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BOOK REVIEW

Dinosaur tracks: the next steps, Edited by Falkingham P.L., Marty D., & Richter A., 2016. Indiana University Press, Bloomington & Indianapolis, 428 p./ISBN 978-0-253-02102-1

Matteo Belvedere[1]

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Vertebrate ichnology is one of the oldest disciplines of paleontology. For many years, it was considered less important than the study of bone remains, even though tracks and traces are the only in situ and in vivo evidence of a fossil animal, and therefore, they provide an important key for understanding extinct animal behavior. Vertebrate ichnology, and in particular dinosaur ichnology, underwent in the last two decades an important renaissance (Lockley 1991, 1998; Lockley and Gillette 1987), that has raised its importance and recognition as a distinct field of research within vertebrate paleontology. Dinosaur ichnologists are abandoning the purely qualitative description of tracks and ichnotaxonomical naming that characterized the discipline some decades ago, and they are moving forward towards a more multidisciplinary approach, integrating knowledge from sedimentology, stratigraphy, biomechanics, and other biological and geological disciplines. However, it has only been in the last decade that dinosaur ichnology really moved away from its qualitative status, through a deep methodological improvement, both in data acquisition and in quantitative data interpretation. The use of up-to-date digitization techniques (e.g., Bates et al. 2008; Petti et al. 2008), combined with a more extensive use of geometric morphometrics (Rodrigues and Santos 2004; Castanera et al. 2015; Lallensack et al. 2016) and other quantitative approaches (Razzolini et al. 2014) are driving the fast development of a quantitative vertebrate ichnology. In 2011, a dinosaur track symposium was held in Obernkirchen (Germany), and during this symposium, the idea was grown to create a reference book reviewing the recent advances made in vertebrate and notably dinosaur ichnology.

Dinosaur tracks: the next steps proposes to review and update the state-of-the-art of dinosaur ichnology, discussing and applying the most recent advances in the discipline. It has 20 chapters, divided into three main sections: (1) "approaches and techniques"; (2) "interpreting paleobiology and evolution from tracks"; and (3) "ichnotaxonomy and morphological diversity".

The first theme gathers papers on the state-of-the-art methodologies and their application: Milàn and Falkingham describe how experimental and computational and comparative ichnology are important for the development of paleoichnology and the improvement in understanding extinct animals' locomotion behavior. Matthews, Noble, and Breithaupt review the history of photogrammetry and its application to vertebrate ichnology, from the first test in the 90s to the latest application, providing also an important and updated overview on the best practice on ichnological applications. Wings, Lallensack, and Mallison use 3D photogrammetric models for geometric morphometric analysis of shape variation of Early cretaceous dinosaur tracks from Münchenhagen (Germany), highlighting the high similarity between the true tracks and their natural infilling, the possibility to evaluate the erosion rate as well as the minimum thickness of the trampled layer. Falkingham faces a key issue in vertebrate ichnology, the reliability of outline drawings, concluding that, even when generated from 3D models, there is no objective outline and suggests that a maximum and minimum outline should be produced to validate outline-based analyses. Gatesy and Ellis offer an alternative view on track formation and on its morphology through particle-based experiments, providing examples from the fossil record to illustrate how such an approach can be a valuable supplement to understanding the origin of track morphology. Belvedere and Farlow propose a numerical scale to quantify the morphological preservation grade of tracks, based on the occurrence or

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✉ Matteo Belvedere
matteo.belvedere@hotmail.com

[1] Section d'archéologie et paléontologie, Paléontologie A16, Office de la Culture, Hôtel des Halles, P.O. Box 64, 2900 Porrentruy 2, Switzerland

lack of morphological details in the track, with the aim to help ichnologists to use only the tracks with the best preservation grades for taxonomical purposes. Finally, Alcalá and colleagues propose an integrated approach to evaluate the regional and global distribution of tracksites, together with their scientific importance, and preservation strategies providing a table to evaluate the scientific, cultural and management values for a tracksite.

The second part of the volume, "Paleobiology and Evolution from Tracks", begins with the contribution of Castanera and colleagues on the variation of sauropod pes and manus track morphology in the Iberian Peninsula from Middle Jurassic to Late Cretaceous showing a higher differentiation of manus tracks than pes impressions. Hall, Fragomeni and Farlow use sauropod tracks to test the functional hypothesis of use of sauropod pedal ungual flexion to increase the grip on the substrate: while there is no evidence to support the traction control function of the unguals, there is some support to a scratch-digging nest-excavation digging function. Milner and Lockley examine the characteristics, context and ichnofacies implications of dinosaur swimming tracks assemblages, pointing out their importance to indicate which groups of aquatic and non-aquatic tetrapods where coexisting in the same paleoenvironment, and, therefore, to create distinct ichnofacies. Hornung and colleagues apply a morphometric approach to the iguanodontian track assemblages from the Barresian of Germany, concluding that ichnotaxonomic separation should be based on qualitative rather than quantitative characters. Their method is promising to evaluate variation in data sets, pending further refinements. Stevens, Scott, and Marty explore the uncertainty and ambiguity in the interpretation of sauropod trackways, through computational simulations and the use of Cadence, a passive solver tool that permit exploring the trackmaker–trackway relationships with a gradual (from general to specific) approach. Cobos and colleagues look at dinosaur tracks as a "four-dimensional phenomenon" with the aim of revealing how different species moved; they study the kinematic indicators of different dinosaur tracks and their correlation with locomotion models.

The "Ichnotaxonomy and Trackmaker identification" part of the book opens with an extensive chapter by Buckley, McCrea, and Lockley using multivariate statistical analyses to resolve the Cretaceous avian ichnotaxonomy. Although not definitive, the analyses demonstrate the strong statistical support of the valid Mesozoic avian ichnotaxa, despite their erection on a mostly qualitative base. Hübner investigates elusive ornithischian tracks form the Barresian "chicken yard" tracksite of Northern Germany, that differ from other small theropod tracks because of their higher symmetry, absence of claw marks and consistent posterior metatarsal border. Richter and Böhme face the description and interpretation of the very diverse and heavily dinoturbated Early Cretaceous "Chicken Yard" tracksite, highlighting the problems and possible solutions when dealing with densely trampled surfaces and very diverse types of tracks. Loope and Milàn provide insights in the track formation, walking kinematics and trackmaker behavior based on dinosaur tracks left in eolian strata. Tracks are often the only evidence of the fauna of eolian environments and the layer-by-layer analysis allows detailed insights in the foot/sediment interactions. Schanz and colleagues present a conceptual approach to interpret fossil track environments through a soil-mechanics-based interpretation of desiccation cracks: experimental investigations and numerical simulation were used to infer subsoil properties and boundary conditions for track formation. D'Orazi Porchetti and colleagues provide a thorough review of the dinosaur track record from Jurassic and Cretaceous shallow marine carbonate depositional environments in the form of a detailed database. Finally, Marty, Falkingham, and Richter provide an updated glossary for dinosaur track terminology, trying to solve the inconsistent and ambiguous use of ichnological terms.

This book clearly expresses the complexity and diversity of dinosaur ichnological studies, and how this field is living a deep renovation, towards a more, but not exclusive, quantitative approach, and towards a more and more interdisciplinary attitude. The picture of dinosaur ichnology given by this book is that of a very lively field, which can provide, even more than in the past, important contribution of dinosaur palaeobiology. Dinosaur tracks: the next steps is a benchmark and a must-have for all researchers working on dinosaur tracks and on dinosaurs in general.

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