

## CROCODYLE-LIKE FOOTPRINTS FROM THE UPPER TRIASSIC (CARNIAN) OF THE ITALIAN SOUTHERN ALPS

MARCO AVANZINI, FABIO M. PETTI, MASSIMO BERNARDI AND RICCARDO TOMASONI

Museo Tridentino di Scienze Naturali, via Calepina, 14 – 38122 Trento, Italy; e-mail: avanzini@mtsn.tn.it (MA); fabio.petti@mtsn.tn.it (FMP); massimo.bernardi@mtsn.tn.it (MB); tomasoni@mtsn.tn.it (RT)

**Abstract**—Here, we report the discovery of several late Carnian (Tuvanian) footprints preserved both as tracks and natural casts. The best preserved manus-pes couple is assigned to *Brachychirotherium eyermani* (Baird, 1957), previously known from some incomplete manus-pes impressions. A quadrupedal crocodile-like archosaur showing possible affinities with the Sphenosuchidae is here suggested as a putative trackmaker.

### INTRODUCTION AND GEOLOGY

In 2006, several archosaur footprints were discovered by two of the authors (M.A. and R.T.) near Cles village, about 48 km north of Trento (Trentino-Alto Adige, Italy) (Fig. 1). The trampled layers belong to the Travenanzes Formation (= upper portion of the “Raibl Beds” *Auct.*) (Neri et al., 2005), a sedimentary sequence (thickness about 50–70 m; Avanzini et al., 2007a) consisting of white-gray aphanitic to silty dolostones, intercalated with reddish or greenish shales. This lithofacies was related to a marginal marine to lagoonal environment consisting of a tidal carbonate mud flat with occasional influxes of distal terrigenous sediments (Gennaro, 2007). This shallow lagoon has been interpreted as periodically subaerially exposed as evidenced by fenestral fabric, mud cracks and scattered chirotherian and dinosaur footprints, found in several localities of the central Southern Alps (D’Orazi et al., 2008). Upward, the Travenanzes Formation transitionally passes into the early-dolomitized tidal flat facies of the Dolomia Principale (Hauptdolomit) without major gaps; only the disappearance of shale beds is commonly used to define a boundary between these two formations (Fig. 2).

In the study area samples of black and gray shales from the lowermost portion of the Travenanzes Formation have yielded a remarkable amount of organic matter, mainly composed of amorphous material, spores and pollen (Gennaro, 2007). According to Roghi (2004), the recorded pollen associations belong to the *Granuloperculipollis rudis* assemblage, indicating a late Carnian (Tuvanian) age.

### MATERIAL

The ichnological material is represented by several footprints recorded on various reddish to greenish carbonate layers and preserved both as tracks and natural casts. The material is now stored in the Museo Tridentino di Scienze Naturali (MTSN), labelled as MTSN 5644–5647 and MTSN 5649–5650. Among them are several pedal and manual imprints made by a quadrupedal archosaur. Although moderately preserved, the footprints provide useful and detailed morphological information (Fig. 3).

### DESCRIPTION

**Pes:** Pentadactyl and plantigrade, longer than wide, with a length/width ratio = 1.68. Digit III > II ? IV > I. Digits I–IV are robust and elongated. Digit III is the longest, whereas digit IV is as long as digit II. The angle between digits I–IV is 46°. The interdigital angle (IDA) between III and IV is similar to that between digits I and II and between digits II and III (about 18°). A probable oval or subelliptical digit V is backward and inward positioned, almost parallel to the long axis through digit IV and slightly recurved distally. No distinct claw mark can be observed on digit V. The “plantar” portion of the footprint is elongate with a U-shaped “heel,” representing half of the entire track. Digit I, and in some cases digits II and III, are curved inward distally. In some cases phalangeal pads and claw traces are preserved on digits I–IV.

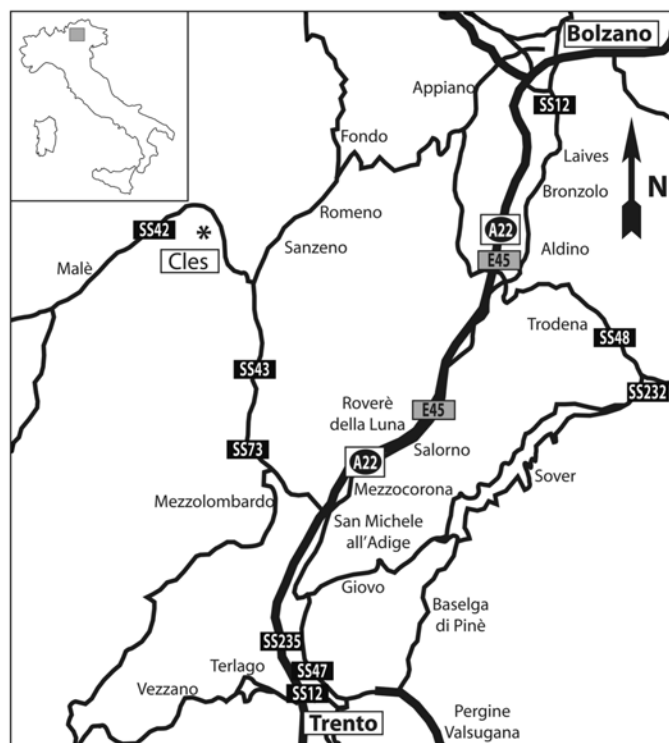


FIGURE 1. Location of the Cles village (Trentino Alto Adige, NE Italy), site of the discovery.

Mean parameters: Pes length (L) 210 mm; pes width (W) 125 mm; digit lengths 42 mm (I), 65 mm (II), 75 mm (III); 62 mm (IV); cross-axis angle equal to about 90°.

**Manus:** The manual imprint is placed in front and medially with respect to the pes. It is pentadactyl and semi-digitigrade. Digits I–IV are subequal in length and show accentuated and pointed claw furrows. Digit V is the longest and clearly separated from digit group I–IV. On this digit, three phalangeal pad impressions and a short, narrow claw mark are visible. Indistinct metacarpal-phalangeal nodes can be observed on digit IV and on the proximal portion of digits II and III. Interdigital angles (IDA) I–IV 38°, I–V 94°. The manus length/pes length ratio is about 0.7.

**Mean parameters:** Manus length (L) 77 mm; Manus width (W) 98 mm; digit lengths 55 mm (I), 54 mm (II), 60 mm (III); 45 mm (IV); 51 mm (V).

**Trackway:** No trackways are known.

### DISCUSSION

Due to the slightly greater length of pedal digit III, the proportions between the other digits (III > II ? IV > I), and the manus positioned

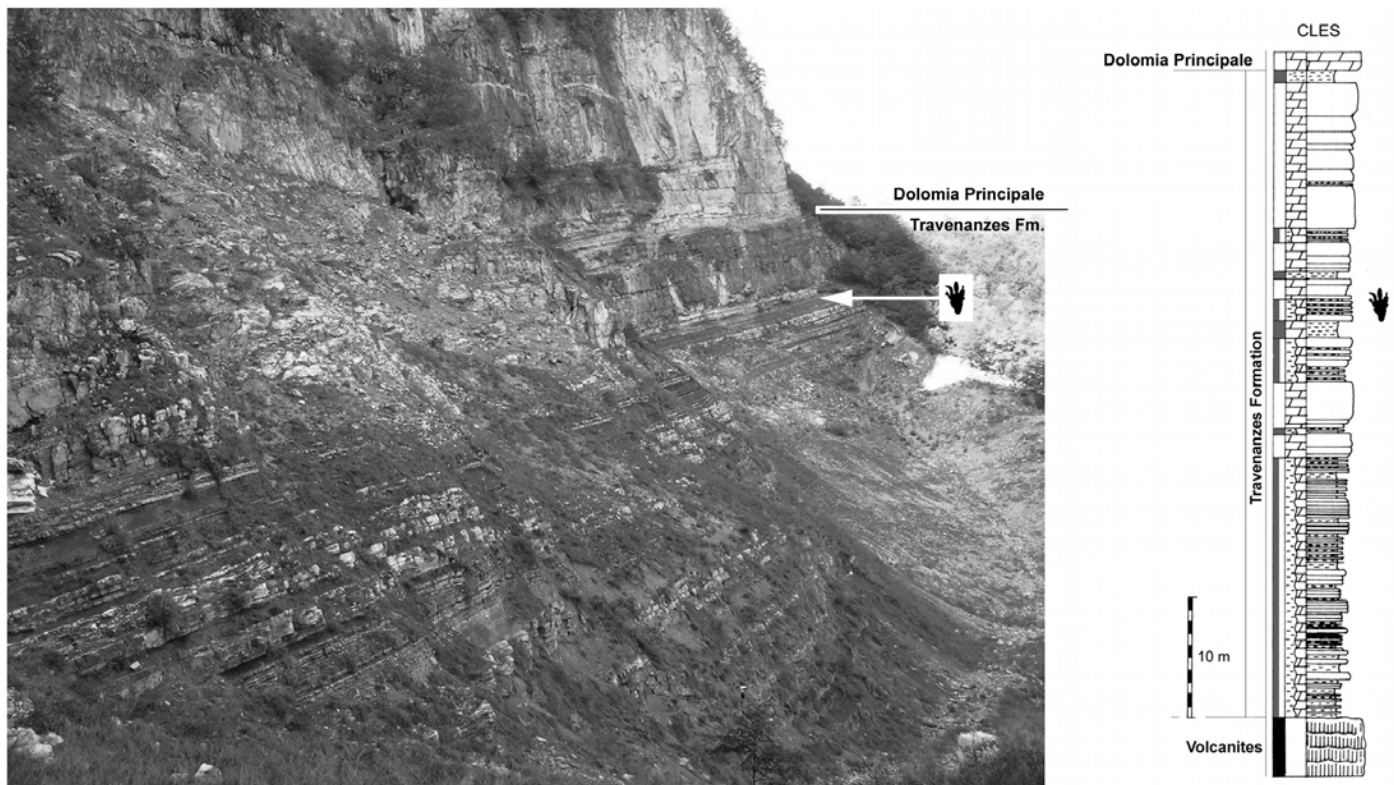


FIGURE 2. The Cles outcrop that yielded the footprints described here. The finely-bedded Travenanzes Formation (Carnian) is clearly visible below the Hauptdolomit/Dolomia Principale Formation (Norian).

medially to the pes, the footprints show a general morphology that closely resembles “chirotheriid” tracks (*sensu* King et al., 2005; see also Haubold, 1971, 1984, 1986; Haubold and Klein, 2002).

At present two non-dinosaurian “chirotheriid” ichnoassociations have been reported from the Upper Triassic of the Southern Alps. One is known from Dogna (Friuli) and is of Carnian age (Dalla Vecchia, 1996; Avanzini et al., 2007b). The footprints from Dogna do not match any known ichnotaxon or models of foot skeletons. They were considered to be a peculiar “chirotheriid” most probably related to an aetosaur trackmaker (Roghi and Dalla Vecchia, 1997; Avanzini et al. 2007b). The second “chirotheriid” ichnoassociation was recently discovered in the lower-middle Carnian of Zone (Brescia, Lombardy) (Petti et al., 2009). This ichnoassemblage consists of six trackways that were referred to quadrupedal trackmakers with large plantigrade and pentadactyl pes and manus imprints (pes length 25–30 cm). All the characters reveal a great correspondence with the specimen assigned to *Brachychirotherium thuringiacum* (Rühle v. Lilienstern, 1938) figured by Karl and Haubold (1998, 2000), coming from the Coburger Sandstein (Middle Keuper, Carnian/Norian, Northern Bavaria).

Both the Italian ichnoassemblages appear different from the footprints described here. The elongated overall shape of the pes and the reduction of pedal digit V in all collected specimens from Cles appear to be peculiar. Digit V is often faint, inward positioned and always parallel to digit IV; in some cases it shows a single elongated pad impression, whose lateral margin does not pass the longitudinal line through the tip of digit IV. Digit V appears much shorter in comparison with other known chirotheriid tracks, and only a faint, proximally suboval and distally pointed trace is recognizable in the posterior-mesial portion of some footprints (i.e., MTSN5650a). Manual digits I–IV are almost parallel and equal in length. Digit V is undoubtedly the longest, laterally and outward oriented with a marked gap between its base and the base of the digit I–IV group.

The pedal imprints from Cles display morphological features that

closely match those observed in the ichnotaxon *Brachychirotherium eyermani* (Baird, 1957). This ichnospecies is represented only by an isolated left imprint from the Upper Triassic of New Jersey (upper Brunswick Formation; Newark Supergroup) (Baird, 1957) and by two specimens described by Olsen and Rainforth (2001) from the upper Carnian of Haverstraw (New York, Stockton Formation). The first of the two specimens assigned to *Brachychirotherium* cf. *B. eyermani* by Olsen and Rainforth (2001) is represented by an incomplete pedal impression (YPM 7731) preserved only in its proximal portion. The second (YPM 8262) records an incomplete manus-pes couple. Notwithstanding the scarcity of the referred specimens, the ichnospecies was considered valid by Karl and Haubold (1998) in their revision of the ichnogenus *Brachychirotherium*.

Digit group I–IV in *B. eyermani* is very recognizable, and digits are stout with evident pad impressions and claw marks. Digit I is more slender and possesses an inward directed claw trace, as observed in the Cles material. The analyzed material and *B. eyermani* both display a strongly reduced digit V positioned in line with IV, similar digit proportions  $III > II > IV > I > V$ , and the occurrence of a “U-shaped” or subrectangular sole (heel).

The general morphology of the elongated pedal and manual imprints reminds us of extant Crocodylia, although their manus is strongly turned outward and possesses a distinctive morphology (Farlow and Elsey, 2010). During the Late Triassic only the crocodylomorph family Sphenosuchidae was crocodile-like in appearance, showing a pes anatomy compatible with the studied specimens. The pes anatomy is documented in several taxa, showing the fifth digit highly reduced up to a metatarsal splint, and the other digits forming a bilaterally symmetrical foot. However, taxa discovered so far are much smaller with respect to the inferred trackmaker (Parrish, 1987, 1989).

## CONCLUSIONS

The Cles tetrapod ichnoassemblage is represented by several iso-

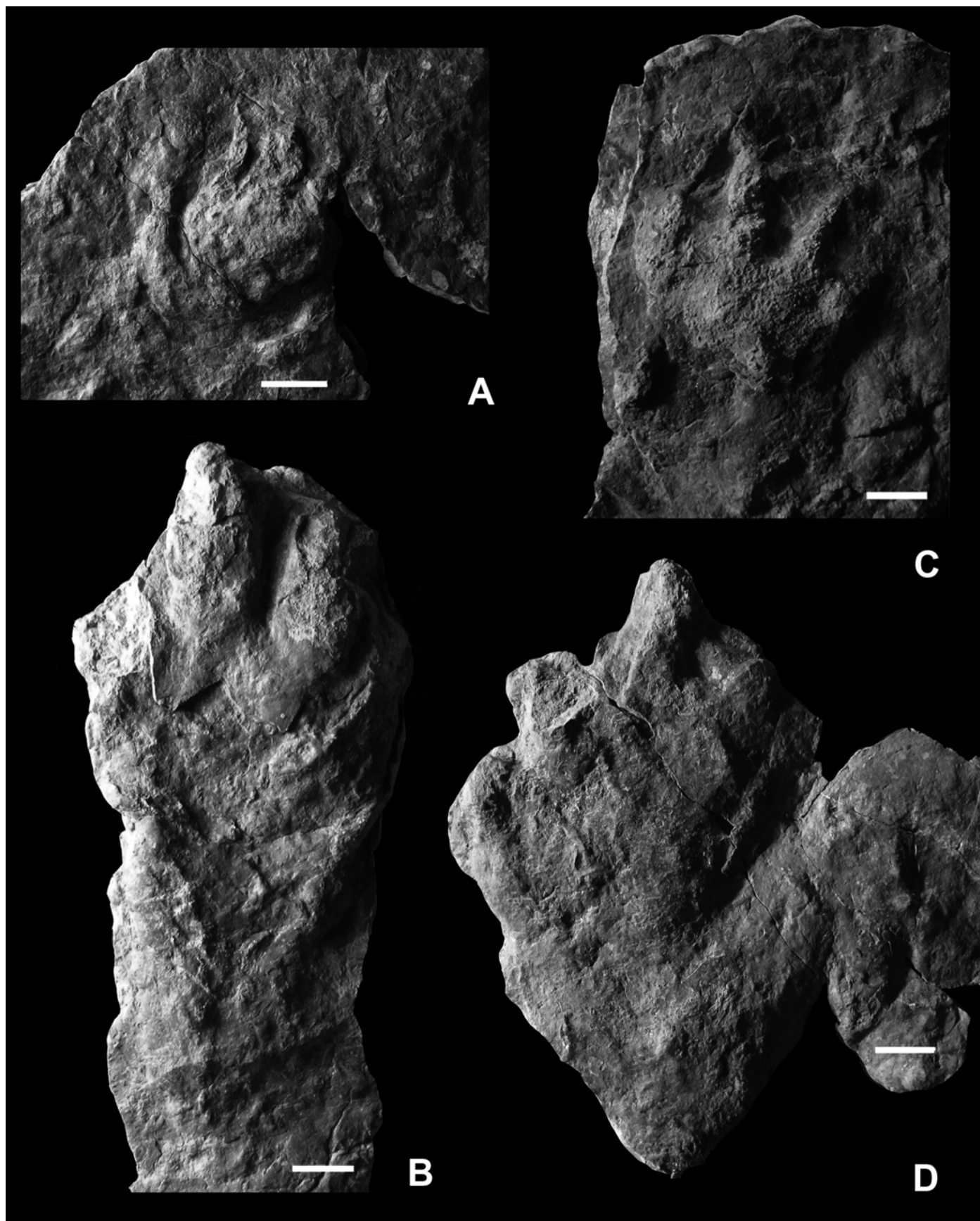


FIGURE 3. Some of the best-preserved specimens (MTSN 5644-5647) from the Cles outcrop. **A, C**, manual, **B, D**, pedal imprints, probably produced by a crocodile-like quadrupedal crurotarsan archosaur. Scale bars = 2 cm.

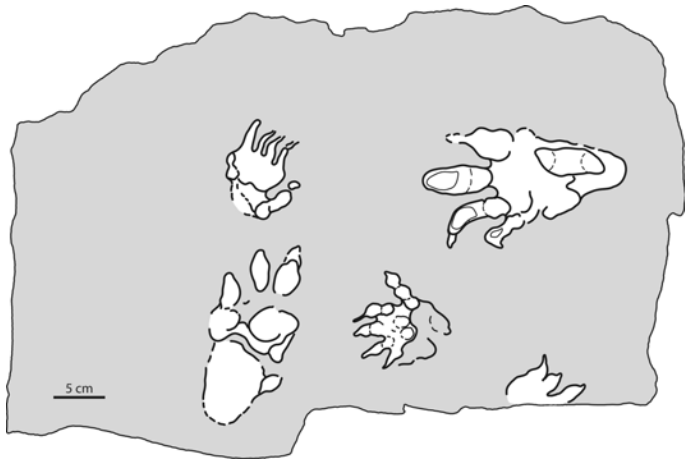


FIGURE 4. MTSN5650, slab preserving two manus-pes couples here assigned to *Brachychirotherium eyermani*. This represents the first evidence of the manus of this ichnospecies.

lated footprints. The best preserved tracks (slab MTSN5650) are associated in two manus-pes couples. The pedal imprint is morphologically identical with Upper Triassic *Brachychirotherium eyermani* (Baird, 1957) (New Jersey, upper Brunswick Formation; Newark Supergroup). Because Baird's (1957) diagnosis was based only on a single pes and Olsen and Rainforth's (2001) description referred only to incomplete material, the discovery described here represents the first evidence of a complete manus-pes couple for this ichnospecies.

The Cles footprints were evidently produced by a quadrupedal trackmaker with a slender pentadactyl (but functionally tetradactyl), elongated foot and pentadactyl manus. The producer was a relatively wide, erect, crocodile-like quadrupedal crurotarsan archosaur showing possibly affinities with the Spheenosuchidae.

#### ACKNOWLEDGMENTS

The authors would like to thank Hendrik Klein (Neumarkt) and Spencer G. Lucas (Albuquerque) for their helpful reviews. This research is supported by the DINOGEO post-doc Project (Servizio Università e Ricerca scientifica, Fondo Unico per i progetti di ricerca della Provincia Autonoma di Trento, L.P. n.3, 20.03.2000), by the CARG P.A.T. 2000 Project and the Provincia Autonoma di Trento SC+6 funding.

#### REFERENCES

- Avanzini, M., Bargossi, G. M., Borsato, A., Castiglioni, G. B., Cucato, M., Morelli, C., Prosser, G. and Sapelsa, A., 2007a, Note illustrative della Carta Geologica d'Italia alla scala 1:50.000, Foglio 026 Appiano: APAT Dipartimento Difesa del Suolo, Servizio Geologico d'Italia, 184 p.
- Avanzini, M., Dalla Vecchia, F. M., Mietto, P., Piubelli, D., Preto, N., Rigo, M. and Roghi, G., 2007b, A vertebrate nesting site in northeastern Italy reveals unexpectedly complex behavior for late Carnian reptiles: *Palaos*, v. 22, p. 465-475.
- Baird, D., 1957, Triassic reptile footprint faunules from Milford, New Jersey: *Bulletin of the Museum of Comparative Zoology*, v. 117, p. 449-520.
- Dalla Vecchia, F. M., 1996, Archosaurian trackways in the Upper Carnian of Dogna valley (Udine, Friuli, NE Italy): *Natura Nascosta*, v. 12, p. 5-17.
- D'Orazi Porchetti, S., Nicosia, U., Mietto, P., Petti F.M. and Avanzini M., 2008, *Atreipus*-like footprints and their co-occurrence with *Evazoum* from the upper Carnian (Tuvallian) of Trentino-Alto Adige; in M. Avanzini and F. M. Petti, eds., *Italian Ichnology: Studi Trentini di Scienze Naturali, Acta Geologica*, v. 83, p. 277-287.
- Farlow, J. O. and Elsey, R. M., 2010, Footprints and trackways of the American alligator, Rockefeller wildlife refuge, Louisiana: New Mexico Museum of Natural History and Science, *Bulletin*, this volume.
- Gennaro M., 2007, The "Raibl Group" alongside the Adige Valley. Università di Padova. Tesi di Laurea ined., A.A. 2006/2007: 144 p.
- Haubold, H., 1971, *Ichnia Amphibiorum et Reptiliorum fossilium: Handbuch der Palaeoherpetologie*, v. 18, 124 p.
- Haubold, H., 1984, Saurierfährten. Wittenberg, Ziemsen, 231 p.
- Haubold, H. and Klein, H., 2002, Chirotherien und Grallatoriden aus der Unteren bis Oberen Trias Mitteleuropas und die Entstehung der Dinosauria: *Hallesches Jahrbuch für Geowissenschaften Reihe B*, v. 24, p. 1-22.
- Haubold, H. 1986, Archosaur footprints at the terrestrial Triassic-Jurassic transition; in Padian, K., ed., *The beginning of the age of dinosaurs: Cambridge*, Cambridge University Press, p.189-201.
- Karl, C. and Haubold, H., 1998, *Brachychirotherium* aus dem Coburger Sandstein (Mittlerer Keuper, Kar/Nor) in Nordbayern: *Hallesches Jahrbuch für Geowissenschaften Reihe B*, v. 20, p. 33-58.
- Karl, C. and Haubold, H., 2000, Saurierfährten im Keuper (Obere Trias) Frankens, die Typen von *Brachychirotherium*: *Berichte der Naturwissenschaftlichen Gesellschaft Bayreuth*, v. 24, p. 91-120.
- King, M. J., Sarjeant, W. A. S., Thompson, D. B. and Tresise, G., 2005, A revised systematic ichnotaxonomy and review of the vertebrate footprint ichnofamily Chirotheriidae from the British Triassic: *Ichnos*, v. 12, p. 241-299.
- Neri, C., Gianolla, P. and Avanzini, M., 2005, Raibl beds (Upper Triassic): A case-history about the use of traditional lithostratigraphic names from central-eastern southern Alps: *Geitalia 2005: V Forum Italiano di Scienze della Terra: Spoleto 21-23 Settembre 2005*, W02-31. 10.1474/Epitome. 01.0031-V.1, p.9.
- Olsen, P. E. and Rainforth, E. C., 2001, The "age of dinosaurs" in the Newark Basin with special reference to the Lower Hudson Valley; in Gates, A.E. and Olsen, P. E., eds., *Geology of the Lower Hudson Valley: New York State Geological Association Field Trip Guide Book*, p. 59-176.
- Parrish, J. M. 1987, The origin of crocodilian locomotion: *Paleobiology*, v. 13, p. 396-414.
- Parrish, J. M., 1989, Phylogenetic patterns in the manus and pes of early Mesozoic archosauriform reptiles; in Gillette, D.D. and Lockley, M.G., eds., *Dinosaur tracks and traces: Cambridge University Press, Cambridge*, p. 249-258.
- Petti, F. M., Avanzini, M., Nicosia, U., Girardi, S., Bernardi, M., Ferretti, P., Schirolli, P. and Dal Sasso, C., 2009, Late Triassic (early-middle Carnian) chirotherian tracks from the Val Sabbia Sandstone (eastern Lombardy, Brescian Prealps, Northern Italy): *Rivista Italiana di Paleontologia e Stratigrafia*, v. 115, p. 277-290.
- Roghi, G., 2004, Palynological investigations in the Carnian of Cave del Predil area (once Raibl, Julian Alps): *Review of Paleobotany and Palynology*, v. 132, p. 1-35.
- Roghi, G., and Dalla Vecchia, F. M., 1997, The palynology and palaeoenvironments of Upper Triassic dolomitic-marly sequence of Dogna valley (Udine, Friuli-Venezia Giulia, NE Italy) with reptile trackways: *Rivista Italiana di Paleontologia e Stratigrafia*, v. 103, p. 183-192.
- Rühle v. Lilienstern, H., 1938, Fährten aus dem Blasensandstein (km 4) des Mittleren Keupers von Südhüringen: *Neues Jahrbuch für Mineralogie, Geologie und Paläontologie, Beilage-Band*, v. 80, p. 63-71.