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Dinosaur Tracks of Mesozoic Basins in Brazil

Impact of Paleoenvironmental and Paleoclimatic Changes

Springer

Chapter 10
New Steps and New Challenges to the Brazilian Dinosaur Track Researches

Ismar de Souza Carvalho and Giuseppe Leonardi

10.1 Introduction

The history of Brazilian dinosaur ichnology begins in 1924 with the description of the first dinosaur footprints from Rio do Peixe Basins. The discovery of the tracks is due the research of Luciano Jacques de Moraes (1896–1968), a Brazilian mining engineer, working for the DNOCS (Departamento de Obras contra as Seccas, the Department of Works against the Drought), surveying the Sousa County, in the Paraíba State, northeast Brazil. Moraes (1924) discovered two dinosaur trackways in the mudstones of the riverbed of Rio do Peixe. Based on these trackways it was possible the first approach of the age (Comanchean, Lower Cretaceous) of the mudstone succession, an important datum to the understanding of the geological framework of the basins. These tracks were not further studied or published, except for a brief mentions (Price 1961; Cavalcanti 1947; Haubold 1971). Giuseppe Leonardi, from December 1975, began a series of thirty-three expeditions to the Rio do Peixe basins (1975–2016) and Ismar de Souza Carvalho, over the last twenty-seven years (from April 1986) with informal groups of researchers, undergraduate and graduate training programs periodically visited the ichnosites of these basins, twice a year, to study the dinosaur tracks. The result has been a great number of studies concerning the research on dinosaur ichnology and the creation of a natural park of the "Dinosaur Valley"

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(Leonardi and Carvalho 2021). Marcelo A. Fernandes and Luciana B. R. Fernandes collected the Botucatu flagstones with ichnofossils establishing one of the largest collections of fossil footprints in Latin America. In 2006, these were incorporated into the institutional collection of the Federal University of São Carlos, enabling the formation of two local museums.

Many other ichnosites were searched for and discovered since then, especially in the Paraná Basin. In the Triassic successions of Rio Grande do Sul State were revealed many of the oldest dinosaur tracks of the world (Silva et al. 2007a, b, 2008, 2012). In the Jurassic and Cretaceous fluvial and aeolian deposits of the Guará and Botucatu formations a great diversity of new specimens was discovered (Francischini et al. 2015, 2020; Fernandes and Carvalho 2007; Leonardi 1994).

10.2 A Footprint in the Past and a Step into the Future

The discovery of a new tracksite is mainly based on the detail observation of natural and artificial outcrops on river banks and dry beds, cliffs, mountain ranges, road pavements, rail-road outcrops and quarries, mines and tunnels. The description, illustration and interpretation of the footprints and trackways changed through time due the new technologies and the comprehension of the importance of their sedimentological and stratigraphic context.

The historical methods of field and laboratory research can sometimes be considered vintage. Nonetheless the mapping of the footprints using compass, metric tape, and strings with the gridded quadrant system and graph paper (Leonardi 1977) or the direct reproduction on PVC sheets are very efficient and allow an excellent approach of the distribution and spatial position of the footprints in the outcrops. Other methodologies, especially concerning the photographic reproduction using individual printed photographs to be later associated manually in a photomosaic is completely outdated due the facilities of the digital cameras and programs for merging photographs (Falkingham et al. 2014b).

After mapping all the footprints they are manually drawn at a small scale, with numberless measurements, for statistical analyses. Although these data can be questioned due the subjectivity of landmarks in footprints, the traditional measurements can yield useful results (Leonardi 1991; Farlow 2018). Despite the correct interpretation of a footprint or trackway is always a complex task, the understanding of these facts is a step forward in their correct understanding (Falkingham et al. 2016a, b).

10.3 New Technologies and New Challenges

Techniques using laser scanning permit imaging with higher detail and precision the shape and position of the footprints, producing digital rock outcrops that can be used to compare with other outcrops and preserved for future studies (Medeiros et al.

2007; Romilio et al. 2017; Leonardi and Carvalho 2021). Also the use of drones (Romilio et al. 2017; Xing et al. 2018; Petti et al. 2018) permit to cover in detail large areas and steep cliffs.

Other important point is the use of the 3D photogrammetry techniques to produce the topographic images allowing a more precise delimitation of the contours and perception of the footprints morphology. The 3D photogrammetry uses softwares to combine multiple photos of an object taken from different directions and angles into one 3D digital model of that object (Vitkus et al. 2023). This technique should be used in the description of the new localities with dinosaur footprints and also as a tool of geoheritage preservation to the known ichnosites.

All new digital technologies of photography and surveying, by means of manned or unmanned aircrafts (today especially by drones), although extremely valuable, do not exempt us from the field work. The preliminary study of geological maps and previous studies to locate the most favorable areas to specific research, the accurate examination of outcrops are essential to the success of new discoveries. This is also the case when the fossil footprints are, as is often the case, on inclined or even vertical rocky walls, on the roofs of mines or tunnels (Staines and Woods 1964; Meyer et al. 1999; Moreau et al. 2020; Belvedere et al. 2008), generally on places of difficult access. Experience has shown that publications of ichnologic material made solely on the basis of photographs taken by others or from far away, almost always lead to make gross mistakes.

10.4 Looking Forward

The ichnotaxonomy presents many problems concerning the trackmakers behavior and the substrate physical properties. Therefore, a prudent and limited use of ichnotaxonomy is recommended, that is, it is advisable to establish new taxa names for new kinds of fossil footprints, only after statistical analysis (Belvedere et al. 2018; Belvedere and Farlow 2016) and only in the case that such tracks have a good or excellent state of impression and morphological preservation (Falkingham et al. 2014a, b; Marchetti et al. 2019; Razzolini et al. 2014, 2016). It should also be avoided to establish new taxa for isolated footprints, even if of excellent quality of preservation. It is therefore suggested to reserve the establishment of new taxa for trackways of at least three footprints (or pairs of footprints) in sequence, including the trackway parameters in the diagnosis. This allows a better understanding of the trackmaker. The methods of geometric morphometric analysis for the dinosaurian ichnodiversity (Castanera et al. 2015, 2018) and trackmakers' behavioral patterns (Citton et al. 2017) should be tested in the Brazilian ichnosites. It is of special importance to follow the standard protocol on these issues put forward by Falkingham et al. (2018).

Other aspect to be evaluated is the land-vertebrate ichnofacies (Lockley 2007; Lockley et al. 1994, 2007; Meyer et al. 1999) and the stratigraphic correlation of distinct outcrops in a same basin or neighboring basins, to apply the concept of megatracksites established by Lockley and Meyer (2023) or as a tool of stratigraphic correlation (Carvalho et al. 2019).

The perspectives in studying the Brazilian fossil tracks include new methods for the documentation, such as laser scanning, aerial and close-range photogrammetry, three-dimensional (3-D) models and biplanar X-ray 3-D motion analysis (Belvedere et al. 2012; Breithaupt and Matthews 2012; Petti et al. 2018; Costa-Pérez et al. 2019; Gatesy and Ellis 2012, 2016; Matthews et al. 2016; Romilio et al. 2017; Wings et al. 2016; Leonardi and Carvalho 2021). It is also important petrographic studies and clay mineral analysis of the matrix where the footprints occur. The petrography will allow recognizing the role of microbial mats in the preservation (Carvalho et al. 2013), and the clay mineral analyses (Dai et al. 2022; Rodrigues et al. 2023), the influence of the clay mineralogy in the morphological pattern of the footprints and paleoenvironmental interpretation.

The experimental analysis (Falkingham and Gatesy 2014; Falkingham et al. 2010; Gatesy and Ellis 2016; Marty 2005, 2012; Marty et al. 2009) are important methods to evaluate the relationships between the physical properties of the substrate, the behavior of the trackmakers and the induced morphological patterns. Previous studies on experimental analysis should be considered in any new analysis of the Brazilian dinosaur footprints. Besides the control of the geological context of the occurrences, the observation of the recent tracks can be very useful to comparisons to the paleoenvironmental interpretations (Carvalho and Leonardi 2021).

The use of AI (Artificial Intelligence) opens new perspectives to ichnology concerning a faster and detailed classification of the footprints. An example of this potential was presented by Ha and Kim (2023) to validate ichnotaxa, employing convolutional neural network-based Xception transfer Learning. This technique allowed to automatically classify ornithopod dinosaur tracks. These machine-learning techniques open new perspectives to verify the ichnotaxonomic assignments and to compare a great number of samples, with the establishment of a global relationship of the ichnofaunas.

A challenge to the future is the in situ and ex situ preservation of trackways and fossil footprints. The in situ preservation is always subject to vandalism, erosion, weathering and limitations to urban expansion. In tropical environments the vegetal covering and weathering induces a great impact in the aspects of the bedding planes with footprints just after few years. The wearing of the surface, chemical weathering and cracking are recurrent aspects that lead to the destruction of the footprints. The employ of airborne and handheld high-resolution LIDAR (light + radar, an acronym for light detection and ranging) for characterization and conservation of fossil tracks (Platt et al. 2018) could be very useful as a tool to the control of natural and anthropogenic destruction of outcrops with footprints. On the other hand, the ex situ preservation in museums, universities, research centers and open air are also difficult. The dimensions, weight and friability of the samples with trackways and footprints are a problem to handle and to house adequately in the paleontological collections (Carvalho 2004). The open-air exhibition in an urban environment, as in the sidewalks of the Araraquara or in São Carlos cities (São Paulo State, Brazil) are also a challenge to preservation as a geoheritage, with the addition of abrasion by the shoes of the passers-by (Francischini et al. 2020). Although they show a great potential for education, these flagstones are exposed to the same damages of the in situ trackways and fossil footprints found in the outcrops.

Another dare is to improve the interest of the "pure" geologists (stratigraphers, tectonists, geophysicists), who normally do not deal with paleontological data, especially in the results of vertebrate ichnology. It is important to present the information and interpretation obtained from the ichnological studies as a scientific data to the increase of the geological knowledge of a region, instead of objects of curiosity.

In the perspective of ichnology popularization, the use of smartphones and tablets to apply augmented reality is a powerful tool for instruction. The possibility to connect the real surfaces with fossil tracks and the reconstruction of life sceneries of the trackmakers has a great educational potential. Other strategies to the dissemination of the dinosaur tracks information from Brazil should include the artificial intelligence, an important new approach to the science vulgarization.

10.5 New Perspectives for Field Exploration in Brazil

Brazil is a sub-continental country, with its 8,510,000 km^2 of area, greater than the area of Europe with the exclusion of European Russia (6,031,000 km^2), little less than that of the United States of America (9,834,000 km^2) and Canada (9,985,000 km^2); and greater than the area of Australia (7,688,000 km^2). Field research often still takes place, in Brazil, in physical environments that are difficult to reach and explore. Several sedimentary basins remain to be partially explored and others totally.

As a result, there are many sedimentary basins whose exploration needs to be increased and/or improved. However, it should also be remembered that, especially in the most densely populated areas, most fossils in general and especially fossil tracks have appeared as secondary products of excavations: for tunnels, mines, highway and rail-road cuts, quarries, building and bridge foundations, water wells, and canals. In Brazil, the complex of Amazonian basins (Acre, Solimões, Alto Tapajós, Amazonas and Marajó, and minor ones) has only been touched, under the aspect of the vertebrate ichnology, with some results in the Tacutu Basin (Barros et al. 2023, 2024a, b, c) and at the margins of the Marajó Basin (Ferreira et al. 1979). There is an immense area to be explored, although the wilderness environments make searching difficult.

The large Parnaíba Basin has a similar situation. Only three ichnosites have been reported: São Domingos of Itaguatins, in the Tocantins State (Leonardi 1980, 1994; De Valais et al. 2015), Fortaleza dos Nogueira locality (Assis et al. 2010) and a site along the Itapecuru river, in the Maranhão State (Menezes et al. 2019). Other large areas have been visited by ichnologists, but the results for now are limited to this, and there is much opportunities for further research. The Paraná Basin has been much more systematically visited, with remarkable results, but there are still good chances of new discoveries.

The Northeastern interior basins, intensely explored by ichnologists, should be periodically revisited, since erosion can highlight new outcrops of layers with fossil footprints. In the basins of the Rio do Peixe, remains to visit the westernmost part of the basin of Sousa, and the northern border of the Triunfo Basin.

All these perspectives are important tasks to the development of the vertebrate ichnology in Brazil. However, there is an unsolved question in the Brazilian paleontological studies that is the recognition and value of the "invisibles of science" as defined by Carvalho and Leonardi (2022). The Brazilian paleontologists cannot continue to be blind about the imperative importance to be aware of the native, enslaved, riverside populations, workers operating in mines and quarries, the population of the villages where fossils are found, field or laboratory assistants who have volunteered or contractually contributed to the assistance of scientists. Their importance should be recognized as relevant to the advancement of knowledge of the science of fossils.

10.6 Conclusion

The fossil footprints should be analyzed in their stratigraphic context and new technical procedures are needed to represent them in the outcrops, including 3D photogrammetry and laser scanning techniques, to their representation in the outcrops. They should be studied neither just like isolated biogenic structures nor just as a record of the passage of individual dinosaurs but rather as populations and associations in their whole paleobiological, sedimentological, and stratigraphic settings. This will allow a better use of them in paleoenvironmental, paleoclimatological, and paleogeographical interpretations. Other important point is to develop new strategies for the geoheritage conservation, including ex situ and in situ conditions. A good strategy is the diffusion of the scientific knowledge through formal and non-formal education.

The new challenges also include the searching for, the discovery and the preservation of outcrops before they disappear due the urban expansion and changes in the mining or quarrying techniques, that nowadays are no more a manual rock extraction. The in situ or ex situ preservation of the dinosaur footprints is certainly the great challenge to the future of this Brazilian geoheritage.

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