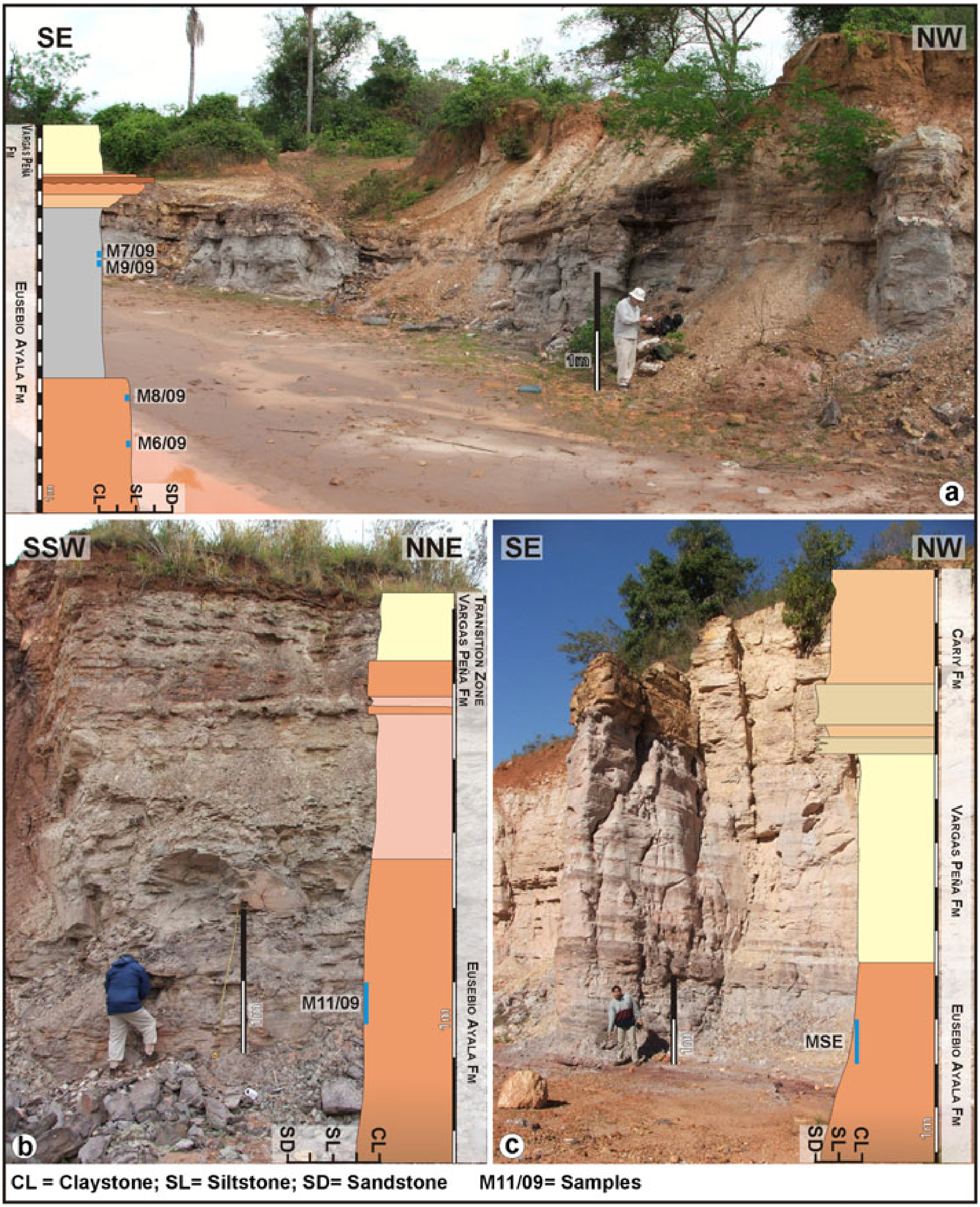

Figure 3. Field photographs and stratigraphic logs of the Eusebio Ayala Formation in the Western Itaugua (**a**), Galeano (**b**) and Santa Elena (**c**) quarries. M6/09, M7/09, M8/09, M9/09, 11/09 and MSE are the levels sampled. This figure is available in colour online at wileyonlinelibrary.com/journal/gj

with strongly sigmoidal curvature parallel to the median septum. Geniculum sharp. Supragenicular walls are straight or slightly inclined to the central axis, and the infragenicular walls are thickened. Median septum complete, exhibiting rounded, or less frequently, angular undulations. Thecae number 14 in 10 mm proximally and 12 in 10 mm distally.

Discussion. The material studied is characterized by having a complete and undulating medium septum, strongly geniculate, sigmoidal thecae, and convex or almost straight supragenicular walls. Although it lacks infragenicular hoods, the infragenicular walls are frequently thickened. The presence of a proximal development type of pattern H, a rounded

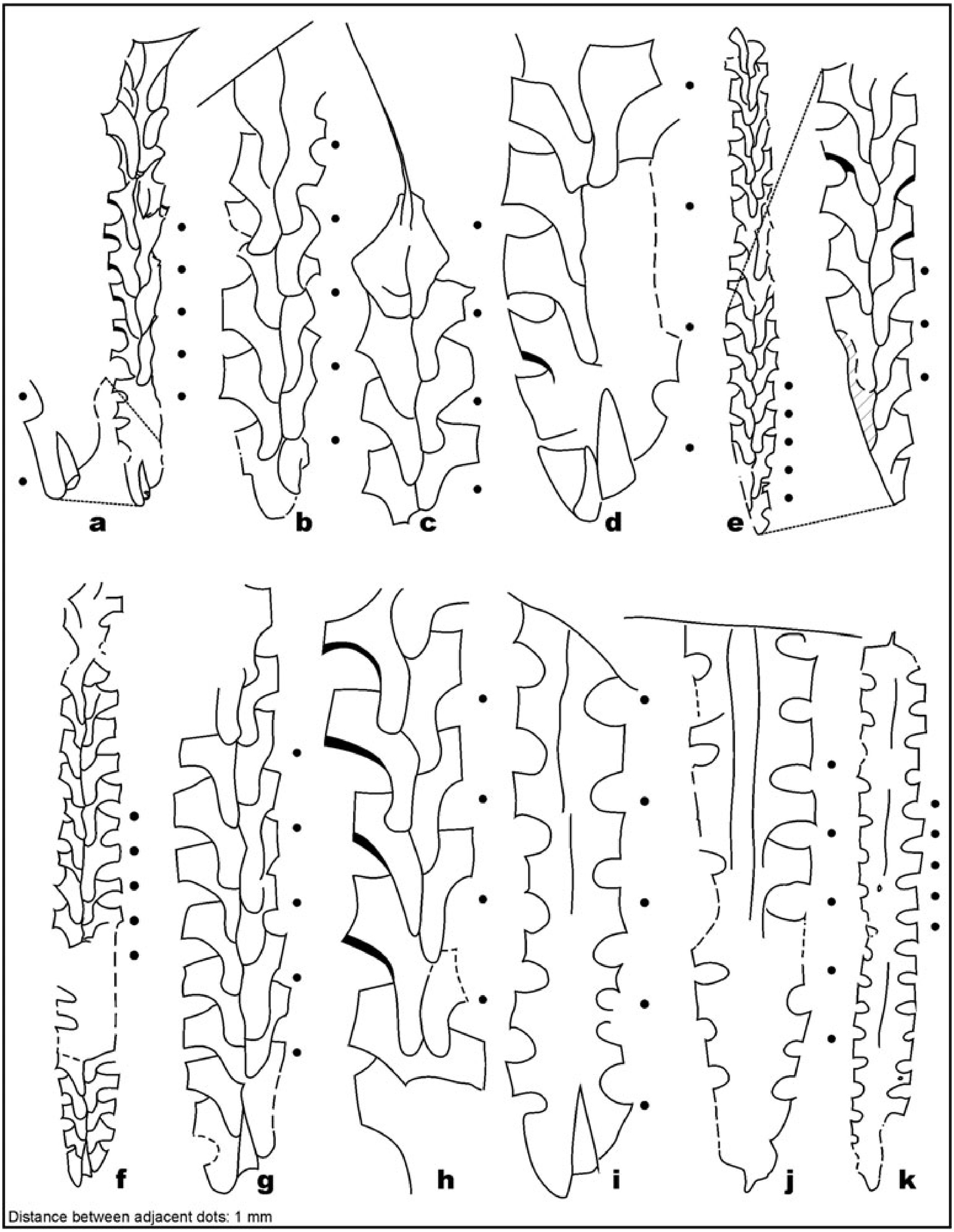

Figure 4. Camera Lucida drawings of representative graptolite specimens from the Eusebio Ayala Formation. **a–h**, *Metaclimacograptus* sp. **a** MLP 32918. **b** MLP 32920. **c** MLP 32924a. **d** MLP 32924b. **e** MLP 32928. **f** MLP 32929a. **g** MLP 32947. **h** MLP 32948. **i** *Normalograptus* cf. *ajjeri* (Legrand, 1977), MLP 32944. **j**, **k** *Normalograptus* cf. *medius* (Törnquist, 1897). **j** MLP 32926b. **k** MLP 32933. Scale: 1 mm between dots.

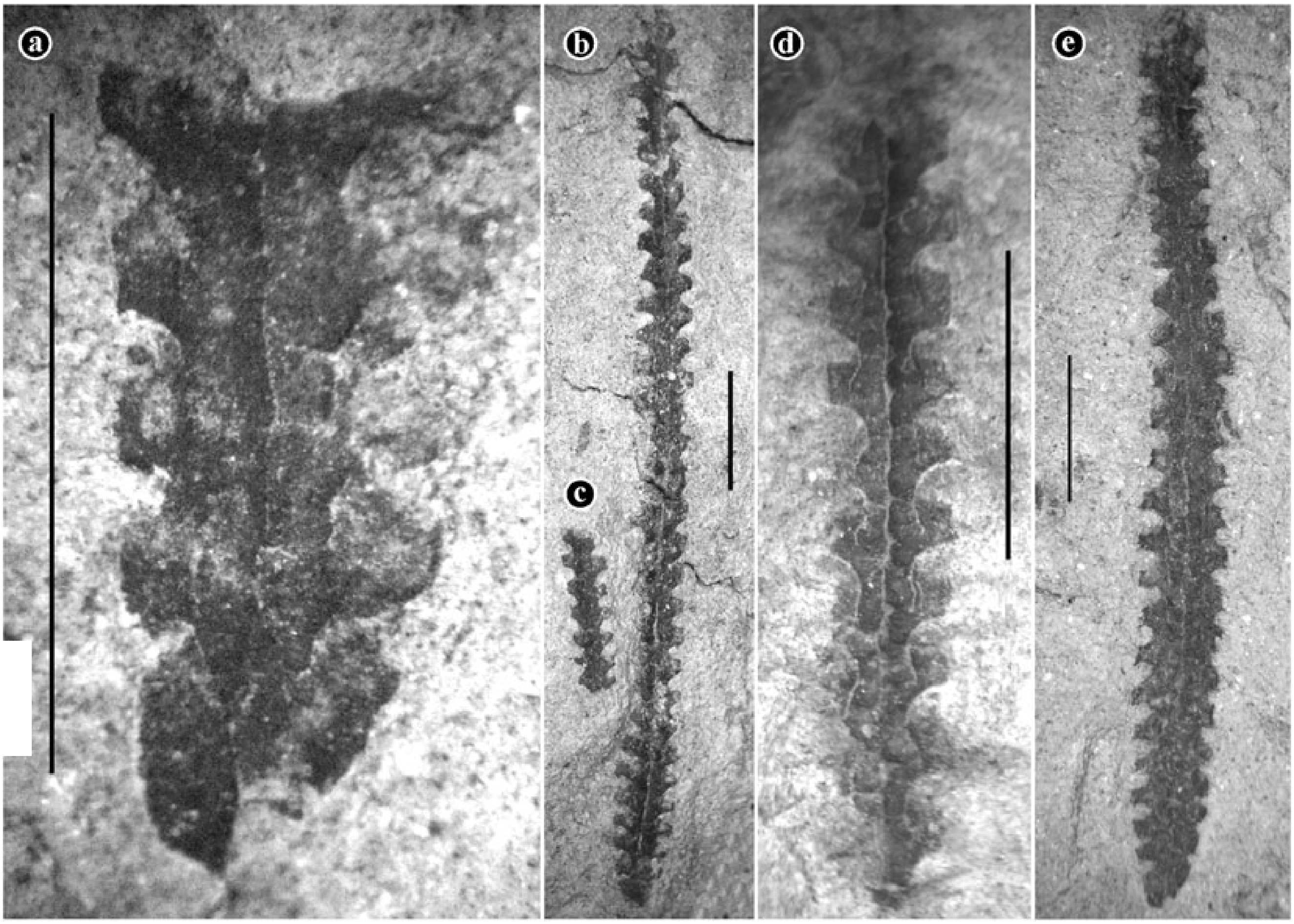

Figure 5. Microphotographs of representative graptolite specimens from the Eusebio Ayala Formation. **a–d** *Metaclimacograptus* sp. (**a**) proximal end, MLP 32929a. (**b**) MLP 32916a. (**c**) MLP 32916b. (**d**) MLP 32949. (**e**) *Normalograptus* cf. *medius* (Törnquist, 1897), distally deformed specimen, MLP 32929b. Scale bars: 3 mm.

proximal end profile, and a short virgella, are features compatible with *Metaclimacograptus* (Bulman and Rickards, 1968, emended diagnosis by Melchin, 1998).

Cuerda *et al*. (1988) identified graptolites [*Talacastograptus leanzai*; *Pseudoclimacograptus (?Metaclimacograptus) robustus*] very similar to *Metaclimacograptus* sp. in the Ordovician–Silurian transition of the La Chilca Formation at Talacasto, Precordillera of San Juan, Argentina. Both *Metaclimacograptus* sp. and *Talacastograptus leanzai* Cuerda, Rickards and Cingolani, 1988 have comparable rhabdosome sizes and thecal spacing, an undulating median septum, and a sharp geniculum, although the latter is distinguished by the presence of conspicuous genicular hooks, which are especially developed on the proximal end of the rhabdosome. Similarly, the present specimens of *Metaclimacograptus* sp. match rather well those of *Metaclimacograptus robustus* (Cuerda *et al*., 1988) from the Precordillera of San Juan mainly in having similar rhabdosome proportions, a complete and undulating median septum, thecae with sigmoidal curvature parallel to the median septum, and a sharp geniculum. However, the former show a closer thecal spacing, and lack saddle incisions and genicular hoods. *Talacastograptus leanzai* and *Metaclimacograptus robustus* were also described from the lower levels of the Lipeón Formation in the Subandean Ranges, northwestern Argentina (Rickards *et al*., 2002). It is important to note that the specimens of *M. robustus* illustrated by Rickards *et al*. (2002, fig. 3j, k) show strong similarities with those of *Metaclimacograptus* sp. from Paraguay.

Genus NORMALOGRAPTUS Legrand, 1987
Normalograptus cf. *ajjeri* (Legrand, 1977)
(Figure 4i)

cf. 1977 *Climacograptus (Climacograptus) normalis ajjeri* Legrand, p. 171, text-figures 9a–d, 10a, b.
cf. 2008 *Normalograptus ajjeri* (Legrand); Štorch and Feist, p. 943, figures 6.14, 7.22.

Material. Twenty-four poorly preserved specimens. They are conserved in total or partial relief and are replaced by iron oxides. Only two colonies are complete, whereas other specimens are represented by proximal ends. Santa Elena, Galeano and Western Itauguá quarries, upper Eusebio Ayala Formation (Rhuddanian) (samples M6/09, M7/09, M8/09, M9/09, M11/09 and MSE).

Description. Specimens studied reach a maximum length of 15 mm. Most colonies preserve their proximal portion. The width is 0.8 to 1.1 mm at the first pair of thecae, widening to 1.2–1.6 mm distally. The sicula has a length of 1.1 to 1.3 mm. The virgella is not preserved in most of the colonies. The proximal end of the rhabdosome shows a typical normalograptid pattern, which gives an asymmetric appearance to this part of the colony. Alternating thecae are like those of the climacograptids, with an acute geniculum, straight supragenicular walls parallel to rhabdosomal axis, and semicircular apertural excavations occupying one-third to one-fourth the width of the rhabdosome. Supragenicular walls are 0.3–0.4 mm long. Proximal thecae are 13–15 in 10 mm, decreasing to 12 in 10 mm distally. The proximal 2TRD is 1.2–1.3 mm and the distal 2TRD is 1.6–1.7 mm. One specimen preserves a full median septum and up to 2-mm-long nema.

Discussion. The material described above and *Normalograptus ajjeri* (Legrand) are similar in rhabdosome dimensions and some proportions, but in our specimens the ratio between supragenicular walls and apertural excavations are slightly lower than in *N. ajjeri*.

Normalograptus ajjeri was first described as a Lower Llandovery species from the Algerian Sahara (Legrand, 1977), and subsequently it was referred to the Hirnantian–lower Llandovery (Legrand, 1988). It is also known from the Rhuddanian of southern France and Jordan (Štorch and Feist, 2008; Loydell, 2007).

Normalograptus cf. *medius* (Törnquist, 1897)
(Figures 4j-k, 5e)

cf. 1897 *Climacograptus medius* Törnquist, p. 7, plate 1, figures 9–15.
cf. 1906 *Climacograptus medius* Törnquist; Elles and Wood, p. 189, plate 26, figure 4a–f; text-figure 122a–c.
cf. 1970 *Climacograptus medius* Törnquist; Rickards, p. 30, plate 1, figure 2.
cf. 1974 *Climacograptus medius* Törnquist; Hutt, p. 19, plate 1, figure 3.
cf. 1975 *Climacograptus medius* Törnquist; Bjerreskov, p. 24, text-figure 9c.
cf. 1983 *Climacograptus medius* Törnquist; Williams, p. 616, text-figure 5f–i.
cf. 1984 *Climacograptus medius brevicaudatus* Churkin and Carter; Lin and Chen, p. 212, plate 4, figures 1, 2.
cf. 1988 *Climacograptus medius* Törnquist; Cuerda, Rickards and Cingolani, p. 755, fig. 5k, l.
cf. 1993 *Normalograptus medius* (Törnquist, 1897); Štorch and Serpagli, p. 23, plate 5, figures 1, 7; text-figure 7D, O.
cf. 1998 *Normalograptus medius* (Törnquist, 1897); Underwood *et al*., figure 5J.
cf. 2008. *Normalograptus medius* (Törnquist, 1897); Štorch and Feist, p. 945, figures 6.7, 6.15, 7.21, 8.10, 8.11.

Material. Eleven poorly preserved specimens were recognized in the upper Eusebio Ayala Formation. They are replaced by iron oxides and preserved in partial relief or flattened. Only four colonies are complete. Santa Elena, Galeano and Western Itauguá quarries, upper Eusebio Ayala Formation (Rhuddanian) (samples M7/09, M8/09 and M11/09).

Description. Rhabdosomes are between 10 and 18.5 mm long. The rhabdosome widens from proximal width of 0.8 to 1.2 mm through 1.6 to 2 mm in medial–distal levels to a maximum distal width of 2.1 mm. The proximal end is typically rounded and asymmetrical. Thecae are of climacograptid type, with a sharp geniculum, straight and short supragenicular wall 0.50 to 0.70 mm in length, and deep aperture excavation occupying one-third the width of the rhabdosome. Thecae count 14 in 10 mm at the proximal end of the rhabdosome, decreasing to 12 in 10 mm distally. The proximal 2TRD is 1.2 mm and the distal 2TRD is 1.6 mm.

Discussion. These specimens match with the concept of *Normalograptus medius* (Törnquist) in the overall rhabdosome features, thecal spacing, and shape of the proximal end (see descriptions of Rickards, 1970; Hutt, 1974; Štorch and Feist, 2008), but our specimens are slightly narrower than those described by Rickards (1970). A mature specimen from Paraguay (Figure 5e) partially agrees with material from the *N. persculptus* Biozone of China described by Chen *et al*. (2005), but the former is much shorter. In addition, Cuerda *et al*. (1988) mentioned a comparable form in the *N. persculptus* and *atavus* zones of the Talacasto Creek (Precordillera of San Juan, Argentina).

4.2. *Trilobites*

Family DALMANITIDAE Vodges, 1890
Subfamily MUCRONASPIDINAE Holloway, 1981
Genus MUCRONASPIS Destombes, 1963
Mucronaspis sp.
(Figure 6a–h)

Material. Four fragmentary cephala, one incomplete thorax, two thorax–pygidia and six pygidia. Some specimens show indications of distortion. Road cut to the south-east of Eusebio Ayala city, Eusebio Ayala Formation (type locality).

Description. Cranidium slightly convex, with rounded anterior margin. Glabella large, moderately elevated above genal region, well defined by narrow and gentle impressed

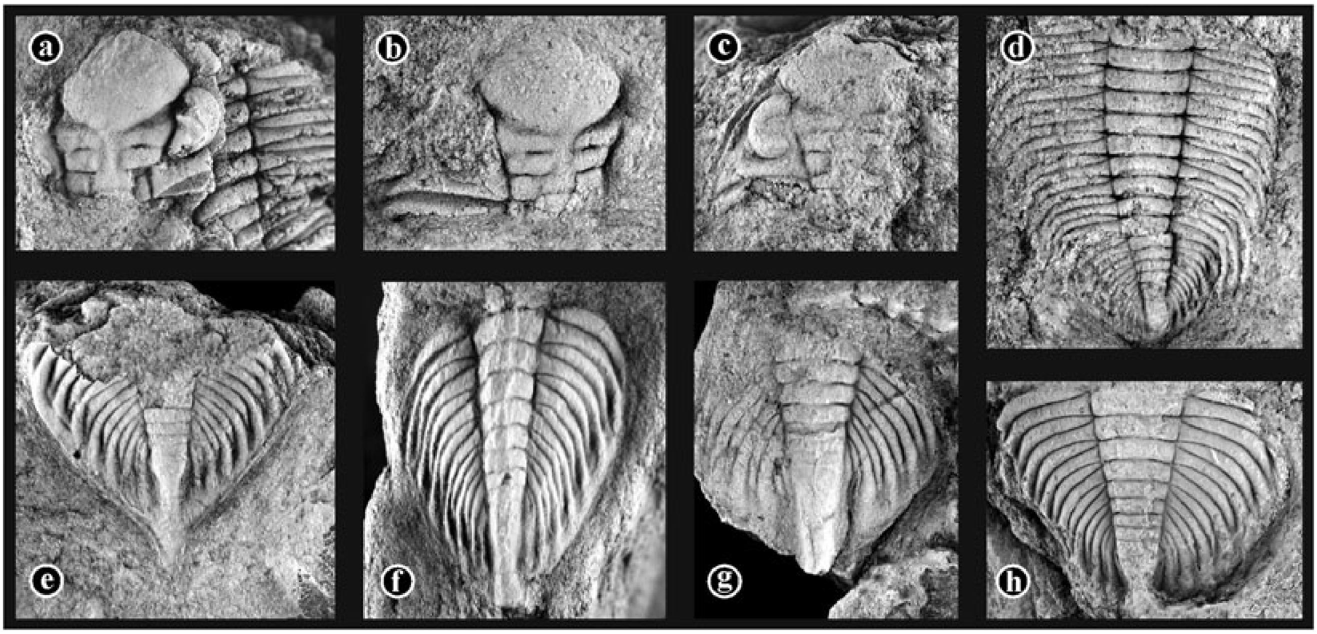

Figure 6. **a–h** *Mucronaspis* sp. from the Eusebio Ayala Formation type locality. (**a**) Fragmentary cephalon and thorax, MLP 32950, x1.9. (**b**) Fragmentary cephalon, MLP 32951, x1.5. (**c**) Fragmentary cephalon, MLP 32952, x2.4. (**d**) Thorax and Pygidium, MLP 32953, x2. (**e**) Pygidium, MLP 32954, x2.1. (**f**) Pygidium, MLP 32955, x2.3. (**g**) Pygidium, MLP 32956, x1.7. (**h**) Pygidium, MLP 32957, x1.5.

axial furrows, expanding weakly between S1 furrow and anterior end of palpebral lobe and strongly thereafter, broadly rounded anteriorly; occipital ring decreases in length adaxially; occipital furrow transverse, deepest at sides and shallow on midline; lateral glabellar furrows disconnected at middle, in contact with axial furrows; S1 and S2 furrows narrow, almost normal to axis; L1 lobe as long as L2; S3 furrow oblique, wide, quite deeply impressed, expanding adaxially; L3 shorter (ax.) than L2 at inner margin, expanding (exsag.) adaxially; inner ends of glabellar furrows joined by a very faint longitudinal furrow; frontal lobe large, subrhombic in outline, more than half the length of the glabella. Palpebral lobe semicircular, about 0.4 length of cranidium, extended between S3 and S1 furrow.

Thorax with 10 segments; axis slightly tapering backwards, width about 0.3 of total width of thorax; pleurae with oblique furrow, ending in spines curved backwards; on more posterior segments pleural tips turned progressively more strongly backwards and spines increase in length.

Pygidium subtriangular–parabolic in outline, 1.5 times as wide as long (sag., excluding mucro), moderately convex. Axis narrow, tapering backwards, with?9 visible axial rings, delimited by narrow axial furrows; axial rings not defined on the posteriormost part of the axis that merges with a mucro; pleural fields only slightly downsloping, with seven pairs of conspicuous pleural and interpleural furrows of similar depth; these furrows are oblique and strongly flexed backwards distally; border furrow absent; border very narrow, fairly flat to concave; lateral margin entire; posterior mucro subcircular in cross-section (partially preserved).

Discussion. The dalmanitid described above bears deep pleural and interpleural furrows on the pygidium, with their distal parts strongly flexed backwards. In addition, the posterior segments of the thorax are characterized by having prominent and strongly turned backwards pleural spines. Such characters are diagnostic of the Subfamily Mucronaspidinae (see Holloway, 1981). Although the specimens examined are fragmentary, the rear part of the pygidium show clear indications of a caudal projection (mucro), pointing out morphological correspondence with *Mucronaspis* Destombes, 1963. This genus is a very common element of the widespread latest Ashgill (Hirnantian) *Hirnantia* shelly fauna (Cocks and Fortey, 1997). In western Gondwana, the latest Ordovician records include those from South Africa and the Argentine Precordillera (e.g. see Cocks and Fortey, 1986; Benedetto *et al*., 2009 and references).

The presence of a wide and shallow glabellar furrow S3 distinguishes *Mucronaspis* sp. from the widespread species *M. mucronata* (Brongniart), from the Hirnantian of Great Britain, Scandinavia, Poland, Sardinia, Bohemia, Kazakhstan, China, southeastern Asia and eastern Canada (e.g. Temple, 1952; Kielan, 1959; Ingham, 1977; Owen, 1982; Cocks and Fortey, 1997); from *M. sudamericana* (Baldis and Blasco, 1975), from the Hirnantian of the Precordillera of San Juan, Argentina; and from *Mucronaspis itacurubensis* (Baldis and Hansen, 1980) from eastern Paraguay (see Jell and Adrain, 2003). *Mucronaspis olini* (Temple), from the latest Ordovician of Sweden, Great Britain, Poland, Siberia, Kazakhstan and South Africa (e.g. Temple, 1952; Kielan, 1959; Cocks and Fortey, 1986) has, in addition, shorter (exsag.) palpebral lobes.

5. IMPLICATIONS OF THE STUDIED FAUNA WITHIN THE ITACURUBI GROUP

As is generally known, the latest Ordovician was characterized by the occurrence of extensive glaciations and glacioeustatic sea-level falls in many Gondwanan areas (Figure 7). These climate events affected many groups of marine organisms and caused the extinction of a significant number of them. Graptolites suffered nearly complete extinction during the Hirnantian, coincident with a sea-level drop. At that time, diverse populations of the Dicranograptidae-Diplograptidae-Orthograptidae (DDO) fauna decreased to only one genus. *Normalograptus* is known to have passed through the Hirnantian (Finney *et al*., 2007; Kaljo *et al*., 2008; Delabroye and Vecoli, 2010). The post-extinction radiation, with a sea-level rise from latest Ordovician into the Silurian, developed entirely from this normalograptid group (Melchin and Mitchell, 1991; Mitchell *et al*., 2007).

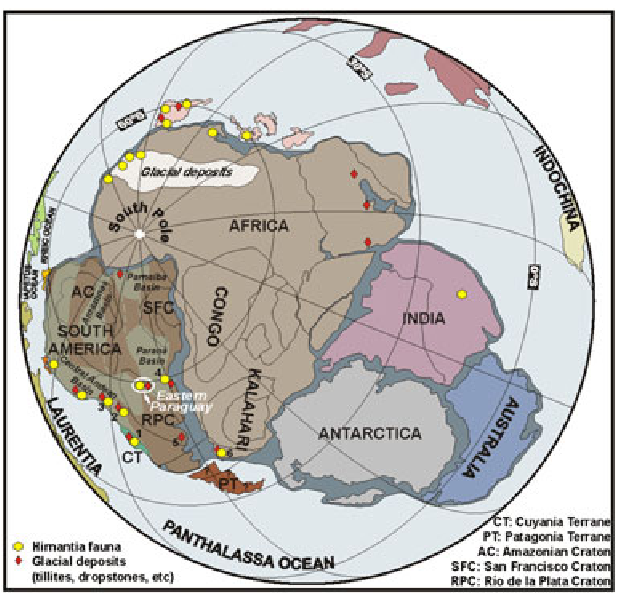

Figure 7. General distribution of glacial deposits and the Ordovician–Silurian transition in South America, Africa, and other domains in Western Gondwana (modified from Cocks, 2001; Ghienne, 2003; Finnegan *et al*., 2011). Note the location of the studied eastern Paraguay sector of the Paraná Basin. Localities: 1, Argentine Precordillera; 2, northwestern Argentina (Zapla Formation); 3, South of Bolivia (Cancañiri Formation); 4, Ponta Grossa Arch region, Brazil (Iapó Formation); 5, South of Rio de la Plata craton (Balcarce Formation); 6, Western Cape Fold Belt (Pakhuis Formation). This figure is available in colour online at wileyonlinelibrary.com/journal/gj

Although typical glacial sediments were not found in the studied outcrops of the Eusebio Ayala Formation, tillites were identified in drill holes in the Santa Elena area (Figueredo, 1995). Preliminary palynological studies revealed a Late Ordovician–early Silurian age for part of this succession (Vergel, 1996). In South America there is also evidence of latest Ordovician glacial events in the Precordillera (Cuyania terrane) and the Amazonas, Parnaíba and eastern Paraná intracratonic basins (Benedetto *et al*., 1992; Rickards *et al*., 1996; Boucot, 1988; Díaz-Martínez and Grahn, 2007).

As noted above, the record of the trilobite *Mucronaspis* sp. provides evidence in favour of a ?Hirnantian age for the isolated type locality of the Eusebio Ayala Formation. On the other hand, the upper part of the unit contains low-diversity graptolites that suggest a Rhuddanian age (Figure 8). *Metaclimacograptus* sp. is the dominant taxon of the graptolite assemblage, followed by *Normalograptus* cf. *ajjeri* (Legrand) and *N.* cf. *medius* (Törnquist). The material of *Metaclimacograptus* from Paraguay appears to be most similar to *Metaclimacograptus robustus* (Cuerda, Rickards and Cingolani) and *Talacastograptus leanzai* Cuerda, Rickards and Cingolani from the lower part of the Lipeón (Subandean Ranges, northwestern Argentina) and La Chilca (Precordillera of San Juan, Cuyania, western Argentina) formations. *Talacastograptus leanzai* was tentatively assigned to the *atavus* Zone, whereas *Metaclimacograptus robustus* is known from the *persculptus* and *acuminatus* zones (Cuerda *et al*., 1988; Rickards *et al*., 2002). In addition, *Normalograptus* cf. *ajjeri* (Legrand) and *N.* cf. *medius* (Törnquist) mostly resemble Rhuddanian material from the *acuminatus* and *atavus* zones of southern France, Sardinia and Great Britain (e.g. Rickards, 1970; Štorch and Serpagli, 1993; Štorch and Feist, 2008).

The record of more varied graptolites [*Normalograptus* cf. *ajjeri* (Legrand), *N.* aff. *rectangularis* (McCoy), *Metaclimacograptus* cf. *asejradi* Legrand, *Paraclimacograptus innotatus* (Nicholson), *P. brasiliensis* (Ruedemann), *Stimulograptus* aff. *sedgwickii* (Portlock), *Monograptus* aff. *priodon* (Bronn), ?*Demirastrites* sp.] and the appearance of several trilobite taxa [*Calymene boettneri* Harrington, *Calymene* sp., *Trimerus* sp., *Dalmanites ypacarayensis* (Baldis and Hansen), *Dalmanites* sp., *Guaranites paraguayensis* Baldis and Hansen, *Eophacops* sp.] in the overlying Llandovery Vargas Peña Formation (Figure 8) coincide with a maximum sea-level attained during the middle Llandovery in the Paraná Basin (Uriz *et al*., 2008b; Tortello *et al*., in press). The influx of new forms probably also indicates the establishment of warmer water conditions. The distribution of graptolite taxa in the Itacurubí Group shows a succession of distinct faunal events that was also documented in other basins of South America and Africa, reflecting large-scale environmental changes that took place in southwestern Gondwana during Hirnantian–early Llandovery times.

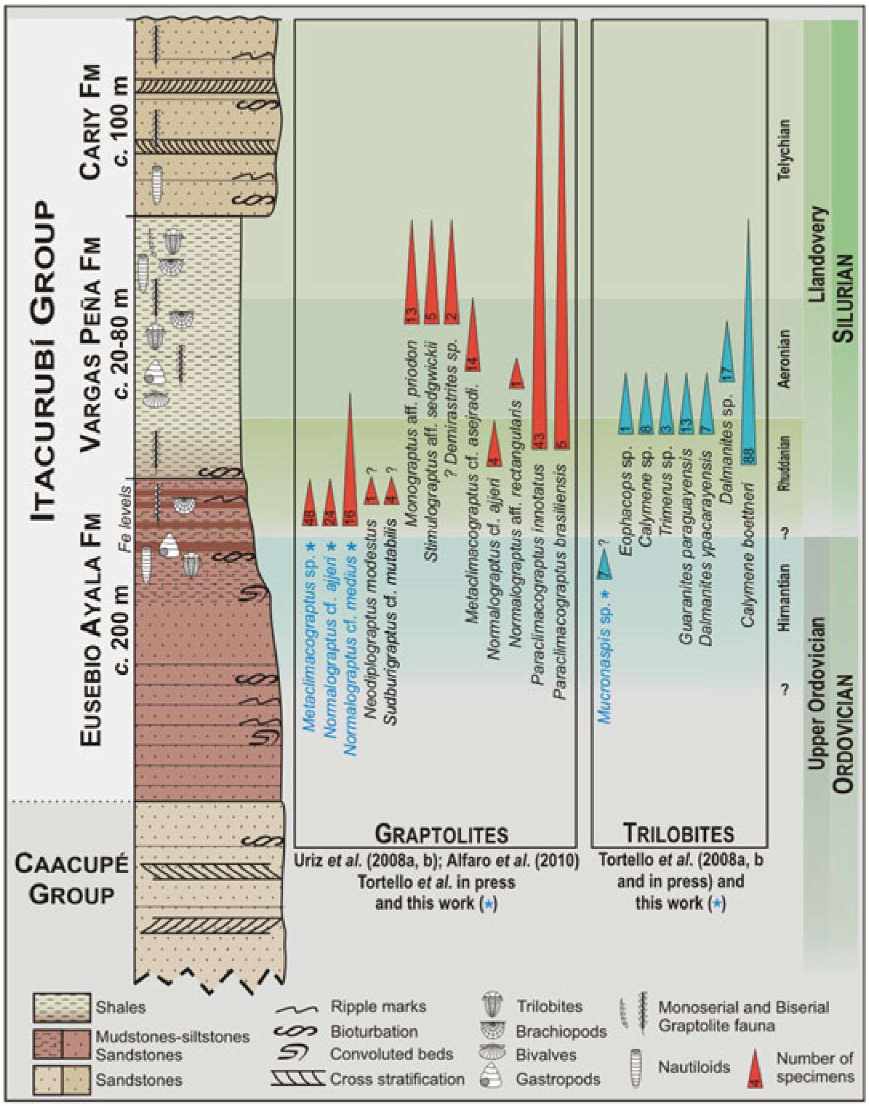

Figure 8. Schematic composite graptolite–trilobite range chart for the Hirnantian?–Llandovery (Itacurubí Group) of eastern Paraguay. The upper Eusebio Ayala Formation is characterized by a low-diversity graptolite fauna. Note that during deposition of the Vargas Peña Formation (lower Llandovery), graptolites and trilobites mark an incoming of a more diverse fauna. This figure is available in colour online at wileyonlinelibrary.com/journal/gj

6. CONCLUDING REMARKS

- (i) A low-diversity graptolite fauna consisting of *Metaclimacograptus* sp., *Normalograptus* cf. *medius* and *N.* cf. *ajjeri* is described from the upper part of the Eusebio Ayala Formation in the western Paraná Basin (eastern Paraguay).
- (ii) In addition, a trilobite assemblage dominated by *Mucronaspis* sp. characterizes the type locality of the unit.
- (iii) The occurrence of these fossil associations, and the evidence of tillites reported from drill holes, allow us to regard the Eusebio Ayala Formation as Hirnantian?–early Llandovery (Rhuddanian) in age.
- (iv) The graptolites studied have affinities with those of other basins of southwestern Gondwana (Subandean Ranges; Precordillera).
- (v) Since the Hirnantian–earliest Llandovery represents a time slice with relevant palaeoclimatic and evolutionary significance, the basal Itacurubí Group may be also a target for future isotope high-resolution stratigraphical studies.

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