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Large striated burrows from fluvial deposits of the Neogene Vinchina Formation, La Rioja, Argentina: A crab origin suggested by neoichnology and sedimentology

Ricardo N. Melchor [a,*], Jorge F. Genise [b], Juan L. Farina [c], María V. Sánchez [b], Laura Sarzetti [d], Graciela Visconti [e]

[a] INCITAP (CONICET and Universidad Nacional de La Pampa), Av. Uruguay 151, 6300 Santa Rosa, La Pampa, Argentina
[b] CONICET, División Icnología, Museo Argentino de Ciencias Naturales, Av. Angel Gallardo 470, 1405 Buenos Aires, Argentina
[c] Museo Municipal de Ciencias Naturales Lorenzo Scaglia, Área Entomología, Plaza España, 7600 Mar del Plata, Argentina
[d] CONICET-Museo Paleontológico Egidio Feruglio, Av. Fontana 140, 9100 Trelew, Chubut, Argentina
[e] Universidad Nacional de La Pampa, Av. Uruguay 151, 6300 Santa Rosa, La Pampa, Argentina

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ABSTRACT

This study includes three aspects: 1) the ichnotaxonomic treatment of large and dominantly vertical burrows ornamented with sharp bioglyphs from the fluvial Neogene Vinchina and Toro Negro formations (northwest Argentina); 2) the description and interpretation of the sedimentary facies where these burrows occur; and 3) neoichnologic observations on large ornamented burrows from seasonal wetlands of the Río Pilcomayo National Park (Argentina) as possible modern analogues of the trace fossils and the sedimentary environment. A new ichnogenus and ichnospecies, *Capayanichnus vinchinensis*, is proposed to include the large striated burrows. The new ichnotaxon is distinguished by a combination of a predominantly vertical orientation, overall "L" shape (when fully developed), absence of lining and burrow bifurcation, a distinct surface texture, and lack of burrow enlargements. The hosting sedimentary facies of the Vinchina Formation can be grouped into fluvial channel and splay (floodplain) facies associations. The rivers of that unit were of two main types: single channel rivers with frequent channel avulsion and overbank flow and multi-channelised rivers with poorly defined margins. At least some of these rivers were ephemeral or with intermittent discharge. The climate was probably seasonal and semiarid, as suggested by sedimentologic evidence. *C. vinchinensis* was dominantly recorded from the top of fluvial channels (interpreted as abandoned channels) and proximal, intermediate and distal splay facies. The large ornamented burrows found in an extant comparable example were constructed by freshwater crabs. These burrows can be distinguished by the overall architecture, the taxonomy and sex of its occupants, and the environmental setting where they were found. The neoichnologic signatures used in the interpretation of the fossil example include the common oval burrow cross-section and the surface texture. In particular, the surface texture in the modern crab burrows includes abundant comma-shaped marks, sets of grooves oblique to burrow axis, and long segmented grooves. The predominantly oval cross-section, absence of lining, and the strongly ornamented burrow surface suggest that *C. vinchinensis* was produced by freshwater crabs. The key features of the surface ornament are long sets of three–four ridges whose width is in average one third of the burrow major axis. Other features that also point to a crab origin are a massive filling, common burrow ends in a casing mudstone, chevron pattern in sets of surface ridges, and possible cheliped marks. The new ichnotaxon is restricted, in the Vinchina and Toro Negro formations, to fluvial facies and is absent in shallow lacustrine facies.

1. Introduction

The most common trace fossil of the continental Vinchina Formation from northwest Argentina are moderately large (about 50–80 mm wide, up to 350 mm long) dominantly vertical burrows that display a characteristic surface texture consisting of sets of long parallel ridges arranged oblique to the burrow axis. These burrows lack enlargements and bifurcations, display a massive filling and were only recorded in fluvial sedimentary successions. The producer of relatively simple fossil continental burrows, as those of the Vinchina and Toro Negro formations, can be difficult to ascertain when body fossils are lacking. In general, simple biogenic structures are more difficult to refer to a definite producer than complex ones. The criteria commonly used to identify the burrow builder include overall burrow

* Corresponding author. Tel.: +54 2954436787x24; fax: +54 2954 432535.
E-mail address: rmelchor@exactas.unlpam.edu.ar (R.N. Melchor).

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architecture (e.g. orientation, branching, presence or absence of enlargements), surface texture or ornamentation (byoglyphs as defined by Ekdale et al., 1984), burrow diameter and cross-section outline, presence or absence and characteristics of burrow lining or wall, burrow orientation, burrow filling, hosting sedimentary facies, and geologic age (e.g. Voorhies, 1975; Martin and Bennett, 1977; Hasiotis et al., 1993; Groenewald et al., 2001; Miller et al., 2001; Verde and Martínez, 2004; Gobetz, 2006; Lewy and Goldring, 2006). Contrasting these burrow features with neoichnological observations or experiments may reveal burrowing signatures that are helpful for identifying the trace maker (e.g. Thoms and Berg, 1985; Dworschak, 1987; Hasiotis and Mitchell, 1993; Gobetz, 2005). Burrow diameter can help to distinguish between an invertebrate or vertebrate producer, although in some cases this feature is not conclusive. The most diagnostic features usually are overall burrow architecture, surface texture and burrow lining (e.g. Hasiotis et al., 1993; Lucas et al., 2006; Bedatou et al., 2008). In addition, the number of burrow shafts and the presence or absence of enlargements may be helpful. Microscopic observation of the burrow wall or lining and fill can provide information on its mode of construction and burrow usage. Fossil remains found within the burrow filling may not belong to the digger, as the history of burrow usage and occupation can be complex (e.g. Martin and Bennett, 1977; Hunt et al., 1983; Genise, 1989). The surface of burrows or burrow fillings may be smooth or contain grooves or ridges that are directly related to burrowing techniques and history of burrow occupation. The known examples of moderately large burrows with a prominent surface texture in the form of well defined ridges or grooves are commonly attributed to tetrapods or decapod crustaceans. Tetrapod burrows ornamented with ridges or grooves commonly were not designated ichnotaxonomically (e.g. Groenewald et al., 2001; Miller et al., 2001; Hasiotis, 2002; Damiani et al., 2003; Hasiotis et al., 2004; Sidor et al., 2008); only the ichnogenera *Daimonelix* and *Alezichnus* have been proposed (Martin and Bennett, 1977; Smith, 1987; Gobetz, 2006; Gobetz and Martin, 2006). The ichnogenera showing surface ridges or grooves that were attributed to decapod crustaceans include *Gyrolithes*, *Rhizocorallium*, *Katbergia*, and *Spongeliomorpha* (Frey et al., 1984; Muñiz and Mayoral, 2001; Seilacher, 2007; Gastaldo and Rolerson, 2008). The two last ichnogenera have been reported from continental deposits, although the examples of *Spongeliomorpha* in nonmarine settings are commonly attributed to insects (e.g. Bromley and Asgaard, 1979). In addition, the ichnogenera *Gyrolithes*, *Glyphichnus*, *Macanopsis*, *Psilonichnus*, *Spongeliomorpha*, and *Thalassinoides* have been ascribed to marine Brachyura (e.g. Frey et al., 1984; Bromley and Goldring, 1992; Carmona et al., 2004), although no ichnotaxon has been proposed to designate freshwater crab burrows. In this paper, the description and interpretation of large striated fossil burrows of the Neogene Vinchina Formation are complemented with observations on extant crab burrows from the wetlands of the Río Pilcomayo National Park (northeast Argentina). The freshwater crabs (and its burrows) and the wetlands of the park are considered as potential modern analogues for the trace makers (and fossil burrows) and the sedimentary environment of the Vinchina Formation. The objectives of this contribution are 1) to describe and assign ichnotaxonomically the large ornamented fossil burrows of the Vinchina Formation, 2) to identify the possible burrow builder using neoichnological observations, and 3) to infer the palaeoenvironmental and palaeoecological meaning of this trace fossil.

2. Study areas and methods

The Sierra de Los Colorados, in northwest La Rioja province, Argentina (Fig. 1A), is composed of a very thick Neogene sedimentary sequence that is mostly assigned to the Vinchina (older) and Toro Negro (younger) formations (see also Turner, 1964; Ramos, 1970). These sediments are part of the filling of a broken Andean foreland trough named as the Vinchina basin that was uplifted during Pliocene times (Ramos, 1999; Limarino et al., 2001; Ciccioli et al., 2008). The Vinchina Formation is a 5100 m thick red bed succession essentially composed of sandstones and mudstones, which has been interpreted as representing different styles of fluvial sedimentation (anastomosed, meandering and braided rivers) with subordinate aeolian and lacustrine deposits (Tripaldi et al., 2001). The unit is divided into a lower (2156 m thick) and an upper member (4428 m thick), which are separated by a low-angle erosive surface (Ramos, 1970; Limarino et al., 2001; Tripaldi et al., 2001). The Vinchina Formation rests on an erosive unconformity over Eocene sediments of the Vallecito and Puesto La Flecha formations (Ciccioli et al., 2008). The top of the Vinchina Formation is separated by a marked erosive surface from the overlying late Miocene–Pliocene Toro Negro Formation (Ciccioli et al., 2005; Rodríguez Brizuela and Tauber, 2006). The Toro Negro Formation is an alluvial succession that includes more than 2000 m of grey–brown sandstones, conglomerates and minor tuff. This unit is composed of a lower sandy member, interpreted as deposited by braided or anastomosing rivers, and an upper gravely member, reflecting deposition in stream-dominated alluvial fan (Ciccioli et al., 2005; Rodríguez Brizuela and Tauber, 2006; Krapovickas et al., 2009). The lower member of the Toro Negro Formation contains invertebrate ichnocoenoses from crevasse splay deposits (including *Taenidium barretti*, *Scoyenia gracilis* and *Palaeophycus tubularis*) and rare invertebrate traces (*Palaeophycus* and *Helminthopsis*) in addition to common mammal (*Macrauchenichnus rector*, cf. *Venatoripes riojanus*, small heteropod footprint, kidney-like footprints, and oval impressions) and bird tracks (*Fuscinapeda sirin*, incumbent footprint, slender anisodactyl footprint) from channel top deposits (Krapovickas et al., 2007; Krapovickas et al., 2009). The Toro Negro Formation is unconformably covered by Pliocene conglomerates assigned to the Santa Florentina (Ramos, 1999; Ciccioli et al., 2005) or El Corral (Ciccioli et al., 2008) formations. The age of the Vinchina Formation is currently considered as ranging from early Oligocene to Miocene. The age is constrained by radiometric ages (8.6 ± 0.3 Ma and 6.8 ± 0.2 Ma) of the upper part of the overlying Toro Negro Formation (Ciccioli et al., 2005), a fission-track age (12.1 ± 1.4 Ma) and magnetostratigraphic studies of the Vinchina Formation near Guandacol (southeast La Rioja province) suggesting deposition between 18 and 12 Ma (Reynolds et al., 1990), stratigraphic relationship with underlying formations (Ciccioli et al., 2008), and an Oligocene (25.3 ± 0.9 Ma) Ar/Ar age for the middle part of the Vinchina Formation (Krapovickas et al. 2009). The Miocene age of the Toro Negro Formation has been questioned on the basis of its vertebrate fossil content, which suggests an early Pliocene age (Rodríguez Brizuela and Tauber, 2006), in agreement with previous fission-track ages (Tabbut et al., 1989).

The Vinchina Formation is outstandingly exposed along the Río de La Troya canyon, which can be easily accessed using provincial road 76 from the San José de Vinchina town. Other surveyed canyons are the nearby Quebrada del Yeso and Quebrada Piedras Moradas (Fig. 1A). For this study, seven sedimentary logs containing large striated burrows and associated trace fossils were measured in the Vinchina Formation along the Río de La Troya canyon (Fig. 1B). Logs # 204 (28° 43′ 56″ S; 68° 14′ .20″ W) and 210 (28° 43′ 33″ S; 68° 15′ 02″ W) belong to the lower member of the formation. The remaining sections were measured in the upper member, including logs # 205 (28° 43′ 43″S; 68° 15′ 23″ W), 206 (28° 44′ 01″ S; 68° 15′ 41″ W), 218-1 (28° 43′ 36″ S; 68° 15′ 58″ W), and 219 (28° 43′ 46″ S; 68° 15′ 19″ W). We also surveyed the lower part of the Toro Negro Formation at the Quebrada Piedras Moradas where the large striated burrows also occur.

The area selected for neoichnological observations was the Río Pilcomayo National Park and the surrounding area, which is located within the Formosa province, northeast Argentina (Fig. 1C). This is the area close to our research center that exhibits a similar sedimentary environment and a seasonal climate as those inferred for the Vinchina Formation (e.g. Tripaldi et al., 2001) and it is inhabited by freshwater crabs, which were considered possible candidates for the organisms