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UPPER TRIASSIC VERTEBRATE TRACKS FROM KRAKÓW–CZĘSTOCHOWA UPLAND, SOUTHERN POLAND

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Abstract: The first Upper Triassic vertebrate fossil tracks are documented from the Zawiercie locality, Kraków–Częstochowa Upland, southern Poland. The most characteristic components of the assemblage are tracks, assignable to archosaurs and dicynodonts. The inferred composition of the fauna is comparable to those of much better studied, contemporaneous sites in Italy, Argentina and the USA.

Key words: vertebrate tracks, Upper Triassic, Kraków–Częstochowa Upland, Poland.

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INTRODUCTION

Southern Poland is an area continuous with the Triassic Germanic Basin (Szulc, 2007). The Upper Triassic strata of this basin outcropping in southern Poland have yielded new palaeontological sites for the last 20 years (see overview in Sulej *et al.*, 2011). Although the findings of Triassic terrestrial body fossils are not new in this area (see references in Rauhut and Hungerbühler, 1998), clearly, there is a growing interest in this field of study. The revitalisation started with the discovery of the fossil site in Krasiejów in Silesia, southern Poland (Dzik and Sulej, 2007), which has yielded, amongst others, body fossils of dinosauromorphs showing some affinities with ornithischians (Dzik, 2003). Subsequently, new sites have been added to the list. These sites are Lipie Śąskie, Woźniki and Poręba. The two sites (Lipie Śąskie and Woźniki) have yielded, amongst others, the body fossils of archosaurs (?dinosaurs) and large dicynodonts (Dzik *et al.*, 2008; Sulej *et al.*, 2011; 2012; Niedźwiedzki *et al.*, 2012).

Up to now, vertebrate tracks have been reported from only two of the three Upper Triassic Silesian sites, Lipie Śląskie and Woźniki (Dzik *et al.*, 2008; Niedźwiedzki and Sulej, 2008; Niedźwiedzki, 2011; Sulej *et al.*, 2011).

Here, by recording the new site and illustrating tracks, the authors supplement the data on the Upper Triassic vertebrate tracks from southern Poland. The new fossil tracks come from Zawiercie, in the Kraków–Częstochowa Upland, southern Poland (Fig. 1). The material described here is the first pertaining to Upper Triassic vertebrate tracks from the Kraków–Częstochowa Upland.

GEOLOGICAL BACKGROUND

The material studied comes from the Zawiercie site, which is located in the Kraków–Częstochowa Upland in southern Poland (Fig. 1). The fossil site is a sequence of Norian (Upper Triassic) strata (see Szulc *et al.*, 2006). These strata were excavated during construction of a city dump in Zawiercie. As a result, all specimens discussed and figured in this paper have been located *ex situ* (on a pile of sediment). Unfortunately, currently there is no a single easily accessible outcrop, where these strata are exposed and suitable for study. This emphasises the significance of the Zawiercie site as a valuable source of palaeontological information on Late Triassic ecosystems in the area.

The Upper Triassic strata, occurring in the Zawiercie site (see Kotlicki, 1967), belong to the belt of Upper Triassic strata which stretches between Opole in the west and Olkusz in the east (Szulc and Becker, 2007; Fig. 1). These Upper Triassic strata from Zawiercie are known informally as the Woźniki Limestone. Limestones, including bivalve coquinas (Racki, 2010, fig. 2), carbonate concretions and conglomerates alternating with red beds, form the Woźniki Limestone, a unit deposited under an arid and semiarid climate (see Pieńkowski, 1988; Szulc *et al.*, 2006).

The conglomerates contain the remains of freshwater bivalves and vertebrate bones (Szulc *et al.*, 2006; Budziszewska-Karwowska *et al.*, 2010; Racki, 2010; Skawina and Dzik, 2011). Vertebrate tracks are preserved on soils of these layers. Carbonate concretions often contain rich plant materials, vertebrate fossils, as well as miospores (*Corollina meyeriana*, *Ovalipolis ovalis*, *Brachysaccus neomun-*

Fig. 1. Location of all Upper Triassic fossil sites in Poland

danus, *Enzonalasporites* sp.), which are well-known morphotypes of the Polish Upper Triassic (cf. Orłowska-Zwolińska, 1985). Stromatolite-like structures also have been found at the site (compare Szulc *et al.*, 2006; Racki, 2010, fig. 3), and these structures are interesting palaeoenvironmental indicators awaiting further study.

The age of the Zawiercie site

According to Szulc *et al.* (2006), Lipie Śląskie is contemporary with the site at Zawiercie. According to this author, both these sites are probably of Norian age (Upper Triassic; see palynological zone IVb in Szulc *et al.*, 2006). However, this view has been challenged by Dzik *et al.* (2008) and subsequently by Niedźwiedzki and Sulej (2008), who postulated a Rhaetian age for the Silesian site (Lipie Śląskie). This significant inconsistency undermines the application of fossil finds from the area for comparison with other sites in the world and restricts their potential utility in any discussion of faunal turnover (extinction) at the Jurassic–Triassic boundary (e.g., Benton, 2005). The Norian age of the Zawiercie site might be confirmed by the presence of the miospore *Corollina meyeriana* (characteristic for sediments of that age) found by Wawrzyniak during palynological analysis of sediments in which the tracks were found. This would support the results of Szulc et al. (2006) about the Norian age. A separate scientific project has been initiated to help in solving this stratigraphic issue (Racki, 2010). Until this problem is solved, the Zawiercie site should be assigned only on a general basis to the Upper Triassic.

MATERIAL AND METHODS

The field work (student summer camps) at the Zawiercie site was conducted every summer since 2009. The summer student camps are organized by the Museum of Faculty of Earth Sciences at the University of Silesia (Sosnowiec, Poland) with logistic support from the city of Zawiercie.

The material collected is diverse and includes: fossil bones of dicynodonts (some bearing bite marks; Budziszewska-Karwowska *et al.*, 2010), archosaurs, fishes, bivalves, remains of plants and vertebrate tracks. This material is held by the Museum of the Faculty of Earth Sciences at the University of Silesia (collection abbreviation is WNoZ). Some of the largest specimens of vertebrate tracks that have been figured and discussed in this paper were left in the field. In such cases, the specimens were covered with a protective veneer of plaster of Paris.

The measurements of track parameters were made in ImageJ and graphics were prepared with Inkscape and Gimp. All three applications are readily accessible in the Ubuntu 10.04 (Lucid Lynx) Software Centre.

Owing to the limited number of specimens collected and in particular their weak state of preservation, the authors have decided not to give precise ichnotaxonomic labels to this material. They note only the similarity of the tracks considered to known ichnotaxa.

VERTEBRATE TRACKS

All of the vertebrate tracks described are preserved as hypichnia (see terminology in Martinsson, 1970), which are natural casts preserved on the lower surfaces of beds representing carbonate conglomerates. The presence of the fossil tracks on the soles of conglomeratic beds may indicate that these trace fossils represent the casts of partially scoured deep tracks and/or scoured and reburied undertracks. This is because some erosion is expected to be associated with energy pulses, resulting in the deposition of gravel-grade material.

Tracks of archosaurs
Fig. 2

Material. Two specimens: WNoZ/SS/2/32 and WNoZ/SS/2/38.
Description. These tracks have traces of three digits (II–IV). In the case of the track illustrated in Figure 2, the traces of the anterior phalangeal pads are missing. However, this is a track with well preserved morphology. There are phalangeal pads demarcated by narrower inter-pad creases (Fig. 2). The trace of digit II has pads 1 and 2 preserved (starting the count from the proximal pad) and is 10 cm long. The trace of digit III has pads 1 (complete) and 2 (fragmentary) preserved. It is 7 cm long. The trace of digit IV has pads 1–3 and a fragment of pad 4 preserved. The trace of digit IV is 12 cm long and pad 1 extends posteriorly, giving the asymmetric appearance to the posterior part of the track (compare Farlow *et al.*, 2000). The length of the track (measured in axis of digit III) is 14 cm, and this is the longest, although still incomplete specimen. The inter-digital angle is low (~39°).
Remarks on potential track-makers. These tracks are preserved well enough to allow some basic conclusions. These tracks display features, such as low inter-digital angle, asymmetric "heel" and in some cases (Fig. 2) visible pads. These features occur in tracks of theropods (see Farlow *et al.*, 2000). In general, the morphology of these tracks resembles that of grallatorid tracks (*Grallator*, *Anchisauripus*; e.g., Olsen *et al.*, 1998; Melchor and Valais, 2006).

Grallator – Anchisauripus – Eubrontes are three typical theropod-made ichnogenera reported from terrestrial deposits of the Upper Triassic and Lower Jurassic strata of North America, South America and Europe (e.g., Hunt *et al.*, 1998; Olsen *et al.*, 1998; Melchor and Valais, 2006; Niedźwiedzki, 2006; Lockley, 2009). These three ichnogenera form a spectrum of size with *Grallator* as the smallest and *Eubrontes* the largest (Lockley, 1991, 2009; Niedźwiedzki, 2006). The morphological differences between these ichnogenera may mirror the taxonomic differences of their respec-

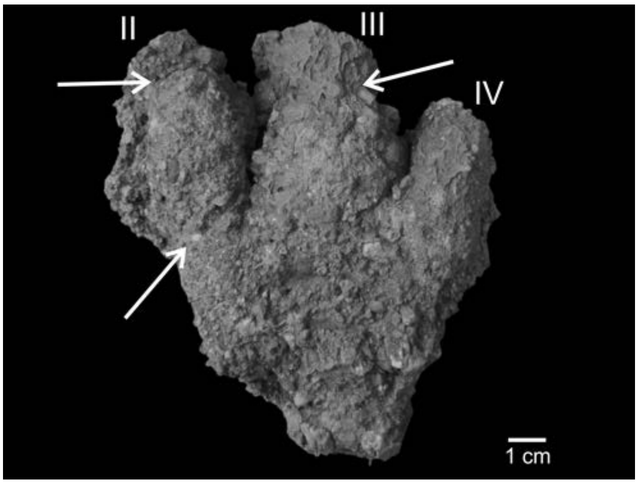

Fig. 2. The fossil track with three traces of digits (Roman numerals: I, II, III indicate traces of digits), with low inter-digital angle and asymmetric "heel"; arrows show narrower zones, which are boundaries between digit pads (WnoZ/SS/2/32)

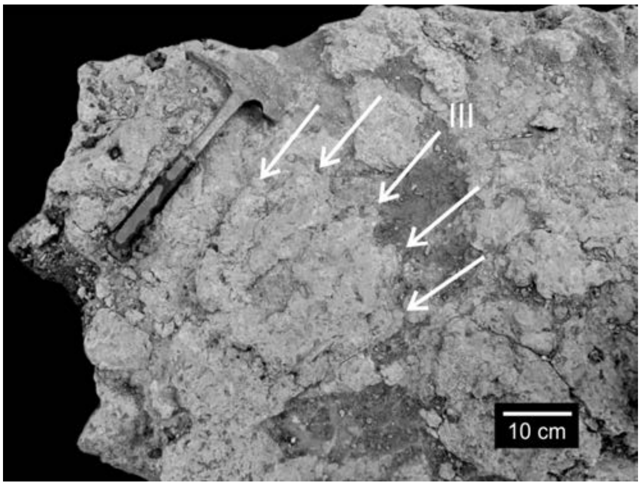

Fig. 3. The isometric fossil track with large metatarsal pad (493 cm^2) and with short traces of digits I–V (field photography, specimen left in the field, Roman numerals: I–V indicate traces of digits)

tive track-makers or record the ontogeny of one trace maker (Olsen *et al.*, 1998).

However, similar track morphologies may occur also in sauropodomorph dinosaur tracks (*Evazoum*, see Lucas *et al.*, 2006; Porchetti *et al.*, 2008) and in incomplete preserved tracks, belonging to the Chirotheriidae ichnofamily (see ichnofamily overview in King *et al.*, 2005). Therefore, owing to the limited material, the assignment to an archosaur trace-maker appears to be the most cautious.

Tracks of ?dicynodonts
Fig. 3

Material. Two large tracks, both specimens were left in the field, because of the large size of the blocks.
Description. These tracks are large and their maximum length is comparable to their width. For example, for the track shown in Figure 3, the length/width ratio is = 0.96 (maximum length: 26 cm, maximum width is 27 cm). These tracks clearly belong to a plantigrade trace-maker. This is because the track morphology is dominated by a large metatarsal pad (with an area of 493 cm^2; Fig. 3). On the other hand, the traces of digits (I–V) are short and of nearly equal length (2–3.5 cm). Traces of external digits (I and V) are slightly shorter than traces of internal digits (II, III and IV). The digit traces have blunt tips, and therefore there is no evidence for sharp claws on the foot of the track-maker.
Remarks on potential track-makers. The isometric shape of the track with short digit traces and blunt endings resembles the tracks of dicynodontids (Hunt *et al.*, 1993; Lucas *et al.*, 2003; Surkov *et al.*, 2007). An isometric track was also figured from Woźniki and attributed to a dicynodont (Sulej *et al.*, 2011).

Unassigned track of ?archosauromorphs
Figs 4, 5

Material. Two specimens: WNoZ/SS/2/34 and WNoZ/SS/2/37.
Description. These poorly-preserved tracks have three traces of digits, all of them similar in length. The lengths of digits for the track from Fig. 4 are as follows: digit II: 5.4 cm, digit III: 5.8 cm, digit IV: 5.4 cm and for track from Fig. 5 are as follows: digit II: 4.9 cm, digit III: 5.8 cm, digit IV: 4.7 cm. These tracks also have a symmetric posterior ("heel") region. These tracks have a wide inter-digital angle between digits II and IV, which is 136° in the track, shown in Fig. 4, and 76° for the track from Fig. 5.

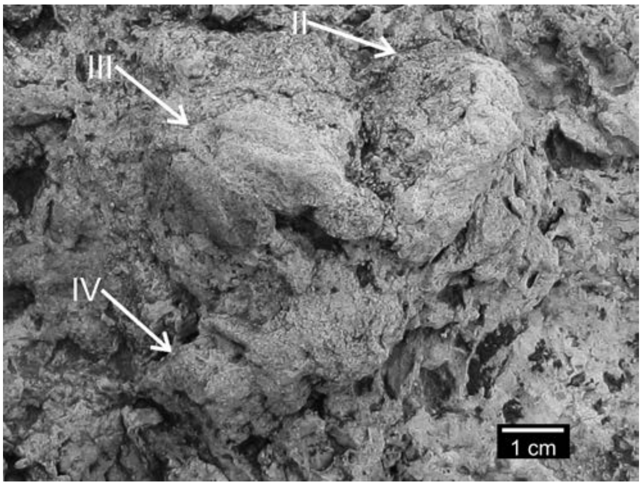

Fig. 4. The fossil track with traces of three digits (Roman numerals: I, II, III indicate traces of digits), being of equal length and with symmetric "heel" and wide inter-digital angle (136°, WnoZ/SS/2/37)

Remarks on potential track-makers. The symmetrical appearance of the posterior part of the tracks, the wide inter-digital angle and digit traces of nearly equal lengths all suggest that the tracks are similar to those of ornithischians (e.g. *Anomoepus*; Lockley, 2003; Olsen and Rainforth, 2003; Niedźwiedzki, 2011). On the other hand, these tracks also might represent theropod tracks, if part of the "heel" is missing (which may be the case, Fig. 4). The track in question also could fit the *Coelurosaurichnus* (Gand and Demathieu, 2005) or even prosauropod tracks (i.e. *Evazoum* (*Pseudotetrasauropus*;, see Lucas *et al.*, 2006), if the digit I is missing. In such a case, a sauropodomorph footprint could readily be mistaken for a theropod or ornithischian footprint (see Farlow and Lockley, 1993). However, the poor state of preservation precludes the possibility of an accurate determination of a track-maker in this case.

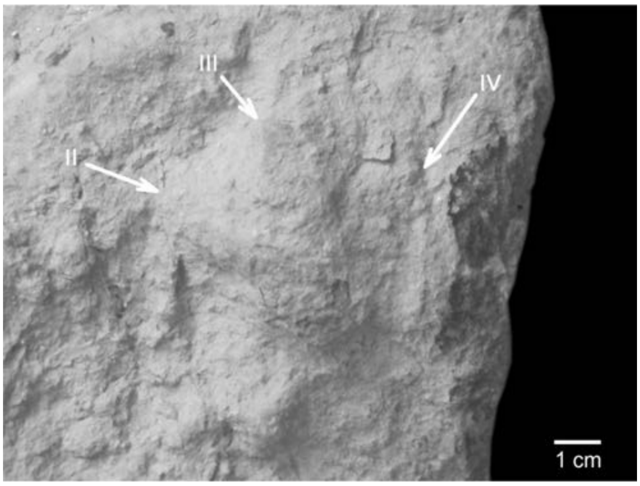

Fig. 5. The fossil track with traces of three digits (Roman numerals: I, II, III indicate traces of digits), being of equal length and with symmetric "heel" and wide inter-digital angle (76°, WnoZ/SS/2/34)

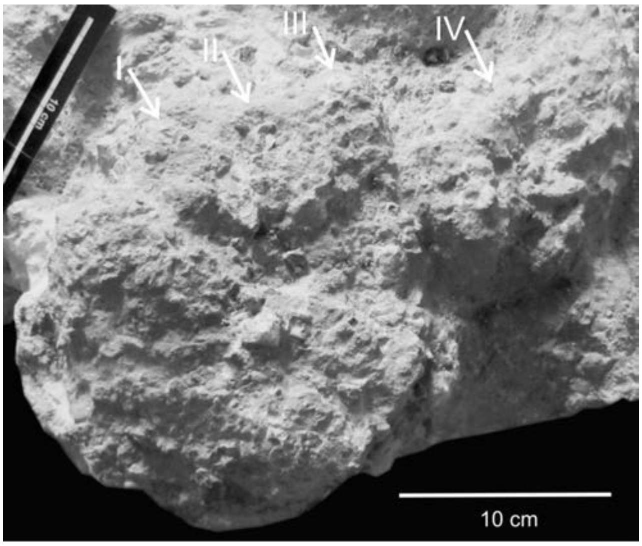

Fig. 6. The fossil track with overall morphology, comparable to *pes* of prosauropods (WNoZ/SS/2/33)

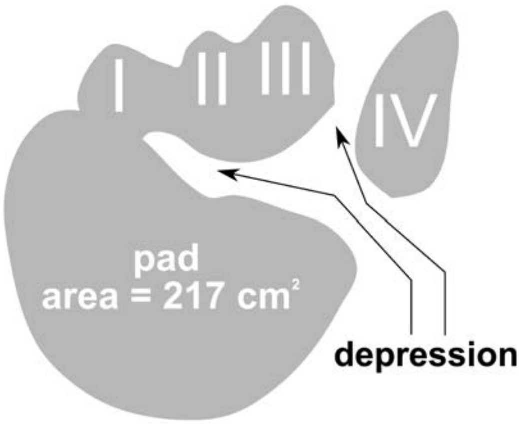

Fig. 7. Drawing of fossil track, shown in Fig. 6, not drawn to scale (Roman numerals: I–IV indicate traces of digits)

Unassigned track of a plantigrade animal
Figs 6, 7

Material. Single specimen: WNoZ/SS/2/33.
Description. The track shown in Figure 6 is a structure 10 cm deep. The length of the track along the axis of the longest digit IV is 29 cm. This track belongs to a plantigrade animal with a morphology dominated by a single metatarsal pad with an area of 217 cm^2. This pad is wider (maximal width: 20.5 cm) than long (maximal length: 12 cm). There are four digit traces in the front of the pad. The lengths of digit traces increase from digit trace I to IV (digit I: 5.5 cm, digit II: 7 cm, digit III: 8 cm, digit IV: 9.3 cm). A wide depression separates the metatarsal pad and digit group II–IV. The width of the depression increases toward the trace of digit IV. An additional longitudinal depression separates digit IV from digit group I–III.
Remarks on potential track-makers. The large metatarsal pad, the pattern of digit lengths (I<II<III<IV) and configuration of depressions are all features which, in this combination, can be found in prosauropod tracks (*pes*). Good examples are *Navahopus coyoteensis*, an ichnotaxon from the Lower Jurassic strata of USA (compare Milàn *et al.*, 2008) and Upper Triassic *Eosauropus* (*Tetrasauropus*, see Lockley *et al.*, 2001; Lucas *et al.*, 2006) whose (*pes*) shows some morphological similarity with the track considered (Fig. 6). Taking into consideration the poor state of preservation of the material studied, the authors only are able to describe this track as attributable to a plantigrade animal. However, it is worth mentioning that some workers (see Hunt and Lucas, 2006) returned to the 'synapsid concept' and suggested that *Navahopus* represents an extramorphological variant of a large tritylodont trackway. Therefore, the possibility of a 'synapsid' origin of the fossil track also should be taken into account.

DISCUSSION OF FAUNAL COMPOSITION

The sample studied, although restricted in quantity, indicates the presence of a diversified vertebrate fauna and is a significant contribution to the knowledge of Late Triassic ecosystems of southern Poland. Tracks assignable to the archosaurs show some similarity to tracks of the grallatorid ichnogenera (*Grallator*, *Anchisauripus*). Accordingly, the authors propose the possibility of linking the origin of these tracks to the theropods, probably to members of the Coelophysoidea (Lockley, 1991), as all of the determinable theropod remains from the Upper Triassic strata of Europe belong to the Coelophysoidea (see Rauhut and Hungerbühler, 1998). Tracks, interpreted as formed by members of the Coelophysoidea, have been reported from Lipie Śląskie and Woźniki (Dzik *et al.*, 2008; Niedźwiedzki and Sulej, 2008; Niedźwiedzki, 2011; Sulej *et al.*, 2011). The ichnological evidence for the presence of Coelophysoidea at the site in Zawiercie would be of special interest. Previously, from the same site, Budziszewska-Karwowska *et al.* (2010) described dicynodontid tibia with tooth marks and attributed those marks to the life activity of members of the Coelophysoidea. However, though assigned to the archosaurs, the tracks also may represent incomplete sauropodomorph tracks (e.g. *Evazoum*, Lucas *et al.*, 2006) or weakly preserved tracks of the Chirotheriidae ichnofamily (King *et al.*, 2005).

The large, isometric plantigrade tracks are attributed here to dicynodonts. Although not proven, this interpretation is quite likely, because the body fossils of dicynodonts are already known from the Polish Upper Triassic, including that of the Zawiercie site (Dzik *et al.*, 2008; Budziszewska-Karwowska *et al.*, 2010; Sulej *et al.*, 2011). Other support for this interpretation comes from a comparison of the outline of one of the studied tracks with the proportions of the osteology of the dicynodontid foot, as exemplified by the foot of Middle Triassic *Tetragonias njalilus* (Fröbisch, 2006; Fig. 8).

The most problematic material is represented by the single track, illustrated in Fig. 6. This is because its morphology resembles tracks, referable to the prosauropods and the dicynodonts. However, the remains (body and trace fossils) of prosauropods are absent from other Polish sites (Krasiejów, Lipie Śląskie, Woźniki; Dzik and Sulej, 2007; Dzik *et al.*, 2008; Sulej *et al.*, 2011). In the contemporaneous strata of Germany, prosauropods are quite common occurrences (Weishampel and Chapman, 1990; Sander, 1992). At present, the authors only can note a similarity of the studied material to the *pes* morphology of some Upper Triassic and Lower Jurassic ichnogenera tracks, interpreted as produced by sauropodomorphs (Milàn *et al.*, 2008; Porchetti *et al.*, 2008). However, the present authors also note that the alternative interpretation as a synapsid track should also be considered.

Long-term collecting is needed to better compare Polish Late Triassic vertebrate communities with German communities and the faunal composition at various Polish sites. Preliminary study of the fossil flora has revealed slight differences between the Lipie Śląskie and Zawiercie sites. The carbonate concretions found at the Zawiercie site contain *Equisetales* stalks and leaves that have not been recorded at Lipie Śląskie (Wawrzyniak, 2010). This may indicate some local climatic differences (e.g. higher moisture at the Zawiercie site). Further study is needed to verify whether possible differences in food composition and/or food availability might be paralleled by differences in the assemblage of first-order consumers at various Polish sites. However, at present in view of the poor state of knowledge of the floral assemblages at both sites, any conclusions would be highly speculative.

In general, the tracks studied can be, with some confidence, attributed to archosaurs and dicynodonts, the remains of which are typical body fossils that one can find at the Silesian sites. Such a composition would be more or less consistent with the better understood ichnofaunas of the Upper Triassic in Europe (Nicosia and Loi, 2003, Italy), South America (Melchor and Valais, 2006, Argentina) and North America (Gaston *et al.*, 2003, USA).

CONCLUSIONS

The Upper Triassic site at Zawiercie has yielded the fossil tracks of vertebrates. This record is the first from the Upper Triassic of the Kraków–Częstochowa Upland in southern Poland. The fossil tracks indicate the presence of archosaurs and dicynodonts. This composition is consistent with other evidence, already recorded from Upper Triassic sites in southern Poland (Krasiejów, Lipie Śląskie and Woźniki) as trace and body fossils.

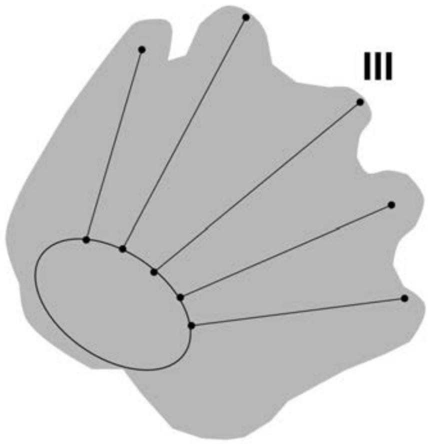

Fig. 8. Dicynodont track and foot compared. Superposition of drawing of dicynodont track based on track shown in Fig. 3 and drawing of osteological proportions of dicynodontid foot based on Fröbisch (2006). The solid black lines indicate relative lengths of metatarsals and digits, whereas the oval shows the tarsalia area. Track and foot drawings are not to scale, but this superposition is intended to show the general similarities in proportions

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