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LATE TRIASSIC (EARLY-MIDDLE CARNIAN) CHIROTHERIAN TRACKS FROM THE VAL SABBIA SANDSTONE (EASTERN LOMBARDY, BRESCIAN PREALPS, NORTHERN ITALY)

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Abstract. A new Late Triassic tetrapod tracksite was discovered north of the Zone village, on the north-eastern side of the Lake Iseo (Southern Alps, Brescia, Lombardy). The tracks are preserved on two distinct bedding planes, belonging to the lower/middle Carnian Val Sabbia Sandstone. The ichnoassemblage is composed of about seventy footprints, arranged in six quadrupedal trackways that exhibit both wide and narrow gauge. All trackways can be attributed to an archosaur trackmaker and at least three of them can be assigned with confidence to the ichnogenus *Brachychirotherium* Beurlen, 1950. The Zone material represents the first well documented report of this ichnogenus from the Upper Triassic of Northern Italy. The footprints have been analyzed both with traditional methods, and with 3D technologies, such as the terrestrial laser scanner. The ichnoassemblage, although not exceptionally preserved, provides new important data about the stratigraphic distribution of chirotherian tracks in the Triassic of Southern Alps.

Riassunto. Un nuovo icnosito con orme di tetrapodi, riferibile al Triassico superiore, è stato scoperto a nord di Zone, sulla sponda nord-orientale del Lago d'Iseo (Alpi Meridionali, Brescia, Lombardia). Le orme sono preservate su due distinte superfici di strato, appartenenti all'Arenaria di Val Sabbia (Carnico inferiore/medio).

L'icnoassociazione è costituita da circa 70 orme, organizzate in sei piste, con scartamento sia largo, sia stretto. Tutte le piste possono essere attribuite a trackmaker appartenenti al gruppo degli arcosauri ed almeno tre di esse possono essere assegnate all'icnogenere *Brachychirotherium* Beurlen, 1950. Le orme rinvenute a Zone rappresentano la prima documentazione certa di questo icnogenere nel Triassico superiore dell'Italia settentrionale. Le orme sono state analizzate sia con le metodologie tradizionali, sia con tecniche 3D, grazie all'utilizzo della tecnologia laser scanner. L'icnoassociazione rinvenuta a Zone, sebbene non ottimamente preservata, aggiunge nuovi ed importanti dati alla distribuzione stratigrafica delle orme chirotheriane nel Triassico delle Alpi Meridionali.

Introduction

After a first notice, on January 2008 tens of tetrapod footprints were discovered north of the Zone village, about 4 km east of the north-eastern side of the Lake Iseo (Southern Alps, Brescia, Lombardy). The outcrop belongs to fluvio-deltaic *vs* coastal-lagoon deposits, located in the uppermost part of the Arenaria di Val Sabbia (Val Sabbia Sandstone), ascribed to the early and middle Carnian (Assereto & Casati 1965; Allasinaz 1966). Chirotherian Triassic tracks, mostly attributed to crurotarsans, are widespread across the eastern sector of the Southern Alps and have been studied since the last century (see Avanzini & Mietto 2008 for a review). They belong to Lower-Middle Triassic continental deposits, mostly Anisian in age (Pelsonian-Illyrian), and are especially localized in the Trentino Alto-Adige region. Late Triassic ichnoassemblages are indeed poorly documented. Unnamed archosaurian footprints, associated with nesting structures, have been recently described from the late Carnian of the Dogna Valley (Udine, Friuli Venezia Giulia), in the north-easternmost sector of Italy (Dalla Vecchia 1996; Avanzini et al. 2007). An enigmatic quadrupedal trackway found in

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the Carnian Pre-Alps (Ciol de la Fratta, Friuli Venezia Giulia), has been referred to a large crurotarsan track-maker (aetosaur) even if a prosauropod has been not excluded (Dalla Vecchia & Mietto 1998; Dalla Vecchia 2006). Finally, on a dolostone block at the base of the southern wall of Monte Pelmetto, a poorly preserved *Brachychirotherium*-like footprint has been reported by Leonardi & Mietto (2000).

The Zone tracksite indeed represents the first definite ichnological record of chirotherians from the lower-middle Carnian of the Southern Alps and their first finding in the Lombardy region.

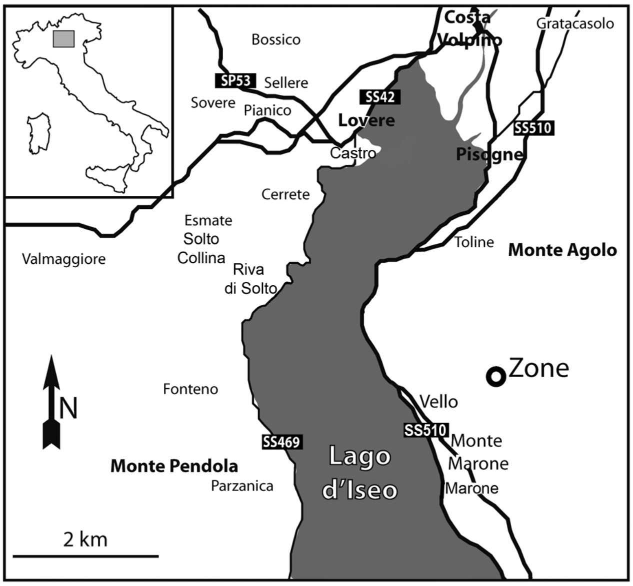

Fig. 1 - Location map of the Zone tracksite (central Lombardy, Northern Italy).

Geological and stratigraphical setting

The analyzed outcrop is situated in the Brescian Prealps, about 1 km north of the Zone village, along an ancient path (Antica Strada Valeriana, Val Valurbes; Lat: 45° 46′ 23.77″N, Long: 10° 06′ 57.47″E), a few kilometers from the north-eastern side of the Lake Iseo (Lombardy, Northern Italy; Fig. 1). The Brescian Prealps belong to the central part of the Southern Alps, a south-verging thrust-belt system located south of the Insubric Lineament (Tonale and South-Giudicarie Lines). The studied tracksite is situated just to the west of the E-W oriented Val Trompia thrust system (Picotti et al. 1995).

The track-bearing horizons belong to the terrigenous-volcanoclastic sequences of the Val Sabbia Sandstone (Assereto & Casati 1965). These deposits outcrop exclusively in Lombardy and have been studied since the 19th century by different authors (Escher von der Linth 1853; Curioni 1855, 1877; Omboni 1869, 1879; Stoppani 1857, 1859; Bittner 1881; Deecke 1885; Arthaber 1906; Desio & Venzo 1954; De Sitter & De Sitter Koomans 1949). The unit was named for the first time as Val Sabbia Sandstone by Assereto & Casati (1965) and was successively characterized by several authors from a stratigraphic, petrographic, palaeoenvironmental and palaeogeographical point of view (Gnaccolini 1983 1987; Garzanti 1985; Garzanti & Jadoul 1985; Gnaccolini & Jadoul 1988, 1990). It is constituted by volcanoclastic sandstones, siltstones and occasionally conglomerates, arranged in fining-upward cycles. The formation is often punctuated by different tractive structures, such as parallel and cross laminations and ripple marks which indicate paleocurrents from the south (Casati & Pace

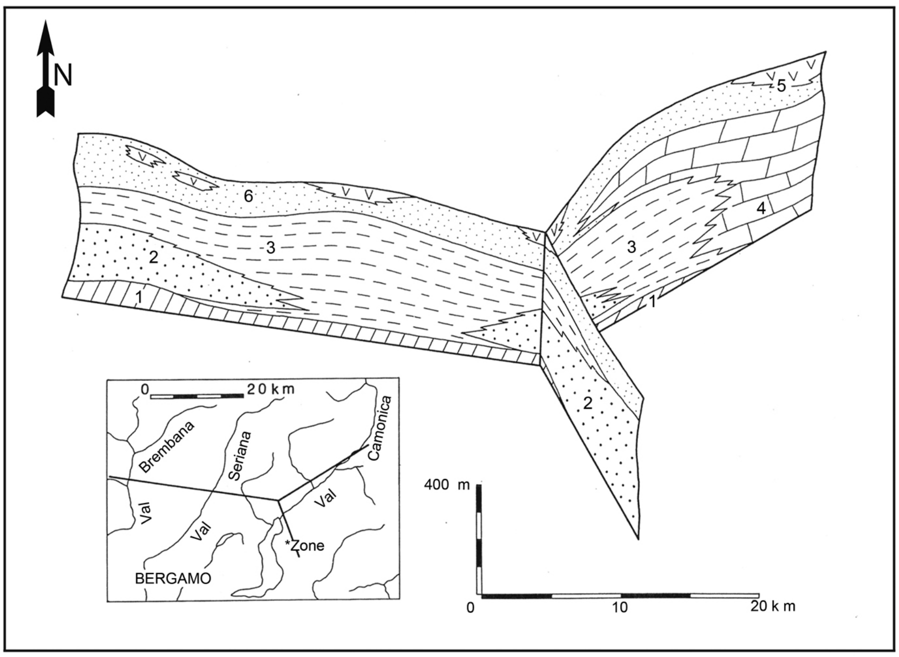

Fig. 2 - Lithostratigraphic relationships among established units in the Carnian of central Lombardy. 1) Calcare Metallifero Bergamasco; 2) Val Sabbia Sandstone; 3) Gorno Formation; 4) Breno Formation; 5), 6) S. Giovanni Bianco Formation (from Gnaccolini 1986, slightly modified).

1968). These lithotypes are sometimes replaced by pelitic deposits, red to green in colour. In the area of Zone the unit lies both on the Ladinian Esino Limestone and on the Wengen Formation (see Carta Geologica d'Italia alla scala 1:50.000, Foglio 99 Iseo). Rarely it overlies the upper Ladinian-lower Carnian Calcare Metallifero Bergamasco (peritidal carbonates Assereto & Casati 1965; «Plattenkalk» *Auct.* or «Calcari lastriformi» *sensu* Cassinis et al. 2008). The Val Sabbia Sandstone passes both laterally, towards the NW, and upwards in the analyzed section, into the lower-middle Carnian Gorno Formation with lagoonal limestone and prodelta siltstones (Assereto & Casati 1965), whereas the unit is generally overlain by the upper Carnian S. Giovanni Bianco Formation that consists of siliciclastic, carbonate and evaporitic deposits (Assereto & Casati 1965; Fig. 2). The chronological attribution of the unit to the early/middle Carnian is based on its stratigraphic relationships with the above mentioned formations. The lithofacies association has been interpreted as an alluvial complex, characterized by semiarid climate, gradually changing toward the north to deltaic systems (red deposits) and to finely laminated prodelta facies (greenish deposits; Assereto & Casati 1965; Gnaccolini & Jadoul 1990). The Val Sabbia Sandstone records two big deltaic systems («brembano lobe» and «bresciano lobe» *sensu* Assereto & Casati 1965), corresponding to the two main outcropping areas (Brembana Valley and Trompia Valley-Val Sabbia Valley), which were pulled apart by a wide embayment characterized by mixed and carbonate sedimentation (Gorno Formation). Towards the northeast (Val Camonica) the lagoonal Gorno Formation passes to the shallow subtidal and peritidal Breno Fm., still early Carnian in age. The Carnian sedimentary succession outcropping in Lombardy hence testifies the environmental change from a shallow water carbonate platform (Calcare Metallifero Bergamasco and Breno Formation) to a carbonate platform, lagoon and delta system passing from the north to the south (namely Breno Formation, Gorno Formation and Val Sabbia Sandstone; Fig. 2) (Assereto & Casati 1965; Gnaccolini & Jadoul 1990). This model fits in a scenario characterized by the occurrences of a series of volcanic edifices, located southwards (Brusca et al. 1982), whose erosion supplied the Val Sabbia Sandstone deltas (Gnaccolini & Jadoul 1990). The geodynamic regime of this sector of the Southern Alps during the late Ladinian-early/middle Carnian interval is still controversial, nevertheless different authors (Garzanti 1985; Armienti et al. 2003; Cassinis et al. 2008) suggest an arc/back arc basin setting characterized by transtensional conditions.

Sedimentology of the outcrop

A sedimentological analysis of the track-bearing horizons and of the immediately underlying and overlying layers was carried out. This short section is stratigraphically located in the uppermost part of the Val Sabbia Sandstone. The base of the analyzed section (Fig. 3), partly covered by vegetation, is composed of fine grained sandstone. The grain size gradually increases upward passing to a coarser ($\Phi < 2$ mm) sandstone interval (6 cm) which underlies a microconglomerate bed (4 cm) constituted by sub-angular/sub-rounded clasts (Φ up to 1 cm). Each described bed overlies an essentially irregular erosion surface. The microconglomerate is sealed by a pelitic level (thickness 2 cm), characterized by desiccation crack polygons, 20 to 30 cm across, and corresponding to the first trampled level. The section continues with a millimetric pelitic layer

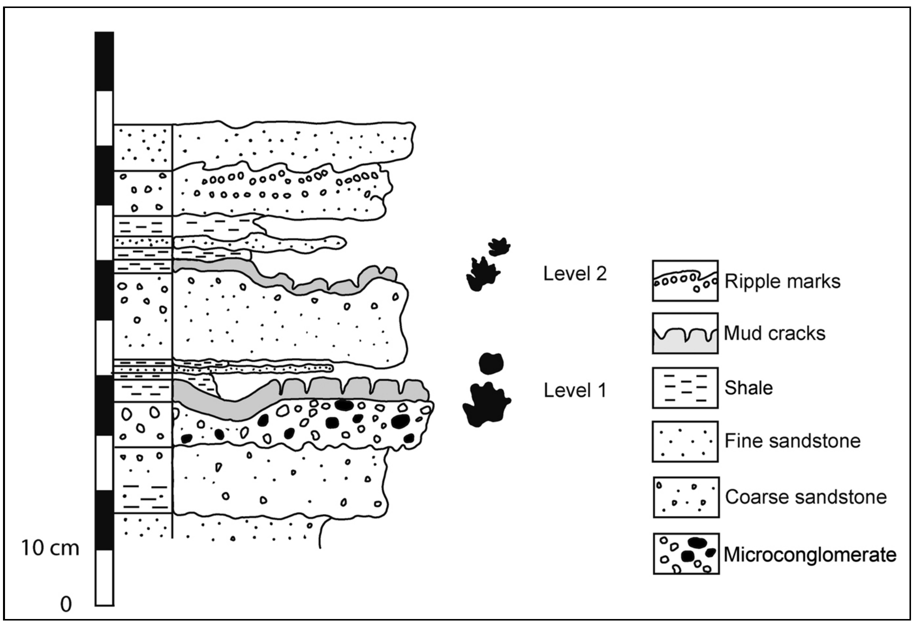

Fig. 3 - Measured stratigraphic log of the Val Sabbia Sandstone at Zone ichnosite, showing the stratigraphic positions of the trampled layers.

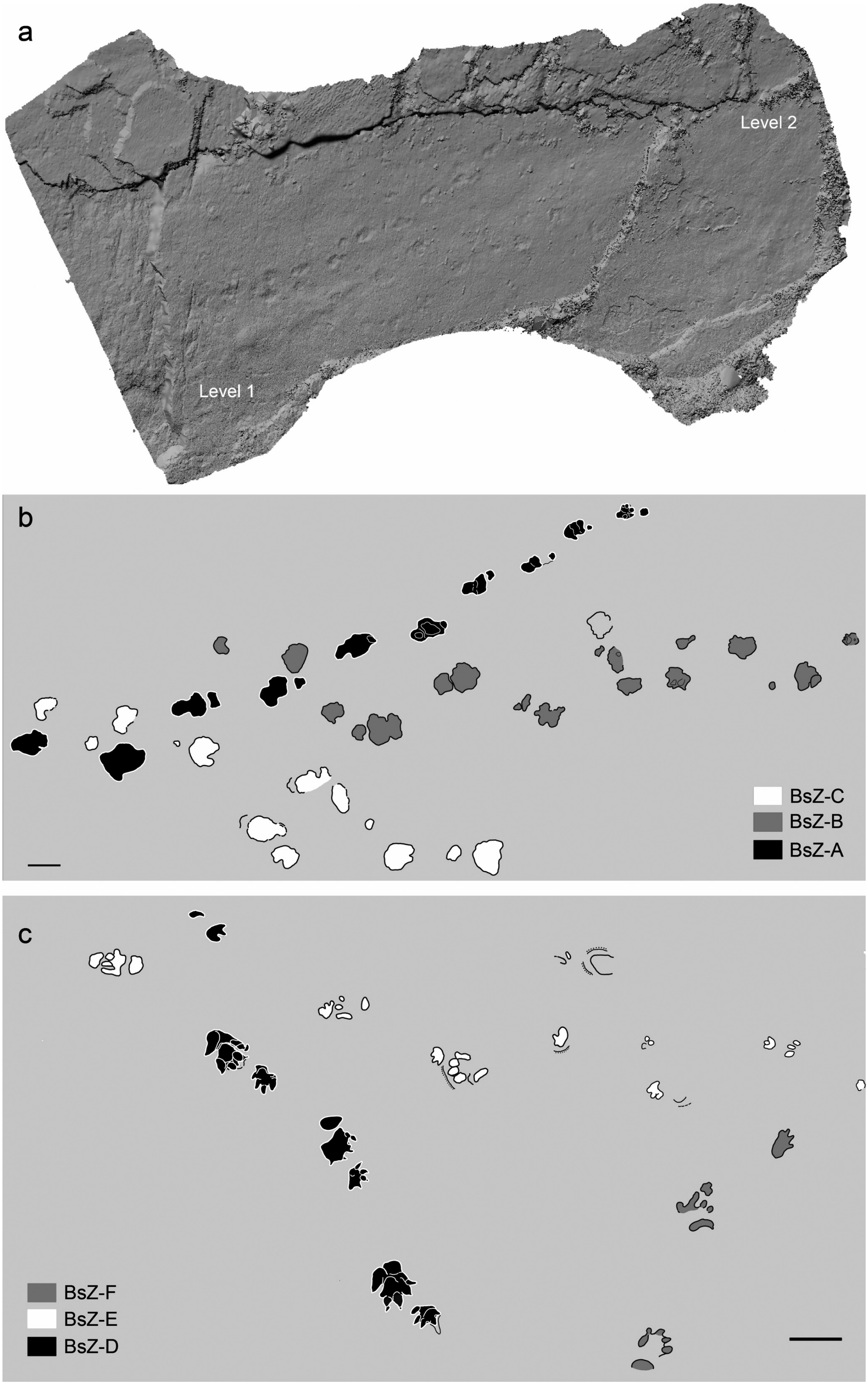

Fig. 4 - The Zone tracksite. a) 3D reconstruction showing both trampled layers. b) Schematic map of the older track-bearing surface (Level 1), scale bar 40 cm. c) Map of the younger trampled level (Level 2), scale bar 20 cm.

(0.5 cm) that is followed upward by a fine up to a coarse grained sandstone (9 cm), sealed at the top by the second pelitic and track-bearing horizon (1 cm). As for the first trampled level, this latter is marked by irregular mud-crack structures (maximum width about 20 cm). On the same bed, groove casts, probably produced by tree branches dragging, occur. This layer is replaced upwards by an alternance of centimetric levels of shale and fine sandstone topped by a coarse grained sandstone with asymmetric and cross ripple marks. These wave-formed structures are typical of shallow water environment affected by low-energy flows. The ripple-mark data, opportunely tilt corrected, and unless to other tectonic deformations, indicate paleocurrents from southwest, that are consistent with the data reported by Casati & Pace (1968).

Up-section, the sequence is overlain by grey to dark marly limestone with *Myophoria kefersteini* (Münster), clearly indicating the lagoonal facies of the Gorno Formation, and thus constraining upward the age of the tracksite to the early-?middle Carnian.

Material and methods

Two different trampled layers are preserved in the Zone ichnosite (Fig. 4). The older level (Level 1) displays three narrow- and wide-gauge trackways made by quadrupedal trackmakers. The younger level (Level 2) yielded three distinct and partial narrow-gauge trackways. All the footprints are present as concave epireliefs. They are only moderately preserved, nonetheless several anatomical details are evident on those of the younger level.

The trampled surfaces have been mapped and measured using traditional methods (drawings, photographs). The best preserved trackway (BsZ-D) was cast in silicone rubber, allowing its analysis in the laboratory under artificial light. The cast is stored at the Museo Tridentino di Scienze Naturali (Trento, Italy).

To obtain a higher degree of precision, 3D digital models of both track-bearing horizons were obtained by means of a terrestrial laser scanner. For the 3D digitization of both surfaces we used a terrestrial laser scanner (TLS), a Leica ScanStation 2, setting a mean point to point spacing of 0.005 m. For the texturization of the 3D model we used the plain pictures obtained by employing a calibrated Kodak DSC Pro SRL camera, 14 Mega pixel, equipped with 50 mm lens. The 3D geometry of the trackway BsZ-D was also derived by scanning its rubber cast with a "triangulation-based system" (ShapeGrabber SG1002), thus providing range data of surfaces in high resolution and with high accuracy (for more details about the instruments see also Avanzini et al. 2008; Petti et al. 2008).

In this paper we used the following abbreviations to indicate footprints and their main parameters: BsZ= Brescia, Zone; PL= Pes length; PW= Pes width; ML= Manus Length; MW= Manus Width; PL/PW= Pes length/width ratio; ML/PL= manus length/pes length ratio; PI^IV= interdigital angle between digits I and IV of the pes; PI^V= interdigital angle between digits I and V of the pes; PIII^V= interdigital angle between digits III and V of the pes; PIV^V= interdigital angle between digits IV and V of the pes; M-P d= Manus-Pes distance; PP= Pes Pace; PS= Pes Stride; MP= Manus Pace; MS= Manus Stride; PPA= Pes Pace Angulation; MPA= Manus Pace Angulation. For the detailed measurements of each trackways see Tab. 1.

Description of the tracksite

Level 1. Level 1 shows three poorly preserved quadrupedal trackways, that cross each other on the surface. These are BsZ-A, BsZ-B and BsZ-C.

Trackway BsZ-A (Fig. 5): it is composed of ten manus-pes couples and 7.13 m long (Fig. 5). The footprints occur as modified true tracks (*sensu* Marty et al. 2009), because their original morphology has been probably altered by washing after they were impressed. The trackway BsZ-A shows a relative narrow gauge. Pedal prints seem to approach or intersect the midline while manus imprints have their long axis almost parallel to it.

Pes: in most cases longer than wide, 27.5<PL<33.57; 16.07<PW<23.21, preserved as two linked sub-circular or sub-elliptical impressions ("eight" shaped), due to the occurrence of two clear notches in its middle and external side.

Manus: manus tracks are always wider than long (7.86<ML<11.43; 8.57<MW<13.21) and sub-circular or sub-elliptical in shape. No digit impressions or other morphological details occur, except in BsZ-A10. In this couple the pes track displays four impressions, probably representing digits II-V. Pedal digit V is pyriform and pointed distally. The manus is positioned antero-laterally and in a short distance to the pes. In some cases, manus and pes tracks coalesce (BsZ-A5, BsZ-A6, BsZ-A8, BsZ-A9).

Trackway BsZ-B (Fig. 6): it shows an indistinct pattern with about nine manus-pes couples. It is about 7.0 m long and it crosses BsZ-A, between BsZ-A4 and BsZ-A5 couples. Tracks are faintly impressed, especially in their rear portions. The trackway is wide (pes oblique pace varies from 70 cm to 92 cm). It belongs to a large-sized individual.

Pes: in best preserved imprints nearly as long as wide (average length about 35 cm, average width about 33 cm) and of irregular shape. The best preserved footprint is BsZ-B4 where four to five short and rounded digits are visible (Fig. 7). Digits II-IV are short, stout and subequal in length. Digit V is slightly curved outward and shows a distinct crease at about two-thirds of its total length.

Manus: supposed manus tracks (BsZ-B7, BsZ-B8) are sub-elliptical to crescent impressions (length 9 cm, width 18 cm). They are straightforward positioned with respect to the pes, the distance to the latter being highly variable.

Trackway BsZ-C (Fig. 4b): it is poorly preserved and footprints are faintly visible with the naked eye. Thus its overall pattern was recognized mainly analyzing the 3D model. It consists of more than a dozen tracks of a quadrupedal animal, characterized by a pro-

Track	PL	PW	PL/PW	ML	MW	ML/PL	PI^IV	PI^V	PIII^V	PIV^V	M-P d
BsZ-A1	31	20.29	1.52								
BsZ-A2	33.21	20.71									
BSZ-A3	27.85	21.42	1.3	7.86	11.43	0.68					2.85
BsZ-A4	31.78	20.71	1.53	11.43	12.14	0.94					3.21
BsZ-A5	33.93	25	1.36	7.86	13.21	0.59					2.14
BsZ-A6	33.92	21.43	1.58	8.57	9.64	0.89					4.28
BsZ-A7	33.57	18.57	1.80	10	11.42	0.87					1.07
BsZ-A8	31.42	17.14	1.83	8.93	9.64	0.92					7.14
BsZ-A9	32.14	16.07	2	8.21	8.57	0.96					2.86
BsZ-A10	27.5	23.21	1.18	10	11.42	0.87					9.64
BsZ-B1	21.43										
BSZ-B2	32.5	34.64	0.94								
BsZ-B3	34.28	33.21	1.03								
BsZ-B4	34.28	33.92	1.01								
BsZ-B5											
BsZ-B6	36.78	28.57	1.28								
BsZ-B7	28.57	30.71	0.93	9.64	19,28	0.5					5.36
BsZ-B8	39.28	32.85	1.19	8.21	17.14	0.48					1.78
Bs-Z-B9	34,30	32.80									
BsZ-C1	34.15	40.10	0.85	15.37	18.78	0.81					13.66
BSZ-C2	30.74	37.57	0.81	8.53	11.95	0.71					29.03
BsZ-C3	34.15	34.15	1.00								
BsZ-C4	23.90	34.15	0.70								
BsZ-C5	25.61	30.74	0.83								
BsZ-D1											
BSZ-D2	24	20	1.2	12.5	13.7	0.52	48°	79°	30°	30°	4.6
BsZ-D3	23.7	22	1.08	10	13.8	0.42	48°	90°	39°	48°	4.6
BsZ-D4	23.7	21.9	1.08	12.5	14.6	0.52	50°	59°		17°	3.07
BsZ-E1				5.5	7.0	0.78					
BSZ-E2				6.25	7.6	0.82					
BsZ-E3				9.72	10.41	0.93					
BsZ-E4											
BsZ-E5	25.6	22.9	1.11	8.33	11.1		41°	65°		24°	
BsZ-E6	21.32	19.18	1.11	8.21	12.32	0.66					
BsZ-E7											
BsZ-E8	26.71	16.4	1.62	8.21	10.96	0.74					
BsZ-F1	30.82	24.65	1.25								
BSZ-F2	23.28	28.76	0.81	8.22	6.84	1.20					
BsZ-F3											

Trackway	PP	PS	MP	MS	PPA	MPA
BsZ-A	79_{1-2}	145_{1-3}				
BsZ-A	79_{2-3}	143_{2-4}			$132°_{1-3}$	
BsZ-A	68_{3-4}	145_{3-5}	75_{3-4}	148_{3-5}	148_{2-4}	
BsZ-A	81_{4-5}	153_{4-6}	78_{4-5}	150_{4-6}	$152°_{3-5}$	$150°_{3-5}$
BsZ-A	76_{5-6}	152_{5-7}	78_{5-6}	150_{5-7}	$152°_{4-6}$	$150°_{4-6}$
BsZ-A	81_{6-7}	151_{6-8}	81_{6-7}	160_{6-8}	$154°_{5-7}$	$140°_{5-7}$
BsZ-A	73_{7-8}	152_{7-9}	85_{7-8}	148_{7-9}	$158°_{6-8}$	$148°_{6-8}$
BsZ-A	81_{8-9}	153_{8-10}	65_{8-9}	147_{8-10}	$162°_{7-9}$	$155°_{7-9}$
BsZ-A	74_{9-10}		85_{9-10}		158_{8-10}	$152°_{8-10}$
Bsz-B	81_{1-2}	137_{1-3}			$104°_{1-3}$	
Bsz-B	92_{2-3}	157_{2-4}			$115°_{2-4}$	
Bsz-B	96_{3-4}	150_{3-5}			$128°_{3-5}$	
Bsz-B	70_{4-5}	142_{4-6}			$124°_{4-6}$	
Bsz-B	89_{5-6}	142_{5-7}			$111°_{5-7}$	
Bsz-B	84_{6-7}	143_{6-8}			$115°_{6-8}$	
Bsz-B	86_{7-8}		91_{7-8}			
BsZ-D	70.7_{2-3}	140.76_{2-4}	65.38_{2-3}	139.23_{2-4}	$154°_{2-4}$	$160°_{2-4}$
BsZ-D	73.84_{3-4}		76.9_{3-4}			
BsZ-E	89.04_{5-6}		75.34_{5-6}			
BsZ-E		153.42_{6-8}		153.42_{6-8}		
BsZ-F	75.34_{1-2}	150.68_{1-3}			$?180°_{1-3}$	

Tab. 1 - Measurements (in cm) of trackways at the Zone tracksite. PL= Pes length; PW= Pes width; ML= Manus Length; MW= Manus Width; PL/PW= Pes length/width ratio; ML/PL= manus length/pes length ratio; PI^IV= interdigital angle between digits I and IV of the pes; PI^V= interdigital angle between digits I and V of the pes; PIII^V= interdigital angle between digits III and V of the pes; PIV^V= interdigital angle between digits IV and V of the pes; M-P d= Manus-Pes distance; PP= Pes Pace; PS= Pes Stride; MP= Manus Pace; MS= Manus Stride; PPA= Pes Pace Angulation; MPA= Manus Pace Angulation.

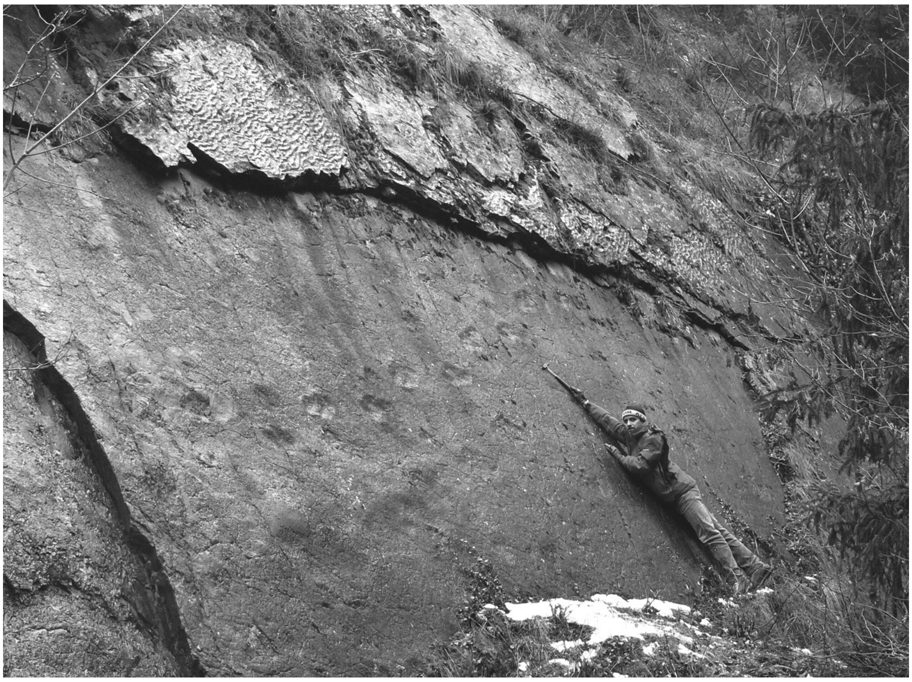

Fig. 5 - Quadrupedal and narrow-gauge trackway (BsZ-A) on the lower track-bearing surface (Level 1). Asymmetric ripple marks are visible on the overlying beds.

Fig. 6 - Partial view of the trackway BsZ-B (Level 1). Note the wide-gauge trackway pattern.

nounced heteropody. The trackway pattern is indistinct and can hardly be recognized due to the poor preservation. BsZ-C crosses BsZ-A between BsZ-A1 and BsZ-A3. It was probably overprinted by BsZ-A2.

Pes: pes prints are deeper impressed in their distal part. Three to four indistinct digits have been noticed in the better preserved pes prints.

Manus: the documented manus impressions are round and placed forward with respect to the pes.

Level 2. The younger layer (Level 2) shows three trackways (BsZ-D, BsZ-E and BsZ-F).

Trackway BsZ-D (Fig. 8-10): it is about 2.40 m long and consists of four well impressed manus-pes couples with clearly identifiable morphological features as digit impressions and claw marks. BsZ-D is narrow and displays a pronounced outward rotation of the manus from the midline.

Pes: it is pentadactyl, plantigrade to semidigitigrade, with short digits and slightly longer than wide (PL= 24 cm; PW= 20-22 cm). BsZ-D4 (Figs. 9, 10) set provides the best preserved pedal print, displaying different anatomical details and giving useful information about the dimensional relationships. Digit III is long-

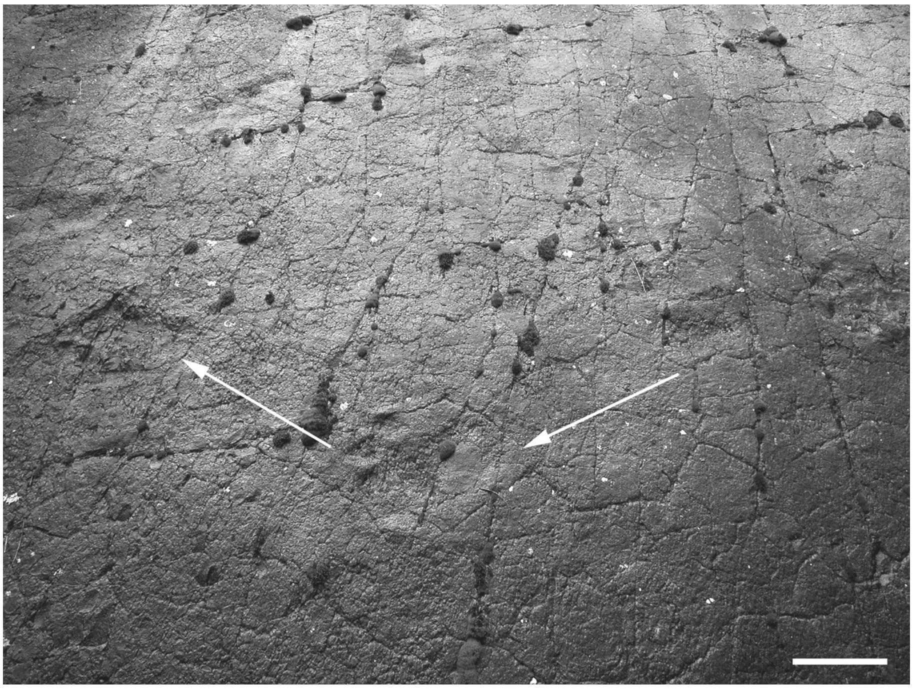

Fig. 7 - Close-up view of the best preserved pes tracks (BsZ-B4) of the BsZ-B trackway (Level 1). Scale bar 20 cm. Dessiccation cracks are clearly evident on the whole surface.

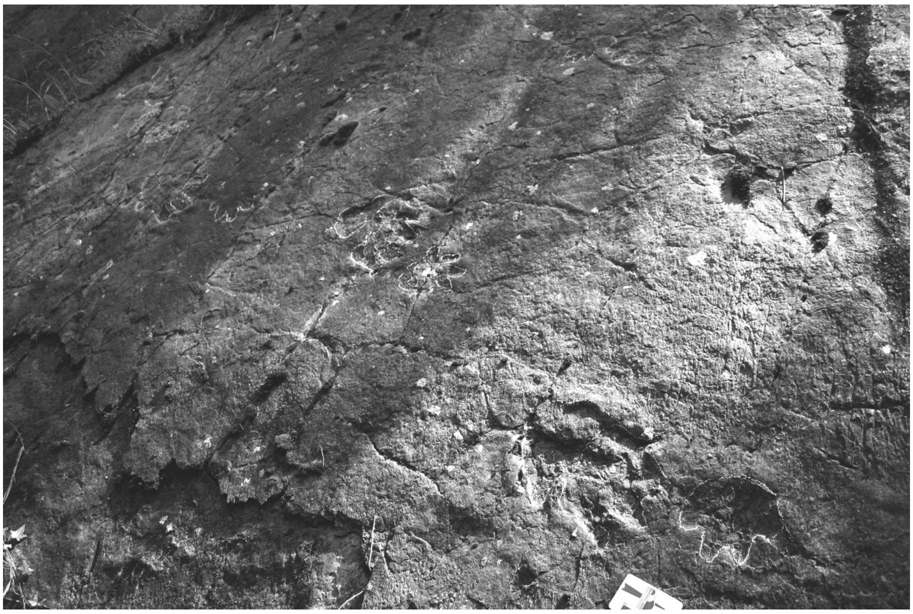

Fig. 8 - BsZ-D trackway on the upper track-bearing level (Level 2). Groove casts are observable in the upper part of the photograph.

est, II and IV are subequal and digit I is shortest. The length of digits is hard to determine because their proximal portion is indistinct. Digit IV could be equal in length with III or even longer. Digits are stubby with rounded to sub-elliptical distal pads, clearly evident in digits I-IV of BsZ-D2 and BsZ-D4. Sub-triangular to sub-elliptical claw marks are well visible in I-IV and are about 2-3 cm in length. Digit I, widened at its distal end, is distinctly inward oriented. Digit V is pyriform, oblique and outward oriented (clearly divergent from the long axis through digit III) but not turned backward; its proximal part is aligned with the axis through digit III. It is placed laterally and behind the digit group I-IV, and subparallel with IV. Digit V tapers distally and its phalangeal portion is not clearly separated from the sub-rounded metatarsal-phalangeal pad. In one case (BsZ-D2) a small notch occurs at half of the length and seems to distinguish the phalangeal part from the metatarsal phalangeal pad. Digit V is isolated from digit group I-IV only in BsZ-D3, while in the other imprints a clear hypex between the two digits is recognizable. Digit angle I-V is widest, I-IV wider or subequal with IV-V. The pes is outward oriented with respect to the midline.

Manus: it is pentadactyl, but in most cases only four digit impressions are preserved, probably corresponding to digit group II-V. Only the manus in BsZ-D3 set displays five well distinguishable digits. Manus

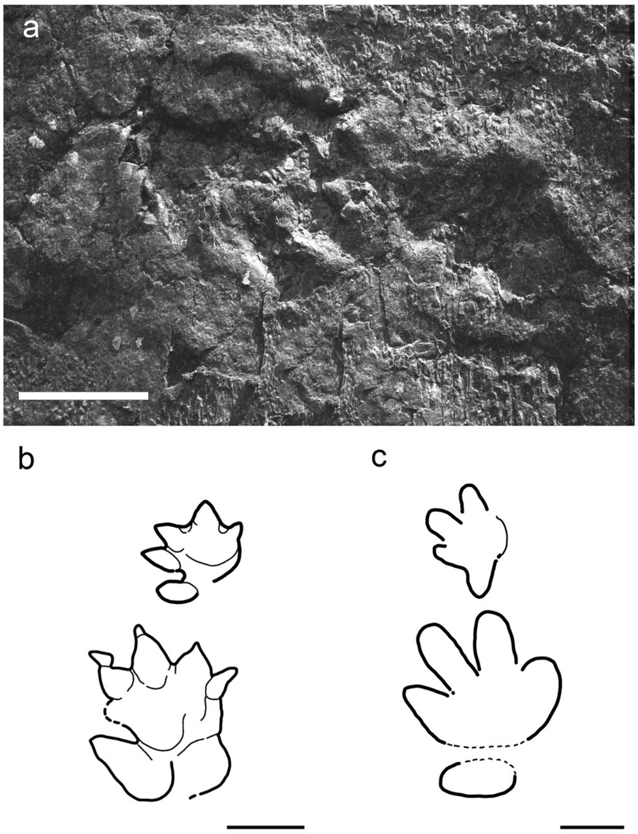

Fig. 9 - a), b) Photograph and outline drawing of BsZ-D4 right manus-pes couple, scale bar 10 cm. c) *Brachychirotherium thuringiacum* (Rühle v. Lilienstern 1938), right manus-pes couple, NKMB F87:62, from Karl & Haubold 2000, scale bar 10 cm.

imprints are slightly wider than long (average PL and PW 12.5 cm and 13.8 cm respectively). An evident crease occurs at the midpoint of its proximal portion. The manus axis is rotated outward, of about 30° on average with respect to the midline.

Digit impressions are spread and taper distally. Digits II-IV are almost equal in length, but II is slightly shorter. I and II are grouped and distinct from III-V. Digits are pointed with distinct claw marks. Phalangeal pad impressions preserved only in II, IV and V.

The manus is placed in front of the pes in a distance between 3.07 to 4.6 cm. It diverges from the long axis of the pes by 10°-43°.

Trackway BsZ-E (Fig. 4c): this trackway indicates an animal moving in the opposite direction to the BSZ-D. It shows less anatomical features, probably due to the different substrate properties. The trackway was left by a quadrupedal trackmaker, however the exact pattern is indistinct. Pace angulation cannot be accurately calculated due to the lack of sure homologous points, though it seems to be less than 180°.

BsZ-E5 could be considered as the best preserved manus-pes couple of the whole trackway and the only one that provides reliable measurement.

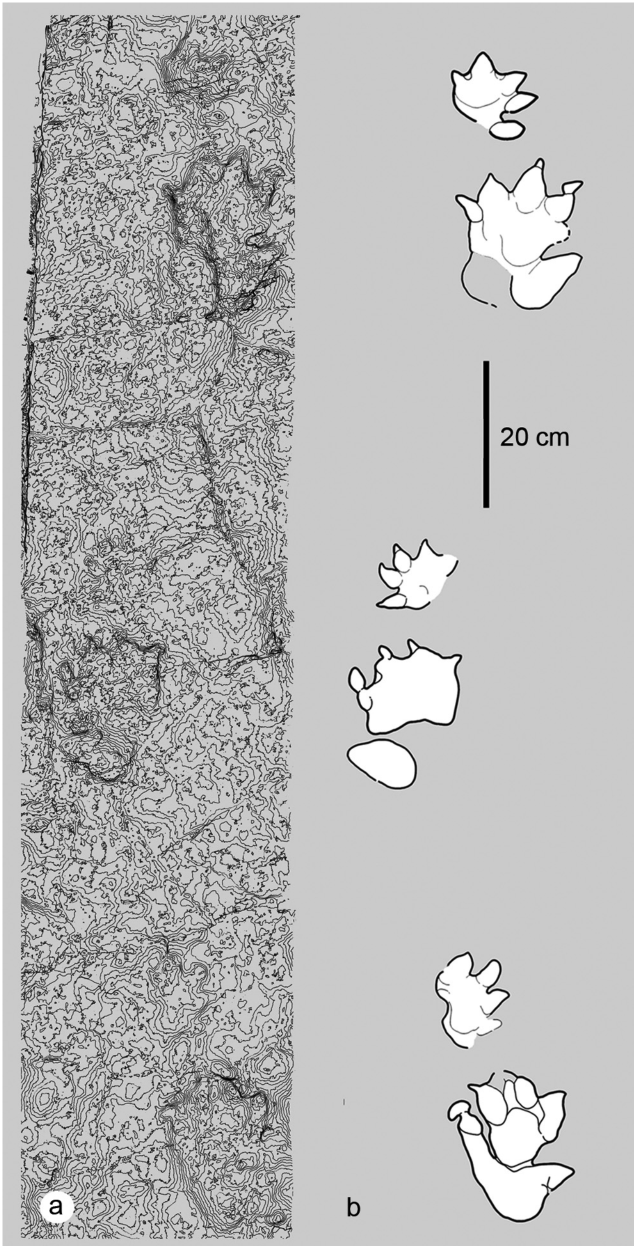

Fig. 10 - *Brachychirotherium thuringiacum* (BsZ-D, Level 1). a) Laser scanner contour map. b) Interpretive drawing. Equidistance = 2mm

Pes: it is clearly pentadactyl and shows short and blunt impressions of distal digits. No claw marks were recognized. Robust and rounded distal phalangeal pads are preserved in digits I-IV. Digit V is slightly rotated outward with respect to the midline while digit I is almost parallel to it, except for its distal end that is distinctly inward oriented. The pes is slightly longer than wide (PL= 25.6 cm; PW= 22.9 cm). The digit width is almost equal for digits II, III and IV (5.5 cm), while for digits I and V it is 2.8 cm and 4.1 cm respectively. Digits II, III and IV with subparallel long axes. Digit III is longest, digits II and IV subequal or IV slightly longer than II. Digit V is placed postero-laterally to digit group

I-IV. It is sub-ovoid in shape and tapers distally. Its length is 11.1 cm and is rotated outward by 24° with respect to digit IV.

Manus: It is wider than long (ML= 8.3 cm, MW= 11.1 cm) and outward rotated (BsZ-E5). Digits II-V are short and pointed at their distal ends, I is missing.

Trackway BsZ- F (Fig. 4c): it includes three partially preserved manus-pes couples.

Pes: the pes is very similar to the one in trackway BsZ-B. It is wider than long (PL= 23.2 cm; PW= 28.7 cm in BsZ-C2). Digit I straight, with two phalangeal pads, bent inward at the distal end and with distinct claw mark. Digits II, III and IV are preserved only by their distalmost portion. As in BsZ-D and BsZ-E, digit V is sub-ovoid.

Manus: it is strongly smaller than the pes, longer than wide and sub-circular in shape (ML= 8.2 cm; MW= 6.8 cm).

Results

Ichnotaxonomy

We herein discuss the trackways of level 2 only, that are the best preserved. Most of the observed features such as the morphology of the imprints, their relative position and the trackway pattern are identical in all three trackways. The comparison of imprints by superimposition of obtained images led us to hypothesize that the analyzed footprints can be referred to the same trackmaker, or rather to trackmakers with comparable functional anatomy of the fore- and hind- limbs. The different morphotypes are more related to substrate or gait than to anatomical features. More in detail, the comparison among the best preserved specimens, namely BsZ-D3, BSZ-E5, BsZ-F1, BsZ-F2, points up close affinities. These are: 1) position of digit V, always aligned with the axis through digit III; 2) morphology of digit I, bent and inward projected distally; 3) correspondence of relative position of manus and pes (i.e. BsZ-D3, BSZ-E5). The different morphological characters of footprints in BsZ-D, BsZ-E and BsZ-F are here interpreted as a consequence of water content increase in the substrate.

The Zone ichnoassemblage was compared with other Triassic tetrapod footprints, namely those attributed to crurotarsans. Dinosaur tracks have been excluded because of their strongly different morphological features.

Chirotherian tracks have a global distribution and different ichnogenera exist, repeatedly revised by many authors using different methodological approaches (e.g. landmark analysis and multivariate statistics; Haubold 1971a, b; Demathieu & Wright 1988; Karl & Haubold 1998; 2000; Demathieu & Demathieu 2004; Klein & Haubold 2004; King et al. 2005; Haubold 2006).

Considering as a paradigm the trackway BsZ-D, can be referred to a quadrupedal trackmaker with plantigrade, pentadactyl pes and manus imprints. Digits shape and proportion match those recorded in footprints of *Brachychirotherium* Beurlen, 1950. *Brachychirotherium* was originally named for footprints from the Upper Triassic (Carnian) of Germany. The following diagnosis has been given for the ichnogenus (after Karl & Haubold 1998): pes-manus posture plantigrade-digitigrade, where pedal digit group I-IV is nearly as wide as long and interdigital angles are the following: I^V > 40°, I^V= 80°-95°, III^V= 40°-~55°, IV^V= ~30°-~45°. Digit V oblique and anterior oriented but never turned backward as in *Chirotherium* isp. No distinct phalangeal portion is visible (Karl & Haubold 1998, 2000; Klein & Haubold 2003; King et al. 2005). The trackway is narrow, imprints show a pronounced outward rotation (Demathieu & Wright 1988), or orientation more parallel to the midline (Lockley & Hunt 1995, fig. 3.2). All these diagnostic characters reveal great correspondence with the analyzed material. Particularly similarities with *Brachychirotherium thuringiacum* (Rühle v. Lilienstern 1938) and described by Karl & Haubold (1998, 2000), from the Coburger Sandstein (Middle Keuper, Carnian/Norian, northern Bavaria) are distinct. More in detail, the specimen NKMB F87:62 (Karl & Haubold 1998, fig. 7a; Karl & Haubold 2000, fig. 10a-11) shares different characters with manus-pes couples of the trackway BsZ-D, such as the morphology and position of digit V, the splayed digits and especially the outward rotation of the manus imprint. The latter displays only four distinct digit impressions, probably II-IV, as in BsZD. No claw marks occur on the German material. Here, digits appear stout and rounded, pointed only in IV. Nevertheless the Zone material differs from *B. thuringiacum* by the angle between digits and because in the latter digit group I-IV is almost wider than long.

The imprints in the trackways of Zone are also similar to following specimens from the German Keuper: MB 1969.54.244 (Karl & Haubold 1998; fig. 6a, lectotypus, Blasensandstein, Hassberge Formation, Südthüringen) and NMC (Karl & Haubold 1998; fig. 6b; without number, Unterer Burgsandstein, Löwenstein Formation, Nordbayern). The striking difference observed in both these specimens, as well as in other specimens attributed to *Brachychirotherium*, is that pedal digit II is longer than IV. The Zone material is characterized by a digit IV sub-equal or even longer than digit II.

Another ichnotaxon of similar morphology is *Brachychirotherium eyermani* (Baird 1957), which is known only by pes imprints. Particularly *B. eyermani* shows a noticeable similarity with the Zone footprints in the morphology of digit I that is bent distally and directed inward. Its overall shape closely resembles that of BsZ-A2, with digit V being isolated from digit group I-IV and by distinct claw traces on all digits. Furthermore digit group I-IV is as long as wide and digits II and IV are subequal.

The poorly preserved trackway BsZ-A from level 1 has a similar trackway pattern to that occurring in the younger one. Even if no anatomical details could be observed neither in the pes nor in the manus, pes and manus posture and the values of pace angulation (around 150°-154°) closely match those gained for BsZ-D. Thus it can be prudentially assumed that both were produced by a trackmaker with similar autopodial proportions and anatomy.

Trackway BsZ-C is too incomplete for ichnotaxonomical purposes, while BsZ-B shows peculiar features that is worth to be discussed. The imprint morphology is typical for chirotherians, especially in the pes, which is pentadactyl, with a suboval, distally pointed and slightly outward oriented digit V. The BsZ-B trackway could be compared with the only two wide-gauge quadrupedal trackways discovered in the Late Triassic of NE Italy, specifically in the western Carnian Pre-Alps (Cio de la Fratta, northern Friuli; Dalla Vecchia & Mietto 1998; Dalla Vecchia 2006) and in the Julian Alps (Dogna Valley, Friuli Venezia Giulia; Dalla Vecchia 1996; Avanzini et al. 2007). The former is characterized by a similar pace angulation with the respect as in BsZ-B but with reduced values of pes length and stride; the pes imprints have slight or no outward rotation as well. The latter is marked by morphologically different pes imprints that, though pentadactyl and plantigrade, are elongate with short and narrow digits. Track and trackway parameters are nearly half of the values measured for the BsZ-B.

Both trackways, tentatively attributed to wide-bodied crurotarsans (aetosaurs; Dalla Vecchia 2006; Avanzini et al. 2007), are therefore quite unlike in their general morphology and trackway pattern.

Trackmakers

After analysis of the trackways in the Val Sabbia Sandstone BsZ-A, BsZ-D, BsZ-E and BsZ-F can be assigned to the ichnogenus *Brachychirotherium*. This ichnogenus is known by a global distribution (Baird 1957; Beurlen 1950; Haubold 1971b; Olsen & Galton 1984; Silvestri & Szajna, 1993; Szajna & Silvestri 1996; Karl & Haubold 1998, 2000; Klein & Haubold 2003, 2004; Szajna & Hartline 2003; Demathieu & Demathieu 2004; Lucas et al. 2005, 2006a, b, 2007; Avanzini & Mietto 2008; Melchor & De Valais 2006; Lucas & Tanner 2007; King et al. 2005; Klein et al. 2006; Hunt & Lucas 2007; Todesco et al. 2008; Diedrich 2008, 2009), mainly in the Middle-Upper Triassic and is generally considered the track of crurotarsan archosaurs. However there is not a shared consensus about the potential trackmaker. *Brachychirotherium* was alternatively referred to derived archosaurs (Karl & Haubold 1998), basal archosauromorphs (i.e. *Euparkeria*; Diedrich 2008, 2009) and rauisuchians (Olsen et al. 2002). For the Late Triassic *Brachychirotherium* Lockley & Hunt (1995), Heckert & Lucas (2000), Hunt & Lucas (2007) considered an aetosaurian affinity as the most suitable. This statement is based on the range of sedimentary environments in which it was found, strongly suggesting a plant eater trackmaker, and on the relative abundance of aetosaurs compared with rauisuchians in the Late Triassic body fossil record.

Conclusions

The Zone tetrapod ichnoassemblage represents the first finding of chirotherian tracks in the Late Triassic (early-middle Carnian) of the Lombardy region. The material is represented by a total of about seventy footprints, arranged in six both wide and narrow gauge quadrupedal trackways. At least three trackways can be assigned with a fair degree of confidence to the ichnogenus *Brachychirotherium* Beurlen, 1950, representing the first documented evidence of this ichnogenus from the Late Triassic of the Southern Alps. The best preserved tracks (BsZ-D) are morphologically similar to *Brachychirotherium thuringiacum* (Rühle v. Lilienstern 1938) from the Late Triassic of Germany. The footprints were probably produced by quadrupedal crurotarsan archosaurs.

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