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Gigantic footprint of a theropod dinosaur in the Early Jurassic of Poland

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A gigantic theropod footprint was discovered in the Hettangian alluvial plain deposits of the Holy Cross Mountains, central Poland. This discovery, along with a previous find in Arizona, provides ichnological evidence of a global occurrence of gigantic predatory dinosaurs in the Early Jurassic. The geographic and stratigraphic distribution of such gigantic theropods in Jurassic times was wider than generally believed. However, it seems justified to assume that very large theropods were less common in the Early Jurassic communities than they became in the Late Jurassic.

The theropod print described in this report was found at the Sołtyków site, known also as Odrowąż (Gierliński & Pieńkowski 1999: fig. 1), in August 1999. The specimen came from the uppermost part of the Sołtyków exposure belonging to the Zagaje Formation (Pieńkowski & Gierliński 1987; Gierliński 1991; Gierliński & Pieńkowski 1999). The exposure is a well known paleontological site containing numerous theropod and sauropod tracks (Gierliński 1991; Gierliński & Sawicki 1998; Gierliński & Pieńkowski 1999), and a typical early Liassic flora (Wcisło-Luraniec 1991). The xeromorphic *Hirmeriella*, the dominant plant in the Early Jurassic forest community of Sołtyków suggests a dry habitat or a dry season (Reymanówna 1991). Frequent forest fires are indicated by charcoal occurrences (Reymanówna 1993). The entomofauna from Sołtyków resembles Early Jurassic insects from Asia (Wegierek & Zherikhin 1997). According to those authors, the Sołtyków insect assemblage suggests warm, subtropical habitat typical for the Euro-Chinese regions in the Early Jurassic times. An early Hettangian age for the Zagaje Formation has been established on the basis of sequence stratigraphy (Pieńkowski 1991; Gierliński & Pieńkowski 1999).

The theropod track is preserved on the underside of a large, isolated sandstone block. The specimen is the largest (54 cm long) theropod footprint ever found in the Lower Jurassic (Liassic) of Poland. It has been brought to the Geological Museum of the Polish Geological Institute, abbreviated as Muz. PIG, and catalogued as specimen no. 1661.II.

Depositional environment and track preservation

The specimen, Muz.PIG 1661.II, is preserved as a natural cast on a sandstone slab. The footprint was left in a muddy substrate, probably in a drying pond on the alluvial plain. Plant roots, which are common elsewhere in the outcrop, are absent around the track. This suggests that the time span between drying of the pond and the subsequent flood event, which brought the sand, was too short to allow development of vegetation. Before the track was formed, the muddy pond was inhabited by numerous bivalves, which left their resting tracks (*Lockeia* sp.) and deeper dwelling structures in the sediment. The trackmaker's foot pushed up the sediment, forming a convex rim around the posterior part of the footprint. Subsequently the muddy surface was quickly cov-

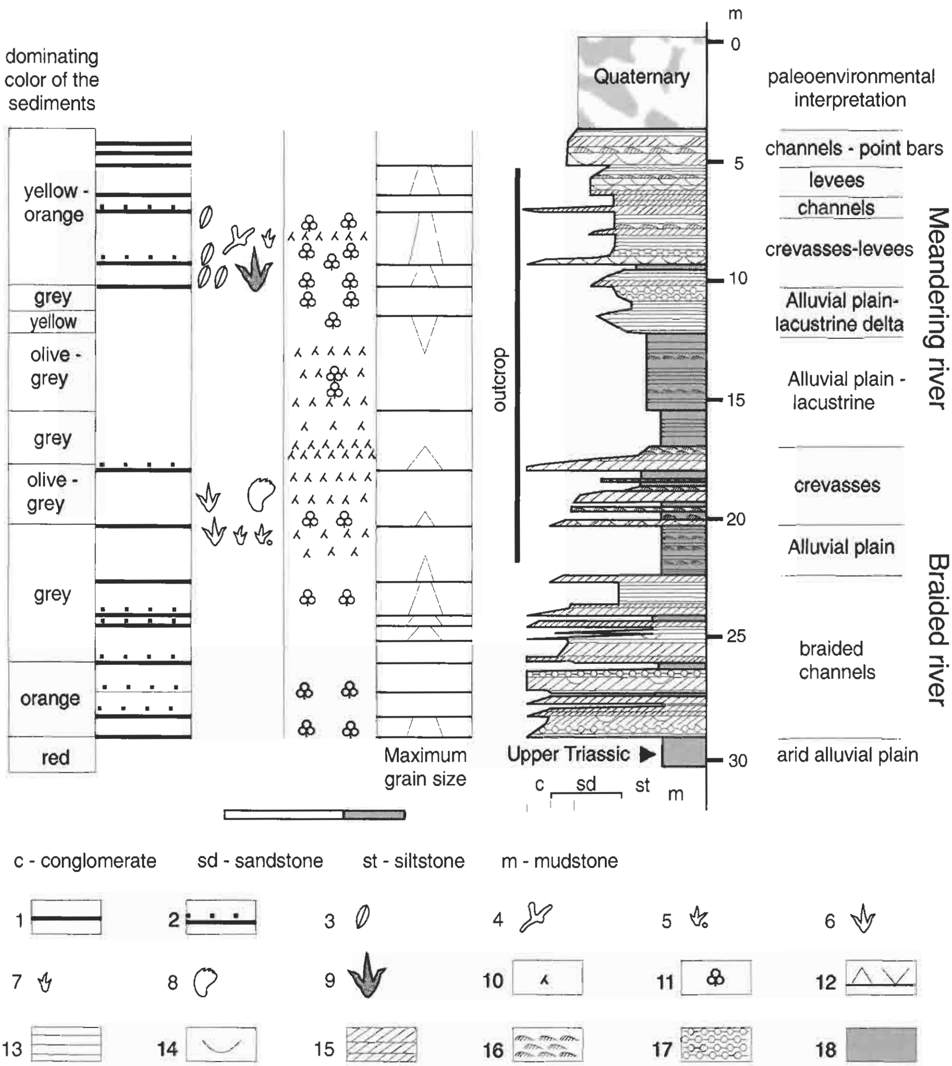

Fig. 1. Stratigraphic and sedimentological profile of the Sołtyków borehole with palaeoenvironmental interpretation. Bar shows the section exposed in the outcrop. 1, erosional surfaces; 2, erosional surfaces with mud clasts; 3, bivalve resting tracks (*Lockeia* sp.); 4, insect burrows (*Spongeliomorpha* sp.); 5, supposed basal ornithischian footprint (?*Anomoepus* sp.); 6, large theropod tracks (*Kayentapus soltykovensis* Gierliński, 1991); 7, medium-sized theropod footprints (*Anchisauripus* sp.); 8, sauropod tracks (*Parabrontopodus* sp.); 9, gigantic theropod track (cf. *Megalosauripus* sp.); 10, plant roots; 11, drifted plant remains; 12, boundaries of cycles and cycle character: fining-upward (left) and coarsening-upward (right); 13, horizontal lamination; 14, trough cross-bedding; 15, tabular cross-bedding; 16, ripple-drift cross lamination; 17, contorted bedding; 18, microlaminated or massive mudstones and claystones.

ered by sand delivered by a flood. In a vertical section, the slab shows large-scale, trough cross-bedding with slightly bent laminae, inclined at about 15°, representing the internal structure of a large megaripple. Mud clasts (up to 2 cm diameter) and plant remains occur along the cross-bedded laminae. The upper surface of the slab is covered by slightly asymmetric ripple marks, which suggest waning energy conditions. All these features clearly indicate that the sand

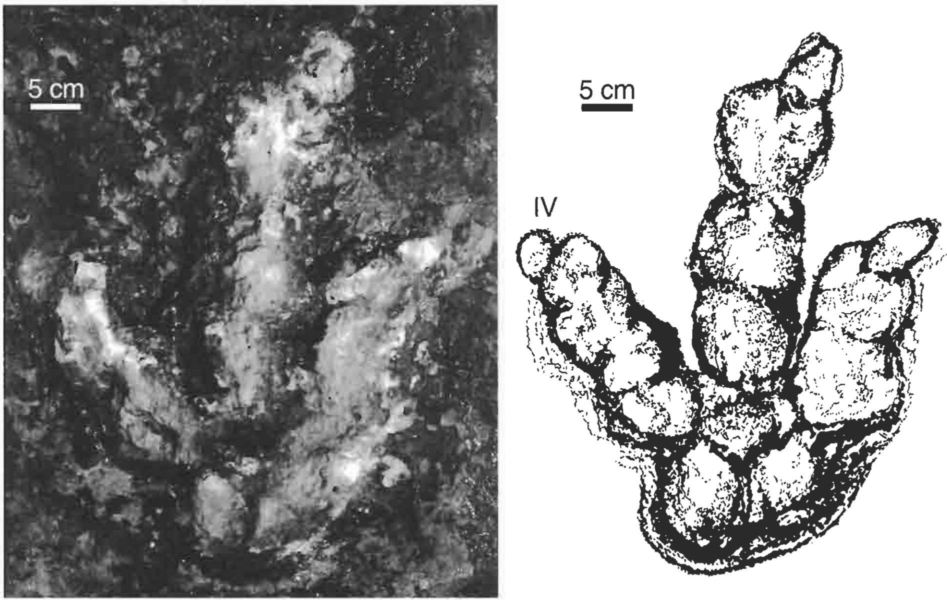

Fig. 2. Natural cast of theropod footprint, Muz.PIG 1661.II, cf. *Megalosauripus* sp. from the earliest Early Jurassic Zagaje Formation of Sołtyków, Poland.

which buried and preserved the footprint was delivered by a single flood event. The slab is a portion of a crevasse splay deposit which forms a layer in the uppermost part of the outcrop (Fig. 1). Similar crevasse splay was described by O'Brien & Wells (1986). The vertical succession of sedimentary structures and compaction cracks visible on the lower, track-bearing surface of the sandstone slab suggest rather rapid sedimentation. The fact that the track was left in a pond or depression may have significantly protected it from the subsequent erosion. The raised rim of displaced sediment around the track was not eroded, and erosion structures such as current marks or groove casts are absent. The preservation potential was clearly high. The favorable preservational conditions such as the cohesive, ductile character of the wet muddy substrate and absence of syndepositional erosion allowed the perfect preservation of the footprint.

Footprint description and discussion

The track (Fig. 2) shows an unusual size and morphology as compared with the Early Jurassic theropod ichnotaxa hitherto extablished. It is 10 cm longer than the largest theropod track of *Eubrontes giganteus* Hitchcock, 1845, from the 'classic' Early Jurassic ichnofauna of the Newark Supergroup (Weems 1992). It has a relatively large 'heel' area, larger than in *Eubrontes*, and is more similar in this feature to large theropod tracks from the Late Jurassic. The so-called 'heel' area, the proximal area of a digitigrade tridactyl foot comprising the metatarsophalangeal pads of all three digits, constitutes 33% of the footprint length in this form. In *Eubrontes*, the 'heel' area makes up only 29% (Lockley & Mickelson 1997).

The ratio of footprint length to length of digit III in our specimen equals 1.50. Interestingly, this ratio resembles that of the Late Jurassic tracks known as *Megalosauripus* Lessertisseur, 1955, ranging between 1.45 and 1.85 (Lockley *et al.* 1996). Moreover, the digit length ratios of the new track, measured according to the method of Olsen *et al.* (1998), are: III/II = 1.90, III/IV = 0.93. These ratios fit neither those of the Newark Supergroup theropod ichnotaxa, nor the corresponding ratios obtained from the Late Triassic and Early Jurassic ceratosaurian feet

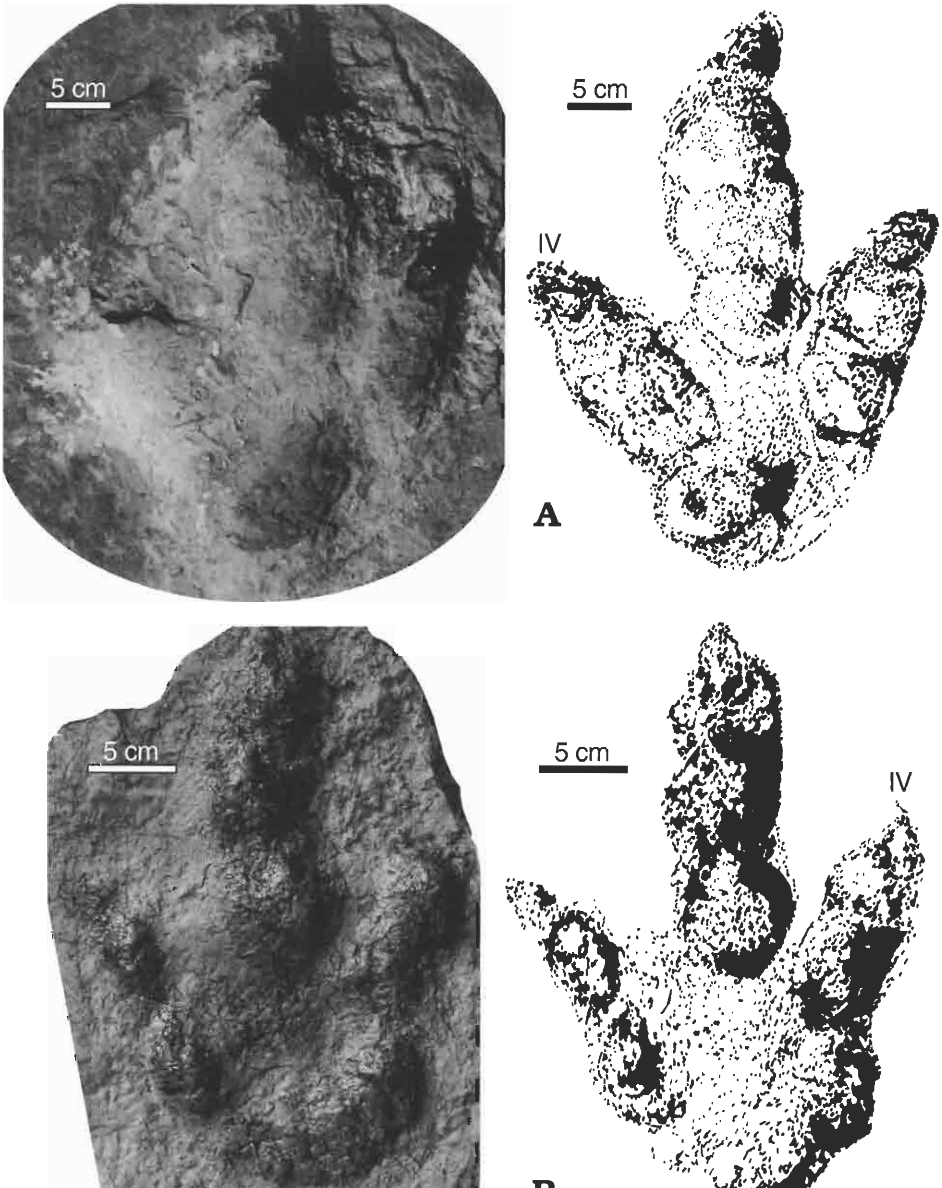

Fig. 3. Theropod footprints (*Megalosauripus* sensu lato) from the Late Jurassic Morrison Formation of Valley City, Utah (**A**) and from the latest Early Jurassic Borucice Series of Idzikowice, Poland, Muz.PIG 1560.II.37 (**B**).

(Olsen *et al.* 1998: table 3). However, they do resemble, for instance, the digit length ratios (III/II = 1.86, III/IV = 0.93) of a theropod track (Fig. 3A) from the Valley City tracksite, Late Jurassic Morrison Formation of eastern Utah (Lockley & Hunt 1995).

Lockley *et al.* (1996) used the name *Megalosauripus*, erected by Lessertisseur (1955), to describe large theropod tracks found close to the Oxfordian-Kimmeridgian boundary in North America, Europe and Asia. Originally, those tracks were referred to megalosaurs, which seems unfortunate, because megalosaurs remain an osteological 'waste basket' (Padian 1997). Their stratigraphic position covers the period of allosauroid dominance in the Northern Hemisphere, and those theropods are also possible candidates for *Megalosauripus* trackmakers.

Recently, Lockley, Meyer, & Santos (1998) and Lockley, Meyer, & Moratalla (1998) have enriched the concept of 'megalosaur' tracks, restricting the name *Megalosauripus* to the footprints with distinct phalangeal pad impressions and erecting an ichnogenus *Therangospodus* for smaller footprints lacking phalangeal pads distinctly imprinted. Interestingly, a specimen almost identical to the holotype of *Therangospodus pandemiscus* Lockley, Meyer, & Moratalla, 1998 – a track from the Moab Megatracksite, Utah, of allosaurid origin (Lockley 1991) – has been described from the late Toarcian of Poland (Gierliński 1995). However, it has better defined phalangeal pads (Fig. 3B). Thus, we are not sure if *Therangospodus* should be distinguished from *Megalosauripus* at the ichnogeneric level. The above mentioned theropod footprint from the Valley City and the Polish Toarcian specimen demonstrate a pattern in between both ichnogenera. The diagnostic features separating them are entirely extramorphological and subject to growth and behavioral changes or potentially influenced by the substrate nature, so they may not reflect real taxonomic differences.

According to the osteometric method of Farlow & Chapman (1997), the morphology of the new Polish specimen suggests the following length ratios of its trackmaker foot: ungual III4/phalanx III2 (%) = 79; phalanx III2/phalanx IV1 (%) = 89. Both ratios correspond to those of allosauroids (see Farlow & Chapman 1997: fig. 36.13).

Given the new discoveries of the Early Jurassic *Cryolophosaurus* Hammer & Hickerson, 1994 from Antarctica and the Middle Jurassic *Monolophosaurus* Zhao & Currie, 1993 from China, the occurrence of tracks likely left by allosauroids *sensu* Sereno (1999) before the Late Jurassic is not a surprise. However, it is worth noting that *Megalosauripus*-like tracks are rare in sediments older than the Late Jurassic. Hitherto, there were only three findings of pre-Oxfordian theropod tracks, which exceed half meter in length, similar to the one described here. One occurrence is known from the Early Jurassic of Arizona (Morales & Bulkley 1996) and two more finds come from the Middle Jurassic of Portugal and England (Lockley & Meyer 2000; Day *et al.* 2000). Thus, it seems justified to assume that their trackmakers were not yet as common in the pre-Oxfordian terrestial ecosystems as they became in the Late Jurassic.

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