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NEW FINDS OF DINOSAUR FOOTPRINTS IN LIASSIC OF THE HOLY CROSS MOUNTAINS AND ITS PALAEOENVIRONMENTAL BACKGROUND

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Hitherto in the Polish Jurassic dinosaur footprints have been know from only one locality (fig. 1, references pos. 2, 3, 4, 5, 6). Their age was estimated at the Upper Hettangian (10) and the footprints should be placed in the upper part of the Przysucha Ore-bearing series (formation) not in the lowermost part of the Sinemurian and Ostrowiec Series (formation) – 5, 6, 11. One should note that the boundary between Przysucha and Ostrowiec formations (series) depends on its sense: it may be regarded as a lithostratigraphical boundary (9, 11) or an allostratigraphical boundary (10).

Sedimentological analysis of the Lower Liassic of the Northern Slope of the Holy Cross Mountains (8, 9, 10, 11) allowed to recognize sedimentary environments and the sedimentary evolution of the Lower Liassic on this area. The lowermost Zagaje series and the uppermost part of Przysucha s. represent entirely a continental deposition. Between those units there are: the Skłoby s. representing deposits of a widespread brackish marine basin and the main part of Przysucha s. which presents deposition under regressive conditions (8, 9, 10). The beginning of the uppermost in the Lower Jurassic Ostro-

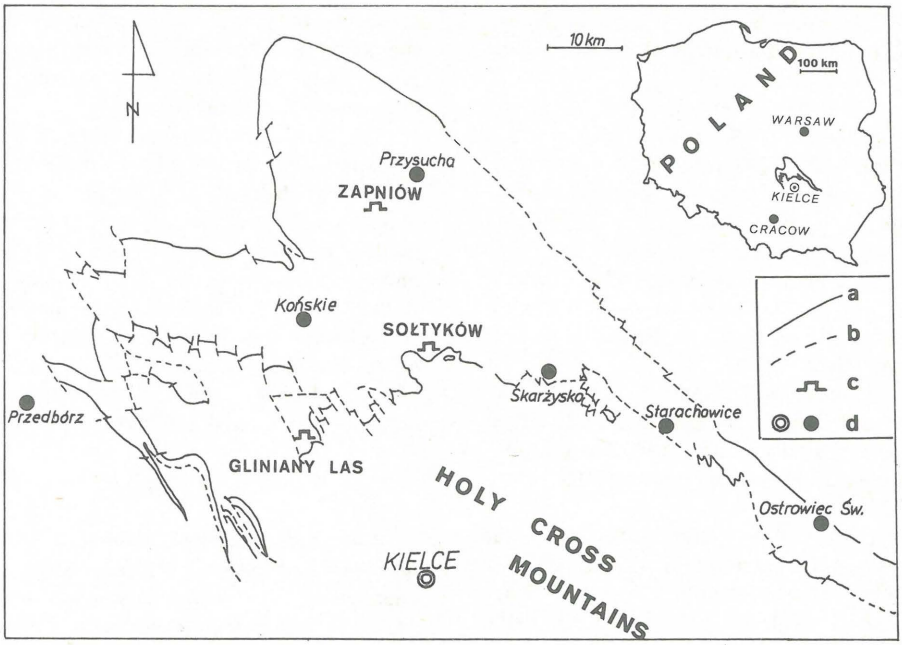

Fig. 1. Location of the outcrops with dinosaur footprints on the Northern Slope of the Holy Cross Mountains

a – boundaries of Lias and older and younger rocks, b – tectonic contact of Lias and other rocks, c – outcrops with footprints, d – major towns

Ryc. 1. Lokalizacja odsłonięć z tropami dinozaurów na północnym obrzeżeniu Gór Świętokrzyskich

a – granice liasu z utworami starszymi i młodszymi, b – tektoniczne kontakty liasu z innymi utworami, c – odsłonięcia z tropami, d – większe miasta

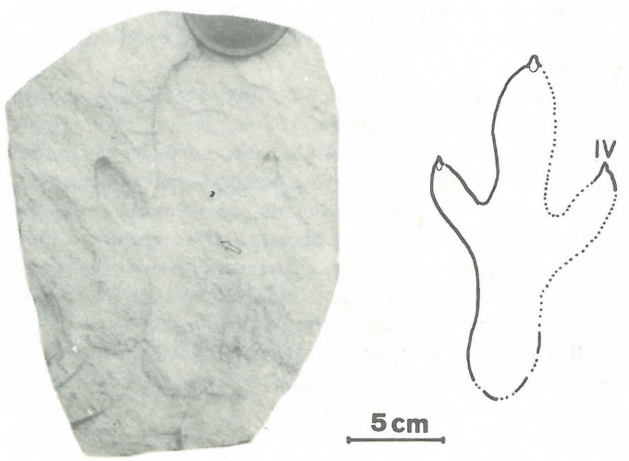

Fig. 2. Anomoepus sp. from Sołtyków. Three digits with claws are visible. Dotted line – eroded part of the track. Note the imprints of rain drops (arrowed)

Ryc. 2. Anomoepus sp. z Sołtykowa. Widoczne trzy palce z pazurami. Linią kropkowaną oznaczono zerodowaną część śladu. Odciski kropel deszczu zaznaczone strzałką

wiec s. is connected with the Lower Sinemurian transgression; higher up the series shows some regressive trends.

So, the highest chances to find dinosaur footprints are in the Przysucha s. (Gliniany Las and Zapniów localities) and in the Zagaje s., where no footprints have yet been found.

During additional sedimentological studies in the field, the first author found two new footprints in two new localities: one was from the Zagaje series (figs. 3, 4), the second one in approximately the same part of the Przysucha series as Gliniany Las locality. In spite of a rather poor state of preservation (specially in the case of the first footprint), the finds are unique in the Polish Liassic and they enrich our knowledge about the palaeoecology of this period. The footprints were denoted by the second author to the ichnogeneric level.

Footprint No. 1, Sołtyków near Odrowąż, West of Skarżysko Kamienna, Zagaje series, Lowermost Hettangian, Museum of the Geological Institute No. 1572.II.1, fig. 2.

Order **Ornitischia** Seeley 1888

Suborder **Ornitopoda** Marsh 1878

Family **"Proiguanodontidae"** Gierliński, Potemska 1987 **in print** (hypothetical)

Ichnofamily *Anomoepodidae* Lull 1953

Ichnogenus *Anomoepus* Lull 1953

This footprint was left by a sitting proiguanodontid on a sandstone layer. This layer is a fragment of well visible in the uppermost part of the Sołtyków outcrop crevasse deposits which are connected with the channels of a meandering river system (figs. 3, 4). Fluvial channel deposits occur within the fluvial plain deposits, the fluvial plain was covered with swamps and oxbow lakes (figs. 3, 4, reference No. 8). In the profile of shallow borehole Sołtyków Sł-2 (fig. 3), the erosional contact between the fluvial Liassic and underlying Rhaetian is visible. The Liassic is characterizied by the fining upward cycles connected with an autocyclical mechanism of fluvial sedimentation (meandering river channels wandering on a swampy fluvial plain). The fluvial plain was covered with small horsetails, very numerous are their roots, rhizomes and redeposited fragments (8).

During bigger floods levees were cut and crevasse channels and sandy sheets were formed (fig. 4). Exactly on the top of such deposits the mentioned footprint was found. Unfortunatelly, the footprint is partly eroded on one side (fig. 2), but the prints of three digits and the outline of a heel are visible. Because the lenght of the heel is half of the lenght of the whole pes, the footprint should be regarded as *Anomoepodidae*; the lack of the interdigital webs indicate to *Anomoepus*. Discovery of the dinosaur footprint in Sołtyków confirms the previous interpreta-

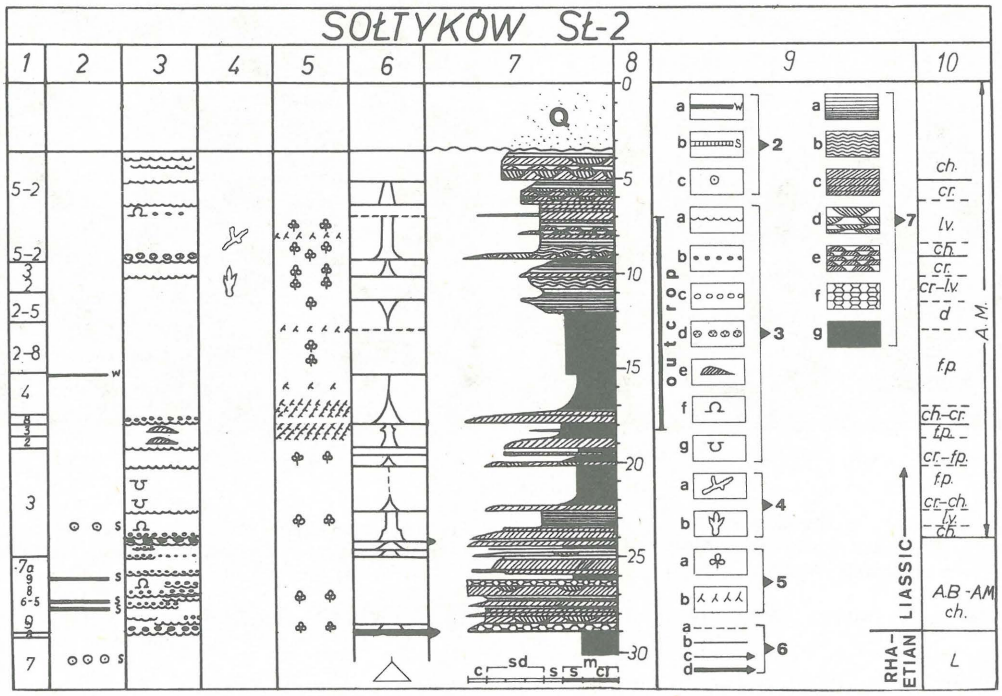

Fig. 3. Section of the Sołtyków Sł-2 borehole showing the contact between the Rhaetian and the fluvial Zagaje Series (after Pieńkowski, 8)

Ryc. 3. Fragment profilu wiercenia Sołtyków Sł-2 z kontaktem między retykiem a fluwialną serią zagajską (na podstawie Pieńkowski; 8)

Column 1 = colour; 2 – white-grey, 3 – grey, 4 – dark-grey, 5 – yellow, 6 – brown, 7 – red, 7a – pinky, 8 – green, 9 – violet; column 2 = additional lithological varieties, a – coal seams, b – siderite bands, c – sideritic nodules; column 3 – a – erosional surfaces, b – mud clasts, c – quartz and quartzite pebbles, d – sandstone clasts, e – current ripples, f – flow structures, g – load casts; column 4 – a – burrows of Arthropoda (cf. *Thallassinoides*), b – *Anomoepus* sp.; column 5 – a – drifted flora, b – roots rhizomes and vegetative shoots of horsetails; column 6 – cycles and their boundaries, a – boundaries of subcycles, b – boundaries of individual fluvial cycles, c – boundaries of sedimentary units (members), d – boundaries of formations and alloformations; width of the bar means the mean grain from conglomerate to claystone; column 7a – horizontal bedding of various scale, b – horizontal wavy bedding, c – tabular cross bedding of various scale, d – trough cross bedding of various scale, e – ripple-drift cross lamination, f – disturbed bedding, g – lamination and streaky lamination in mudstones; m – mudstones, cl – claystones (prevailing), s – siltstones (prevailing), s – siltstones with very fine grained sandstones, sd – sandstones (fine, medium and coarse-grained), c – conglomerates column 8 – thickness in meters, column 9 – explanations to the column 2, 3, 4, 5, 6, 7; exposed part of the section is marked, column 10 – interpretation of the palaeoenvironments, L – lagoons and lakes of an arid climate, A.B. – braided rivers, A.M. – meandering rivers, subenvironments, ch – channels with point bars, l.v – levees, cr – crevasses, f.p – fluvial plain with backswamps and oxbow lakes, d – crevasse delta

Kolumna 1 = barwa; 2 – białoszara, 3 – szara, 4 – ciemnoszara, 5 – żółta, 6 – brunatna, 7 – czerwona, 7a – różowa, 8 – zielona, 9 – fioletowa; kolumna 2 – dodatkowe odmiany litologiczne, a – przewarstwienia węgla, b – warstewki syderytów, c – konkrecje syderytu; kolumna 3, a – powierzchnie erozyjne, b – klasty mułowe, c – otoczaki kwarcu i kwarcytów, d – klasty piaskowców, e – zmarszczki prądowe, f – struktury spływowe, g – pogrązy; kolumna 4, a – tunele Arthropoda (cf. *Thallassinoides*), b – *Anomoepus* sp.; kolumna 5 – a – napławiona flora, b – korzenie, kłącza i pędy wegetatywne skrzypów; kolumna 6 = cykle i ich granice, a – granice subcykli, b – granice poszczególnych cykli fluwialnych, c – granice kompleksów sedymentacyjnych (ogniw), d – granice formacji i alloformacji; szerokość słupka odzwierciedla grubość ziarna najczęstszego – od zlepieńców do iłowców; kolumna 7, a – warstwowanie poziome różnej skali, b – warstwowanie poziome zafalowane, c – warstwowanie przekątne tabularne różnej skali, d – warstwowanie rynnowe różnej skali, e – warstwowanie zmarszczkowe, f – warstwowanie zaburzone, g – laminacja i warstwowanie smugowane w mułowcach; kolumna 8 – miąższość w metrach; kolumna 9 – objaśnienia do kolumn 2, 3, 4, 5, 6, 7; kolumna 10 = interpretacja paleośrodowisk, L – laguny i jeziora klimatu suchego, A.B. – rzeki roztokowe, A.M. – rzeki meandrujące; subśrodowiska, ch – kanały z łachami meandrowymi, l.v. – wały brzegowe, cr. – krewasy, f.p. – równia zalewowa z bagnami i starorzeczami, d – delta krewasowa

tion of sedimentary palaeoenvironments in this interesting outcrop (8). This dinosaur was not connected with amphibious mode of life, most probably it was a typical terrestial "runner". It should be mentioned that one may find very abundant plant remains in Sołtyków, some of them are very large (the famous jet from Sołtyków). Remains of trees were brought by floods to this swampy area from higher parts covered with an coniferous forest. There the basic biotope of running proiguanodontids should be placed. Sometimes, the animals could enter the swampy fluvial plain utilizing more stabile crevasse deposits.

Footprint No. 2, Zapniów open pit near Przysucha, Przysucha Ore-bearing series, the base of the first "Ore Level", Upper Hettangian, Museum of the Geological Institute No. 1572.II.2, fig. 5.

It is a deeply impressed print of pes with three digits and it was left by an animal wading on a sandy surface in a shallow water. On the same surface one may find asymmetrical wave ripples. The digits are short, thick, widely spaced and linked by the distinct outline of the interdigital webs. Hallux print is lacking. The footprint was found on the upper surface of very thick sandstone layer, which is covered by the clays of a lagoonal origin. Above the clays there are fluvial sandstones lying on the erosive surface (fig. 6). The sandstone with footprint represents the strand-line deposits of a widespread basin; most probable it was a sandy barrier system separating shallow lagoons of the Przysucha series (see 9, fig. 10). One may compare the collection of footprints from Gliniany Las (2, 3, 8) with the footprint from Zapniów and consider them together to reconstruct the mechanism

Fig. 4. Sołtyków outcrop, fragment of the profile marked on the fig. 3

ch – channel deposits, cr – crevasse deposits, fp – fluvial plain deposits. Arrowed – the place where the footprint *Anomoepus* comes from

Ryc. 4. Odsłonięcie w Sołtykowie, fragment profilu zaznaczony na ryc. 3

ch – osady kanałowe, cr – osady krewasowe, fp – osady równi zalewowej. Strzałką zaznaczono miejsce, skąd pochodzi trop *Anomoepus*

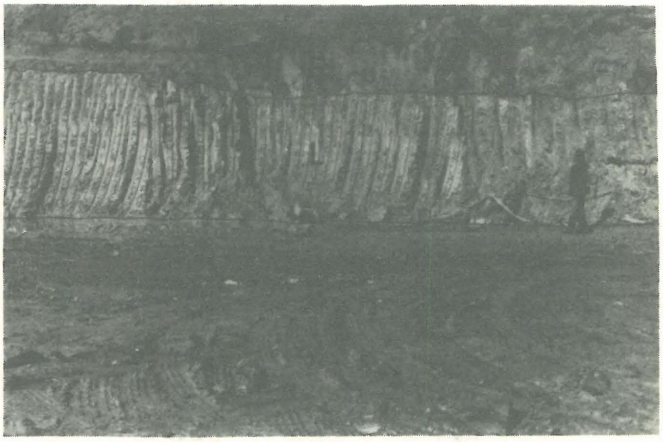

Fig. 5. Zapniów open pit. B – upper surface of the barrier sandstone

L – lagoonal clays (epigenetically weathered), F – fluvial sandstones laying on the erosional surface. The footprint was found on the top of barrier sandstone (arrowed)

Ryc. 5. Kopalnia odkrywkowa w Zapniowie. B – górna powierzchnia piaskowców barierowych

L – iły lagunowe (zwietrzałe epigenetycznie), F – piaskowce rzeczne leżące na powierzchni erozyjnej. Trop został znaleziony na stropie piaskowców barierowych (strzałka)

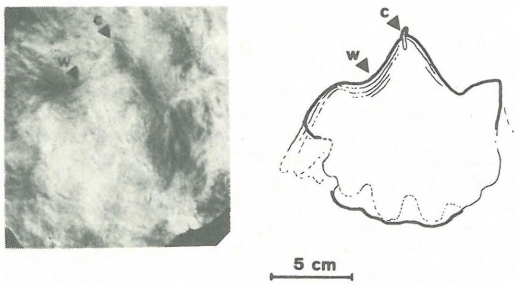

Fig. 6. Moyenisauropus sp. from Zapniów (mould). Three digits with interdigital web (w) and claw (c) are imprinted. Thick line = well visible outline of the footprint; thin lines = imprints of the web and not well visible outline of the footprint; dashed lines = inner structures of the footprint and unknown structure to the left of the footprint (effect of sliping?)

Ryc. 6. Moyenisauropus sp. z Zapniowa (odlew). Widoczne odciski trzech palców z błoną pławną (w) i pazurem (c). Grubą linią oznaczono zarys tropu, cienkie linie oznaczają odciski błony pławnej i słabo widoczny zarys tropu, linia kreskowana oznacza wewnętrzne struktury tropu i nieznaną strukturę na lewo od tropu (efekt poślizgu?)

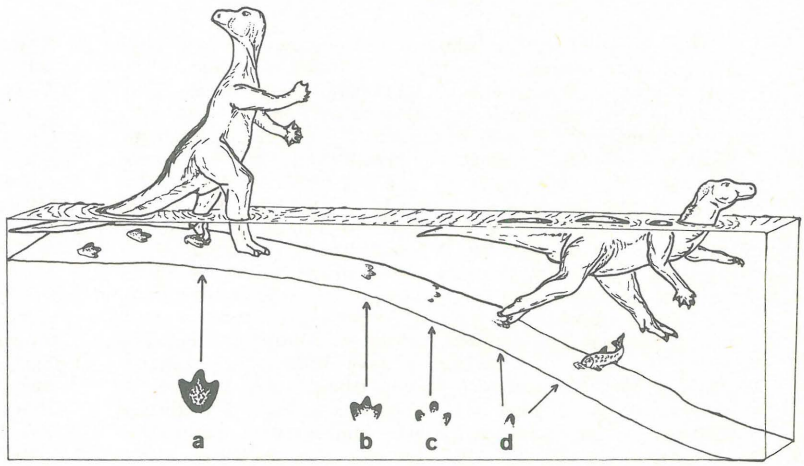

Fig. 7. Hipothetical trackway based on various footprints from Gliniany Las and Zapniów. The animal wading in a very shallow water left deeply impressed footprints (a). When going deeper and deeper into the water the animal left footprints with only digits (b) or phalangeal pads (c) impressed. When swimming, the animal could scratch the bottom by claw (d). It is not clear if some of those singular marks should be related to fish-made bottom structures (d)

Ryc. 7. Hipotetyczny ciąg tropów oparty na różnych tropach z Glinianego Lasu i Zapniowa. Zwierzę brodzące w bardzo płytkiej wodzie pozostawiało głęboko odciśnięte ślady (a). W trakcie wchodzenia do coraz głębszej wody zwierzę pozostawiało tropy tylko z odciskami palców (b) lub poduszek palcowych (c). Podczas płynięcia zwierzę było w stanie zarysować dno pazurem (d). Pozostaje niewyjaśnionym, czy część tych pojedyńczych hieroglifów nie powinna być powiązana ze strukturami dennymi tworzonymi przez ryby (d)

of forming of different footprints regarding a depth of water in which the proiguanodontids were in a given moment (fig. 7).

The animal wading in a very shallow water left deeply impressed, "complete" footprints (fig. 7a, some footprints from Gliniany Las and the Zapniów specimen). When going deeper and deeper into the water, the animal left shallowly impressed, „incomplete" footprints (here belong many specimens from Gliniany Las with only digits or phalangeal pad prints – fig. 7b, c). At last the animal lost contact with the bottom and could only "scratch" the bottom by claw (fig. 7d). In this contact it should be mentioned that the peculiar marks from Gliniany Las had once been interpreted as, maybe, fish-made (11).

This interpretation was carried out before such numerous footprints have been found. The marks under question are buble-, herrinbone-, horse-shoe-, or fan-shaped and they are randomly scattered on the bottoms of sandstones. The „fan-shaped forms were described by Karaszewski (4) as *Flabellichnus lewińskii*. Some of those marks (specially those herringbone-shaped) may represent marks of swimm-

ing dinosaurs scratching the bottom, the rest may have been left by fishes (fig. 7d). The problem must be left open. The hypothesis of the connection between the speed of running of a dinosaur and the shape of the footprints (3) should be rejected, because majority of the footprints were left under the water.

The shallow lagoons of the Upper Hettangian of the Holy Cross Mountains were inhabited by ethologically hadrozaurian – like proiguanodontids feeding on strand – line plants. Probably they were good swimmers. The *Moyenisauropus* footprints from Lesotho were related to amphibious ethology by Ellenberger (1).

While *Anomoepus* from the Zagaje s. represents a terrestial proiguanodontid, *Moyenisauropus* from the Przysucha s. represents an amphibious proiguanodontid.

For the preservational dilemma it is important that we did not find any trackway. Partly it was caused by not enough extensive surfaces (as this in Zapniów), partly by destroying agents as currents and rain (as in Sołtyków case) and partly by subaqueous forming of the footprints (Zapniów and most specimens from Gliniany Las). One should also postulate that the footprints were covered by the sediment in a considerably short period of time, otherwise the subaqueous footprints would have been destroyed.

Many of the footprints were left outside the main biotope of the trace – makers (swamps with crevasses in the Sołtyków case, barriers in the Zapniów case), while the main biotopes were respectively forests and landward parts of lagoons with dense vegetation. This fact should also positively influence the preservational potential because dense footprints tend to obliterate one another.

In Lower Jurassic Central Poland was inhabited by at least two groups of dinosaurs belonging to one hypothetical family *Proiguanodontidae* (2): one group was adapted to terrestial life, the second to amphibious life. It could serve as evidence for the considerable capability of adaptation of the hypothetical proiguanodontids.