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# A NEW DINOSAUR TRACKSITE FROM THE ARARIPE BASIN (BRAZIL) AND THE PUTATIVE EARLY PALEOZOIC AGE FOR THE MAURITI FORMATION

ISMAR DE DOUZA CARVALHO[a], JAIME JOAQUIM DIAS[a], DANIEL SOUZA DA SILVA[a], LEONARDO BORGHI[a], JOSÉ ARTUR FERREIRA GOMES DE ANDRADE[b], MARIA SOMÁLIA SALES VIANA[c], MÁRIO FERREIRA LIMA FILHO[d], RENATA DA SILVA SCHMITT[a], ARISTÓTELES DE MORAES RIOS NETTO[a], SILVÉRIO DOMINGUES FIGUEIREDO[c], and GIUSEPPE LEONARDI[f]

[a]Universidade Federal do Rio de Janeiro, Instituto de Geociências, Departamento de Geologia, 21.910-200, Rio de Janeiro, Brazil, e-mails: ismar@geologia.ufrj.br, jaimejoaquimdias@gmail.com, daniel.silva@geologia.ufrj.br, lborghi@geologia.ufrj.br, schmitt@geologia.ufrj.br; [b]Agência Nacional de Mineração, 63100-440, Crato, Ceará, Brazil, jartur.andrade@yahoo.com.br; [c]Universidade Estadual Vale do Acaraú, Museu Dom José, 62010-295, Sobral, Brazil, email: vianasomalia@gmail.com; [d]Universidade Federal de Pernambuco, Departamento de Geologia, 50670-901, Recife, Brazil, email: mflf1962@gmail.com; [e]Instituto Politécnico de Tomar, 2300-313, Tomar, Portugal, email: silverio.figueiredo@ipt.pt; [f]Istituto Cavanis, 898, 30123, Venezia, Italy, email: leonardigiuseppe879@gmail.com, rios.netto@geologia.ufrj.br

**Abstract—**Footprints in the Araripe Basin (Northeastern Brazil) are previously known in the Mauriti Formation only from the Milagres ichnosite (Milagres County, Ceará State) on coarse- to fine-grained sandstones. Since this lithostratigraphic unit is considered and mapped as Silurian-Devonian (despite the fact that no macro- or microfossils established its age) the presence of such footprints shows a temporal inconsistency. The dinosaur footprints found in a new ichnosite (Mauriti County, Ceará State) reinforce the Mesozoic age for the Mauriti Formation, and due to the proximity of the nearby Rio do Peixe basins and to the similarity of their dinosaur footprints, a particularly Early Cretaceous age is suggested. This new ichnosite, herein named as Mauriti ichnosite, presents seven isolated footprints. There are four tridactyl, mesaxonic isolated footprints with pointed (?theropod) and rounded digits (?ornithopod). The other imprints are rounded depressions with no clear digit impressions, surrounded by displacement rims or presenting fluidization features of indeterminate trackmakers. The partial sandstone filling of the footprints is similar to the surrounding matrix. They range from 30-48 cm in length and 25-48 cm in width. The paleoenvironmental interpretation of the dinoturbation strata is fluvial braided. The trackmakers are small and large bipeds, despite some pointed digits induce to consider them as theropods related to those already known in the Araripe Basin's Cretaceous formations. This new tracksite confirms the need to revise the age of the Mauriti Formation and the involved paleogeography, establishing a new stratigraphic framework for the lower successions of the Araripe Basin.

## INTRODUCTION

The Araripe Basin is the largest onshore sedimentary basin in Northeastern Brazil (Fig. 1) covering an approximate area of 12,200 km² (Carvalho et al., 2012; Fambrini et al., 2020; Dias et al., 2022). Its origin is related to wrench tectonics occurred during the Early Cretaceous, controlled by Proterozoic lineaments and regional E–W faulting, related to the opening of the South Atlantic Ocean (Matos, 1992), particularly to the Brazilian Equatorial Margin's basins. Besides the high quantity and quality of its invertebrate and vertebrate macrofossils (e.g., Maisey, 1991; Martill et al., 2007; Carvalho et al., 2015a,b, 2019c; Agnolin et al., 2020; Iniesto et al., 2021; Kroth et al., 2021; Carvalho et al., 2023a; Dias and Carvalho, 2020, 2022; Dias et al., 2022, 2023; Santos et al., 2023), dinosaur footprints are commonly found in four lithostratigraphic units: Mauriti, Rio da Batateira, Crato, and Exu formations (cf. Carvalho et al., 1995, 2018, 2019a,b, 2021a,b, 2022, 2023b).

The footprints in the Araripe Basin are imprints observed on the bedding surface and by deformational structures (undertracks) produced by dinosaur trampling. The paleoenvironmental context of the dinosaur footprints from the Araripe Basin includes substrates at fluvial sand bars and floodplains, deltas plains, and saline-alkaline lake shores; these rocks are, at least, Mesozoic.

Footprints found in the Mauriti Formation (Carvalho et al., 1995, 2023b) reveal a special importance since this lithostratigraphic unit has been considered and mapped as Silurian-Devonian – by its basal stratigraphic position in the basin and the lithological correlation to other Brazilian basins. The presence of such footprints shows a chronostratigraphic inconsistency in the Araripe Basin's stratigraphic columns and charts, and impacts the tectonic and stratigraphic evolution of other onshore NE Brazilian basins.

## GEOLOGICAL CONTEXT

The lowermost strata of the Araripe Basin are generally considered as belonging to a lower Paleozoic sequence, followed by three Upper Jurassic to Lower Cretaceous sequences known as Pre-Rift, Rift, and Post-Rift (Ponte and Appi, 1990; Assine, 2007; Assine et al., 2014). The full stratigraphic column (Fig. 2) rests in nonconformity on the igneous and metamorphic rocks of the Precambrian Borborema Province (Brito-Neves et al., 2000).

Initially designated as Cariri Formation, of Neocomian age (Beurlen, 1962), it was renamed as Mauriti Formation (Gaspary and Anjos, 1964). It has been interpreted as indicative of an early depositional event – prior to the rifting phases (or sequences) – during the early Paleozoic (ca. Late Ordovician to Early Devonian). This was based on lithological comparisons and lithostratigraphic correlations (Ponte and Appi, 1990; Assine, 1992) with the Serra Grande Group (Parnaíba Basin), and the Tacaratu Formation (Jatobá Basin), despite the fact that itself is devoid of any age assignment by macro- or microfossils. Recent sedimentary provenance approaches based on detrital zircon U-Pb dating, and trace-elements analyses in detrital rutile only point out that the sedimentation of the Mauriti Formation started after the late Cambrian (Cerri et al., 2022). On the other hand, the identification of theropod and possibly ornithopod tracks in the Milagres and Mauriti ichnosites (Carvalho et al., 1995, 2023b) may indicate a Late Jurassic to an Early Cretaceous age for the Mauriti Formation. This lithostratigraphic unit is restricted to the faulted borders of the Araripe Basin, pointing out that the beginning of deposition is restricted to the end of the Mesozoic (viz. Carvalho et al., 1995, 2023b), what is also supported by

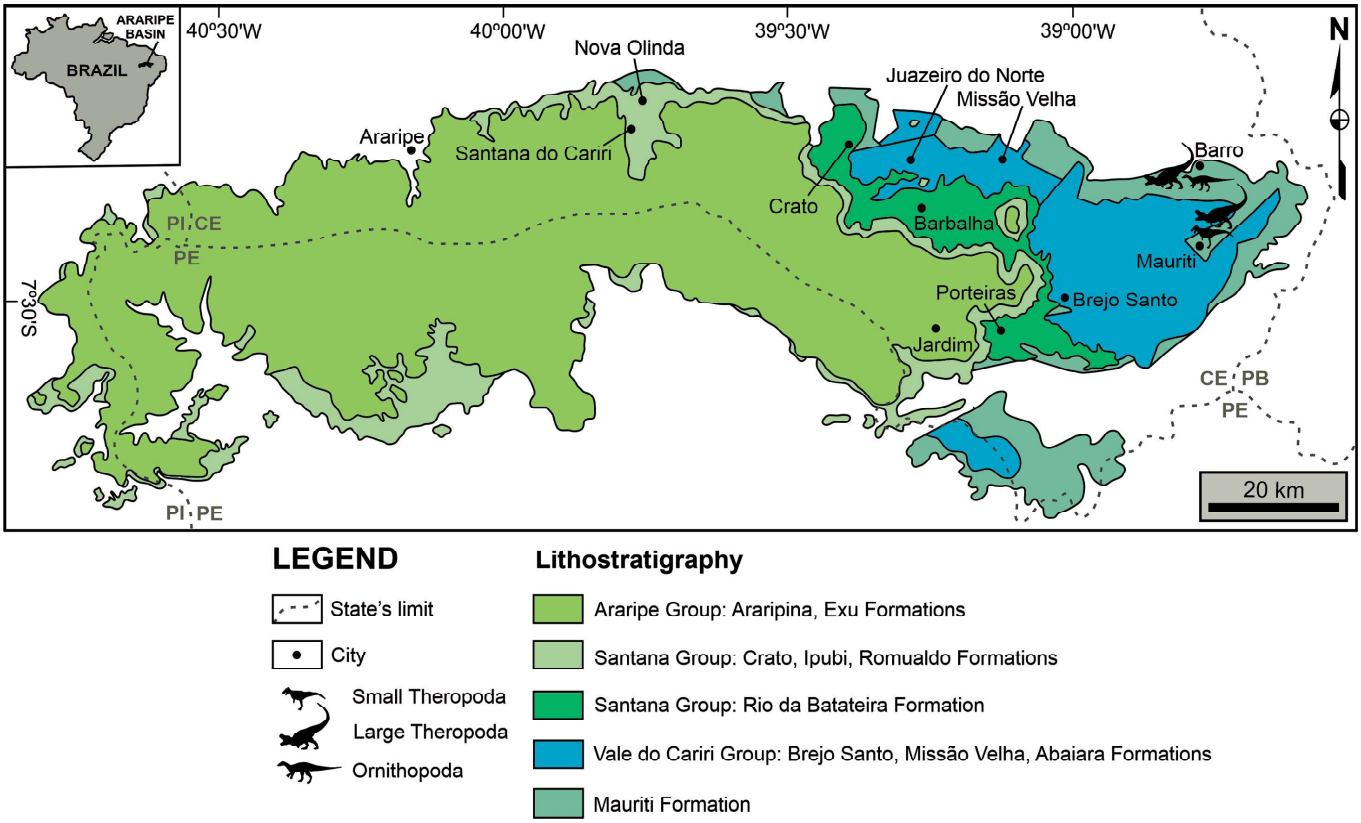


FIGURE 1. Geological map of the Araripe Basin and the location of the dinosaur footprints from the Mauriti ichnosite. Based in Ponte and Appi (1990), Fambrini et al. (2011), Rios-Netto et al. (2012), Assine (2007) and Arai and Assine (2020).

tectonic and sedimentary analyses (Berthou, 1990; Mabesoone, 1990).

The Upper Jurassic Pre-Rift sequence of the Araripe Basin (Assine, 2007; Assine et al., 2014) consists of the Brejo Santo and Missão Velha formations interpreted as alluvial and lacustrine sedimentary systems (Ponte and Appi, 1990; Assine, 1992, 2007; Fambrini et al., 2011, 2013); the following Neocomian Rift sequence (Abaiara Formation) was deposited in shallow lakes and braided channel fluvial plains related to the rifting of Gondwana in the Early Cretaceous (Assine, 1992, 2007). The upper Santana Group (Rio da Batateira, Crato, Ipubi, and Romualdo formations) indicates the beginning of the Aptian Post-Rift sequence (Assine, 2007; Assine et al., 2014), interpreted as deposits of fluvial-lacustrine, deltaic, lacustrine and lagoonal, affected by marine ingressions (Chagas et al., 2007; Neumann and Cabrera, 2002a,b; Neumann et al., 2003; Paula Freitas and Borghi, 2011; Goldberg et al., 2019; Araripe et al., 2021; Lopes and Barreto, 2021; Varejão et al., 2021; Santana et al., 2022; Lemos et al., 2023; Nascimento et al., 2023; Kroth et al., 2021). A late Albian to an early Cenomanian (Early/Late Cretaceous) sedimentation (Araripina and Exu formations) represents the uppermost strata of the Araripe Basin (Assine, 1992, 2007).

## THE MAURITI FORMATION TRACKSITE

Although dinosaur tracks are commonly found in the surrounding basins of Sousa, Uiraúna-Brejo das Freiras, Malhada Vermelha, and Lima Campos, they are still rare in the Araripe Basin (Leonardi, 1994; Leonardi and Spezzamonte, 1994; Carvalho, 2000; Carvalho et al., 2013, 2021a, b, 2022, 2023b). The footprints from the Araripe Basin are found in the Mauriti, Rio da Batateira, Crato, and Exu formations, which were deposited in very distinct temporal, paleobiotic, and paleoenvironmental contexts.

The Mauriti Formation is constituted of conglomerate and pebbly sandstones that grade up to medium- to coarse-grained sandstones, interpreted as a braided fluvial system during a hot and dry climatic context, in which invertebrate and vertebrate trace fossils, the latter such as dinosaur footprints, are found (Ponte and Appi, 1990; Assine, 1992; Carvalho et al., 1995; Batista et al., 2012; Cerri et al., 2022). Footprints were previously identified in the Milagres ichnosite (Milagres County, Ceará State) in a succession of coarse- and fine-grained sandstones (Carvalho et al., 1994). The Milagres ichnosite presents theropod and ornithopod tracks. The theropod tracks are three isolated footprints and a short trackway with three footprints. All of them are tridactyl, mesaxonic, with pointed digits, some of them with claw impressions. The rear borders of the footprints are V-shaped or angular. The footprints are large, ranging from 28-40 cm in length and 20-30 cm in width (Carvalho et al., 1995). Although the footprints from the Milagres ichnosite are certainly older than the Aptian/Albian age, the probable trackmakers are large theropods related to the groups that are already known in the Cretaceous deposits of the Araripe Basin, such as the Spinosauridae (Martill et al., 1996). There is also an isolated footprint, tridactyl and mesaxonic with rounded digit extremities and wide U-shaped hypexes. This footprint is interpreted as produced by an ornithopod trackmaker (Carvalho et al., 1995). Osteological elements of this group are unknown in the Araripe Basin, although tracks are also found in the surrounding Rio do Peixe basins.

The new locality with dinosaur footprints in the Mauriti Formation is the Mauriti ichnosite (Fig. 3), Mauriti county, Ceará State. There are four tridactyl, mesaxonic isolated footprints with pointed (?theropod) and rounded digits (?ornithopod). The other imprints are rounded depressions with no clear digit

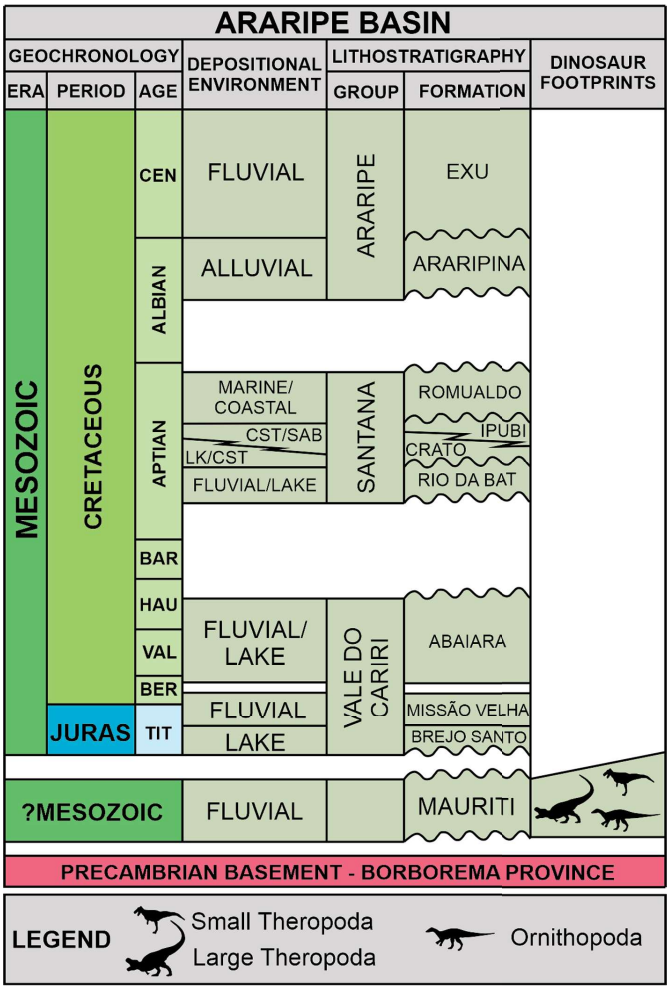


FIGURE 2. Schematic stratigraphic chart of the Araripe Basin and the Mauriti Formation ichnosites. Abbreviations: JURAS: Jurassic; TIT: Tithonian; BER: Berriasian; VAL: Valanginian; HAU: Hauterivian; BAR: Barremian; CEN: Cenomanian; LK: Lake; CST: Coastal environment; SAB: Sabhka; RIO DA BAT: Rio da Batateira Formation. The geochronological data and nomenclature of the lithostratigraphic units were based in Ponte and Appi (1990), Fambrini et al. (2011), Rios-Netto et al. (2012), Assine (2007) and Arai and Assine (2020).

FIGURE 3. Surface of the Mauriti ichnosite of the Mauriti Formation located at Mauriti County, Ceará State.

impressions, surrounded by displacement rims or presenting fluidization features of indeterminate trackmakers (Fig. 4). The partial sandstone filling of the footprints is similar to the surrounding matrix. They range from 30-48 cm in length and 25-48 cm in width. The trackmakers of the tridactyl footprints are bipeds similar to the ones from the Milagres ichnosite (Carvalho et al., 2023b).

## DISCUSSION

The paleoenvironmental interpretation of the Mauriti Formation deposits is coalescent alluvial fans (bajadas) and a braided fluvial with high energy, formed in a hot and more arid climatic context (Ponte and Appi, 1990; Carvalho et al., 1995; Batista et al., 2012). The few isolated footprints and trackways in the Milagres and Mauriti ichnosites may reflect the time between periods of sediment accumulation and the nature of the substrate (Fig. 5). It is possible that the grain size, low water content, and lack of sediment plasticity did not allow the preservation of a large number of footprints, indicating a potential preservation bias (Carvalho et al., 1995).

The Milagres and Mauriti ichnosites (Carvalho et al., 1995, 2023b) present a temporal inconsistency, as the Mauriti Formation is frequently considered part of an Early Paleozoic depositional cycle (Ponte and Appi, 1990; Assine, 1992; 2007; Cerri et al., 2022). The north-west paleocurrents indicates that the main source areas for the Mauriti fluvial system are located in the Transversal and Southern zones of the Borborema Province (Cerri et al., 2022). Meanwhile, the presence of

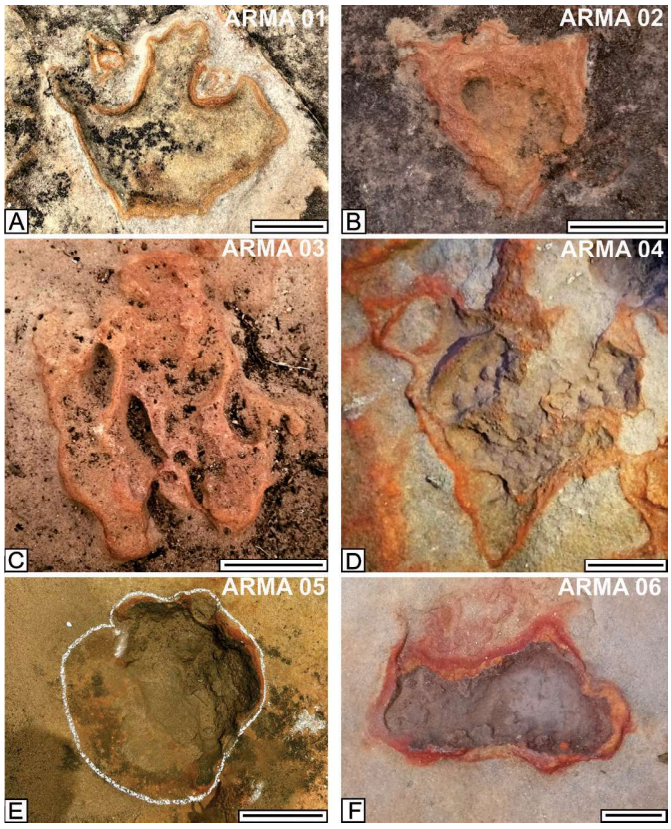


FIGURE 4. Footprints from the Mauriti Formation, Mauriti ichnosite. **A-D,** Isolated footprints of small and large biped dinosaurs (ARMA 01, ARMA 02, ARMA 03, ARMA 04), scale bars 10 cm; **E,** A rounded footprint of indetermined trackmaker, scale bar 10 cm; **F,** irregular outline track? of indetermined trackmaker. The red color surrounding the footprints is related to the sediment permeability to recent fluids. ARMA, abbreviation for Araripe Basin, Mauriti ichnosite.

dinosaur footprints in the Mauriti Formation suggests that it is certainly a Mesozoic unit (Carvalho et al., 1995, 2023b). Due to the geographical proximity with Rio do Peixe basins, that present similar dinosaur tracks, a probable Early Cretaceous age is suggested (Carvalho et al., 2023b).

The importance of these two ichnosites confirms the need to revise the age of the Mauriti Formation and the paleogeographical context of these footprints, establishing a new stratigraphic framework for the lower successions of the Araripe Basin (Carvalho et al., 2023b). If the Cretaceous age, or at least a Mesozoic age is confirmed, the paleogeography of the Mauriti Formation will not be related to the Western Paleozoic Gondwana, as indicated by Cerri et al. (2022), but with the Mesozoic Gondwana supercontinent evolution during the Late Jurassic to the Cretaceous.

## CONCLUSIONS

The dinosaur footprints from Mauriti Formation are chronostratigraphic markers of subaerial exposition surfaces, recording cyclical changes in a braided fluvial environment formed during a hot and arid climate. This environmental context limited the preservation of a larger number of footprints. It is possible that the high energy of the environment context, grain size, low water content, and lack of sediment plasticity did not allow the preservation of a large number of footprints, indicating a potential preservation bias. The importance of the new Mauriti ichnosite (Mauriti County, Ceará State) confirms the presence of dinosaur footprints in deposits previously considered from the early Paleozoic. The footprints reinforce the Mesozoic age for the Mauriti Formation, and a particularly Early Cretaceous time interval similarly to the other tracksites of the neighboring basins.

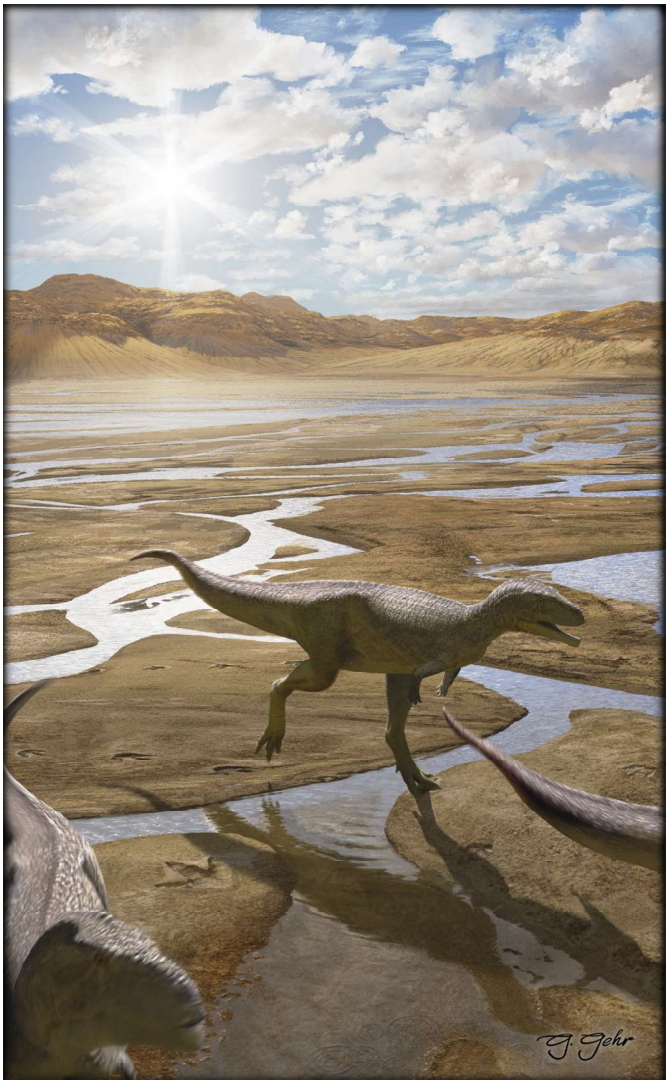


FIGURE 5. Environmental reconstruction of the Mauriti ichnosite and some of the probable trackmakers of the isolated footprints. Art by Guilherme Gher.

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