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Silurian (Llandovery) monograptids from the Vargas Peña Formation (Paraná Basin, Eastern Paraguay)

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ABSTRACT

The Itacurubí Group is a siliciclastic Silurian sequence exposed in eastern Paraguay (Paraná Basin). It includes from bottom to top the Eusebio Ayala, Vargas Peña and Cariy formations. The entire sedimentary group has yielded a rich association of invertebrates, ichnofossils and palynomorphs. The low-diversity graptolite fauna found within the uppermost beds of the Vargas Peña Formation is described herein. The monograptids comprising this fauna are *Stimulograptus* aff. *sedgwickii* (PORTLOCK), *Monograptus* aff. *priodon* (BRONN) and ?*Demirastrites* sp. These taxa confirm the presence of late Aeronian-early Telychian deposits. The accompanying fossil assemblage also suggests a Mid-Llandovery age for this unit. The recognized graptolite biozones allow us to correlate the Vargas Pena Formation with other Silurian units in South America. From the palaeoenvironmental point of view this sector of the Parana Basin reflects a shallow shelf with high tolerance to oxygen invertebrates association.

KEYWORDS | **Graptolites. Monograptid. Biostratigraphy. Silurian. Paraguay. Gondwana.**

INTRODUCTION

The Silurian rocks of Paraguay are confined to two narrow outcrop belts that are located east of the Asunción city (eastern region of the Paraná Basin) (Fig.1). These rocks are included in the Itacurubí Group, which carries a rich fossil fauna, *e.g*., foraminifers, ostracods, trilobites, brachiopods, bivalves, gastropods and graptolites.

The graptolite record reported from the Itacurubí Group was, in general, poor and lacked detailed systematic descriptions. Harrington (1950) made the first regional geologic study of eastern Paraguay and assembled the first graptolite collection from beds in the Vargas Peña Formation (Fm). This material was identified by Turner and Bulman (in Harrington 1950) and later described by Turner (1960), who referred them to *Climacograptus innotatus brasiliensis* RUEDEMANN 1947 and *Diplograptus modestus* LAPWORTH 1876. Based on this graptolite content, the Vargas Peña Fm was assigned to the "Valentian" age (Lower Llandovery). Cocks (1972) mentioned the presence of *Monograptus lobiferus* (M'COY 1850) and *M.* aff. *sedgwickii* (PORTLOCK 1843), and these were assigned to a Llandovery age (*D. convolutus* or S. *sedgwickii* Zone) by Rickards (in: Cocks, 1972). It is also noteworthy that Dyck (1991) described a specimen of *Climacograptus*

innotatus brasiliensis from beds within the Vargas Peña Fm, and he also noted the presence of *Diplograptus* ? sp.

Further stratigraphic studies assigned the Vargas Peña Fm to a Middle Llandovery age (Aeronian, *D. convolutus* Zone), based on the microfossils content (spores, phytoplankton and chitinozoans) of the same graptolite-bearing beds (Rickards in: Gonçalvez de Melo and Boucot, 1990). Finally, based on its content of acritarchs, chitinozoans and spores, Wood and Miller (1991, 1997) and Grahn et al. (2000) suggested a late Aeronian-early Telychian age. Benedetto (2002) also agreed with this age in his review of the generic status of *Atrypina*? *paraguayensis* HARRINGTON 1950, collected from the Vargas Peña Fm.

This paper deals with the description of new records of Silurian Monograptids from the Eastern Paraná Basin (Vargas Peña Fm). It also aims at extending uniserial graptolite zone to Paraguay and compares them with the Silurian graptolite biozonation in other regions.

GEOLOGICAL – PALEOGEOGRAPHIC SETTING

Two broad regions, differing in both litho- and biostratigraphic characteristics, may be distinguished in this area of the continent of Gondwana: the Andean region along the western margin of southern South America and a Cratonic region, including the Paraná, Parnaiba, and Amazonas basins (Fig. 2).

The Paraná Basin, extends from eastern Paraguay (eastwards from Asunción), to south and southeast of Brazil, the central region of Uruguay, and northeastern Argentina. The basin was characterized by continuous siliciclastic sedimentation spanning the Ordovician to the

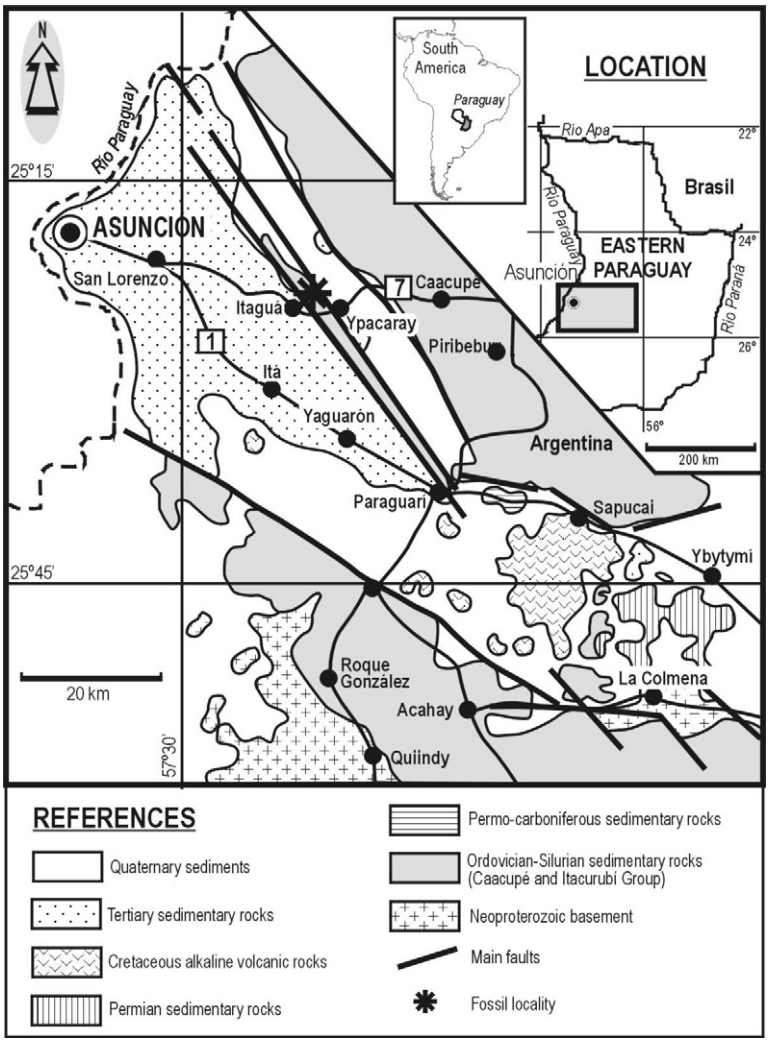

FIGURE 1 | **Geological map showing the geological setting of Ordovician–Silurian units (Caacupé and Itacurubí Groups). Modified from Velázquez et al., 1998.**

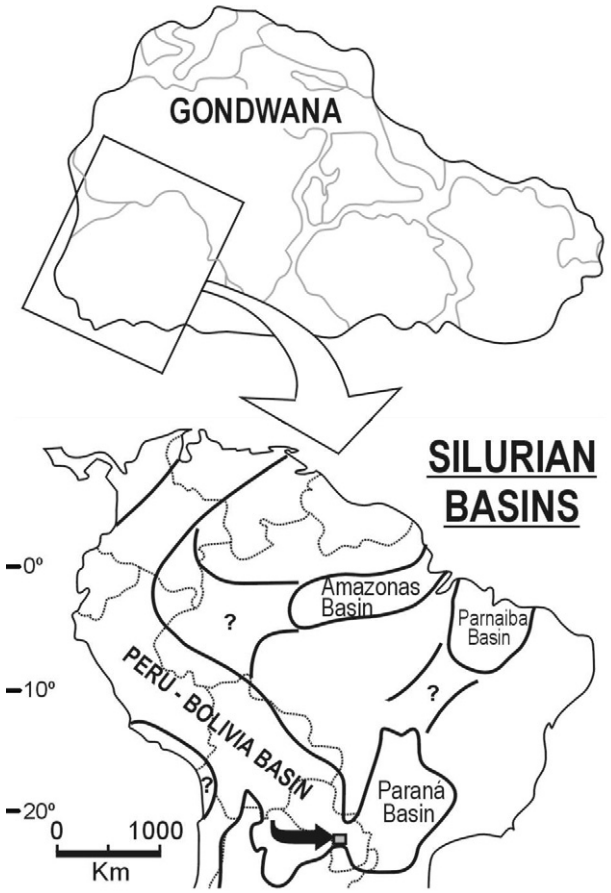

FIGURE 2 | **Gondwana Palaeogeographic sketch and Silurian Basin in South America (from Díaz-Martínez, 1998).**

Lower Devonian. In eastern Paraguay, the pre-Carboniferous units include a basal cratonic sedimentary sequence that overlies Precambrian rocks. This basal succession includes the Upper Ordovician Caacupé Group (Harrington, 1972) that includes, in ascending order, the Paraguari, Cerro Jhú, and Tobatí formations, composed by thick clastic successions of conglomerates and coarse-grained sandstones. The Silurian Itacurubí Group (Harrington, 1972), overlies tillite deposits linked to the Ashgillian-Hirnantian glaciations. The Itacurubí Group is a sequence of very fine- to fine-grained sandstones and shales with an abundant fossil content. The Eusebio Ayala, Vargas Peña and Cariy formations appear to encompass the entire sedimentary sequence of the Silurian. The first unit consists of fine micaceous sandstone and reddish shale, with abundant brachiopods, biserial graptolites and ichnofossils. It is transitionally overlain by the Vargas Peña Fm, which is dominated by whitish clay and fossiliferous micaceous shales. This unit yielded the uniserial graptolites studied herein. Biserial graptolites, trilobites, brachiopods, mollusks, conularids and probable cephalopods, were also found in these beds. The group ends with the Cariy Fm, which is characterized by yellowish micaceous sandstone, laminated sandstone, and sandstone beds linked to tempestites, with abundant biserial graptolites and trace-fossils.

The study material was collected from shales exposed in the San Fernando quarry, next to the town of Itaguá, 60 km to the east of the city of Asunción. In this region, the Vargas Peña Fm shows a transitional contact with the Eusebio Ayala Fm. This area is locally characterized by coarse grain-size sands and intercalations of shale and mudstone with reddish brown tonalities, changing to grey and greenish. The approximate thickness of the unit is about 100-120 m, with N140°-N145° orientation and variable dip (SE 12° to SE 20°). The monograptid specimens were found in the upper levels of the unit (GPS S25°22'44.4''-W57°19'48.8''), about 2 meters below the Quaternary deposits that truncate the section (Fig. 3).

SYSTEMATIC PALAEONTOLOGY

A systematic graptolite collection was performed at the quarry front where the Vargas Peña Fm is well exposed. At the laboratory the graptolite fauna was drawn under stereomicroscope with lucid-camera and the best-preserved specimens were photographed.

The specimens documented herein are deposited in the Department of Invertebrate Palaeontology at the Museum of La Plata (MLP), Argentina. MLP: 18461 to 18480.

Order: Graptoloidea LAPWORTH, 1875
Superfamily: Diplograptoidea LAPWORTH, 1880; emend. Mitchell, 1987
Family: Monograptidae LAPWORTH, 1873

GENUS ***Monograptus*** GEINITZ, 1852

Type species: *Lomatoceras priodon* BRONN, 1835

Monograptus aff. priodon (BRONN, 1835)
Figures 4 (A-M); Figures 5 (A-D)

Material: MLP: 18461-18473. Thirteen specimens well preserved as a carbonaceous film, some of them in relief. We recognize ten fragments of rhabdosomes of different lengths and two proximal ends with preserved sicula. One of the proximal ends was truncated.

Description: The rhabdosome is straight or slightly flexuous. Its extreme proximal end is dorsally curved. The maximum length measured is 41 mm. The width increases from 0.5-0.7 mm at the th 1 reaching 0.7-0.9 mm

at the th 5. The maximum width of the distal fragments is 1.4-1.5 mm. In the specimens preserved in relief, a common canal extends along the dorsal side of the rhabdosome. The thecae show a hooked-shaped metatheca; its width is one-half of the width of the rhabdosome. The thecal aperture rim is approximately perpendicular to the rhabdosome axis and its width is 0.2 mm. The interthecal septa are preserved in some specimens. Thecae overlap for about one-half their length. Proximal thecae 10-13 in 10 mm, distal thecae 8.5-9.0 in 10 mm. The sicula is preserved in two specimens; but in one, only the apical portion remains. The single complete sicula is 1.6 mm long, and its aperture is 0.6 mm wide and carries a 0.5 mm virgellar spine. The sicula apex is approximately level with the dorsal wall of the th 2.

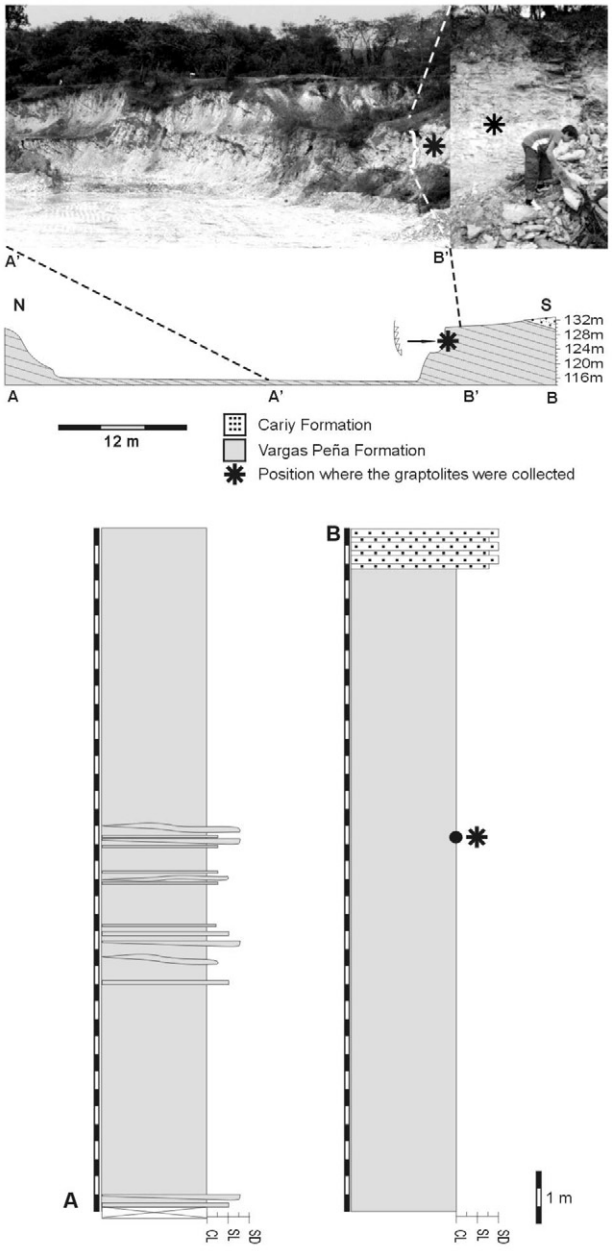

FIGURE 3 | **San Fernando quarry cross section and stratigraphic log of the Vargas Peña Formation. The asterisk (*) shows the position where the graptolites were collected.**

Discussion: The material share features of the proximal end, progressive expansion of the rhabdosome and thecal morphology with *M. priodon* (BRONN 1835), by comparison with Bjerreskov (1975). They differ in distal fragment width, in being considerably narrower.

The specimens collected are similar to *M. marri* (PERNER 1897) and *M. pandus* (LAPWORTH) in dimensions of the rhabdosome, but differ mainly in the shape of the hook of the thecae and in their greater thecal concentration. *M. marri* has a bigger retroversion of the apertural region of the thecae, which occupies less than half of the width of the rhabdosome. *M. pandus* show shorter and less conspicuous hooks, which take up a third of the rhabdosome and are in contact toward the proximal end of the rhabdosome. *M. pandus* is considered as an intermediate form among *M. priodon* and *M. marri* (Elles and Wood, 1901-1918).

It also differs from *M. lobiferus* M'COY in thecal morphology. In that species, the thecae present a strong retroversion and torsion of the apertural region, presenting a prominent lobe.

Monograptus priodon has a broad biostratigraphic range; in Great Britain, ranges from the *Spirograptus turriculatus* Zone to the *Cyrtograptus centrifugus* Zone (Elles and Wood, 1911), whereas in Artic Canada, it ranges into the Lower Homerian, *Cyrtograptus lundgreni* Zone (Lenz and Kozlowska-Dawidzink, 2001) In South America, *M. priodon* was earlier found in beds of the La Chilca Fm, in the region of Talacasto (San Juan, Argentina). Kerlleñevich and Cuerda (1986) assigned these strata to a Late Llandovery-Early Wenlock age. Albanesi et al. (2006) noted this species in the same lithostratigraphic unit, and assigned the strata to a Telychian age (Late Llandovery).

GENUS Stimolograptus PŘIBYL and ŠTORCH, 1983

Type species: *Graptolithus halli* BARRANDE, 1850

Stimulograptus aff. ***sedgwickii*** (PORTLOCK, 1843)
Figures 4 (P-T); Figure 5 (E)

Material: MLP: 18474, 18477-18480. Five specimens, sicula preserved in two proximal ends and three rhabdosome fragments corresponding to the distal part, preserved as a carbonaceous film.

Description: The rhabdosome fragments are either straight or moderately curved, with a maximum length of

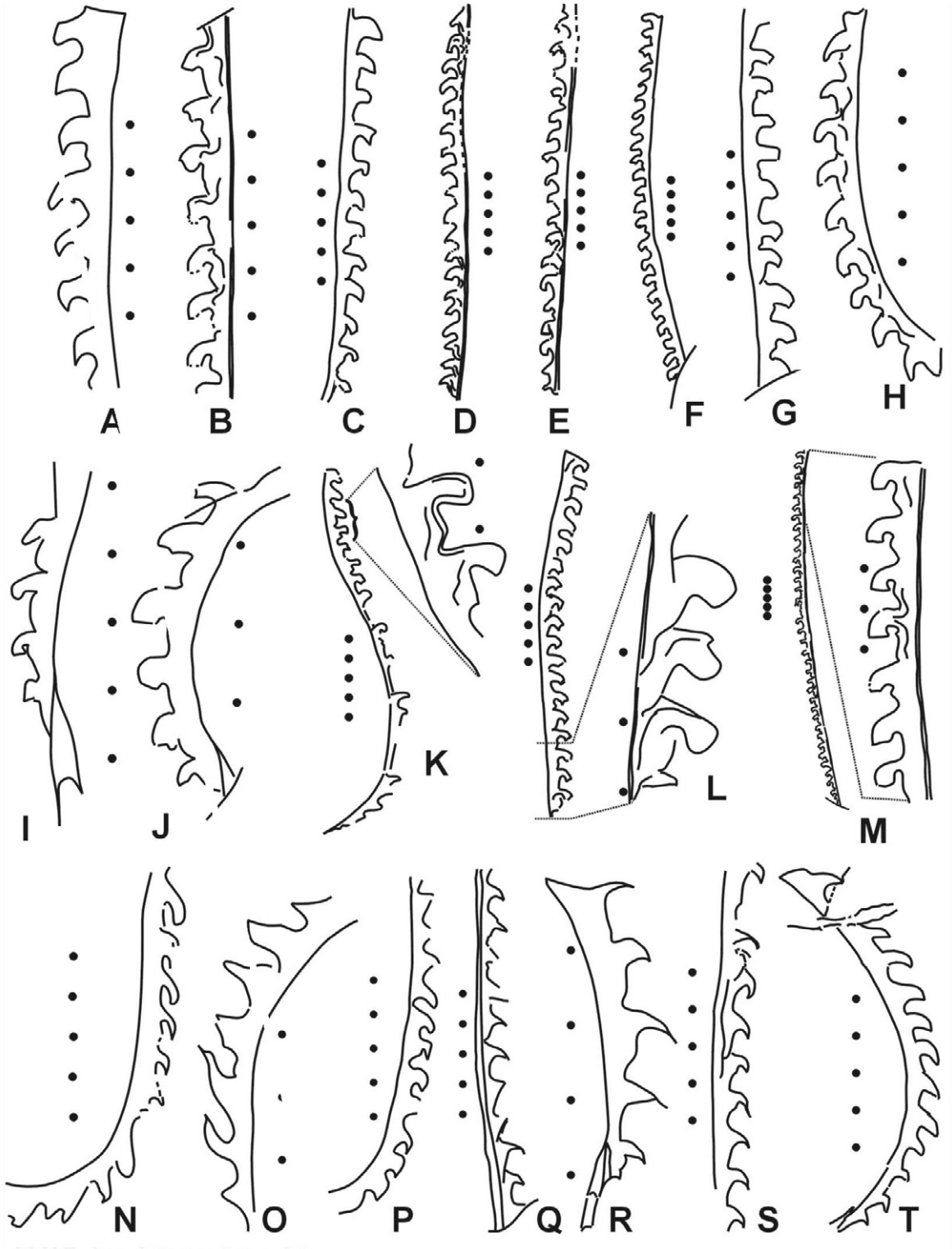

FIGURE 4 | **A-M) *Monograptus* aff. *priodon* (BRONN) MLP, 18461-18473. P-T) *Stimulograptus* aff. *sedgwickii* (PORTLOCK) MLP, 18474, 18477-18480. N and O) ?*Demirastristis* sp. MLP, 18475-18476. Scale: 1 mm between two points.**

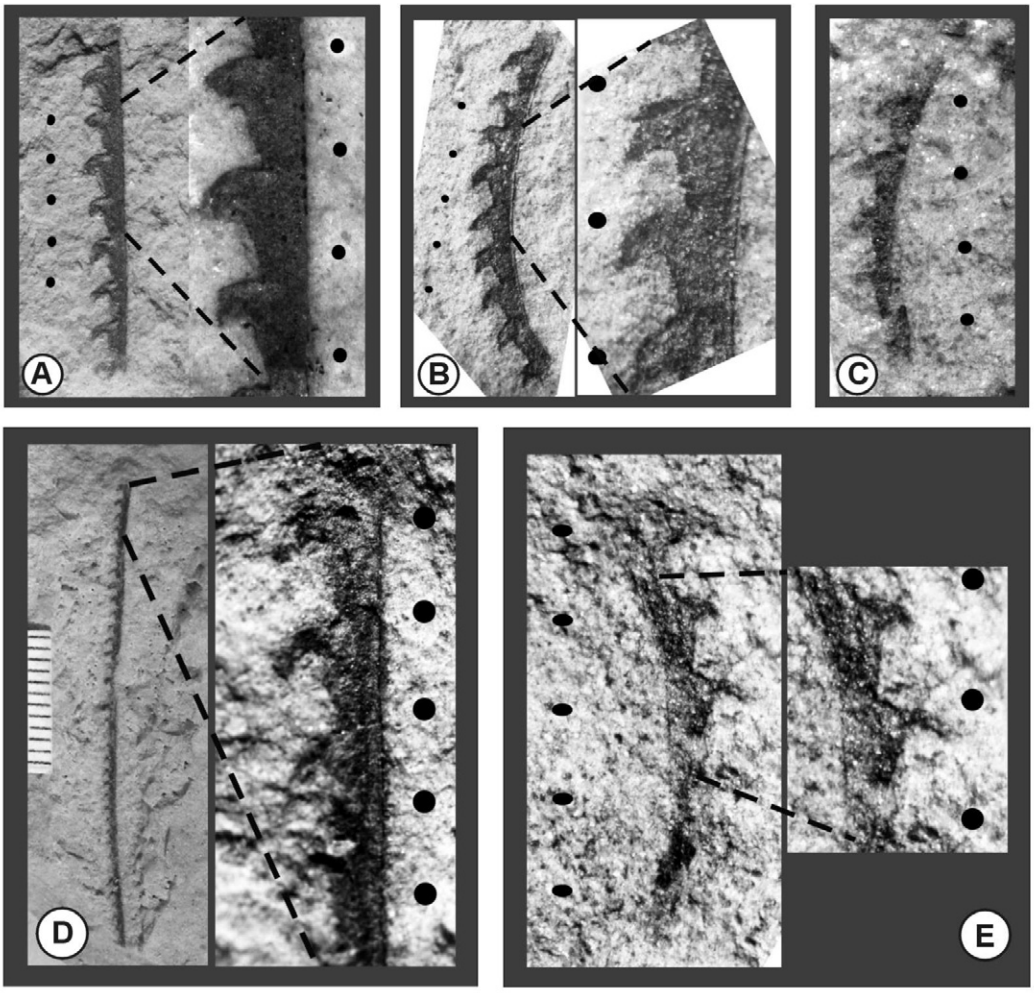

FIGURE 5 | **A-D) *Monograptus* aff. *priodon* (BRONN), A, B, D distal fragment and distal thecae detail. MLP, 18462-18468-18473; C, proximal end showing sicula. MLP, 18469. E) *Stimulograptus* aff. *sedgwickii* (PORTLOCK), proximal end showing sicula and thecal detail. MLP, 18478.**

11.8 mm and a uniform width of 1.0 mm. A common canal is preserved on the dorsal side of the rhabdosome. The thecae are approximately triangular in profile; the apertural region is retroverted, forming a hook that occupies half of the width of the rhabdosome. In a few thecae, the dorsal edge of the thecal apertures is extended as a not very conspicuous spine of 0.3 mm in length. The thecal count is 9.5-10 in 10 mm. The sicula is 1.3 mm in length and its aperture is 0.2 mm wide. Their apex reaches the level of the hook of the th 1. The th 1 width is 0.5 mm, and the following thecae increase gradually in width, reaching 0.8 mm at the level of the th 3-th 4.

Discussion: The main characteristics of the genus *Stimulograptus* is the presence of triangular thecae with apertural margins and thorns. Two species have been identified: *S. halli* (BARRANDE) and *S. sedgwickii* (PORTLOCK). Both species are very similar. Elles and Wood (1901-1918) distinguishes the species *S. sedgwickii* by: 1) it reaches the maximum width less quickly, 2) its proximal end is more flexuous and has a lax appearance, 3) smaller amount of overlap of the thecae, and 4) smaller retroversion of the apertural regions. On the other hand, Sherwin (1974) mentions that *S. halli* have thecae more hooked and a higher thecal concentration (the thecae are hooked and closely spaced), and their distal fragments are rigid and straight.

The specimens studied are assigned to *S. sedgwickii* because of their similarity in their proximal ends, dimensions and level reached by the sicula apex (Elles and Wood, 1901-1918; Rickards, 1970; Loydell, 1993), gradual expansion of the rhabdosome, form of the thecae, presence of apertural spines, and thecal concentration.

Stimulograptus sedgwickii characterizes the eponymous biozone for Great Britain (Rickards, 1976), at the

upper boundary of the Aeronian stage. Rickards (in: Cocks, 1972), identified *M.* aff. *sedgwickii* in Paraguay, assigning it to the *D. convolutus* or *S. sedgwickii* biozone. Toro (1995) described *S. sedgwickii* for the Eastern Cordillera, north-western Argentina (South America), where the form is associated with *Paracli- macograptus innotatus* (NICHOLSON 1869). Albanesi et al. (2006) mentions with doubts the presence of the genus ?*Stimulograptus* PŘIBYL and ŠTORCH in Precordillera of San Juan, in the Talacasto Range, together with *Monograptus* cf. *priodon* (BRONN), and assigns a late Aeronian age to the beds with *Stimulograptus*.

GENUS Demirastrites eisel, 1912; emend. ?TORCH AND SERPAGLI, 1993

Type species: *Rastrites triangulatus* HARKNESS, 1851

? ***Demirastrites*** sp.
Figures 4 (N-O)

Material: MLP: 18475-18476. Two poorly preserved fragments of rhabdosome. The maximum length reaches 10.0 mm and the maximum width of the rhabdosome is 1.2 mm. The minimum width measured is 0.8 mm. The fragments show a dorsal curvature. Rastriform thecae were not found. The thecae are triangular and they become narrower and longer towards the apertural region, presenting a gentle curvature that forms a weak hook. Thecae on convex side of rhabdosome. The thecal count is 10-12 in 10.0 mm.

Discussion: The specimens studied are similar to the genus *Demirastrites* EISEL 1912, as regards the dorsal curve of the rhabdosome, and disposition and morphology of the thecae that correspond to the mid-distal part of the rhabdosome in *Demirastrites* sp. A generic diagnosis is hampered by the poor preservation of the material, *i.e.*, the absence of rastriform thecae that characterize the proximal part of that genus.

BIOSTRATIGRAPHIC AND PALAEOENVIRONMENTAL REMARKS. CORRELATION

The set of graptolites described is characteristic of the Middle-Late Llandovery (Aeronian-Telychian). *S. sedgwickii* is a guide fossil of the eponymous zone (late Aeronian) of the British Islands (Rickards, 1976). For Canadian sequences Lenz (1982) mentioned this species for the equivalent zone and for the basal part of the *Spirograptus turriculatus* Zone. *M. priodon* ranges between *S. turriculatus* and *Cyrtograptus lundgreni* Zones (Lenz and Kozlowska-Dawidziuk, 2001). On the other hand, Štorch and Serpagli (1993) identified this species for the southwest of Sardinia in the *Monoclimacis griestoniensis* Zone (Middle Telychian).

During the Llandovery, a marine transgression covered areas of present-day South America such as Venezuela, Perú, Bolivia, Argentina, Paraguay, and Brazil. In the last two countries, this transgression was restricted to the intracratonic Paraná Basin. Toro (1995) noted the presence of graptolite faunas in sedimentary sequences of Early Silurian age in the Eastern Cordillera, north-western Argentina. She identified *Paraclimacograptus innotatus* (NICHOLSON) and *Clinoclimacograptus retroversus* BULMAN and RICKARDS, together with *Stimulograptus sedgwickii* (PORTLOCK). Toro (1995) assigned this graptolite bearing bed to Middle to Middle-Late Llandovery age.

Rubinstein and Brussa (1999) based on studies of palynological assemblages and graptolite associations proposed a correlation for the Silurian La Chilca and Los Espejos Fms in the Central Precordillera Basin. They recorded five palynomorph assemblages. The assemblage 2 would correspond to the upper *Stimulograptus sedgwickii*-lower *Spirograptus turriculatus* zones (upper Aeronian-lower Telychian). The graptofauna is composed by *Monograptus* aff. *halli* and *Monograptus* sp. together with acritarchs, prasinophytes and less abundant cryptospores. Albanesi et al. (2006) described *Monograptus* cf. *priodon* (BRONN) together with probable remains of *Stimulograptus* PŘIBYL and ŠTORCH, from the Precordillera of San Juan, and assigned a late Aeronian age to the beds with *Stimulograptus* and Late Llandovery to Early Wenlock to the strata with *Monograptus* cf. *priodon* (Fig. 6).

The graptolite-based ages agree with those based on the established biozones of chitinozoans (Grahn et al., 2000) and miospores and chitinozoans (Mendlowicz Mauller et al., 2004), recorded in these, and equivalent, units of the Paraná Basin in Brazil. Benedetto (2002) assigned a similar age when reviewing the generic status of the rhynchonellid brachiopod *Eocoelia*.

Štorch (1998) recognized three depth- and oxygen/nutrient-related graptolite sub-faunas on the Early Silurian peri-Gondwanan shelf basins of Europe. The faunal association recognized in the Itacurubí Group, corresponds well to the sub-fauna 1 pattern proposed by Štorch (1998), *i.e.*, a shallow shelf environment with records of tempestites, and a tolerance to oxygen, low-diversity graptolite fauna (scarce biserial taxa, *Retiolites* and *Monograptus* ex. gr. *priodon*) associated with brachiopods, bivalves, trilobites and cephalopods.

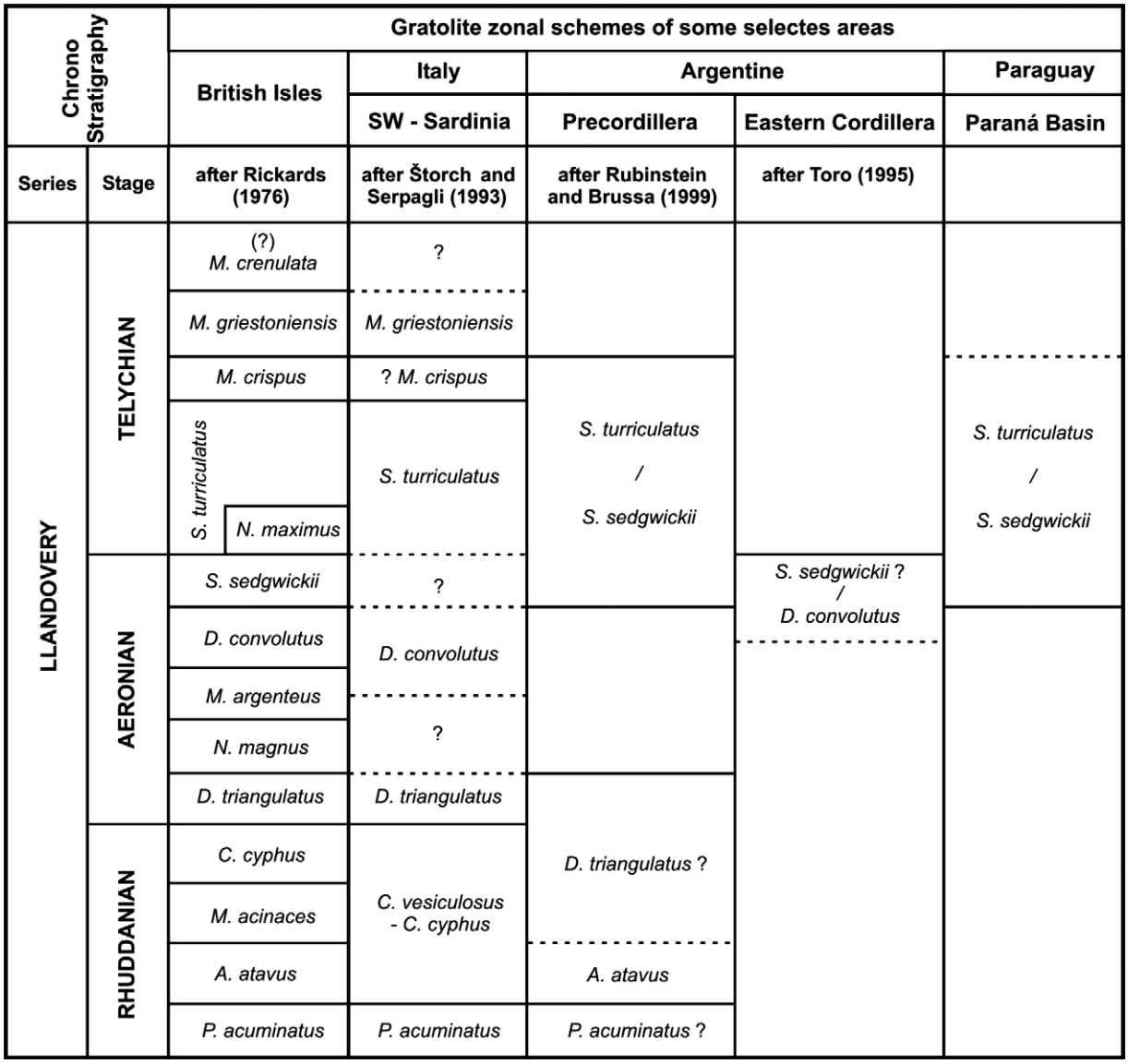

FIGURE 6 | **Llandovery graptolite biozonal correlation chart.**

CONCLUSIONS

The low-diversity fauna of uniserial graptolites recovered from the shales of the Vargas Peña Fm helps in the recognition of the palaeoenvironmental conditions, and biostratigraphically constrains the age of the bearing units in Paraguay. Therefore, it is a matter of great interest the correlation of this unit with others carrying equivalent graptolite faunas in South America. The association of monograptids in the Vargas Peña Fm (Paraná Basin, Eastern Paraguay) allows its correlation with the Llandovery units of the Eastern Cordillera and Precordillera in San Juan (western Argentina).

From a palaeoenvironmental point of view, the associations of graptolites recognized in the Vargas Peña Fm, together with invertebrate macrofossils in the same beds, suggest an oxygen-rich environment, with in a shallow shelf. In the Precordillera, Silurian deposits are characterized by clastic shelf facies with bivalves, conodonts and graptolites in restricted beds (Albanesi et al., 2006).

We conclude therefore, the beds bearing the graptolite fauna described in the present work are of the late Aeronian-early Telychian age and that the palaeoenvironmental conditions coincide with the sub-fauna 1 pattern proposed by Štorch (1998).

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