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New ornithischian dinosaur footprints in the Jurassic of Poland

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New stratigraphic horizons with the ornithischian footprints have been found in central Poland. Basal thyreophoran ichnites are reported from the middle Hettangian Skłoby Formation of Gromadzice. They support the previous conclusion that small and medium-sized Early Jurassic ornithischians preferred a coastal habitat with low-rise vegetation. Another find, an ornithopod footprint, came from the early Kimmeridgian Głowaczów Formation of Ożarów quarry. The track was discovered within the shallow-marine succession of calcareous deposits, which contributes to the interpretation of synsedimentary emersion of that area during the early Kimmeridgian.

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INTRODUCTION

The largest ornithischian track assemblage in Poland is known from the late Hettangian coastal barrier-lagoon deposits of Gliniany Las (Gierliński and Potemska, 1987; Gierliński, 1991, 1999; Gierliński and Pieńkowski, 1999). Less numerous specimens of ornithischian footprints have been also found in the similar coastal palaeoenvironments of the Hettangian of Zapniów (Pieńkowski and Gierliński, 1987) and in so-called lower Gromadzice outcrop (Gierliński and Pieńkowski, 1999). Those previous finds led to the supposition that small and medium-sized Jurassic ornithischians preferred a coastal (barrier-lagoon and delta plain) habitat with low and dense vegetation rather than the inland forest habitat invaded by high browsing adult sauropods (Gierliński and Pieńkowski, 1999). The discovery of ornithischian tracks in the upper Gromadzice outcrop supports such a viewpoint.

The second find reported herein, the ornitopod footprint from the Upper Jurassic of Ożarów, indicates a temporary emergence of that area during the early Kimmeridgian times and correspond with the coastal environment supposed to be a part of the ornitischian habitats.

THYREOPHORAN FOOTPRINT FROM GROMADZICE

The upper Gromadzice outcrop (Fig. 1B) of the deltaic middle Hettangian deposits of the Skłoby Formation (Pieńkowski, 1991) hitherto revealed only unusually small tracks of diminutive or juvenile sauropods (Gierliński, 1997). Recently two ornithischian footprints have been found in this horizon.

The outcrop reveals complete section of a delta sequence (Fig. 1C). This particular deltaic environment was characterised by flat prodelta slope, intermediate wave energy, considerable littoral drift and intermediate discharge of fluvial sediments. It resulted in the “composite sequence”, in which the delta cycle is divided into two parts separated by the barrier (delta-front) facies formed in the wave-breaking zone. The “inner delta facies” are represented by deposits formed in stagnant lagoons (interdistributary bays) and marshes, covered by quickly prograding distributary (fluvial) facies (Pieńkowski, 1991). The footprints were preserved on the bottom surface of the gray sandstone representing distributary channel facies. The distributary channel facies covers the clayey coal bed with dense plant roots beneath (palaeosoil). It points that the animal entered an area with relatively high water-table level and

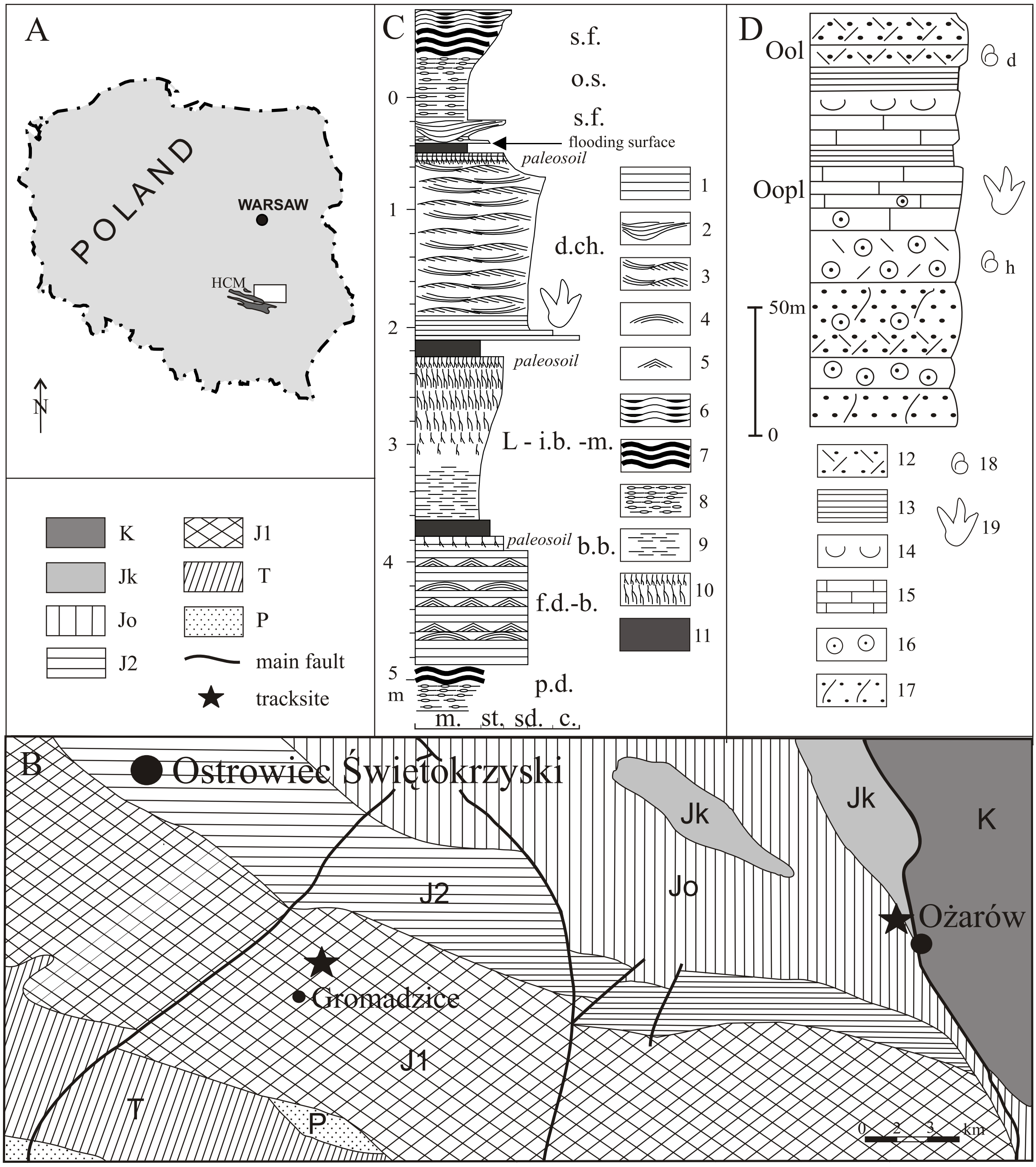

Fig. 1. **A** — Location of the studied area

B — Geological sketch of the northeastern slope of the Holy Cross Mountains (HCM)

P — Permian, T — Triassic, J_1 — Lower Jurassic, J_2 — Middle Jurassic, J_o — Oxfordian, J_k — Kimmeridgian, K — Cretaceous

C — Sedimentological section of the Hettangian deposits in the upper Gromadzice outcrop (after Pieńkowski, 1991)

1 — parallel bedding, 2 — large-scale cut-and-fill trough cross-bedding, 3 — small- and medium-scale trough cross-bedding, 4 — hummocky cross stratification, 5 — wave ripples, 6 — flaser bedding, 7 — wavy bedding, 8 — lenticular bedding, 9 — parallel lamination in mudstones, 10 — plant roots, 11 — coal and coal-bearing mudstone; **lithologic scale**: m. — mudstone, st. — siltstone, sd. — sandstone, c — presence of mud clasts; **facies**: o.s. — offshore, s.f. — shoreface, p.d. — prodelta, f.d.-b. — delta front-barrier, b.b. — backbarrier, L-i.b.-m. — lagoon-interdistributary bay-marsh system, d.ch. — distributary channel

D — Simplified lithostratigraphic section of the Kimmeridgian deposits in Ożarów quarry (after Gutowski, 1998)

12 — biogenic and intraclastic grainstones and packstones, 13 — clays and marls, 14 — oyster shell-beds, 15 — micritic limestones, 16 — oolites, 17 — chalky limestones, 18 — ammonite (d — *Divisum*, h — *Hypselocyclum*), 19 — dinosaur footprints; **lithologic units**: Oopl — Ożarów oolite and platy limestone, Ool — Ożarów oyster lumachelle

low-rise vegetation. Erosion at the bottom of the distributary channel was insignificant due to the weak currents, which increased the preservation potential of the tracks.

Both ornitischian footprints are preserved as natural casts in a sandstone slab (MUZ PIG OS-221/35). They may belong to the same trackway or to two parallel trackways. The ichnites show a typical anomoepodid pattern, a functionally tridactyl pes with relatively short and highly divaricated digits. However, they have exceeded the typical *Anomoepus* size, reaching the length of 20.7 cm and showing only two phalangeal pads on digit III. Their morphology fits almost perfectly between the more gracile tracks of *Anomoepus* Hitchcock, 1848 and the more robust *Moyenisauropus karaszevskii* Gierliński, 1991. Such a morphological pattern has been described from the Lower Jurassic of Lesotho as *Moyenisauropus natator* Ellenberger, 1974 and it has been also reported from the Lower Jurassic, from the Kayenta-Navajo transition zone of Utah (Lockley *et al*., 1998*a*).

Some authors consider Ellenberger's *Moyenisauropus* as junior synonym of *Anomoepus* (Olsen and Galton, 1984; Thulborn, 1994). Gierliński (1991) agreed that most of *Moyenisauropus* tracks are indeed *Anomoepus*, except for *M. natator* and possibly *M. levicauda*. Recently, Lockley and Meyer (2000) contended that all seven ichnospecies of *Moyenisauropus* should be transferred to *Anomoepus*, while the Polish form of *M. karaszevskii* should be classed as a completely different, new ichnogenus. However, the present authors share the opinion of Gierliński and Pieńkowski (1999). *Moyenisauropus natator* is morphologically intermediate between *Anomoepus* and *M. karaszevskii*. Even if *M. karaszevskii* would fall into a different ichnogenus, the ichnogenus *Moyenisauropus sensu* Gierliński (1991) would be valid to comprise such an intermediate form.

The discussed sample of *M. natator* from the upper Gromadzice outcrop (Fig. 2A) shows digit divarication as follows: I–II = 86°, II–III = 36°, III–IV = 27°, II–IV = 63°. Digits II and III are subequal in length, whereas digit IV is the longest. Their length ratios measured according to the method of Olsen *et al*. (1998) equal III/II = 1.10 and III/IV = 0.62, thus fitting closely those of the foot of *Scelidosaurus harrisonii* Owen, 1861 (see Gierliński and Pieńkowski, 1999, tab. 1).

ORNITHOPOD FOOTPRINT FROM OŻARÓW

The second ichnite reported herein, the specimen MUZ PIG 1663.II.2, came from the Late Jurassic limestones of Ożarów quarry (Fig.1B). The tridactyl footprint is a well preserved natural cast of the right pes impression (Fig. 2B). This print demonstrates morphology clearly different from the Early Jurassic *Anomoepus-Moyenisauropus* morphotypes. The imprint is nearly as long as wide (18 cm long and 19 cm wide), very symmetrical with almost the same angle between the axes of digit II and III (40°) as between digit III and IV (41°). Very similar ornithopod footprints from the Kimmeridgian Morrison Formation of Utah have been named *Dinehichnus* by Lockley *et al*. (1998*b*). However, the type material from Utah shows the "heel" pad impression, a distinctive metatarsal-phalangeal pad of the fourth digit, more circular and discrete than the Polish specimen. If the shallow posteromedial mark was produced there by a hallux, it might be another character differing it from the typical *Dinehichnus* tracks.

The digit length ratios (III/II = 1.35 and III/IV = 0.75) of the Polish ichnite resemble those of supposed dryosaur footprint from the Morrison Formation of Como Bluff in Wyoming (III/II = 1.32 and III/IV = 0.78) reported by Bakker (1996). However, the presence of probable hallux imprint in the Ożarów specimen speaks against its dryosaur origin, suggesting rather camptosaurid affinity of its trackmaker.

Highly intriguing is the palaeoenvironmental background of this find. Ornithischian dinosaurs were not demonstrably associated with aquatic environments and Bakker (1996) even concluded that the compact-footed herbivores such as camptosaurus and dryosaurus preferred rather areas with well-drained soil than swampy terrain. However, the sediment that has preserved (casted) the discussed footprint has been evidently deposited in marine environment.

During the Late Jurassic the northeastern margin of the Holy Cross Mts. (HCM) as well as the surrounding regions of the Central Poland were predominantly covered by shallow epicontinental seas. The nearest lands situated to the south-east (the Ukrainian shield) and to the north (the Baltic shield) lied some hundreds kilometres away from the HCM (Ziegler, 1990). During the middle Oxfordian an extensive carbonate ramp developed on the stable basement of the East European Craton, probably close to the Ukrainian shield (Kutek, 1994). It prograded to the north-west and (together with smaller ones that grew on the local elevations) was a source of carbonates in the Polish Basin. Thus from the middle Oxfordian until the early Kimmeridgian sedimentation was dominated by carbonates on the substantial part of this area. Different types of calcareous rocks with biogenic, intraclastic, micritic and oolithic limestones, coral and sponge-algal bioherms, gaizes and marls build today a huge series of deposits, reaching approximately 600 metres thickness in the neighbourhood of Ożarów quarry. Lithological diversity and a presence of stratal discontinuities suggest changes in depositional regime during this time and allow to distinguish sedimentary sequences of various significance. Depositional sequences can also be recognised on geophysical logs (e.g. gamma rays) of boreholes drilled in this region like Bąkowa IG1 and Ciepielów IG1 (Niemczycka, 1974, 1975). The find of ornithischian dinosaur footprint suggests a regional surface of depositional discontinuity.

The surface into which the dinosaur track was printed has not been found. Thus, there is no possibility of checking up if it shows any signs of erosional structures, karstification or pedogenic modification. The natural cast of the ornithopod footprint found in the Ożarów quarry came from the shallow-marine succession of mostly calcareous deposits. A fifty centimetres thick layer of pale micritic limestone was qualified by M. Połońska from the Polish Geological Institute (PGI) as a mudstone/wackestone. Besides carbonates it contains quartz (about 2%) and mica grains, ferrum oxides and hydroxides, aggregates of some opaque minerals, lidites and plant remains. The microfossil analysis, kindly done by J. Smoleń (from PGI), revealed content of benthic foraminifers shells as well as very abundant fragments of echinoderms. Among the foraminifers

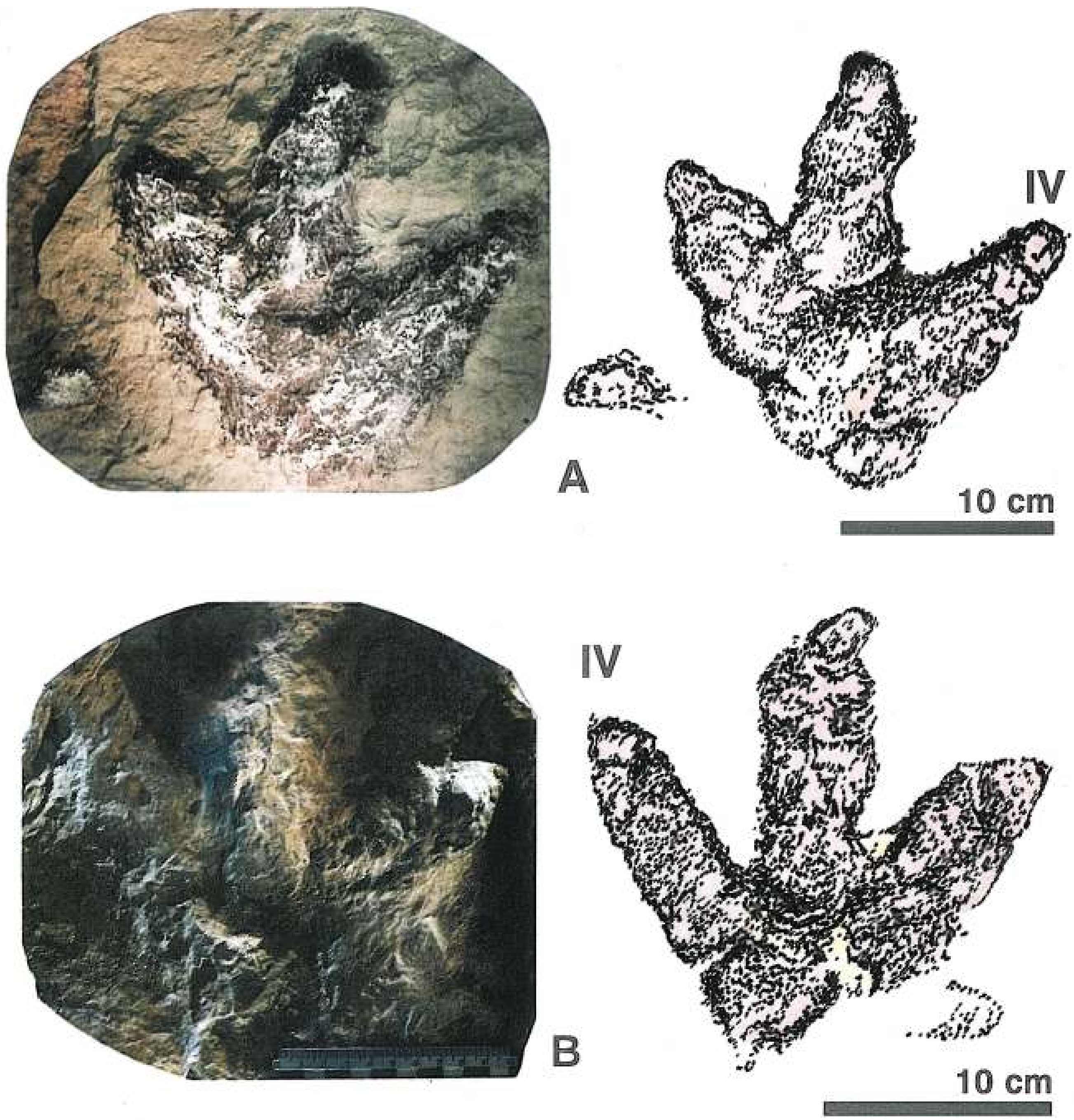

Fig. 2. **A** — *Moyenisauropus natator* Ellenberger, 1974 from the Early Jurassic Skłoby Formation of Gromadzice, MUZ PIG OS-221/35A; **B** — cf. *Dinehichnus* sp. from the Late Jurassic Głowaczów Formation of Ożarów, MUZ PIG 1663.II.2

dominant ones are these of the genus *Spirillina* (*S. tenuissima* Gümbel) and *Trocholina*. The whole sequence, about fifty eight metres thick, contains also cross-bedded grainstones and intercalations of oolites (Fig.1D). It was distinguished by Gutowski (1998) as the "Ożarów oolite and platy limestone" (Oopl) in his informal lithostratigraphic scheme. This author designated also an early Kimmeridgian age for that sequence corresponding to the ammonite *Hypselocyclum* Zone. The faunal content does not allow to accurately date the boundary between the Oxfordian and Kimmeridgian in the mentioned section. Within the superimposed sequence of lumachelle limestone (Oll), the *Divisum* Zone of the lower Kimmeridgian was recognised (Gutowski, 1998). Earlier in the northwestern part of the Lublin Upland and adjacent area of the HCM Niemczycka (1976) distinguished some formal lithostratigraphic units. A shallow-water succession containing calcareous and dolomitic oolites, lumachelles, intraclastic and oncolithic limestone as well as storm induced deposits has been named the Głowaczów Formation. The early Kimmeridgian age have also been indicated for it. Dąbrowska (1983) emphasised an extremely shallow-water (nearshore) environment for the early Kimmeridgian sedimentation in the vicinity of Iłża that is situated some forty kilometres north-westwards to Ożarów. Moreover, she postulated a temporary emersion in this part of the sedimentary basin. In the lower Kimmeridgian sedimentary succession, she observed abundant shellbeds, wave related structures and increased input of terrigenous material to the basin resulted in deposition of sand beds and conglomerates.

It is also noteworthy that Liszkowski (1972) found well preserved and abundant plant remains in the Upper Jurassic of this area. Besides branches and seeds, they included delicate leaves, pieces of flowers and cones, excluding long transport. The fossils were attributed to some groups of the Gymnospermophyta; the dominance of representatives of the Coniferales pointed to an arid climate. These fossil plants occurred in transgressive shallow-marine succession of carbonate deposits containing basal conglomerate, oolites and platy limestones with lenticular-shape intercalations of oolites. Lithological features of deposits indicate near-shore sedimentation and give evidences for synsedimentary emersion. The author suggested the late Oxfordian age for this sequence, but no fossils of stratigraphic importance have been found there. The succession studied is very similar to these of the lower Kimmeridgian.

Of course, further and more detailed investigations, especially in the terms of sequence stratigraphy, should be carried on in the Upper Jurassic sections of HCM. However, we can conclude, that sedimentary succession of the lower Kimmeridgian in the northeastern margin of the HCM gives evidences of temporary emergence of the area. The dinosaur footprint reveal evidence of a regional sea level fall. It had to be pronounced enough to result in connection of this area with distant land(s). According to Haq *et al*. (1988), the considerable fall of sea level caused by eustasy in the early Kimmeridgian is dated for 144 Ma. This event is correlated with the lower part of boreal ammonite *Cymodoce* Zone. The find of the ornithopod footprint in the lower Kimmeridgian of HCM contributes to the interpretation of sedimentary periodicity and a succession of palaeoenvironments in this region.

Abbreviations of cited repositories: MUZ PIG — Geological Museum of the Polish Geological Institute, Warsaw, Poland; MUZ PIG OS — Holy Cross Mts. Branch of the Polish Geological Institute, Kielce, Poland.

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