

Tetrapod tracks in a marginal lacustrine setting (Middle Triassic, Argentina): Taphonomy and significance

Claudia Alicia Marsicano^{a,*}, Adriana Cecilia Mancuso^b, Ricardo Manuel Palma^a, Verónica Krapovickas^a

^a Departamento de Ciencias Geológicas, Facultad de Ciencias Exactas y Naturales, Universidad de Buenos Aires, CONICET, Ciudad Universitaria Pabellón II, C1428EHA Buenos Aires, Argentina

^b Ianigla, CCT-CONICET-Mendoza, Adrián Ruiz Leal s/n, Parque Gral. San Martín 5500, Mendoza C.C.330, Argentina

ARTICLE INFO

Article history:

Received 13 July 2009

Received in revised form 25 November 2009

Accepted 8 March 2010

Available online 15 March 2010

Keywords:

Tetrapod tracks

Taphonomy

Paleobiology

Lacustrine environment

Basin evolution

Triassic

Argentina

ABSTRACT

Fossil tetrapod footprints not only provide valuable information about trackmaker paleobiology but also to give insight into details of the depositional conditions of the substrate at the time of imprinting. Therefore, in the present study the mode of formation and taphonomy of footprints in different substrates was used to investigate the gait and walking dynamics of the trackmakers as well as a source of additional information on the environmental conditions of the track-bearing beds during imprinting.

The analyzed section corresponds to thick Middle Triassic lacustrine/deltaic deposits of the Ischichuca/Los Rastros Formation (Ischigualasto–Villa Unión Basin) that crops out at the Quebrada de Ischichuca in northwestern Argentina. Part of the track-bearing surfaces correspond to the top of sandy distributary channel mouth bars in a distal delta front setting that were exposed along the lake margin during a lake level fall. Cross-cutting relationships observed among ripple-marks, the footprints, and invertebrate traces of a softground suite of the *Scoyenia* ichnofacies suggest an omission surface. Measured trackway orientations in the sandstones are perpendicular to the paleo-shoreline, with the animals coming and going along the exposed top of the bars, probably for drinking. Laterally, the distal delta front deposits interfinger with track-bearing wackestone beds of palustrine origin deposited in a restricted local embayment lateral to the delta influenced environment. Trackway orientations in the wackestones are, in contrast, consistent with the animals moving nearly parallel to the lake border, probably along a preferred route. Evidences of a relative high groundwater table at the time of imprinting in the track-bearing surfaces are revealed by the well developed rims of extruded sediment and collapsed digits in the studied tracks and the nearly absence of associated desiccation cracks on the same surfaces. Nevertheless, temporary emergence cannot be ruled out when paleosol formation was probably promoted as can be observed in the microstructure of both sandstones and wackestones. Moreover, footprint preservation in the wackestones might have been enhanced by partial hardening of the trampled surface during subaerial exposure. Combining ichnofossil content and taphonomy with facies analysis we identified in the lower part of the Ischichuca/Los Rastros succession a relatively rapid withdrawal of the water basinward that was probably due to a forced regression during early rifting of basin evolution.

Footprints can also provide valuable information about locomotion dynamics and trackmaker behavior. Thus, the sideways deformation observed in the studied footprints, attributed to basal archosaurs and putative basal dinosaurs, can be related to an outward rotation of the foot during the step cycle, a condition that might allied to the development of the parasagittal posture in Archosauria. Besides, the densely trampled surface described herein constitutes the first documented evidence of putative social behavior among therapsid dicynodonts, the most important group of herbivorous animals in the early Mesozoic terrestrial ecosystems throughout Gondwana.

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1. Introduction

It is widely acknowledged that fossil tetrapod footprints not only provide valuable information about trackmaker paleobiology, but also to give insight into details of the depositional conditions of the substrate

at the time of imprinting (e.g. Lockley, 1986; Thulborn, 1989, 1990; Avanzini, 1998; Gatesy et al., 1999; Milàn, 2006; Bohacs et al., 2007; Scott et al., 2007; Genise et al., 2009). Thus, particular attention has been paid recently to the mode of formation and taphonomy of footprints in a variety of substrates to investigate the gait and walking dynamics of the trackmakers (e.g. Allen, 1997; Avanzini et al., 1997; Avanzini, 1998; Gatesy et al., 1999; Fornós et al., 2002; Manning, 2004; Milàn, 2006; Milàn et al., 2006; Milàn and Bromley, 2008).

* Corresponding author. Tel./fax: +54 11 45763329.

E-mail address: claumar@gl.fcen.uba.ar (C.A. Marsicano).

In the Ischigualasto–Villa Unión Basin in northwestern Argentina, thick Middle Triassic lacustrine/deltaic deposits of the Ischichuca/Los Rastros Formation have been extensively studied, with more recent work focusing on its body fossil content and taphonomy (Mancuso, 2003, 2005; Melchor, 2004; Ottone et al., 2005; Martins-Neto et al., 2005, 2006; López-Arbarello et al., 2006; Ottone and Mancuso, 2006; Mancuso and Marsicano, 2008). The tetrapod record of the succession is almost exclusively composed of tracks and trackways, as the whole column is virtually devoid of tetrapod bone remains. In all cases, the track-bearing strata were interpreted as having been deposited along paleo-lake shorelines and proximal deltaic settings (Arcucci et al., 1995; Marsicano et al., 2004, 2007).

Detailed analysis of the track-bearing interval in the Cerro Bola area (Quebrada de Ischichuca) in the northwest end of the basin was recently completed in order to clarify the environmental conditions that controlled its deposition. The present contribution includes results obtained during that research on the tracks and their mode of preservation. Their role in the paleoenvironmental analysis of the track-bearing beds and in our understanding of early phases of the basin evolution is also explored. Moreover, a discussion about trackmaker behavior and locomotor dynamics based on the taphonomic analysis of the tracks is also included.

2. Geological setting and paleoenvironments

The Triassic sedimentary record of central–western Argentina is entirely non-marine and related to extensional depocenters formed along the western margin of southern South America during the

Permo-Triassic (Uliana and Biddle, 1988; Uliana et al., 1989). The Ischigualasto–Villa Unión Basin is located along the border between San Juan and La Rioja provinces (Fig. 1) and contains up to 4000 m of continental rocks, of predominantly alluvial, fluvial, and lacustrine origin. The Middle–Late Triassic Agua de la Peña Group unconformably overlies the Early Triassic Talampaya–Tarjados succession and is separated by a regional unconformity from the overlying Cretaceous and Cenozoic rocks (López-Gamundí et al., 1989; Milana and Alcober, 1994; Caselli et al., 2001).

Within the Agua de la Peña Group, the Middle Triassic black shale and sandstone of the Los Rastros Formation conformably cover the fluvial–lacustrine tuffaceous deposits of the Chañares Formation and are unconformably covered by the fluvial sandstone, mudstone, and tuff of the Late Triassic Ischigualasto Formation. The Triassic succession culminates with the thick fluvial “redbeds” deposits of the Los Colorados Formation (e.g. Caselli et al., 2001; Milana and Alcober, 1994; Rogers et al., 2001).

The Los Rastros outcrops are well exposed along the basin, particularly in the northwest and near the border between the La Rioja and San Juan provinces (Fig. 1). The succession is characterised by shallowing-upwards cyclic deposits dominated by an alternation of laminated dark gray to black carbonaceous claystones and tabular fine to coarse-grained sandstones, although there are vertical and lateral variations in the facies arrangement among the different outcrops. In a recent study on the Los Rastros succession (Mancuso and Marsicano, 2008), two types of depositional cycles were identified (Fig. 2). Type I cycles are 3–10 m thick and characterised by horizontally laminated gray-black carbonaceous claystones grading upwards into tabular

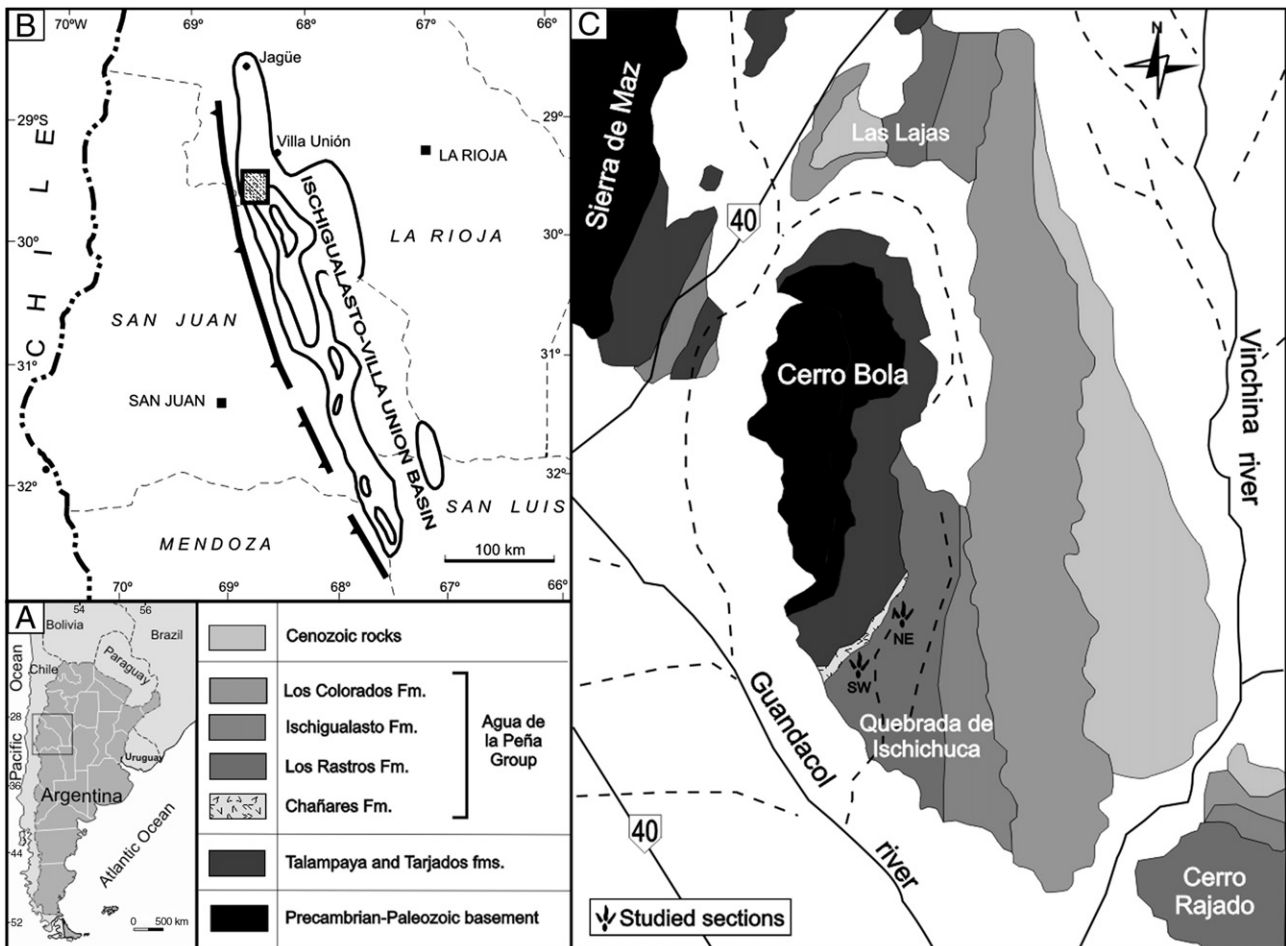


Fig. 1. Map of west-central Argentina showing the location of the Ischigualasto–Villa Unión Basin, and geological map of the Cerro Bola area (modified from Stipanovic and Marsicano, 2002; Mancuso and Marsicano, 2008).

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