J.C. Gutiérrez-Marco, I. Rábano and D. García-Bellido (eds.), *Ordovician of the World.*
Cuadernos del Museo Geominero, 14. Instituto Geológico y Minero de España, Madrid. ISBN 978-84-7840-857-3

THE HIRNANTIAN-EARLY LLANDOVERY TRANSITION SEQUENCE IN THE PARANÁ BASIN, EASTERN PARAGUAY

C.A. Cingolani[1,2], N.J. Uriz[1], M.B. Alfaro[1], F. Tortello[2,4], A.R. Bidone[1] and J.C. Galeano Inchausti[3]

[1] División Geología, Museo de La Plata, Facultad de Ciencias Naturales y Museo de La Plata, Paseo del Bosque s/n, 1900, La Plata, Argentina. cingola@fcnym.unlp.edu.ar, nuriz@fcnym.unlp.edu.ar, malfaro@fcnym.unlp.edu.ar, andreabidone@fcnym.unlp.edu.ar
[2] CONICET.
[3] Ministerio de Obras Públicas y Comunicaciones de Paraguay.
[4] División Paleoinvertebrados, Museo de La Plata, Facultad de Ciencias Naturales y Museo, La Plata, Argentina.

Keywords: SW Gondwana, Paraná Basin, Eastern Paraguay, *Normalograptus persculptus* Biozone, Hirnantian-Llandovery transition.

INTRODUCTION

The Lower Paleozoic Itacurubí Group (Harrington, 1972) is exposed in the western border of the intracratonic Paraná Basin of eastern Paraguay (Fig. 1). This group (*c.* 350 m thick) includes from base to top the Eusebio Ayala, Vargas Peña and Cariy siliciclastic formations. It was traditionally assigned to the Llandovery (*e.g.* Harrington, 1950; Dyck, 1991; Benedetto et al., 1992; Benedetto, 2002; Galeano Inchausti and Poiré, 2006; Uriz et al., 2008a, 2008b and references therein) based on a marine fossil record mainly of graptolites, shelly fauna, and palynofacies assemblages. The new records of graptolites and some trilobites from the Eusebio Ayala Formation, exposed in clay quarries to the east of Asunción allow the comparison with other sequences bearing similar faunal associations known in west Gondwana. These records are discussed here, taken into account that the mentioned interval was a relevant paleobiogeographical time slice during the Lower Paleozoic (Cocks, 2001).

GEOLOGY

The great South American Paraná basin extends from the Asunción arch, as a western boundary near Paraguay River, to the south and southeast of Brazil, the central region of Uruguay, and northeastern Argentina (Milani et al., 2007). The geological evolution of this intracratonic basin was influenced by the geodynamics of southwestern Gondwana, with compressional stresses derived from an active convergent margin. During the Late Ordovician–Lower Devonian, the basin was filled by continuous and thick siliciclastic sequences named from base to top: Caacupé and Itacurubí groups. The latter represents a complete transgressive-regressive cycle, where the sandstones of the Eusebio Ayala Formation mark the base of this cycle, which is composed by yellowish, brownish, and reddish to purple micaceous sandstones with intercalated mudstone-siltstone beds with iron rich levels. The sandstones are laminated and wave-

CONTENTS

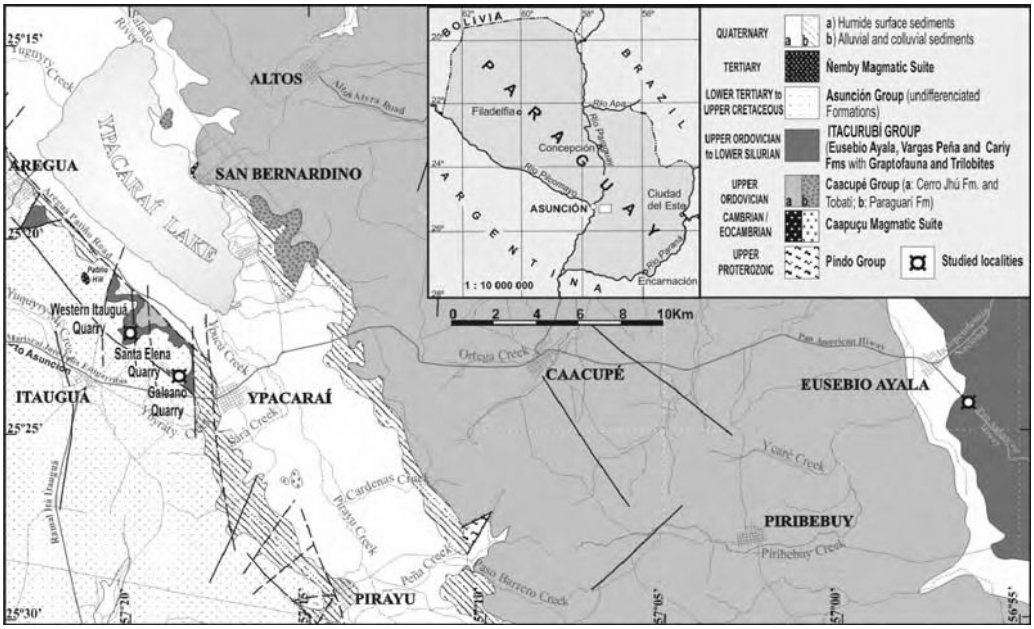

Figure 1. Geological sketch map of the Itauguá-Eusebio Ayala region (east of Asunción; based on Dionisi, 1999) with location of the studied outcrops.

cross stratifications are frequent. Reddish fine sandstone levels are fossiliferous and have bedding planes covered by detrital micas. Mudstones and siltstones show some bioturbation and wavy-linsen structures. The sandstone unit that bears the invertebrate fossils was deposited at the beginning of the transgression in a shallow marine environment during a flooding event described in the Paraná Basin (Milani et al., 2007).

GRAPTOLITE-TRILOBITE RECORD FROM THE HIRNANTIAN-LLANDOVERY INTERVAL

A low diversity graptolite fauna composed of *Normalograptus persculptus*, *Normalograptus normalis* and *Normalograptus medius*, in association with the trilobite *Mucronaspis sp.* was recently described from the Eusebio Ayala Formation, in beds also yielding brachiopods, bivalves and cephalopods (Alfaro et al., 2011). The identification of the *N. persculptus* Biozone allows us to assign the studied stratigraphical levels close to the Hirnantian-Llandovery interval (Fig. 2). As we can see in the composite graptolite-trilobite range chart, the Hirnantian-Rhuddanian transition shows a low-diversity graptolite assemblage in the upper part of the Eusebio Ayala Formation. During the Early Llandovery, the record of the first Silurian graptolites and trilobites (Tortello et al., 2008a, 2008b) was accompanied by the arrival of a diverse fauna, during a flooding event that improved the environmental conditions on the Paraná Basin under a warm-water influx, favoring a biological colonization. *Climacograptus innotatus brasiliensis*, an apparently endemic South American graptolite (Underwood et al., 1998) was also recorded in the succession. The sequence of graptolite taxa would reflect distinct faunal events, also known in other Gondwanan outcrops, related to a dramatic change of environmental conditions during the Hirnantian-Llandovery transition.

CONTENTS →

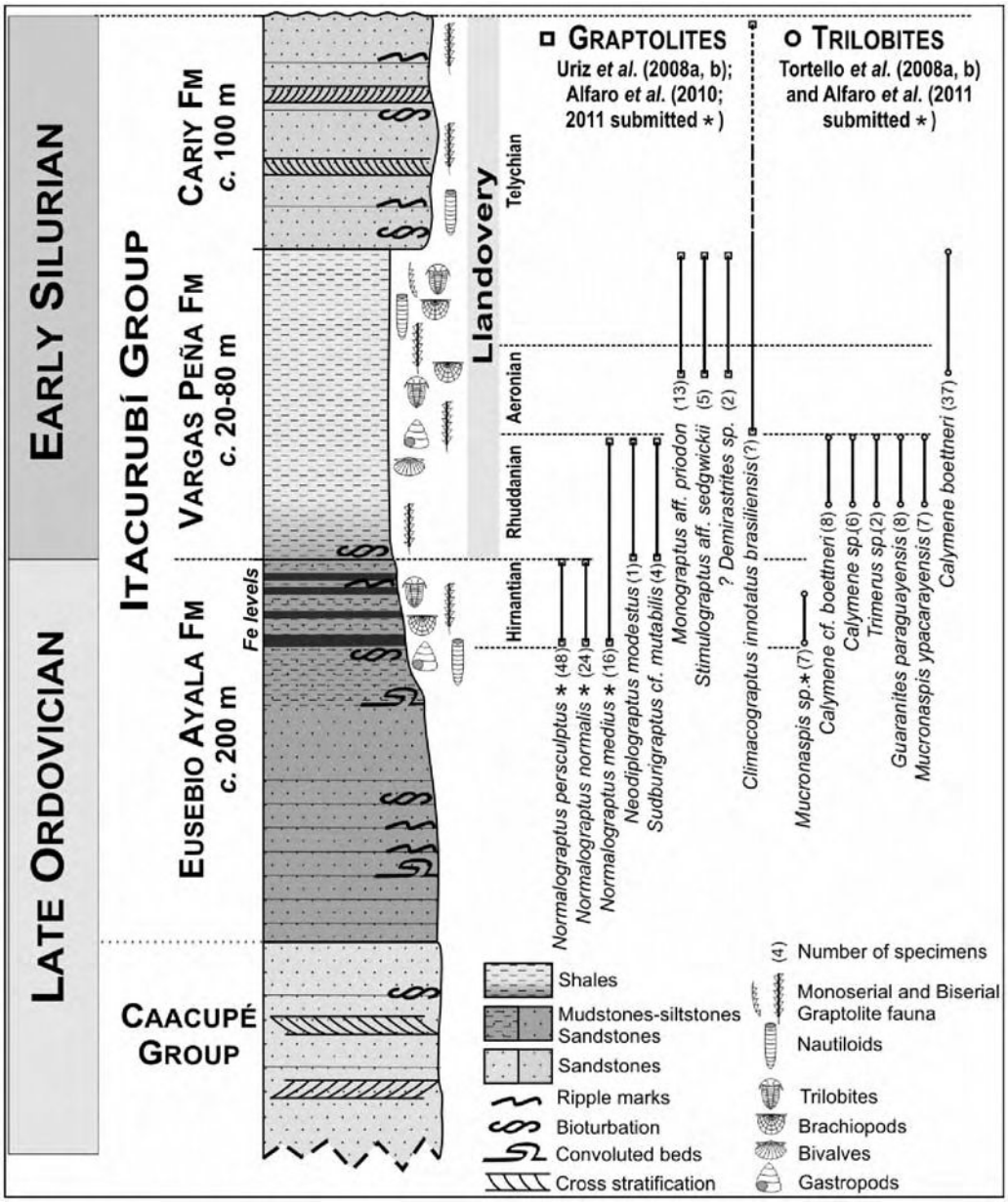

Figure 2. Composite graptolite-trilobite range chart for the Ordovician-Silurian boundary interval, in the Itacurubí Group of eastern Paraguay.

CONTENTS →

CORRELATION WITHIN SW GONDWANA

In Western Gondwana, a large ice sheet is assumed to have covered most of Africa and South America. The South Pole would have been located in west-central Africa at the time (Underwood et al., 1998; Cocks, 2001; Ghienne, 2003; Legrand, 2009). Late Ordovician glacial deposits are found in the Pakhuis Formation in the Western Cape Fold Belt, South Africa (Young, 2004). The black shales of the Soom unit have been assigned to the Late Ordovician *N. persculptus* graptolite Biozone.

In South America, there is evidence of the record of this glacial event in the 'Central Andean Basin', in the Precordillera region (Cuyania terrane), and in the Amazonas, Parnaíba and Paraná intracratonic basins. In Perú, Bolivia and northwestern of Argentina, as part of the 'Central Andean Basin', identification of diamictites and an erosional surface near the Ordovician-Silurian boundary characterizes the setting of a glaciogenic environment that would have extended to Silurian times (Benedetto et al., 1992; Díaz-Martínez, 1997; Díaz-Martínez and Grahn, 2007). These glaciogenic conditions in northwestern Argentina are recognized in the Late Ordovician levels of the Zapla Formation and in the lowermost levels of the Lipeón Formation (Monteros et al., 1993), as well as in their equivalent units from southern Bolivia (Schönian et al., 1999). In the Precordillera region (part of the Cuyania terrane) of San Juan, Argentina, tillite levels were recorded at the base of the Don Braulio Formation (Peralta and Carter, 1999). Benedetto (1986) recognized a brachiopod association at the base of this unit and referred it to the Hirnantia fauna, while Peralta and Baldis (1990) described *N. persculptus* towards the top of the same sequence. Also in the regions of Talacasto and Cerro del Fuerte-Cerro La Chilca (San Juan) it was possible to define the boundary between both systems by the record of the *N. persculptus* and *P. acuminatus* biozones (Cuerda et al., 1988; Astini and Benedetto, 1992; Rickards et al., 1996). On the Río de la Plata craton (Tandilia System, Argentina) the presence of a diamictite level was mentioned in the Balcarce Formation; Zimmermann and Spalletti (2009) based on mineralogical provenance studies suggested a possible Hirnantian age for this glacial event. In the Amazonas and Parnaíba intracratonic basins, northeastern Brazil, there are potential tillite deposits referred to the Late Ordovician, suggesting a glaciogenic influx.

For the western border of the Paraná Basin (Paraguay), in the quarries bearing *N. persculptus*, *N. medius* and *N. normalis* within the Eusebio Ayala Formation, typical glacial sediments were not found, although tillites were described from drill cores (Figueredo, 1995). Fifty meters of tillites were described at the base of these cores, followed by 150 m of sandstones with conglomeratic levels, and 200 m of fine sandstones with interbedded shales and claystones. Preliminary palynostratigraphic studies for the interval between -198 to -385 m reveal Upper Ordovician-Lower Silurian ages for the section (González Nuñez et al., 1999), while Steemans and Pereira (2002) described an interesting Llandovery palynomorph assemblage coming from three boreholes from central Paraguay. A graptolite association collected in the upper levels of the Eusebio Ayala Formation (Uriz et al., 2008a) indicated a Rhuddanian age. Another record that proves the continental glaciation in other sectors of the Paraná Basin is revealed in the Ponta Grossa structural arch in the Apucaran sub-basin (Brazil) where the less than 20m-thick Iapó Formation is essentially composed of diamictites covering large areas, and included in the 'Río Ivaí Supersequence' (Milani et al., 2007).

The Paraguayan lower Itacurubí Group that documented the Ordovician-Silurian transition (Fig. 2) and recorded graptolites and other invertebrate groups, could be a suitable sequence for high-resolution studies on stable isotope chemostratigraphy. These may constraint shallow-water environmental changes associated with a mass extinction in Western Gondwana, and may be used to correlate the organic-inorganic carbon isotope excursion models known from other paleocontinents such as Baltica, Laurentia, South China and North Gondwana (Finney et al., 2007).

CONTENTS →

Acknowledgements

Financial support was partially provided through projects PIP-CONICET-647 and UNLP 11/547. We are also grateful to the Subsecretaría de Minas y Energía of Paraguay for the logistical assistance during the fieldworks. Thanks to M. Manassero and P. Abre for English revision.

REFERENCES

Alfaro, M. B., Uriz, N. J., Cingolani, C. A., Tortello, F., Bidone, A. R. and Galeano Inchausti, J. C. 2011. Normalograptus persculptus Biozone record (graptolites and trilobites) in the Eusebio Ayala Formation: New Hirnantian-Llandovery sequence within Paraná basin in Eastern Paraguay. *Geological Journal* (submitted).

Astini, R. A. and Benedetto, J. L. 1992. El Ashgilliano tardío (Hirnantiano) del Cerro La Chilca, Precordillera de San Juan, Argentina. *Ameghiniana*, 29, 249-264.

Benedetto, J.L. 1986. The first typical Hirnantia Fauna from South America (San Juan Province, Argentine Precordillera). In Racheboeuf, P.R. and Emig, C. (eds.), *Les Brachiopodes fossiles et actuels.* Biostratigraphie du Paleozoïque, 4, 439-477.

Benedetto, J.L. 2002. The Rhynchonellide brachiopod Eocoelia in the Llandovery of Paraguay, Paraná basin. *Ameghiniana*, 39, 307-312.

Benedetto, J.L., Sánchez, T.M. and Brussa, E.D. 1992. Las Cuencas Silúricas de América Latina. In Gutiérrez Marco, J.C., Saavedra, J. and Rábano, I. (eds.), *Paleozoico Inferior de Ibero-América*. Universidad de Extremadura, Madrid, 119-148.

Cocks, L.R.M. 2001. Ordovician and Silurian global geography. *Journal of the Geological Society*, 158, 197-210.

Cuerda, A.J., Rickards, R.B. and Cingolani, C.A. 1988. A new Ordovician-Silurian boundary section in San Juan Province, Argentina, and its definitive graptolitic fauna. *Journal of the Geological Society*, 145, 749-757.

Díaz-Martínez, E. 1997. Facies y ambientes sedimentarios de la Formación Cancañiri (Silúrico inferior) Cumbre de La Paz, norte de la Cordillera Oriental de Bolivia. *Geogaceta,* 22, 55–57

Díaz-Martínez, E. and Grahn, Y. 2007. Early Silurian glaciation along the western margin of Gondwana (Peru, Bolivia and northern Argentina): palaeogeographic and geodynamic setting. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 245 (1-2), 62-81.

Dionisi, A. 1999. *Hoja Caacupé 5470, Mapa Geológico de la República del Paraguay*. Ministerio de Obras Públicas, Viceministerio de Minas y Energía, Dirección de Recursos Minerales de Paraguay (unpublished).

Dyck, M. 1991. *Stratigraphie, Fauna, Sedimentologie und Tektonik im Ordovizium und Silur von ost-Paraguay und Vergleich mit den Argentinisch-Bolivianischen Anden*. Ph.D. Thesis, Hannover University, 263 pp.

Figueredo, L. 1995. Descripción del pozo RD 116 Santa Elena-Paraguay, Coop. Geol. Paraguayo/Alemana, informe interno, San Lorenzo. In González Núñez, M., Lahner, L., Cubas, N. and Adelaida, D. 1999. *Mapa Geológico de la República del Paraguay, hoja Coronel Oviedo 5670 1:100.000*. Cooperación técnica BGR-MOPC, Asunción, 30 pp.

Finney, S.C., Berry, W.B.N. and Cooper, J.D. 2007. The influence of denitrifying seawater on graptolite extinction and diversification during the Hirnantian (latest Ordovician) mass extinction event. *Lethaia,* 40, 281-291.

Galeano Inschausti, J.C. and Poiré, D.G. 2006. Trazas fósiles de la Formación Eusebio Ayala (Silúrico inferior), Paraguay. *4º Congreso Latinoamericano de Sedimentología y 11º Reunión Argentina de Sedimentología.* Resúmenes, Bariloche, Argentina.

Ghienne, J.F. 2003. Late Ordovician sedimentary environments, glacial cycles, and post-glacial transgression in the Taoudeni Basin, West Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 189, 117-145.

González Núñez, M., Lahner, L., Cubas, N. and Adelaida, D. 1999. *Mapa Geológico de la República del Paraguay, hoja Coronel Oviedo 5670 1:100.000.* Cooperación técnica BGR-MOPC, Asunción, 30 pp.

Harrington, H.J. 1950. *Geología del Paraguay Oriental.* Facultad de Ciencias Exactas, Físicas y Naturales, Contribuciones Científicas, Serie E, Geología, 1, 1-82.

Harrington, H.J. 1972. Silurian of Paraguay. In Berry, W.B.N. and Boucot, A.J. (eds.), *Correlations in South American Silurian rocks*. Geological Society of America, Special Papers 133, 41-50.

Legrand, P. 2009. Faunal specificity, endemism and paleobiogeography: the post-glacial (Hirnantian-early Rhuddanian) graptolite fauna of the North-African border of Gondwana: a case study. *Bulletin de la Societé Géologique de France*, 180 (4), 353-367.

Milani, E.J., Gonçalves de Melo, J.H., De Souza, P., Fernandes, L.A. and Barros França, A. 2007. Bacia do Paraná. *Boletim Geociências Petrobras*, 15 (2), 265-287.

Monteros, J.A., Moya, M.C. and Cuerda, A.J. 1993. Graptolitos Ashgilliano-Llandoverianos en la base de la Formación Lipeón, Sierra de Zapla, Jujuy. Su importancia en la correlación con el Silúrico de la Precordillera Argentina. *XII Congreso Geológico Argentino y II Congreso de Exploración de Hidrocarburos,* Actas 2, 304-314.

Peralta, S.H. and Baldis, B.A. 1990. *Glyptograptus persculptus* en la Formación Don Braulio (Ashgilliano Tardío-Llanvirniano Temprano) en la Precordillera Oriental de San Juan, Argentina. *5º Congreso Argentino de Paleontología y Bioestratigrafía*, Tucumán, Actas 1, 67-72.

Peralta, S.H. and Carter, C.H. 1999. Don Braulio Formation (Late Ashgillian-Early Llandoverian, San Juan Precordillera, Argentina): stratigraphic remarks and paleoenvironmental significance. *Acta Universitatis Carolinae: Geologica*, 43, 225-28

Rickards, R.B., Brussa, E., Toro, B. and Ortega, G. 1996. Ordovician and Silurian graptolite assemblages from Cerro del Fuerte, San Juan Province, Argentina. *Geological Journal*, 31, 101-122.

Schönian, F., Egenhoff, S.O, Marcinek, J. and Erdtmann, B.D. 1999. Glaciation at the Ordovician-Silurian boundary in southern Bolivia. *Acta Universitatis Carolinae: Geologica,* 43, 175–78

Steemans, Ph. and Pereira, E. 2002. Llandovery miospore biostratigraphy and stratigraphic evolution of the Paraná Basin, Paraguay-Palaeogeographic implications. *Bulletin Societé Géologique de France*, 173 (5), 407-414.

Tortello, M.F., Clarkson, E.N.K., Uriz, N.J., Alfaro, M.B. and Galeano Inchausti, J.C. 2008a. Trilobites from the Vargas Peña Formation (Llandovery) of Itauguá, eastern Paraguay. In Rábano, I., Gozalo, R. and García–Bellido, D. (eds.), *Advances in Trilobite Research*. Cuadernos del Museo Geominero, 9. Instituto Geológico y Minero de España, Madrid, 395-401.

Tortello, M.F., Clarkson, E.N.K., Uriz, N.J., Alfaro, M.B. and Galeano Inchausti, J.C. 2008b. Trilobites de la Formación Vargas Peña (Silúrico Inferior) de Itauguá, Paraguay oriental. *Acta Geologica Lilloana,* 21 (1). Suplemento Resúmenes de las 2as Jornadas Geológicas de la Fundación Miguel Lillo, 71-72.

Underwood, Ch.J., Deynoux, M. and Ghienne, J.F. 1998. High palaeolatitude (Hodh, Mauritania) recovery of graptolite faunas after the Hirnantian (end Ordovician) extinction event. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 142, 97-103.

Uriz, N.J., Alfaro, M.B., Galeano Inchausti, J.C. 2008a. Graptolitos de la Formación Eusebio Ayala (Silúrico Inferior) Cuenca de Paraná, Paraguay. *17º Congreso Geológico Argentino*, Jujuy, 3, 1057-1058.

Uriz, N.J, Alfaro, M.B. and Galeano Inchausti, J.C. 2008b. Silurian Monograptids (Llandoverian) of the Vargas Peña Formation (Paraná Basin, Eastern Paraguay). *Geologica Acta*, 6 (2), 181-190.

Young, G.M. 2004. Earth's earliest extensive glaciations: Tectonic setting and stratigraphic context of Paleoproterozoic glaciogenic deposits. In Jenkins, G.S. et al. (eds.), *The Extreme Proterozoic: Geology, Geochemistry and Climate*. Geophysical Monograph, 146, Washington, D.C., American Geophysical Union, 161-181.

Zimmermann, U. and Spalletti, L.A. 2009. Provenance of the Lower Paleozoic Balcarce Formation (Tandilia System, Buenos Aires Province, Argentina): Implications for paleogeographic reconstructions of SW Gondwana. *Sedimentary Geology*, 219, 7-23.