Analysis of the ichnogenus *Herradurichnus* in quartzites of the Balcarce Formation (lower Silurian) from the Tandilia System of Argentina

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The Balcarce Formation is an unit barren of body fossils but very rich in ichnofossils (e.g., Borrello, 1967; Poiré & del Valle, 1996). The ichnological diversity documented since the earliest geological expeditions in the nineteenth century. However, only more than a century later was the first detailed ichnological study published by Borrello (1967). His material comprised his own collections and specimens supplied by other researchers, in particular material already housed in museums and retrieved during expeditions in mapping projects at the beginning of regional geological studies. It is a seminal work in many senses because it was the first ichnological study of the Balcarce Formation and the first attempt to use some ichnofoils of the unit as a correlation tool. In particular, the presence of ichnogenera such as *Arthrophycus* Hall, 1852 and *Cruziana* d’Orbigny, 1842 permitted the author to suggest an Ordovician age for the succession, an assessment reinforced many years later for most of the succession by detrital zircon dating methods (Rapela et al., 2011). A *Cruziana*-based ichnostratigraphy was proposed by Seilacher (1970) for which the material of this unit that Borrello (1967) assigned to *Cruziana* proved to be relevant. Also, based on the presence of *Arthrophycus alleghanensis* Harlan, 1831 and two ichnospecies of *Cruziana* in the unit, Seilacher et al. (2002) restricted the younger parts of the succession to the Silurian. Some stratigraphic aspects of the basal contact remain controversial (Pazos & Rapalini, 2011).

The material described, illustrated and interpreted by Borrello (1967) is exquisitely preserved. Some of the specimens are horizontal, subhorizontal or oblique with respect to the bedding plane, and are recorded in fine-grained to very coarse-grained sandstones. Other characteristics are also described in detail. The holotype of *Herradurichnus scagliai* (Borrello, 1967) has been recovered. Material previously included in *Crescentichnus Romano & Whyte, 2015* is now reassigned to *Herradurichnus*. Xiphosurans and trilobites are disregarded as possible tracemakers of *Herradurichnus*. The producers were able to construct structures oriented with the convex side of the arch in an opposite sense to the main paleocurrents. This ichnogenus is now reappraised and found to range from the Cambrian to the lower Silurian of Gondwana.

**KEY WORDS** - Ichnotaxonomy, ichnology, Gondwana, Silurian, *Herradurichnus*, Balcarce Formation.

**ABSTRACT** - *Herradurichnus* Poiré & del Valle, 1996 from the Balcarce Formation (lower Paleozoic of the Tandilia System, Argentina) is an enigmatic ichnogenus previously considered as problematic. In this paper, *Herradurichnus* is revised and key material from collections is redescribed together with other specimens documented in situ from outcrops and quarries. The diagnosis is emended to include its morphological variability. The revised *Herradurichus* includes negative, epichnial, U-shaped, V-shaped and parabolic depressions. The specimens are horizontal, subhorizontal or oblique with respect to the bedding plane, and are recorded in fine-grained to very coarse-grained sandstones. Other characteristics are also described in detail. The holotype of *Herradurichus scagliai* (Borrello, 1967) has been recovered. Material previously included in *Crescentichnus Romano & Whyte, 2015* is now reassigned to *Herradurichus*. Xiphosurans and trilobites are disregarded as possible tracemakers of *Herradurichus*. The producers were able to construct structures oriented with the convex side of the arch in an opposite sense to the main paleocurrents. This ichnogenus is now reappraised and found to range from the Cambrian to the lower Silurian of Gondwana.
his assignments remain valid, such as *Arthropycus alleghianensis*, while others have been revised (Häntzschel, 1975; Seilacher et al., 2002; Rindsberg & Martin, 2003). The material that Borrello (1967) assigned to *Corophioides* (sic; see below) and included in a new ichnospecies (*C. scagliai*) was later reassigned to the new, monotypic ichnogenus *Herradurichnus* by Poiré & del Valle (1996). They also documented and illustrated material in the field at the Cabo Corrientes locality in the city of Mar del Plata. *Herradurichnus* Poiré & del Valle, 1996 remains a problematic ichnogenus. Many of the authors who have commented on *Herradurichnus* did not discuss the original work by Borrello (1967) and only considered morphological aspects and decisions taken by Poiré & del Valle (1996) together with figures included in later works (e.g., Poiré et al., 2003). *Herradurichnus* has been attributed to worms (Borrello, 1967) and trilobites (Poiré & del Valle, 1996) and also frequently compared with resting and feeding traces attributed to xiphosurans, such as those included in *Selenichnites* Romano & Whyte, 1990.

The aim of this paper is threefold: to study the material originally analysed by Borrello (1967), highlighting and expanding the varied morphological features previously mentioned by him; to revise the in situ material at the Cabo Corrientes (Fig. 1) and Punta Cantera localities (Mar del Plata city) where Poiré & del Valle (1996) and Poiré et al. (2003) analysed specimens in the field; and to present the results of the revision of *Herradurichnus*.

**MATERIALS AND METHODS**

The studied material includes field specimens and others housed in two museums: the Museo Municipal de Ciencias Naturales Lorenzo Scaglia (MMP) in Mar del Plata, and the Museo de La Plata (MLP), both located in Buenos Aires Province, Argentina. However, most of the material examined was unnumbered, including the holotype of *Herradurichnus scagliai*. Accordingly, a collection number is given for the holotype for future references (i.e., MMP 5715). In the same way, some material that Borrello (1967) mentioned as housed in the Comisión de Investigación Científica de la Provincia de Buenos Aires (CIC) was found in the Museo de La Plata. The localities studied in outcrops are Cabo Corrientes (S38°01.694’ W57°52.433’) and Punta Cantera (S38°04.989’ W57°32.223’), both within Mar del Plata city. The Cabo Corrientes logged section included here (Fig. 2) has been modified from Poiré et al. (2003). Some blocks coming from quarries around Mar del Plata are used in groynes in the Santa Clara del Mar beaches northward from Mar del Plata and contain some material that was also examined.

Over 100 trace-fossil specimens were analysed. The morphological terms used in the ichnosophistic section were based on previous studies (Borrello, 1967; Poiré & del Valle, 1996) and redefined in this work. Other associated trace fossils found within the logged section have already been described by Poiré & del Valle (1996), Seilacher et al. (2002) and Poiré et al. (2003) and are not analysed further in this study.

**GEOLOGICAL SETTING**

**Stratigraphy and age**

The Balcarce Formation (Dalla Salda & Íñiguez, 1979) is the uppermost unit that unconformably covers lower Paleozoic and Precambrian successions in the Tandilia System. This system is a part of the western area of the Río de la Plata Craton, a terrane with a complex tectonic evolution; it was assembled to Gondwana previous to the Balcarce Formation deposition (see Rapela et al., 2007).
The Rio de la Plata Craton is a collage of different terranes accreted during the Precambrian with assembly almost complete by the end of the Cambrian (Rapela et al., 2007). It is composed of several blocks; the Tandilia System (or Tandilia Belt) is a morphostructural entity that includes a Paleoproterozoic basement unconformably covered by a sedimentary succession of Neoproterozoic-Cambrian units included in the Sierras Bayas and La Providencia Groups and the Cerro Negro Formation (see Arrouy et al., 2016).

The Balcarce Formation (Dalla Salda & Íñiguez, 1979) was defined for the uppermost part of the succession of the La Tinta Formation, in which Borrello (1967) documented the ichnofossils discussed in this paper. It rests unconformably over the Paleoproterozoic basement to the east of the Tandilia System or over sedimentary units of the Sierras Bayas Group (Poiré et al., 2003) and La Providencia Group and the Negro Formation to the west (Arrouy et al., 2016). The complete thickness of the unit, about 400 m, was only documented in a borehole named Punta Mogotes (Marchese & Di Paola, 1975) very close to Cabo Corrientes, the main locality analysed in this paper. At Punta Mogotes, the basement is composed of metamorphosed pelites and is younger than the Paleoproterozoic basement (Rapela et al., 2007). This permitted Rapela et al. (2007) to suggest that the Mar del Plata Terrane is located to the east of a suture, taking into account the different basement origin. This terrane is mostly situated under the Atlantic Ocean and exhibits affinity with its counterparts in west Africa. Later, Rapela et al. (2011) relocated the suture very close to Mar del Plata, while others like Pángaro et al. (2016) situated this suture in the Atlantic. In outcrops close to the city of Balcarce, at Sierra del Volcán (Fig. 1), between the Paleoproterozoic basement and the classical quartzites (Balcarce Formation) rest diamictites and pelites with dropstones, less than 10 m thick and of indisputably glacial origin. These are unconformably covered by the Balcarce Formation (Spalletti & del Valle, 1984). Pazos et al. (2008) correlated this glacial record with the Playa Hermosa Formation in Uruguay (Pazos et al., 2003) but Ordovician detrital zircons obtained from the diamictites allowed Zimmermann & Spalletti (2009) to correlate this glaciogenic event with the well known Hirnantian glaciation (Late Ordovician). This correlation was supported by narrowly bracketed detrital zircon ages (Van Staden et al., 2010). The new correlation of the glacial deposits had two implications. First, the Balcarce Formation was redefined to include the glacial deposits located at the base of the succession (Zimmermann & Spalletti, 2009). These are equivalent to the Pakhuis and Cedarberg formations in Africa (Zimmermann & Spalletti, 2009). The second implication was that the basin depocenter during this time was situated in Africa where prior to the glaciation more than 3500 m of quartzites deposited (Young et al., 2004). Taking into account that the glacial event is located very close to the overlying Nardouw Subgroup, the classical Balcarce Formation composed of quartzites must be equivalent to the Nardouw Subgroup. However, this subgroup is only 160 m thick, contrasting with the 400 m of the Balcarce Formation, which implies a thickening to the west, contrary to the preglacial event situation. This change in the polarity of the basin necessarily demands time and a different tectonic setting between both parts. Interestingly, detrital zircon dating obtained for the middle unit of the Nardouw Subgroup indicates ages as young as late Silurian-Early Devonian (Fourie et al., 2011, fig. 6a). This permits the conclusion that such a correlation is unlikely, as the Balcarce Formation is pre-Devonian according to regional correlations based on detrital zircon patterns documented in the Lower Ventana Group, which precedes the Upper Ventana Group of Devonian age in the Ventana Fold Belt (Ramos et al., 2014). The Hirnantian glaciation reached the early Silurian in the Parana Basin (Eyles & Eyles, 1993) and this event may be correlatable with the event of the Balcarce Formation. Therefore, the typical quartzites of the Balcarce Formation are early Silurian, in agreement with the ichnostratigraphy of Cruziana d’Orbigny, 1842 and Arthropycus alleghaniensis Harlan, 1831 according to Seilacher et al. (2002).

Paleoenvironmental setting

The trace fossils documented at Cabo Corrientes were located in a 6-m-thick logged section by Poiré et al. (2003). These authors suggested that the facies recorded are subtidal with bar and interbar deposits, Herradurichnus being the only documented ichnogenus in the interbar deposits, here considered to be subtidal flats (Fig. 2). The study of the entire outcrop at this locality allowed us to identify channels with east-west axes with an open sea located to the west-southwest, similar to the paleocurrent pattern suggested by Turuggi (1964). In the subtidal flats we documented decimetric laminated scale claystones with starved ripples and 0.1-0.2 m sandstone beds with tabular to tangential cross-stratification, in some cases with iron oxidized drapes similar to the mud-drapes of tidalites. Herradurichnus was documented in Cabo Corrientes on top of two fine- to medium-grained sandstone beds (levels A and B; Fig. 2) interpreted here as stabilized small (1 m in height) tidal bars covered by claystones settling mainly by decantation but also containing starved ripples that do not show any evidence of subaerial exposure and suggest a submerged setting. These deposits were probably developed between bar progradation stages rather than laterally or “between” bars. Metric tidal bedforms with reactivation surfaces were documented in Punta Cantera, another locality mentioned by Borrello (1967).

ICHNOLOGY

Summary of previous studies and discussion

Borrello (1967) published the description of several ichnofossils of the Buenos Aires Province. Among them was the material now known as Herradurichus from strata of “La Tinta Formation”, now Balcarce Formation, which he described from specimens observed in eight different localities during numerous field trips since 1934 and from material collected by others. Borrello (1967) gave a thorough description of these traces and emphasized their morphological variability, from parabolic to U-shaped, the former being most common. His description only included material from others. Borrello (1967) also documented the ichnofossils discussed in this paper. At Punta Cantera, another locality mentioned by Borrello (1967).

Herradurichnus

Herradurichnus was a trace fossil described by Borrello (1967) from the Silurian of Argentina. It is characterized by a U-shaped trace with a central depression, resembling a footprint. The bounding surface is often smooth or slightly wavy, and the preserved depth is typically less than 1 cm. The trace is usually found in mudstone or siltstone, and it is associated with other trace fossils like Herradura, Arthrophycus, and Herradurichnus. The ichnotaxon is commonly found in deposits from the Silurian age, and it is interpreted as a trace made by an infaunal organism that lived in shallow marine environments. The presence of Herradurichnus is indicative of a stable, low-energy environment, possibly with a muddy substrate. The ichnostratigraphic significance of Herradurichnus is well-documented, and it is often used as a marker for certain sedimentary environments.
Balcarce Formation at Cabo Corrientes

Legend

- Conglomerates
- Medium to coarse-grained sandstone
- Fine-grained sandstone
- Very fine-grained sandstone
- Pebby sandstones
- Ripple cross lamination
- Cross-stratification
- Herradurichnus levels
name Corophioides Smith, 1893 (this was later corrected by Hántzschel, 1975: “Corophioides Borrello, 1967, p. 11, nom. null.”). Borrello made explicit (Borrello, 1967, p. 12) that the holotype is an unnumbered specimen (Borrello, 1967, pl. XII, fig. 1) in the collection of the Museo Municipal de Ciencias Naturales Lorenzo Scaglia in Mar del Plata, retrieved from the Los Curros Quarry, Chapadmalal, Buenos Aires Province.

Based on the orientation of these traces, Knox (1973) placed C. scagliai in Rhizocorallium but with doubts due to the lack of a spreite. Poiré & del Valle (1996) disregarded the possible assignment to Rhizocorallium based on the lack of a tube. They erected a new ichnogenus, Herradurichnus, and reassigned C. scagliai to this new ichnotaxon based only on field material and one collected specimen (MPL.27489) hosted in the Museo de La Plata. They did not mention the specimen chosen as holotype by Borrello (1967). They provided a short diagnosis for Herradurichnus which, unlike the description by Borrello (1967), only included horseshoe and U-shaped forms. However, they described the traces as subparallel to bedding and bearing a central ridge of limited height, information not previously noted by Borrello (1967). They did not include a diagnosis for their new combination Herradurichnus scagliai (Borrello, 1967), including only a description at ichnospecific level. Later, these traces were again mentioned and briefly described by Poiré et al. (2003), the most current sedimentological work on the Balcarce Formation.

Gibb et al. (2011) established Herradurichnus as a junior synonym of Selenichnites Romano & Whyte, 1990, based on the general “horseshoe” shape, and therefore reassigned its only ichnospecies as Selenichnites scagliai (Borrello, 1967). In the same work, Gibb et al. (2011) created a new ichnospecies within Selenichnites, S. tesiltus, and compared it to other Selenichnites ichnospecies. They mentioned that S. scagliai displays a similar, simple horseshoe morphology to that of S. tesiltus and found different length to width ratios in the latter and only one in the former. They mentioned the possibility of these two ichnospecies being synonymous but decided to keep them as distinct.

In a recent review of Selenichnites and similar ichnotaxa, Romano & Whyte (2015) claimed that Poiré & del Valle (1996) did not provide a diagnosis for Herradurichnus but only a description. However, Poiré & del Valle (1996, p. 93) did provide a diagnosis for Herradurichnus; what they did not include was a diagnosis at the ichnospecific level: neither the original diagnosis by Borrello (1967) nor an emended diagnosis for H. scagliai. Romano & Whyte (2015) also stated that Poiré et al. (2003) provided a different diagnosis for Herradurichnus without an emendation, but Poiré et al. (2003) included only a description, not a diagnosis. Romano & Whyte (2015) selected the specimen figured by Poiré & del Valle (1996) in their “fig. 5I” as holotype for H. scagliai. However, there is no figure 5I in that work; evidently they meant to refer to figure 5I in Poiré et al. (2003), which illustrates a field specimen. Regardless of the incorrect subsequent designation of a holotype, Romano & Whyte (2015) selected one based on their understanding that no type material had originally been designated. Unfortunately, this is in error because, as mentioned above, Borrello (1967) clearly stated which specimen was the holotype of what he then called C. scagliai. The synonymy between Herradurichnus and Selenichnites established by Gibb et al. (2011) was disregarded by Romano & Whyte (2015).

**SYSTEMATIC ICHNOLOGY**

Ichnogenus Herradurichnus Poiré & del Valle, 1996

Type ichnospecies Corophiodes [sic] scagliai Borrello, 1967

Ichnogenera and ichnospecies belonging to Herradurichnus:

1967 *Corophiodes* [sic] *scagliai* ichnosp. nov. - *Borrello*, p. 11, Pls XII-XVII.
1973 *Rhizocorallium* *scagliai* (Borrello) - *Knox*, p. 142.
1996 *Herradurichnus* *scagliai* *Poiré* & *del Valle*, p. 94-95, Pls 1-2.
2003 *Herradurichnus* *scagliai* (Borrello) - *Poiré* & *del Valle*, 1996, p. 51-54, figs 4, 5G-4, 7E.
2011 *Selenichnites* *tesiltus* *Gibb*, *Chatterton* & *Pemberton*, p. 159, figs 3-5.
2015 *Crescentichnites* *tesiltus* (Gibb et al.) - *Romano* & *Whyte*, p. 282, fig. 7.

Original diagnosis - Poiré & del Valle (1996, p. 93): “Traza en herradura subparalela a la estratificación constituida por una depresión en forma de U, que presenta una cresta central de escasa altura, la cual divide a la traza en dos lóbulos epichniales negativos” (= Horseshoe-shaped trace subparallel to bedding plane consisting of a U-shaped depression, which presents a central crest of limited height that divides the trace into two negative epichnial lobes).

Emended diagnosis - Negative, epichnial, horizontal, subhorizontal, or oblique, U-shaped, parabolic or V-shaped depression composed of two limbs joined in an arch or at an angle. The limbs are mostly straight but slightly curved in some specimens. In the U-shaped forms the limbs are relatively constant in width while in the V-shaped and parabolic forms they are dominantly wider towards the ends of the depression. In some cases a shallow central ridge is preserved inside the depression.

Description - The material is preserved as epichnial, open depressions (Fig. 3; Pl. 1) showing different orientations with respect to the bedding plane but most are subhorizontal. Three main morphologies are observed:

Fig. 2 - Logged section of the Balcarce Formation at Cabo Corrientes (modified from Poiré & del Valle, 1996). Arrows indicate levels A and B, where *Herradurichnus* was documented.
U-shaped (Fig. 3; Pl. 1, figs 1-2, 6), V-shaped (Fig. 3; Pl. 1, figs 1-2, 7) and parabolic (Fig. 3; Pl. 1, figs 1, 3-4, 6-7). In the U-shaped forms the limbs join forming an arch, while in the V-shaped type the limbs join in an angle. The limbs in the parabolic forms exhibit intermediate morphologies. All of these different morphologies are unrelated to the grain size, which ranges from medium (Pl. 1, figs 2, 4, 6-7) to very coarse sandstones (Pl. 1, fig. 3) in the specimens. In some of the cases only the limbs are preserved (Pl. 1, fig. 1).

The width (Fig. 3) of each limb is between 0.2 cm and 1.2 cm. The width of the trace fossil as a whole and measured in the outer side of the ends of the limbs is between 1 cm and 7.9 cm. The depth of the depressions is between 0.4 cm and 0.8 cm. No infill or wall is present. No spreite is observed in any specimen. In some parabolic forms preserved in very coarse sandstones the width of the depression decreases where the limbs join. In these cases, the internal side of the trace is beneath “hanging” host material.

In some specimens a central ridge (Fig. 3; Pl. 1, figs 2, 4) is present. This structure is rounded and smooth (see detail in Fig. 3). Depending on the degree of weathering the central ridge can be present only in the limbs, in their coalescence area or throughout the specimen. The width of the crest is constant within each specimen.

**EXPLANATION OF PLATE 1**

*Herradurichnus scagliai* (Borrello, 1967). u = U-shaped form; v = V-shaped form; p = parabolic forms; r = central ridge; b = intermediate bridge. The dotted lines enclose examples of the way specimens are found in contact with each other (cases i, ii, and iii). i = two or more specimens similarly oriented and aligned in a way that their limbs meet on approximately the same imaginary line; ii = two specimens in which their ends intersect forming an epsilon shape; iii = two or more specimens similarly oriented but not aligned.

Fig. 1 - Holotype (MMP 5715) of *Herradurichnus scagliai* housed in the Museo Municipal de Ciencias Naturales Lorenzo Scaglia in Mar del Plata. Graphic scale = 1 cm.

Fig. 2 - Field photograph of specimens in Cabo Corrientes, Mar del Plata. Graphic scale = 1 cm.

Fig. 3 - Field photograph of specimens in groynes, Santa Clara del Mar. Graphic scale = 1 cm.

Fig. 4 - Field photograph of specimens in Cabo Corrientes, Mar del Plata. The ruler is in mm increments.

Fig. 5 - Specimen housed in Museo de La Plata (MLP 341), also documented by Borrello, 1967 (pl. XIV, fig. 3) retrieved from Punta Cantera, Mar del Plata. Graphic scale = 1 cm.

Fig. 6 - Field photograph of specimens in groynes, Santa Clara del Mar. The ruler is in cm increments.

Fig. 7 - Unnumbered specimen housed in the Museo Municipal De Ciencias Naturales Lorenzo Scaglia in Mar del Plata. The ruler is in mm increments.
and is consistently lower than the minimum depth of the depression. The crest is mostly found in the parabolic forms.

In some specimens oblique to bedding plane an intermediate bridge (Pl. 1, fig. 5; sensu Borrello, 1967) is found inside the depression in coincidence with the area where the limbs would meet. In some cases where the bridge collapsed, the host material is preserved “hanging”, and the depression is without fill.

Usually two or more specimens are found on the same surface. In both surfaces (levels A and B; Fig. 2) the outer or convex side of the area where their limbs meet is mostly oriented towards the SE to E. Most of them are not in contact with each other and the morphology and size remain similar in nearby specimens. For example, they present only the limbs (Pl. 1, fig. 1), or the limbs are incomplete but the area where they join is present (Pl. 1, fig. 6), or the entire structure is preserved (Pl. 1, fig. 6).

Although most specimens are not in contact with each other, some are. This contact occurs with: 1) two or more specimens similarly oriented and aligned in a way that their limbs meet on approximately the same imaginary line (Pl. 1, fig. 7); 2) two specimens in which their ends intersect forming an epsilon shape (Pl. 1, fig. 7) as also noted by Borrello (1967, p. 12); or, 3) two or more specimens similarly oriented but not aligned (Pl. 1, figs 6-7).

**Remarks** - The restudy of the material analysed first by Borrello (1967) and later by Poiré & del Valle (1996) showed that the morphological variability of these trace fossils was greater than what was comprised in the original diagnosis of *Herradurichnus*, including characteristics already described by Borrello (1967). The original diagnosis of *Herradurichnus* by Poiré & del Valle (1996) neglected parabolic and V-shaped forms. On the other hand, these authors meant to incorporate such forms in *H. scagliai* as can be deduced from their choice (Poiré & del Valle, 1996, p. 94) to include in this ichnospecies all the material figured by Borrello (1967). In the present work we agree with Romano & Whyte (2015) in that *Herradurichnus* is not a synonym of *Selenichnites*, and we propose an emendation of the diagnosis of *Herradurichnus* to include the morphological variability found in the entire analysed material. The nomenclature used herein is based on Borrello (1967) and Poiré & del Valle (1996) but revised to include the aforementioned variability and to avoid future confusion between *Herradurichnus* and similar ichnotaxa and also unnecessary inferences on possible trace makers.

*Herradurichnus* Poiré & del Valle, 1996 has been compared to ichnegnera such as *Selenichnites, Limulicubichnus, Lunatubichnus* and *Rhizoconullum*. The lack of a marginal tube is important to differentiate *Herradurichnus* from *Rhizoconullum* Zenker, 1836. *Selenichnites* Romano & Whyte, 1990 always presents a rounded anterior margin and paired lobes, while *Limulicubichnus* Miller, 1982 is characterized by a teardrop or oval shape and a posterior elongate terminus (see emended diagnosis by Romano & Whyte, 2015). None of these characteristics is shared with the material here included in *Herradurichnus*. *Lunatubichnus* Trewin & McNamara, 1995 resembles some specimens of *Herradurichnus* superficially but is actually a rather deep (up to 7 cm in depth) “vertical hole” with a crescentic cross section and a medial ridge/groove. *Faciennichnus* Romano & Whyte, 2015 presents a linear imprint nestled in the concave margin; in *Herradurichnus* no structure is found in that area. Also, the lack of vertical forms disallows any possible assignment to ichnotaxa such as *Diplocraterion* Torell, 1870 and *Arencolites* Salter, 1857.

*Crescentichnus* Romano & Whyte, 2015 includes “crescent- or lunate-shaped to horseshoe-shaped, shallow to deep depressions (negative epichnia) or mounds (positive hypichnia)” (Romano & Whyte, 2015, p. 280). These trace fossils might occur in isolation or in a series, and may exhibit transverse lineations in “posterior medial portion”. According to Romano & Whyte (2015), *Crescentichnus* includes three ichnospecies: *C. antarcticus* (Weber & Braddy, 2004), *C. langridgei* (Trewin & McNamara, 1995) and *C. tesiltus* (Gibb et al., 2011). Romano & Whyte (2015) stated *Herradurichnus* has features in common with *Crescentichnus* but they did not consider it to be congeneric. They remarked the difficulty of the interpretation from figures by Poiré et al. (2003) which was a mainly sedimentological and stratigraphical work where the presence of *Herradurichnus* in their studied sections was only mentioned and briefly described along with other 19 ichnegnera. *C. antarcticus* bears transverse lineation (Weber & Braddy, 2004) and *C. langridgei* exhibits “scratch marks” (Trewin & McNamara, 1995), both characteristics not found in *Herradurichnus*. However, part of the material first included in *Selenichnites* (selenichnites *tesiltus* Gibb et al., 2011) and then recombined by Romano & Whyte (2015) as *Crescentichnus* *tesiltus* is here considered to be a junior synonym of *Herradurichnus scagliai*. This is based on the diagnosis of *S. tesiltus* and the specimens from the middle Cambrian of Morocco figured and described by Gibb et al. (2011). In particular, the specimens in figure 4B and 4D in Gibb et al. (2011) exhibit the V-shaped to parabolic forms comprising *H. scagliai*, while the specimen in figure 4F (T20c, the holotype of *S. tesiltus*) of the same work shows U-shaped morphology. This similarity was also discussed by Gibb et al. (2011), who, based on the only specimen of *H. scagliai* figured by Poiré & del Valle (1996, pl. 1, fig. 2), argued that “*S. scagliai*” presents a 1:1 length:width ratio, and that this ratio was not included in the ratios “characteristic of *S. tesiltus*”. However, they only mentioned the range of length/width ratios for *S. tesiltus* (0.54-1.19; Gibb et al., 2011), not which ratio was characteristic. The specimens assigned to *Selenichnites* isp. by Draganits et al. (2001) from the Lower Devonian of India were first included in *S. tesiltus* by Gibb et al. (2011) and later reassigned as *Crescentichnus* isp. by Romano & Whyte (2015). In the present work, those specimens are also considered included in *H. scagliai*.

**Stratigraphic range** - Cambrian-lower Silurian.

Ichnospecies *Herradurichnus scagliai* (Borrello, 1967) (Pl. 1)

**Emended diagnosis** - As for ichnegnera because of monotypy.
Type material - Four of Borrello’s (1967) types of *C. scagliai* are housed in two collections. The holotype, fixed in the original publication by Borrello (1967, p. 12, pl. XIII, fig. 1) from unnumbered material, is housed in the Museo Municipal de Ciencias Naturales Lorenzo Scaglia in Mar del Plata (Museo Municipal de Ciencias Naturales Lorenzo Scaglia). The holotype is here given the collection number MMP 5715 for future reference. Of the remaining material (paratypes) mentioned by Borrello (1967), some (e.g., Borrello, 1967, pl. XII; pl. XIV, fig. 3) are housed in the Museo de La Plata, while the rest are, for the moment, considered to be lost.

Type locality - The holotype comes from Los Curros quarry, located 2 km east of Batán, Buenos Aires Province (see Borrello, 1967, p. 12). This quarry is located on a private property and currently inaccessible to the public.

Ethological discussion - Different biota have been proposed as potential producers of *Herradurichnus*. Borrello (1967) attributed the material to the action of annelids. Poiré & del Valle (1996) stated that trilobites were possible producers; they interpreted the U-shaped forms as imprints of a trilobite cephalon associated with a feeding behaviour (even predatory behaviour) or as imprints of a pygidium during egg-laying. The arthropod interpretation might have been biased by the apparent resemblance to *Limalubicichnus* and *Selenichnites*. These have been attributed to xiphosurids and other arthropods such as trilobites, crustaceans (e.g., phyllocarids, euthycarcinoids), aglaspids and eurypterids (Romano & Whyte, 2015, and references therein).

As mentioned above, the fill is not preserved. However, in the specimens where a bridge or a “hanging” host material is observed if the depression had been passively filled by the clays overlying horizons A and B, both the bridge or the “hanging” host material (see above) would have collapsed previously to diagenesis. The fill was probably sand of finer grain size than the host rock that suffered differential diagenesis and was therefore weathered out in the exposed sections. If not passive, this fill was related to the tracermaker activity, possibly feeding or dwelling/feeding. However, since the fill is not preserved any behavioural interpretation would be highly speculative.

No scratch traces or tracks indicative of appendage action are found inside these trace fossils or associated on the same beds, respectively, although this could be the result of the grain size. The action of a trilobite cephalon or pygidium is contradicted by the presence of a central ridge. Also, the attribution to trilobite or xiphosuran tagmata did not take into account the full range of morphologies (especially the V-shaped forms) and the specimens oblique to the bedding plane (especially because there is no relation between a particular morphology and the orientation with respect to the bedding plane). After a closer look at the morphology of *Herradurichnus*, trilobites and xiphosurans are considered as unlikely producers. For the moment, the makers remain unidentified. They were able to construct the structures oriented with the convex side of the arch in an opposite sense to the main paleocurrents. This preferential orientation might have affected water circulation within these open structures.

CONCLUSIONS

After a thorough revision of field and museum material, the complex ichnysystematic situation of the material assigned to *Herradurichnus* has been resolved. The diagnosis of this ichnogenus is emended to include its morphological variability, some of which was contemplated in the pioneering work of Borrello (1967). The holotype of *Herradurichnus scagliai* has been recovered. Some material previously assigned to *Selenichnites* and *Crescentichnus* is included in *Herradurichnus*. The producers were able to construct the structures with a preferential orientation against the main paleocurrents. Trilobites and xiphosurans are here considered as unlikely producers. The logged section studied in this work is within the typical quartzites of the Balcarce Formation (Silurian). There, *Herradurichnus* is found in a transgressive interval in a tide-dominated setting (subtidal flat deposits). The record of *Herradurichnus* is now restricted to the Cambrian-lower Silurian of Gondwana.

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Borrello A.V. (1967). Paleontografía Bonaerense; Fascículo V. Balcarce Formation (Silurian). There, *Herradurichnus* is considered as unlikely producers. The logged section studied in this work is within the typical quartzites of the Balcarce Formation (Silurian). There, *Herradurichnus* is found in a transgressive interval in a tide-dominated setting (subtidal flat deposits). The record of *Herradurichnus* is now restricted to the Cambrian-lower Silurian of Gondwana.

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