

Bird-like tracks from the Imilchil formation (Middle Jurassic, Bajocian-Bathonian) of the Central High Atlas, Morocco, in comparison with similar Mesozoic tridactylous ichnotaxa

Gierliński G., Lagnaoui A., Klein H., Saber H., Oukassou M., Charrière A.
Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

© 2017, Mucchi Editori s.r.l. All rights reserved. Small bird-like tracks have recently been discovered at three outcrops of the Imilchil Formation (Middle Jurassic, Bajocian-Bathonian) in the Central High Atlas of Morocco. The track-bearing strata are part of a marine-continental transitional succession, the studied surfaces being sandy marls and limestones of a brackish depositional environment. The footprints strongly resemble the ichnogenus *Trisauropodiscus* Ellenberger, 1970, from the Lower Elliot Formation (latest Triassic) of Lesotho, southern Africa and are assigned to *Trisauropodiscus* sp. These are functionally tridactyl, widely divaricated pes tracks with digit III being longest and a trace of the reverted digit I (hallux) being occasionally imprinted. In contrast to some former studies suggesting *Trisauropodiscus* as a junior synonym and extramorphological variation of the ornithischian ichnogenus *Anomoepus*, this ichnotaxon is considered here as a distinctive morphotype among similar theropod tracks found in Jurassic-Cretaceous ichnoassemblages. An amended diagnosis is proposed focusing on the features that are here discussed and considered as key characters of this ichnotaxon. An avian interpretation of the trackmaker is problematical, especially against the background of the stratigraphic range of *Trisauropodiscus* back to the Late Triassic. Presently, theropods with very bird-like feet are the more likely producers. Future analyses and comparison of *Trisauropodiscus* with pes skeletons of avian and non-avian theropods might enlighten this.

<http://dx.doi.org/10.4435/BSPI.2017.19>

Keywords

Bird-like tracks, *Carmelopodus*, Middle Jurassic, Morocco, Ornithomimipodidae, *Trisauropodiscus*

References

- [1] Abrahams M., Bordy E.M., Sciscio L. & Knoll F. (2017). Scampering, trotting, walking tridactyl bipedal dinosaurs in southern Africa: ichnological account of a Lower Jurassic palaeosurface (upper Elliot Formation, Roma Valley). *Historical Biology*, 29: 958-975.
- [2] Belvedere M., Dyke G., Hadri M. & Ishigaki S. (2011). The oldest evidence for birds in Northern Gondwana? Small tridactyl footprints from the Middle Jurassic of Msemrir (Morocco). *Gondwana Research*, 19: 542-549.
- [3] Bonaparte J.F. (1991). Los vertebrados fósiles de la Formación Rio Colorado, de la Ciudad de Neuquén y Cercanías, Cretácico Superior, Argentina. *Revista del Museo Argentino de Ciencias Naturales "Bernardino Rivadavia"* e Instituto Nacional de Investigación de las Ciencias Naturales. *Paleontología*, 4: 17-123

- [4] Bouchouata A., Canérot J., Souhel A. & Gharib A. (1995). Stratigraphie séquentielle et évolution géodynamique du Jurassique de la région Talmest-Tazoult (Haut Atlas central, Maroc). *Comptes Rendus de l'Académie des Sciences, Paris Série II*, 320: 749-756.
- [5] Calvo J.O. (1991). Huellas fosiles de dinosaurios en la Formacion Rio Liis (Albiano-Cenomaniano), Pictin Lcufki, Provincia del Neuquen, Argentina. (*Ornithischia-Saurischia: Sauropoda-Teropoda*). *Ameghiniana*, 28: 241-258.
- [6] Calvo J.O. (2007). Ichnology. In Gasparini Z., Salgado L. & Coria R.A. (eds), *Patagonian Mesozoic Reptiles*. Indiana University Press, Bloomington: 314-334.
- [7] Ellenberger P. (1970). Les niveaux paléontologiques de première apparition des mammifères primordiaux en Afrique du sud et leur ichnologie. Etablissement de zones stratigraphiques détaillées dans le Stormberg du Lesotho (Afrique du Sud) (Trias supérieur à Jurassique). *Second Gondwana Symposium, Proceedings and Papers*. Council for Scientific and Industrial Research, Pretoria: 343-370.
- [8] Ellenberger P. (1972). Contribution à la classification des pistes de vertèbres du Trias: les types du Stormberg d'Afrique du Sud (I): Palaeovertebrata, *Mémoire Extraordinaire*: 1-111
- [9] Ellenberger P. (1974). Contribution a la classification des Pistes de Vertèbres du Trias: les types du Stromberg d'Afrique du Sud (II): Paleovertebrata, *Memoire Extraordinaire*: 1-201.
- [10] Ettaki M., Ibouh H., Chellai E.H. & Milhi A. (2007). Les structures « diapiriques » liasiques du Haut-Atlas central Maroc: exemple de la ride d'Ikerzi. *Africa Geoscience Review*, 14: 73-99.
- [11] Fiorillo A.R., Hasiotis S.T., Kobayashi Y., Breithaupt B.H. & McCarthy P.J. (2011). Bird tracks for the Upper Cretaceous Cantwell Formation of Denali National Park, Alaska, USA: a new perspective on ancient polar vertebrate biodiversity. *Journal of Systematic Palaeontology*, 9: 33-49.
- [12] Frizon de Lamotte D., Zizi M., Missenard Y., Hafid M., El Azzouzi M., Maury R.C., Charrière A., Taki Z., Benammi M. & Michard A. (2008). Chapter 4. The Atlas System. In Michard A., Saddiqi O., Chalouan A. & Frizon de Lamotte D. (eds), *Continental evolution: The Geology of Morocco*. *Lecture Notes Earth Sciences*: 1-116.
- [13] Gabunija Gabuniya L.K. (1951). On the tracks of dinosaurs from the Lower Cretaceous deposits of Western Georgia. *Proceedings of the USSR Academy of Science*, 81: 917-919 [in Russian]
- [14] Gierliński G.D. (1991). New dinosaur ichnotaxa from the Early Jurassic of the Holy Cross Mountains, Poland. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 85: 137-148.
- [15] Gierliński G.D. (1996). Avian theropod tracks from the Early Jurassic strata of Poland. *Zubia*, 14: 79-87.
- [16] Gierliński G. (2000). Feather and avian origin in the light of ichnological data. *Vertebrata Palasiatica*, suppl. to vol. 38: 13
- [17] Gierliński G.D. (2016). Middle Jurassic avialan footprints from Imilchil in Morocco. In Baucon A., Neto de Carvalho C. & Rodrigues J. (eds), *Ichnia 2016: abstract book*. UNESCO Geopark Naturtejo/International Ichnological Association, Castelo Branco: 98-99.
- [18] Gierlinski G.D., Klein H., Lagnaoui A., Saber H., Oukassou M., Charrière A. & Adach L.A. (2017). Mid-Cretaceous dinosaur track assemblage from the High Moulouya region of Morocco. In Gierlinski G.D., Lockley M.G. & Milner A.R.C. (eds), *Abstract Book, Utah Friends of Paleontology Symposium and Annual Meeting, April 28-30th 2017*: 15-17.
- [19] Gierliński G.D. & Lockley M. (2013). A trackmaker for *Saurexallopus*: Ichnological evidence for oviraptorosaurian tracks from the Upper Cretaceous of western North America. In Titus A. & Loewen M.A. (eds), *At the top of Grand Staircase: The Late Cretaceous of southern Utah*, Indiana University Press, Bloomington: 526-529.
- [20] Gierlinski G.D., Menducki P., Janiszewska K., Wicik I. & Boczarowski A. (2009). A preliminary report on dinosaur track assemblages from the Middle Jurassic of the Imilchil area, Morocco. *Geological Quarterly*, 53: 477-482.
- [21] Gierliński G. & Sabath K. (1998). Protoavian affinity of *Plesiornis* trackmaker. *Journal of Vertebrate Paleontology*, 18, suppl. To no. 3: 46A.
- [22] Godefroit P., Cau A., Dong-Yu H., Escuillie F., Wenhao W. & Dyke G.J. (2013). A Jurassic avialan dinosaur from China resolves the early phylogenetic history of birds. *Nature*, 498: 359-362
- [23] Harris J.D. (1997). Four-toed theropod footprints and a paleomagnetic age from the Whetstone Falls Member of the Harebell Formation (upper Cretaceous: Maastrichtian), northwestern Wyoming: a correction. *Cretaceous Research*, 18: 139.
- [24] Haubold H. (1971). *Ichnia Amphibiorum et Reptiliorum fossilium*. *Encyclopedia of Paleoherpptology*, 18: 1-124.
- [25] Hitchcock E. (1848). An attempt to discriminate and describe the animals that made the fossil footmarks of the United States, and especially New England. *Memoirs of the American Academy of Arts and Science*, 3: 129-256.
- [26] Hitchcock E. (1858). *Ichnology of New England. A Report on the Sandstone of the Connecticut Valley, especially its fossil footmarks*. 220 pp. William White, Boston.
- [27] Ibouh H. (1995). Tectonique en décrochement et intrusions magmatiques au Jurassique; tectogenèse polyphasée des rides jurassiques d'Imilchil (Haut Atlas central, Maroc). 225 pp. Thèse 3ème cycle. Université Marrakech, Maroc (on deposit Société Géologique de France).

- [28] Ibouh H. (2004). Du rift avorté au bassin sur décrochement, contrôles tectonique et sédimentaire pendant le Jurassique (Haut Atlas central, Maroc). 224 pp. Thèse d'Etat. Université de Marrakech, Maroc. (on deposit Société Géologique de France)
- [29] Kim J.Y., Lockley M.G., Seo S.J., Kim K.S., Kim S.H. & Baek K.S. (2012). A paradise of Mesozoic birds: the world's richest and most diverse Cretaceous bird track assemblage from the Early Cretaceous Haman Formation of the Gajin tracksite, Jinju, Korea. *Ichnos*, 19: 28-42.
- [30] Knoll, F. (2004). Review of the tetrapod fauna of the "Lower Stormberg Group" of the main Karoo Basin (southern Africa): implication for the age of the Lower Elliot Formation. *Bulletin de la Société Géologique de France*, 175: 73-83.
- [31] Lagnaoui A., Oukassou M., Charrière A. & Ibouh H. (2016). Sountate Geosite (Imilchil District, High Atlas, Morocco): an exceptional Jurassic palaeontological heritage threatened by local population activity and natural erosion. Sixième Rencontre Internationale sur la Valorisation et la Protection du Patrimoine Paléontologique, November 8-10, Casablanca, Morocco: 51-52.
- [32] Lee Y.N. (1997). Bird and dinosaur footprints in the Woodbine Formation (Cenomanian), Texas. *Cretaceous Research*, 18: 849-864.
- [33] Leonardi G. (1987). Glossary and manual of tetrapod footprint palaeoichnology. 117 pp. Ministerio das Minas e Energia, Departamento Nacional da Producao Mineral, Brasilia
- [34] Li J.J., Lockley M.G., Zhang Y.G., Hu S.M., Matsukawa M. & Bai Z.Q. (2012). An important ornithischian tracksite in the Early Jurassic of the Shenmu Region, Shaanxi, China. *Acta Geologica Sinica*, 86: 1-10.
- [35] Lockley M.G. (1999). Pterosaur and bird tracks from a new Late Cretaceous locality in Utah. In Gillette D.D. (ed.), *Vertebrate Paleontology in Utah*. Utah Geological Survey, Miscellaneous Publications, 99: 355-359.
- [36] Lockley M.G., Cart K., Martin J. & Milner A. (2011). New theropod tracksites from the Upper Cretaceous "Mesaverde" Group, western Colorado: implications for ornithomimosaur track morphology. *New Mexico Museum of Natural History Bulletin*, 53: 321-329.
- [37] Lockley M.G. & Gierlinski G.D. (2006). Diverse vertebrate ichnofaunas containing *Anomoepus* and other unusual trace fossils from the Lower Jurassic of the western United States: implications for paleoecology palichnostratigraphy. In Harris J.D., Lucas S.G., Spielmann J.A., Lockley M.G., Milner A.R.C. & Kirkland J.I. (eds), *The Triassic-Jurassic Terrestrial Transition*. New Mexico Museum of Natural History and Science Bulletin, 37: 176-191.
- [38] Lockley M.G., Gierliński G.D., Houck K., Lim J.D., Kim K.S., Kim D-Y., Kim T.K., Kang S.H., Hunt Foster R., Li R., Chesser C., Gay R., Dubicka Z., Cart K. & Wright C. (2014). New excavations at the Mill Canyon Dinosaur Tracksite (Cedar Mountain Formation, Lower Cretaceous) of eastern Utah. *New Mexico Museum of Natural History and Science Bulletin*, 62: 287-300.
- [39] Lockley M.G. & Harris J. (2010). On the trail of early birds: A review of the fossil footprint record of avian morphological evolution and behavior. *Trends in Ornithological Research*, Novapublishers, Hauppauge:1-63.
- [40] Lockley M.G., Hunt A P., Paquette M., Bilbey S-A. & Hamblin A. (1998). Dinosaur tracks from the Carmel Formation, northeastern Utah: Implications for Middle Jurassic paleoecology. *Ichnos*, 5: 255-267.
- [41] Lockley M.G., Matsukawa M., Ohira H., Li J.J., Wright J., White D. & Chen P.-J. (2006). Bird tracks from Liaoning Province, China: new insights into avian evolution during the Jurassic-Cretaceous transition. *Cretaceous Research*, 27: 33-43.
- [42] Lockley M.G. & Rainforth E. (2002). The tracks record of Mesozoic Birds and Pterosaurs: An ichnological and paleoecological perspective. In Chiappe L. & Witmer L.M. (eds), *Mesozoic Birds Above the Heads of Dinosaurs*. University of California Press: 405-418.
- [43] Lockley M.G., Yang S.Y., Matsukawa M., Fleming F. & Lim S.K. (1992). The track record of Mesozoic birds: evidence and implications. *Philosophical Transactions of the Royal Society of London, Series B*, 336: 113-134.
- [44] Marsh O.C. (1881). Principal characters of American Jurassic dinosaurs. Part V. *American Journal of Science*, 21: 417-423
- [45] McCrea R.T., Buckley L.G., Guy Plint A., Currie P.J., Haggart J.W., Helm C.W. & Pemberton S.G. (2014). A review of vertebrate track-bearing formations from the Mesozoic and earliest Cenozoic of western Canada with the description of a new theropod ichnospecies and reassignment of an avian ichnogenus. *New Mexico Museum of Natural History and Science, Bulletin*, 62: 5-94.
- [46] Von Meyer H. (1861). *Archaeopteryx lithographica* (Vogel-Feder) und *Pterodactylus* von Solenhofen. *Neues Jahrbuch für Mineralogie, Geognosie, Geologie und Petrefakten-Kunde*, 1861: 678-679.
- [47] Michard A., Ibouh H. & Charrière A. (2011). Syncline-topped anticlinal ridges (STARs) from the High Atlas: a Moroccan conundrum, and inspiring structures from the Syrian Arc, Israel. *Terra Nova*, 23: 314-323.
- [48] Nicosia U., Petti F.M., Perugini G., D'Orazi Porchetti S., Sacchi E., Conti M.A. & Mariotti N. (2007). Dinosaur tracks as paleogeographic constraints: New scenarios for the Cretaceous geography of the Periadriatic region. *Ichnos*, 14: 69-90.
- [49] Niedźwiedzki N., Soussi M., Boukhalfa K. & Gierliński G.D. (2017). Middle-Upper Triassic and Middle Jurassic tetrapod track assemblages of southern Tunisia, Sahara Platform. *Journal of African Earth Sciences*, 129: 31-44.

- [50] Olsen P. E. & Galton P. (1984). A review of the reptile and amphibian assemblages from the Stormberg of southern Africa, with special emphasis on the footprints and the age of the Stormberg. *Paleontologica Africana*, 25: 87-110.
- [51] Olsen P.E. & Rainforth E.C. 2003. The Early Jurassic ornithischian dinosaurian ichnogenus *Anomoepus*. In LeTourneau P.M. & Olsen P.E. (eds), *The great rift valleys of Pangea in eastern North America*, volume 2. Columbia University Press: 314-367
- [52] Panin N. & Avram E. (1962). Noe urme de vertebrate in Miocenul Subcarpatilor rominesti. *Studii si Cercetari de Geologie*, 7: 455-484.
- [53] Piñuela L., Garcia-Ramos J.C. & Lires J. (2002). Huellas de dinosaurios avianos del Jurásico de Asturias; In Pérez-Lorente, F (ed.), *Dinosaurios y otros reptiles Mesozicos de Espana. Resúmenes de las comunicaciones ponencias y paneles*, Universidad de LaRioja -X aniversario: 48-49.
- [54] Saura E., Vergés J., Martín-Martín J.D., Messager G., Moragas M., Razin Ph., Grélaud C., Jousseaume R., Malaval M., Homke S. & Hunt W.D. (2014). Syn- to post-rift diapirism and minibasins of the Central High Atlas (Morocco): the changing face of a mountain belt. *Journal of the Geological Society*, 171: 97-105
- [55] Sternberg C.M. (1926). Dinosaur tracks from the Edmonton Formation of Alberta. *Geological Survey of Canada, Bulletin*, 44: 85-87.
- [56] Sternberg C.M. (1932). Dinosaur tracks from the Peace River, British Columbia. *Annual Report of the National Museum of Canada for 1930*: 59-85.
- [57] Studer M.R. (1987). Tectonique et pétrographie des roches sédimentaires, éruptives et métamorphiques de la région de Tounfite-Tirrhist. (Haut Atlas central, Mésozoïque, Maroc). *Notes et Mémoires du Service Géologique, Maroc*, 321: 1-225
- [58] Valais De S. & Melchor R.N. (2008). Ichnotaxonomy of bird-like footprints: An example from the Late Triassic-Early Jurassic of northwest Argentina. *Journal of Vertebrate Paleontology*, 28: 145-159
- [59] Xing L.D., Abbassi N., Lockley M.G., Klein H., Jia S.H., McCrea R.T. & Persons W.S. IV. (2017). The first record of *Anomoepus* tracks from the Middle Jurassic of Henan Province, Central China. *Historical Biology*, 29: 223-229.
- [60] Xing L.D., Buckley L.G., McCrea R.T., Lockley M.G., Zhang J., Piñuela L., Klein H. & Wang F. (2015). Reanalysis of *Wupus agilis* (Early Cretaceous) of Chongqing, China as a large avian trace: Differentiating between large bird and small non-avian theropod tracks. *PLoS ONE*, 10(5):e0124039.
- [61] Xing L.D., Lockley M.G., Hu N.Y., Li G., Tong G.H., Matsukawa M., Klein H., Ye Y., Zhang J.P. & Persons W.S.IV. (2016b). Saurischian track assemblages from the Lower Cretaceous Shenhuangshan Formation in the Yuanma Basin, Southern China. *Cretaceous Research*, 65: 1-9.
- [62] Xing L.D., Lockley M.G., Klein H., Falkingham P.L., Kim J.Y., McCrea R.T., Zhang J.P., Persons W.S.IV., Wang T. & Wang Z.Z. (2016a). First Early Jurassic small ornithischian tracks from Yunnan Province, southwestern China. *Palaios*, 3: 516-524
- [63] Youbi N., Martins L.T., Munhá J.M., Ibouh H., Madeira J., Ait Chayeb E.M. & El Boukhari A. (2003). The Late Triassic-Early Jurassic volcanism of Morocco and Portugal in the geodynamic framework of the opening of the central Atlantic Ocean. In Hames W.E., McHone J.G., Renne P.R. & Ruppel C. (eds), *The Central Atlantic Province; insights from fragments of Pangea*, 136, American Geophysical Union, *Geophysical Monograph*: 179-207.
- [64] Zeng X.Y. (1982). Dinosaur footprints found in red beds of the Yuan Ma Basin, west of Hunan, Xingxi. *Hunan Geology*, 1: 57-58.