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Dinosaur nesting ground from the Early Jurassic fluvial deposits, Holy Cross Mountains (Poland)

Grzegorz PIEŃKOWSKI

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Two different kinds of rounded structures (spherical and ellipsoid ones), filled by clayey-ferruginous sediment, occur in the fine- grained sandstone of a crevasse splay origin (meandering river environment) in the Early Hettangian Zagaje Formation, in the locality called Sołtyków, nearby little town of Odrowąż, central Poland. The structures are interpreted as dinosaur eggs, precisely as the "post-egg structures". They are strongly altered by diagenetic processes and no obvious eggshell structure is preserved. However, faint embryo remains found inside one of the ellipsoid structures and characteristic circular clutch of the spherical structures, allows conclusion that the structures represent dinosaur eggs. This conclusion is supported by other evidences, such as regular size and shape of the structures and joint occurrence with numerous dinosaur footprints. While the circular clutch laid in a shallow depression represents an *in situ* nest, the smaller, ellipsoid eggs were probably transported a short distance by the current associated with a flood event. The circular clutch of unhatched egg structures most probably represents a nest of earliest sauropods; their footprints and trackways have been found nearby. The smaller ellipsoid egg structures are difficult to classify, they may represent either basal ornitishian or theropod eggs. This is the first find of dinosaur egg structures in Poland and the second known Lower Jurassic dinosaur nesting ground world-wide. It may also stimulate discussion on diagenetically altered dinosaur eggs.

Grzegorz Pieńkowski, Polish Geological Institute, Rakowiecka 4, 00-975 Warszawa, Poland *(received: 2.12.1998; accepted: 7.12.1998).*

Key words: dinosaur nest, earliest sauropods, egg structures, taphonomy, diagenetic alteration, embryonic remains, Lower Hettangian.

INTRODUCTION

The structures presented in this paper are interpreted as strongly altered dinosaur eggs. No eggshell ultrastructure is preserved but taphonomical, sedimentological and petrological evidence point to their egg origin. Dinosaur eggs and nests older than Cretaceous are relatively rare world-wide (K. Hirsch, 1994). Lower Jurassic egg clutch have been described from South Africa (J. W. Kitchling, 1979; F. E. Grine, J. W. Kitchling, 1987). Jurassic eggs occur also in Portugal (A. F. de Lapparent, G. Zbyszewski, 1957; P. Dantas, 1991). Fairly rich Upper Jurassic material has been described from localities in Colorado and Utah (USA) (K. Hirsch, 1994). The Polish find is important because it would be only second known Lower Jurassic nesting ground world-wide (K. Carpenter, K. Alf, 1994).

GEOLOGICAL AND STRATIGRAPHICAL BACKGROUND

In the Early Jurassic time the terrigenous, continental, deltaic, nearshore and marine deposition was taking place in a large epeiric basin along the Teisseyre-Tornquist Line in Europe (Fig. 1). Early Jurassic sedimentation commenced with continental, fluvial and lacustrine deposition, which is represented by the Zagaje Formation (G. Pieńkowski, 1983, 1991; G. Pieńkowski, G. Gierliński, 1987). These deposits are known both from the shallow boreholes and outcrops. Sołtyków represents one of the classical outcrops of the lower part of the Zagaje Formation (Figs. 2, 3; Pl. I, Fig. 1). The outcrop reveals deposits of a meandering river plain, with laterally accreting channels, flood plain/lacustrine deposits and numerous crevasse splays (Figs. 2, 3a; Pl. I, Fig. 1). The Early

Fig. 1. Map of Poland showing range of the Lower Jurassic deposits and locality of the Sołtyków outcrop
1 — range of Lower Jurassic deposits, 2 — range of Lower Jurassic deposits with thickness greater than 400 m

Mapa Polski ukazująca zasięg osadów dolnojurajskich i położenie odsłonięcia Sołtyków
1 — zasięg osadów dolnojurajskich, 2 — zasięg osadów dolnojurajskich o miąższości większej niż 400 m

Liassic age of these deposits is confirmed by the floral remains (E. Wcisło-Luraniec, 1991*b*) as well as by the sequence stratigraphy correlation (G. Pieńkowski, 1991, 1997). It is a lower part of the type 2 Hettangian sequence corresponding to the initial phase of the *planorbis–liassicus* transgressive system tract (TST), which initiated backstepping of sedimentary package (a "pre-trangressive" part of the TST below the transgressive surface; G. Pieńkowski, 1991, 1997). Besides detailed sedimentological studies, palaeobotanical (E. Wcisło-Luraniec, 1991*a*, *b*) and entomological studies (P. Wegierek, V. V. Zherikhin, 1997) were carried out.

SEDIMENTOLOGY, PALAEOECOLOGY AND PALAEOICHNOLOGY

The structures occur in the lower part of the outcrop, at the boundary of two sandstone layers separated by a subordinate bounding surface with little amount of muddy substance on it (Pl. I, Fig. 2). The sandstone layers show considerable lateral extension, and tabular and trough cross-bedding of different scale, with fan-like pattern of the current directions (Pl. I, Fig. 2). The sandstone layers are separated by the mudstone layers with numerous plant roots (paleosol levels) (Fig. 2; Pl. II, Fig. 4). The sandstones represent typical wackestones, rich in muddy matrix. In places they are highly ferruginous (high content of iron hydroxides). Drifted flora remains (mostly horsetails and conifers) are very abundant. The plant fossils in the Sołtyków section are abundant and well preserved, but not very diverse (E. Wcisło-Luraniec, 1991*a*, *b*). The lower part of the flood plain was dominated by a horsetail vegetation (G. Pieńkowski, G. Gierliński, 1987), while the higher parts were covered by a coniferous forest dominated by *Hirmeriella* (E. Wcisło-Luraniec, 1991*a*, *b*). Floristic assemblage includes mainly thermophilous taxa indicating a warm and humid climate (E. Wcisło-Luraniec, 1991*a*, *b*). Numerous dinosaur footprints have been found since 1987 (G. Pieńkowski, G. Gierliński, 1987; G. Gierliński, 1994, 1995). Dessication mud cracks occur in several levels. In places, bivalve resting tracks (*Lockeia* = *Pelecypodichnus*) are common (Pl. III, Fig. 4). Also insect burrows (*Spongeliomorpha* sp.) and arthropod burrows (*Scoyenia* sp.) are fairly abundant. Interesting finds of fossil beetles (P. Wegierek, V.V. Zherikhin, 1997) are worth mentioning in this context. This part of the section is interpreted as crevasse splay deposits formed by floods on the flood plain (Fig. 2).

Crevasse splay deposits in the lower part of the outcrop yielded most of the dinosaur footprints known from this locality (G. Pieńkowski, G. Gierliński, 1987; G. Gierliński, 1994, 1995). The footprints ichnocoenosis comprise: large theropods footprints *Kayentapus soltykovensis* (left by *Dilophosaurus* — Pl. II, Fig. 1), small theropod footprint, basal ornitishian footprints represented by *Anomoepus* sp. (Pl. II, Fig. 2) and, most interestingly, sauropod footprints (*Parabrotopodus* sp.) — Pl. II, Fig. 3. The present author found one isolated and relatively small *pes* footprint, but recently the whole trackway has been described (G. Gierliński, G. Sawicki 1998). The footprints point to the presence of diversified and numerous dinosaur fauna, although no dinosaur bones have yet been found.

DESCRIPTION OF THE STRUCTURES

There are two separate kinds of the structures: larger, spherical, slightly flattened and smaller, ellipsoid ones (Pl. II). All the structures are clearly pre-depositional, i.e they existed before deposition of the host sediment. It is proved by the style of arrangement of cross-bedding lamine around the structures (Fig. 4; Pl. III, Fig. 3).

SPHERICAL STRUCTURES

The structures show uniformity in their shape and size and form a half-rim (Pl. I, Fig. 2; Pl. III, Figs. 1, 2 structures **A–D**). The rim is not fully preserved, because the rest of the layer is missing. However, assuming its diameter, another 2 oval objects lack to form a complete rim. Two of the structures seem to occur in a pair (**B** with **C**). One structure (**E**) occurs separately. Structures are slightly flattened, the longer axis reaches 10 cm, shorter is about 8 cm. The structures are filled with detrital clayey-ferruginous material, which represents a mixture of illite and iron hydroxides (Fig. 5). In places one may observe little amount of silty-sandy filling with rare small, detrital plant fragments. The outer surfaces of the structures are covered with numerous irregular, about 1.5 mm thick plates ("chips") built of clay minerals, sometimes mixed with thin lamine composed of iron hydroxides. Similar chip-like plates are scattered randomly on the surface of the layer, but they are clearly concentrated along the surfaces of the oval and ellipsoid structures (Pl. III, Fig. 1).

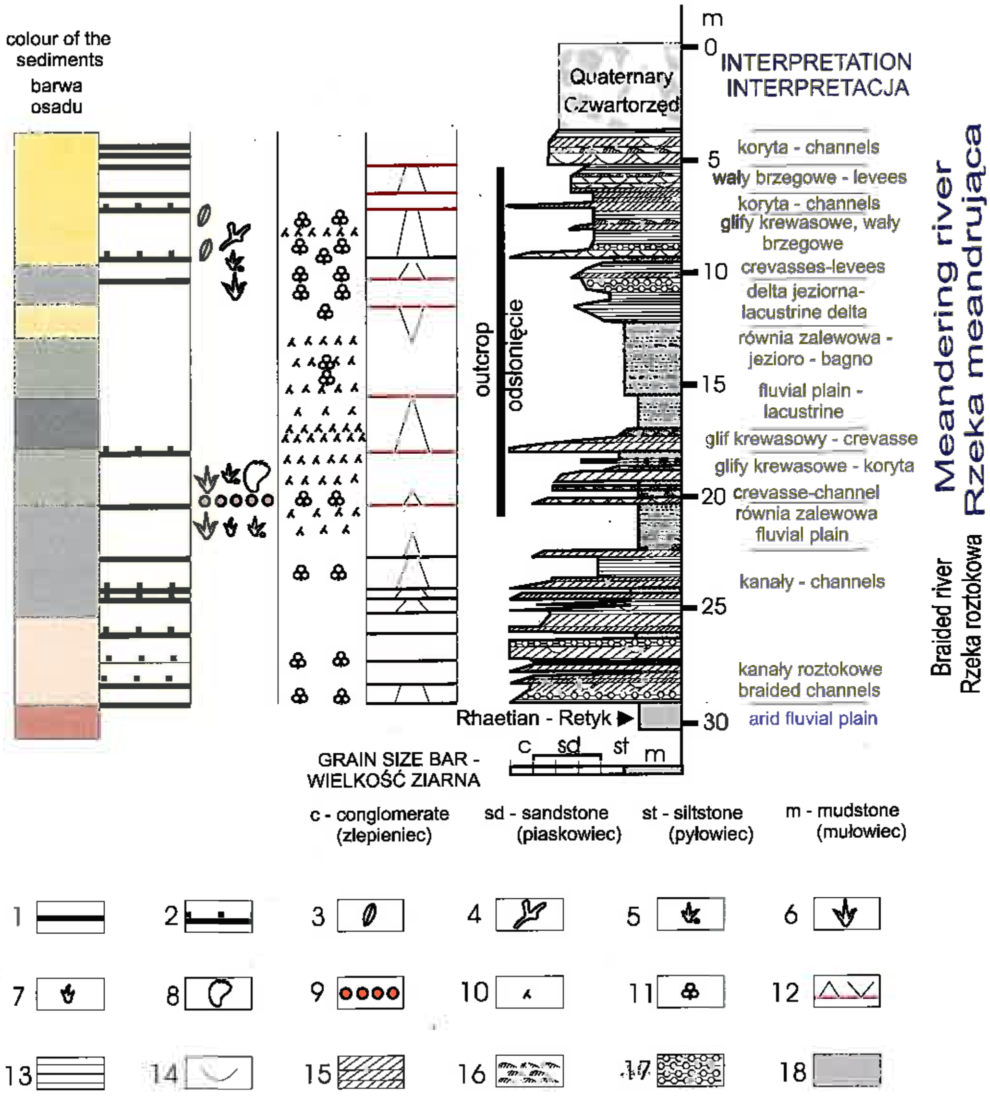

Fig. 2. Section of the Sołtyków borehole (section exposed in the outcrop is marked by the bar) and sedimentological interpretation

1 — erosional surfaces, 2 — erosional surfaces with mud clasts, 3 — bivalve resting tracks (*Lockeia* sp.), 4 — insect burrows (*Spongeliomorpha* sp.), 5 — basal ornitishian footprints (*Anomoepus* sp.), 6 — large theropod — Dilophosaur footprints (*Kayentapus soltykovensis*), 7 — small theropod footprints (*Grallator* sp.), 8 — sauropod footprints and trackways (*Parabrontopodus* sp.), 9 — dinosaur nests, 10 — plant roots, 11 — drifted plant remains, 12 — cycles boundaries and cycles: 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 claystones and mudstones; the colours of the sediment regard borehole, not outcrop, where they are altered

Profil otworu Sołtyków (fragment odsłonięty zaznaczono pionowym odcinkiem) wraz z interpretacją sedymentologiczną

1 — powierzchnie erozyjne, 2 — powierzchnie erozyjne z klastami mułowymi, 3 — ślady spoczynku małżów (*Lockeia* sp.), 4 — jamki owadów (*Spongeliomorpha* sp.), 5 — tropy wczesnych dinozaurów ptasiomiednicznych (*Anomoepus* sp.), 6 — tropy dużych dinozaurów drapieżnych — dylofozaurów (*Kayentapus soltykovensis*), 7 — tropy małych dinozaurów drapieżnych (*Grallator* sp.), 8 — tropy zauropodów (*Parabrontopodus* sp.), 9 — gniazda dinozaurów, 10 — korzenie roślin, 11 — napławiona flora, 12 — granice cykli i cykle: o ziarnie malejącym ku górze (z lewej) i o ziarnie rosnącym ku górze (z prawej), 13 — laminacja pozioma, 14 — warstwowanie przekątne rynnowe, 15 — warstwowanie przekątne tabularne, 16 — warstwowanie zmarszczkowe, 17 — warstwowanie konwolutne, 18 — mułowce i iłowce z mikrolaminacją lub bez widocznych struktur sedymentacyjnych; barwa osadu dotyczy rdzenia wiertniczego, a nie odsłonięcia, w którym barwy są zmienione

ELLIPSOID STRUCTURES

The structures are scattered within the sandstone layer with no clear orientation (Pl. III, Figs. 1, 2 — structures **a–j**). The fill is similar to the fill of the oval structures (detrital muddy-ferruginous substance). In some objects one may observe more sandy material (object **j**). Most of the structures are placed obliquely in the sediment, with various inclination angle. Objects **e** and **j** lie nearly horizontally. The objects are about 8 cm long and 4 cm wide. In places where a more sandy infilling occurs, one can find invertebrate burrows (Pl. III, Fig. 4). Object **i** shows some tiny structures inside (Pl. III, Fig. 5). They are straight, flattened, cylindrical structures built of darker matter. To find more information about these objects they were examined under the scanning electron microscope (SEM). The following results were obtained:

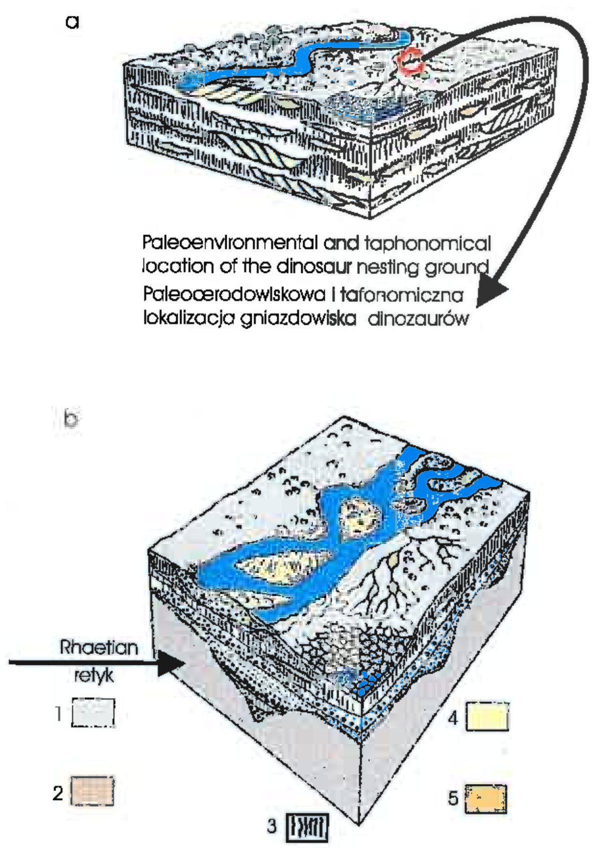

Fig. 3. Spatial reconsturtion of the Sołtyków palaeoenvironments

a — younger complex, meandering river regime, river was flowing approximately from the north to the south according to the measurements taken in the outcrop, but the channel directions were very changing; even more changing were directions of the crevasse splay channels and fan-like sheets; lower flood plain terrains were covered with horsetail vegetation, higher terrains were covered with coniferous forest; this was the biotope of the dinosaurs; **b** — older complex, not visible in the outcrop; the regime was dominated by the low-sinuosity rivers, the erosional gradient was higher and the climate was somewhat drier; facies: 1 — flood plain, 2 — crevasse splays, 3 — palaeosol levels, 4 — channel facies (sandstones), 5 — lacustrine facies (mudstones, claystones, coal)

Przestrzenna rekonstrukcja paleośrodowisk w Sołtykowie

a — kompleks młodszy, reżim sedymentacyjny rzeki meandrującej; według pomiarów w odsłonięciu rzeka płynęła w przybliżeniu z północy na południe, ale kierunki kanałów często się zmieniały; jeszcze bardziej zmienne były kierunki kanałów i stożkowych pokryw glifów krewasowych; niższe tereny zalewowe pokrywała wegetacja skrzypów, wyższe tereny porastał las szpilkowy; tak wyglądał biotop dinozaurów; **b** — starszy kompleks, niewidoczny w odsłonięciu; reżim sedymentacyjny był zdominowany przez rzeki roztokowe, gradient erozyjny był większy, a klimat nieco bardziej suchy; facje: 1 — równia zalewowa, 2 — glify krewasowe, 3 — poziomy gleb kopalnych, 4 — piaszczyste facje kanałowe, 5 — facje jeziorno-bagienne (mułowce, iłowce, węgle)

1. The cylindrical structures show internal fibrolamellar texture (Figs. 6, 7). The lamellae are 5–10 μ wide and in places show a branching pattern. Lamellae are built of chalcedony (Fig. 8), but in places some encased, small fragments with high calcium content are preserved (Fig. 9).

2. The structures are covered by globular iron hydroxides cover (Fig. 7).

INTERPRETATION

At first glance, the structures under question look like large ferruginous nodules — it is a very natural supposition, because such nodules are common in fluvial/lacustrine sediments deposited in warm, humid climate. But first of all they are only partly ferruginous — in other parts they are built chiefly of clay minerals and fine quartz grains. They also show rather laminated than concentric structure. Moreover, ferruginous nodules (in this setting they were formerly sideritic, subsequently "limonitic" = goethite + lepidocrocite) usually represent diagenetic structures, while objects under questions were present in its shape before sedimentation of the host rock (see Fig. 4; Pl. III, Figs. 1–3). So, could they have been mud clasts? First problem is that they would have been unusually big mud clasts — usually, the maximum grain size in this locality is up to 3 cm. Moreover, those "mud clasts" would have been astonishingly regular in their size and shape — to make the thing more complicated, they would have occurred in two "bimodal" classes, i.e. in two distinct, separate groups characterised by different size and shape, which is rather unlikely for the mud clasts. At last, some of those structures must have been arranged (by a current!) in a form of a regular rim. Needless to say, such possibilities are much less than remote — they are practically impossible. In some of the structures one can find a very high concentration of iron minerals, but this would be the only similarity with ferruginous nodules. Ferruginous content has nothing to do with the origin of the structures — they were something else, concretions inside or around them developed much later (compare with R. Cousin *et al.*, 1994; p. 68, fig. 5.13).

On a "negative" way of reasoning (i.e. eliminating what it can not be), one has to exclude their inorganic origin. If we agree that biological factor must have been responsible for such a regularity in shape and arrangement, we have to ponder what kind of organic structures they might represent. There are few possibilities, such as plant fragments (most likely seeds or fructifications), animal coprolites or stomach stones. As far as concerns floristic remains from Sołtyków, their stage of preservation is excellent, and coal is common in those fossils. Except for some plant detritus, these structures do not contain any large plant structures and coal matter. It is very unlikely that so large floristic remains would not contain coal or identifiable plant tissue (compare with Pl. II, Fig. 4), when everywhere around plant fossils are so well preserved. Therefore a plant origin of the structures must be excluded. Coprolites of that age are still little known, but again the regular, spherical shape and arrangement of some structures exclude such a possibility. Stomach stones of ruminant mammals (K. F. Hirsch, D. K. Zelenitsky, 1997) show a very different, concentric structure. Besides, large, ruminant mammals did not exist in Early Jurassic. All the mentioned "organic" explanations must be excluded. As a result of elimination, the egg interpretation is the most probable one. Further support

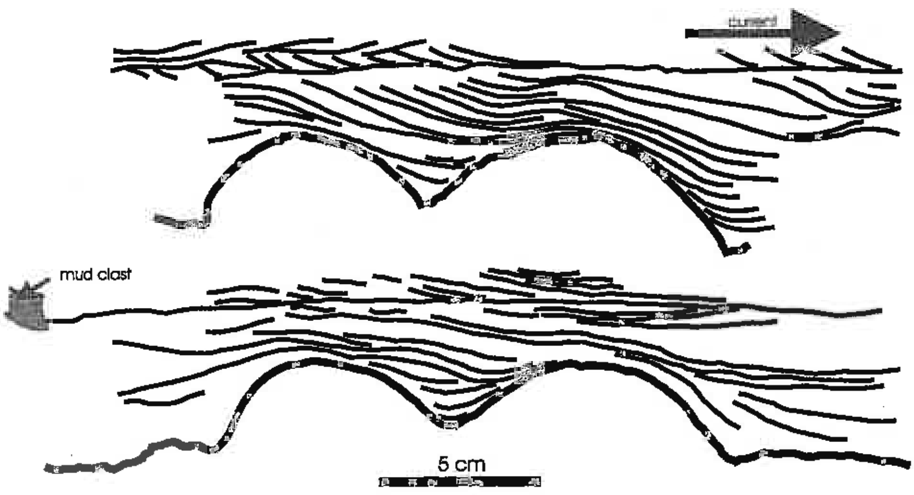

Fig. 4. Cross-section of the nest showing the cross-bedding in the sediment covering the egg structures. Note the concordant arrangement of the cross lamine, proving that the structures were present before the deposition of the host sediment

Przekrój gniazda ukazujący osad pokrywający struktury jajowe. Widoczne zgodne ułożenie lamin warstwowania przekątnego, co dowodzi, że struktury kuliste były obecne przed sedymentacją osadu otaczającego je od góry

of such an interpretation comes from the "positive" facts, indicating what it can be:

1. Regular shape and rim-like arrangement. As mentioned before, the structures represent two kinds: spherical and ellipsoid ones. Particularly, the spherical structures are very suggestive. The similarity to sauropod nests and eggs described by many authors (J. W. Kitchling, 1979; F. E. Grine, J. W. Kitchling, 1987; J. J. Moratalla, J. E. Powell, 1994; L. M. Chiappe *et al.*, 1998) is striking. Spherical eggs are also attributed to hadrosaurs but they did not exist in the Lower Jurassic time. It is important that the structures form part of a rim in a shallow depression (Pl. III, Fig. 3) and they seem to occur in pairs (Pl. III, Figs. 1, 2). J. W. Kitchling (1979) and F. E. Grine and J. W. Kitchling (1987) described a clutch of six spherical eggs from South Africa. Basing on preserved embryo remains, the authors attributed those eggs to prosauropods. J. J. Moratalla and J. E. Powell (1994) stated, that sauropods laid eggs in circular clutches, parallel rows, or arcs. Sauropods could also dig shallow nests with the forefeet, possibly with the enlarged ungual phalanx of digit I (J. J. Moratalla, J. E. Powell, 1994). Likelihood, that the structures occur in pairs, is also consistent with the way on which the dinosaur eggs were laid — it is connected probably with their twin oviducts.

2. Association with sauropod footprints. A well preserved, probably juvenile sauropod *pes* print (*Parabrontopodus* sp., Pl. II, Fig. 3) has been found by the present author in the same place. G. Gierliński and G. Sawicki (1998) described a whole sauropod trackway just about 60 m apart, in the same complex of strata. Those unique finds point to the fact, that fairly large sauropods were common in the Sołtyków fluvial plain area in the earliest Jurassic times.

3. Chip-like, platy fragments around the structures (Pl. III, Figs. 1, 3). They are strongly altered and under the SEM (Fig. 10) it is visible that they are built of clay minerals (illite, smectite) and iron hydroxide and oxide. They show laminar structure but little more can be said about them. In places, one can find poorly preserved, parallel or slightly radial tiny canals, which are approximately perpendicular to the plate's surface (Fig. 10). The "chip-like" structures might be tentatively interpreted as diagenetically altered fragments of egg-shells, but such a supposition is highly hypothetical.

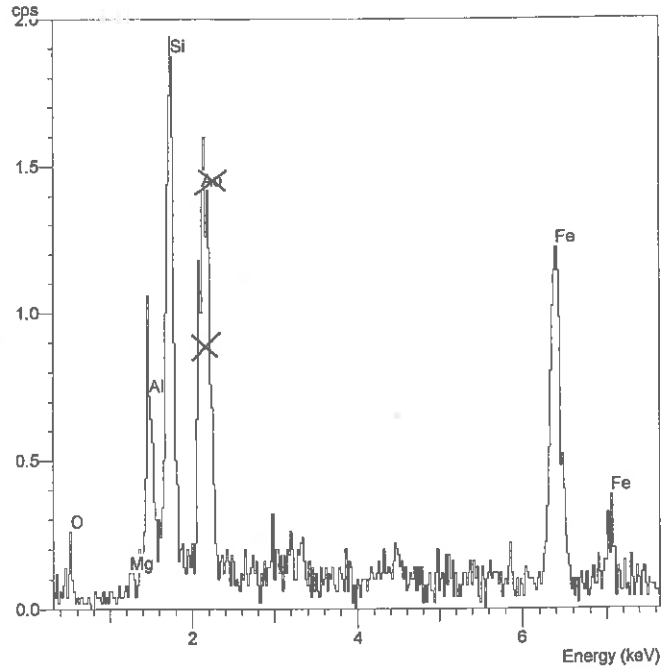

Fig. 5. Elements present in the infilling of the egg structures (EDS). Typical picture of illite mixed with iron hydroxides/oxides and some silica

Pierwiastki obecne w wypełnieniach struktur jajowych w badaniu sondą EDS. Typowy obraz dla illitu zmieszanego z wodorotlenkami/tlenkami żelaza, z domieszką krzemionki

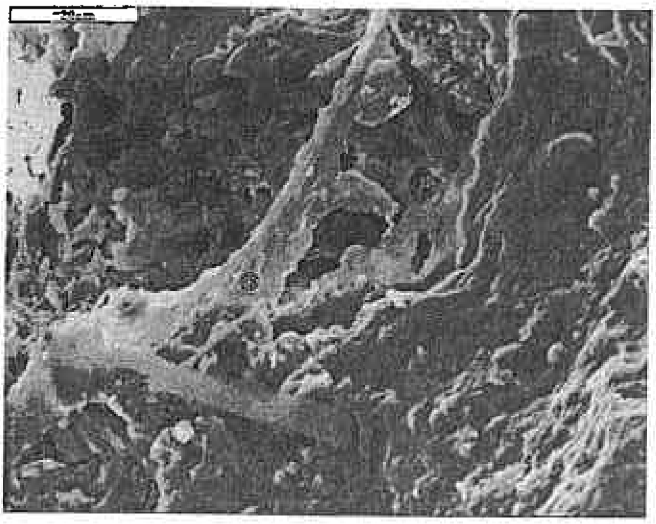

Fig. 6

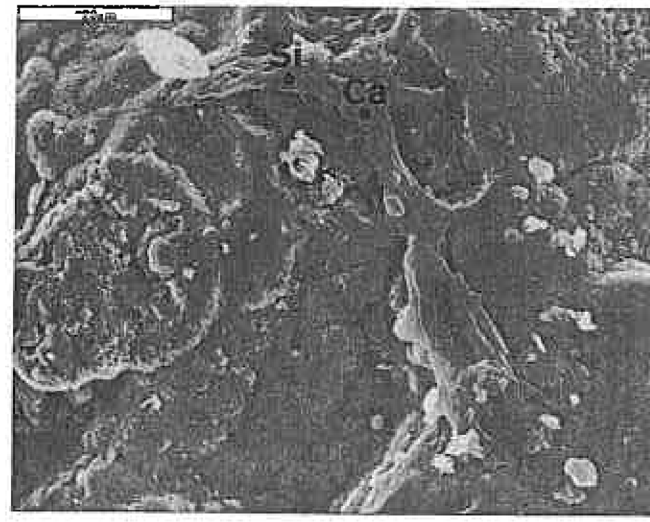

Fig. 7

Fig. 6. Fragment of the inner ultrastructure of the dark substance taken from the cylindrical structures shown in Pl. III, Fig. 5. Note fibrolamellar ultrastructure. In the EDS (marked) presence of pure silica was indicated

Fragment wewnętrznej ultrastruktury ciemnej substancji pobranej z cylindrycznych struktur przedstawionych na tabl. III, fig. 5. Widoczna ultrastruktura włóknisto-blaszkowa. Sonda EDS (zaznaczony punkt) wykazała obecność czystej krzemionki

Fig. 7. Fragment of the inner and outer ultrastructure of the dark substance taken from the cylindrical structures shown in Pl. III, Fig. 5. Note fibrolamellar ultrastructure. In the EDS, one point shows typical siliceous composition, while in the other place one can find remnants of the encased substance rich in calcium (see Figs. 8 and 9). The outer ultrastructure is globular — the globules are built of iron hydroxides/oxides, which gives the structures their dark colour

Fragment wewnętrznej i zewnętrznej ultrastruktury ciemnej substancji pobranej z cylindrycznych struktur ukazanych na tabl. III, fig. 5. Widoczna ultrastruktura włóknisto-blaszkowa. Jeden punkt badany sondą EDS pokazuje typową budowę krzemionkową, a inny resztki pierwotnej, otoczonej krzemionką substancji bogatej w wapń (patrz fig. 8 i 9). Zewnętrzna ultrastruktura ukazuje budowę groniastą — grona zbudowane są z wodorotlenków/tlenków żelaza, co nadaje strukturom ciemny kolor

4. Flattened, cylindrical objects with fibrolamellar ultrastructure. The infilling of the structure i comprises several elongated, cylindrical, strongly flattened, dark objects (Pl. III, Fig 5). Similar structures have been illustrated by S. G. Lucas (1994, p. 193, fig. 13.11) in the cross-section of a hypsilophodontid egg showing some of the bones of the embryonic dinosaur. Under the SEM those objects show fibrolamellar ultrastructure with lamellae built of chalcedony. However, there are some remnants of the primary matter encased within the chalcedony framework. This matter is very rich in calcium (traces of phosphorus are also present) and was obviously sealed in silicified fibrolamellar structure. In the Sołtyków outcrop, calcium is generally absent — it was totally removed due to the low pH conditions during sedimentation and particularly at the burial stage. Fibrolamellar pattern of the objects in question is not a coincidence and it needs explanation. I tentatively identify the collection of long, narrow structures as ossified embryonic skeletal elements, which were subsequently silicified. The dinosaur embryonic bones were highly vascularized, soft and flexible. They show fibrolamellar structure (J. R. Horner, P. J. Currie, 1994); besides bones, abundant calcified cartilage columns were found (J. R. Horner, P. J. Currie, 1994). A fibrolamellar framework found in Sołtyków specimen could represent both kinds of tissue.

In the subsequent stage of diagenesis the fibrolamellar structures were covered with globular iron minerals, most likely as a result of microbial activity — CO_2 waste attaches to Fe^{2+} to produce siderite, which was later transformed into iron oxides/hydroxides (K. Carpenter, 1998) — see Fig. 7.

It is difficult to say what kind of dinosaur those remains might represent. Elongated egg structures may be attributed both to basal ornitishians or theropods. Footprints of both groups of dinosaurs are common in the Sołtyków outcrop (Pl. II, Figs. 1, 2). One should shortly comment on the possibility, that the egg structures might represent other animals, for example tortoises. However, the size of the structures, the pattern of the clutch and the lack of any evidence of the presence of other potential egg-laying animals other than dinosaurs, makes this supposition very unlikely.

To sum up, I interpreted both spherical and ellipsoid structures as strongly altered dinosaur eggs (more precisely, I would call them the "post-egg structures"). Spherical structures would represent sauropod eggs, while ellipsoid ones might be laid by either basal ornitishians or theropods. The nesting site was found in just one place, but sandy, crevasse splay sediments deposited on a flood plain might represent a favourable nesting ground for many groups of dinosaurs. The coexistence with numerous, fairly diversified dinosaur footprints tends to support such a supposition. Joint occurrence of two different kinds of eggs in the same location can be easily explained by the taphonomical factors.

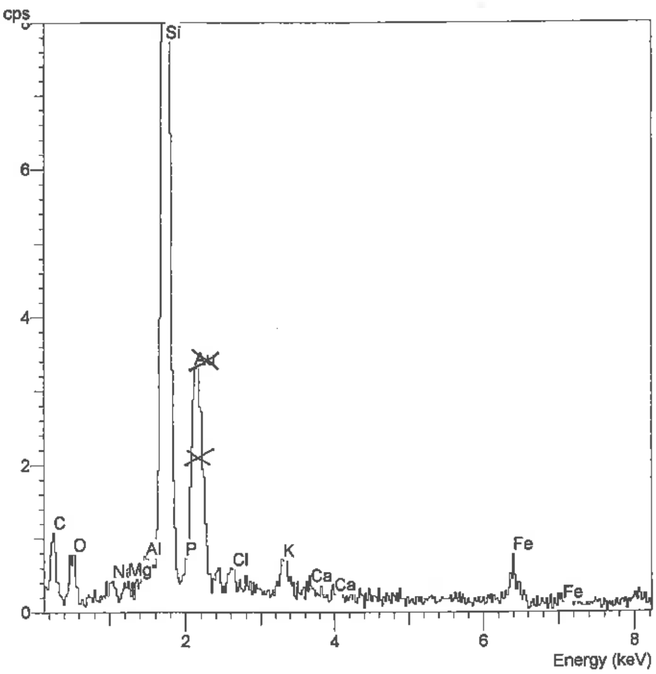

Fig. 8

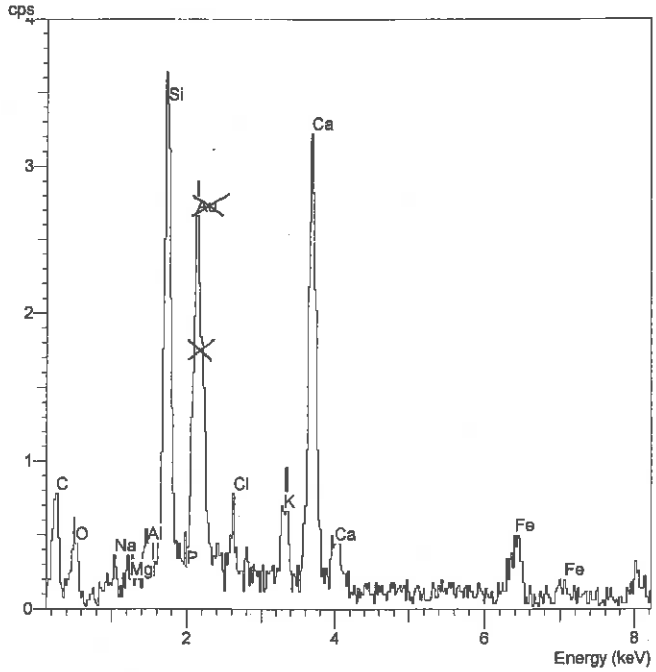

Fig. 9

Fig. 8. "Si" point from the Fig. 7 in the EDS — note the domination of silica

Punkt „Si" z fig. 7 badany sondą EDS — widoczna dominacja krzemionki

Fig. 9. "Ca" point from the Fig. 7 in the EDS — note high calcium content, presence of carbon, and some traces of phosphorus. Most probably, calcium occurs in form of $CaCO_3$, possibly with some phosphate admixture

Punkt „Ca" z fig. 7 badany sondą EDS — zaznacza się wysoka zawartość wapnia, obecność węgla oraz śladowo fosforu. Wapń występuje najprawdopodobniej w formie węglanowej, możliwie z niewielką domieszką fosforanu

TAPHONOMY AND DIAGENESIS

All the described structures represent unhatched eggs. Because the spherical sauropod egg structures occur in the preserved nest structure, it is obvious that they represent an *in situ* nesting ground. In the contrary, ellipsoid egg structures are scattered throughout the sediment with different inclination angle and very chaotic pattern. It is also obvious that these eggs were redeposited from a nearby nesting site, most probably by the same flood current which covered the sauropod nest with sandy deposits. The sauropod eggs, which were heavier, spherical in shape, and laid in a shallow depression were much more current-resistant than the lighter and elongated ellipsoid eggs, which could have been easily moved and transported by a flood current. Dinosaur eggs can be transported a considerable distance (T. Tokaryk, J. Storer, 1991). The flood event probably caused the death of eggs and embryos. Eggshell domes acted as a "vault" for some time, until the empty space inside, left after decay of soft parts, was infilled by muddy matrix infiltrating through cracks and pores. In places, where some sandy materials entered the shells, burrow systems might develop (Pl. III, Fig. 4). Needles to say, decomposing eggs provided a very attractive "nutrition storage", but the oxygen condition was a major problem. More porous sandy material could let some oxygen to get into the egg filling, changing conditions from anaerobic to dysaerobic and providing a "feeding bonanza" for a brief period. Perhaps at that stage the remnants of some embryonic bones were silicified, which protected them from further decomposition. Solubility and mobility of silica could be temporarily raised by the presence of ammonia originating from decaying organic matter. Ammonia could also slow down the dissolution of calcium carbonate of the eggshell, but generally (in case of an unhatched egg) dissolution of eggshell can begin shortly after the death of the egg or embryo. Decay of the organic matter produces carbon dioxide and hydrogen sulphide lowering the pH of the water in the vicinity of the egg making the calcium carbonate of the shell more soluble (K. Carpenter *et al.*, 1994*a*). After burial, dissolution can occur by hydrolysis involving groundwater (K. Krauskopf, 1979). The rate of dissolution grows as the pH gets lower. Fluvial deposits of Sołtyków oucrop were characterised by the low pH, so eggshells built of calcium carbonate were dissolved and gradually replaced by an infiltrating clayey substance. Such a "mud capture" in sand producing mud matrix has been described by K. S. Matlack *et al.* (1989). At the next stage (associated with a deeper burial) precipitation of siderite occurred. In the vicinity of lacustrine deposits supersaturation of the iron ions delivered by the humus acids is characteristic. Siderite may precipitate as a result of bacterial metabolism. The latest stage was dominated by oxidation — this occurred after tectonical inversion of the Mid-Polish Trough and uplifting of the Holy Cross Mountains area, which occurred in

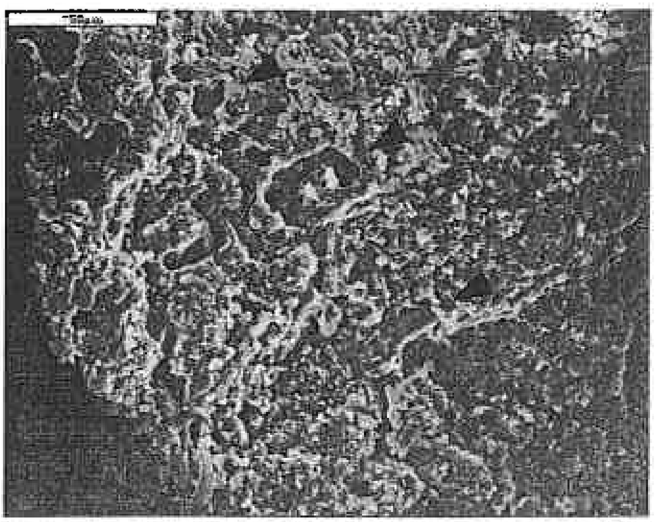

Fig. 10. Ultrastructure of the clayey chip-like plate from the outer surface of the egg structure C (Pl. III, Fig. 2). Note chaotic framework of clay minerals with some parallel canals (arrowed)

Ultrastruktura płytki ilastej z zewnętrznej powierzchni struktury jajowej C (tabl. III, fig. 2). Widoczna chaotyczna struktura minerałów ilastych z kilkoma równoległymi kanalikami (strzałki)

earliest Tertiary. Liassic deposits underwent extensive weathering, kaolinisation and oxidation. Siderite was replaced by iron oxides and hydroxides (limonite), which filled joints and impregnated many levels in Liassic rocks. Taphonomy and diagenetic stages are summarised in Fig. 11.

CONCLUSIONS

The eggs are strongly diagenetically altered and no obvious eggshell ultrastructure can be observed, therefore the egg parataxonomy (K. Sabath, 1991; K. Mikhailov *et al.*, 1994) can not be applied in this case. According to some standards, there should be the evidence of eggshell structure to prove that a specimen is an egg (K. F. Hirsch, D. K. Zelenitsky, 1997). Despite that, one can state that the evidences shown in the present paper allow to name the objects eggs, or more precisely, the post-egg structures. Further examinations, including X-ray and computer tomography, will be performed to check the objects inside. Acidic conditions eliminated the eggshells, but the preservation potential for embryonic skeletons might be slightly better. All this might serve as a hint, that in many deposits of fluvial origin fossil dinosaur eggs may be in fact fairly abundant, but due to their poor state of preservation, caused by the low pH conditions they are often overlooked. In this context, one should not automatically reject indirect or circumstantial evidences, because they may help to eliminate some irrelevant interpretations and point to the accurate ones. Examining structures, which are so difficult to interpret, needs an interdisciplinary approach, including careful sedimentological and palaeoecological studies. K. Carpenter *et al.* (1994) proposed a scheme of such an approach. Following their scheme (perhaps it should be called the "egg identification form"), it is possible to "submit" a brief report on the material from Poland:

1. Nest environment: moderate — warm and humid climate, fluvial plain, prevailing horsetail and coniferous vegetation.

2. Sedimentological and chemical analyses of the nest and area adjacent to the nest: crevasse splay sandstones (wackestones), subordinately mudstones, deposited during flood events on a broad flood plain of a high-sinuosity, meandering river. Palaeosols with numerous plant roots and coal seams are common, numerous mud cracks, bivalve resting tracks and burrows, arthropod burrows and dinosaur footprints. Associated subfacies of river channels, levees and flood plain lakes have been recognised. Quartz, illite, kaolinite, smectite, iron minerals and various types of coal dominate; diagenetic processes involve calcium carbonate dissolution, infiltration of clay minerals, and iron minerals dissolution and precipitation. Low pH prevailed during sedimentation and after burial.

3. Type, shape and size of the nest: single, rounded, shallow (few centimetres deep) buried in substrate, about 30 cm of diameter, with up to six (with four preserved) post-egg structures. Ellipsoid egg structures were redeposited — the type of their original nest is unknown.

4. Associated flora and fauna within the nest: some scattered, unidentified floral remains; sauropod, theropod and basal ornitopod footprints were found nearby.

5. Arrangement of eggs within the clutch: a rim-shaped, regular clutch, 25 cm in outer diameter (four egg structures preserved, there were probably six of them).

6. General morphology (macrostructure) of the egg and eggshell: regular, spherical, slightly flattened, longer axis 10 cm, shorter 8 cm, covered with chip-like plates up to 3 cm^2 and 1.5 mm thick. Chip-like plates are laminated, built of clay minerals with lamina of secondary iron minerals. Same chip-like plates are found around egg structures and are scattered on the surface of egg-bearing layer. Egg structures are built of the clayey-silty-ferruginous matrix coated by a thin, discontinuous clayey-ferruginous coating.

7. Egg and embryonic histostructure — egg histostructure can not be described because of total diagenetic alteration. Inside the redeposited egg structures, some accumulations of faint, flattened, cylindrical structures have been found — they reveal silicified, fibrolamellar ultrastructure with some remnants of primary matter, which is rich in calcium. They probably represent embryonic remnants.

8. Biochemical analysis of the shell — impossible to perform.

9. Taphonomy: matrix is fluvial, rate of sedimentation was rapid (flood), the current transported and dispersed the smaller eggs from nearby nesting grounds and covered the nest of the spherical eggs with sandy sediment. In a case when the egg infilling was more sandy, some burrows can occur

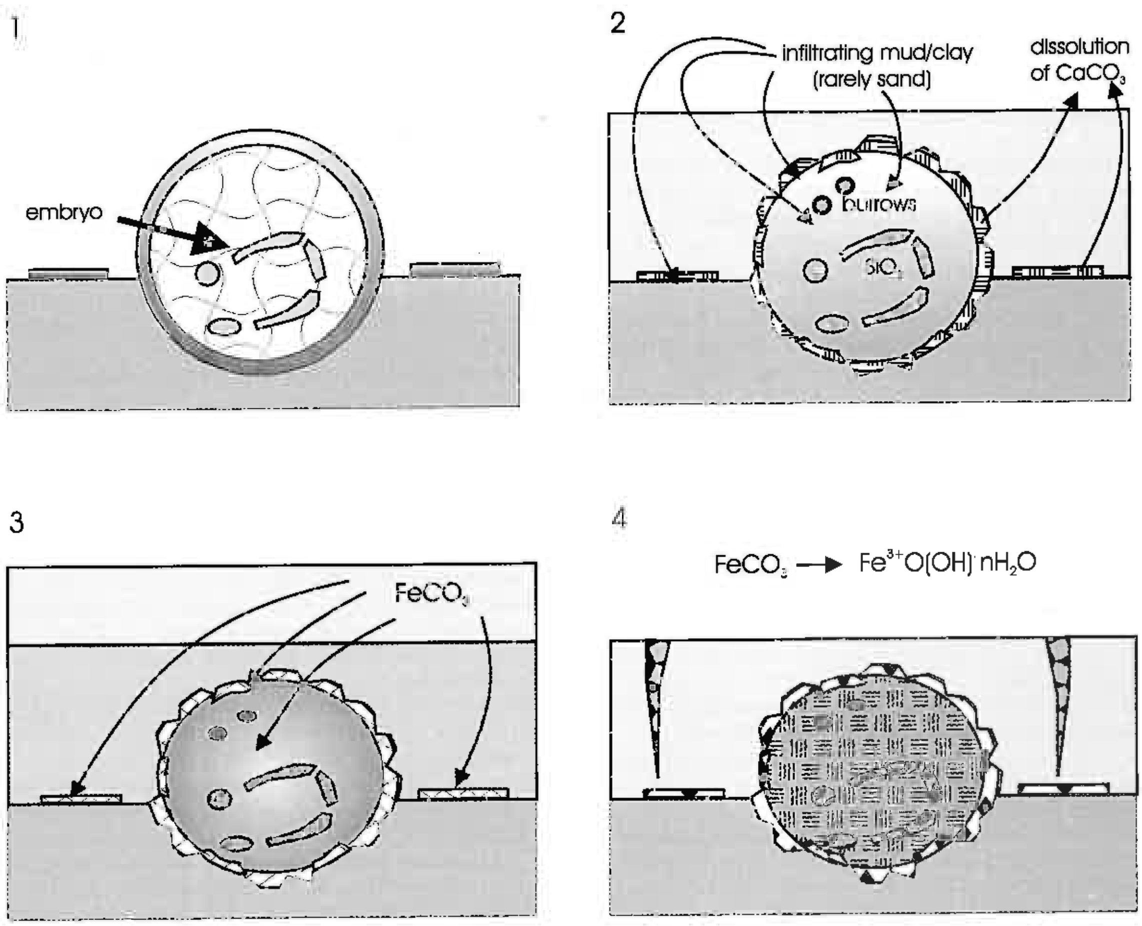

Fig. 11. Scheme showing stages of taphonomy and diagenesis of the post-egg structures

1 — eggs are laid in the sediment, some crushed eggshells are derived from broken or hatched eggs; **2** — burial by the flood event, quick decomposition of the soft parts, infilling of the eggs by infiltrating detrital mud/clay (rarely sand) matrix through incipient cracks and pores (burrows can locally develop at this stage), local, inner silification associated with temporal presence of ammonia, and subsequent dissolution of $CaCO_3$ caused by acid conditions associated with gradual replacement by clay minerals by infiltration; **3** — deeper burial stage, compaction, precipitation of siderite; **4** — epigenetic stage, oxidation of siderite to limonite (=goethite and lepidocrocite), cracks infilling by iron minerals

Schemat przedstawiający cztery stadia tafonomii i diagenezy struktur jajowych

1 — jaja złożone w osadzie, naokoło pewna ilość pokruszonych skorupek pochodzących z pokruszonych lub wyklutych jaj; **2** — stadium pogrzebania przez powódź, szybki rozkład miękkich części, wypełnienie przez infiltrujący, detrytyczny muł i ił (rzadko piasek), przez zaczątkowe pęknięcia i pory (jamki żerowiskowe mogą się lokalnie rozwinąć w tym stadium), lokalna, wewnętrzna sylifikacja wywołana okresową obecnością amoniaku oraz następujące potem rozpuszczenie $CaCO_3$ spowodowane zakwaszeniem środowiska, postępujące wraz z rozpuszczaniem wypełnianie pustych przestrzeni przez minerały ilaste na drodze infiltracji; **3** — głębsze pogrzebanie, kompakcja i wytrącanie syderytu; **4** — epigenetyczne stadium utleniania syderytu do limonitu (getytu i lepidokrokitu), szczeliny wypełniane minerałami żelazistymi

10. Diagenesis: decomposition of soft tissue, partial cracking of the eggshell, infilling with clayey-silty matrix, in the same time local silicification associated with presence of ammonia, dissolution of calcite eggshell, gradual replacement by clay and ferruginous material, late epigenetic oxidation.

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GNIAZDA DINOZAURÓW Z WCZESNOJURAJSKICH UTWORÓW RZECZNYCH Z GÓR ŚWIĘTOKRZYSKICH

Streszczenie

W dolnoliasowym (dolny hettang) odsłonięciu Sołtyków koło Odrowąża (województwo świętokrzyskie) znaleziono sferyczne i elipsoidalne struktury, które zostały zinterpretowane jako struktury powstałe w miejsce jaj dinozaurów. Jaja zostały pierwotnie złożone w piaszczystej ławicy reprezentującej glif krewasowy, w obrębie równi zalewowej rzeki meandrującej. Zostały one silnie zmienione przez procesy diagenetyczne i nie zachowała się pierwotna ultrastruktura skorupek. Badania wnętrza jednej ze struktur struktur ujawniły niewielkie, ciemne, spłaszczone, cylindryczne struktury. Pod mikroskopem elektronowym ukazują one włóknisto-lamelarną budowę zbliżoną do budowy kości lub zwapniałej chrząstki embrionalnych dinozaurów. Inną ważną przesłanką jest ułożenie większych, sferycznych struktur w postaci pierścienia charakterystycznego dla wylęgu zauropodów. Dodatkowymi przesłankami jest regularna wielkość i kształt znalezionych struktur. Pierścieniowy wyląg jest gniazdem zauropodów zachowanym *in situ*. W pobliżu gniazda znaleziono tropy zauropodów.

Interpretacja wydłużonych struktur jest trudniejsza, mogą one reprezentować zarówno jaja wczesnych dinozaurów ptasiomiednicznych, jak i drapieżnych teropodów. Obie grupy dinozaurów pozostawiły liczne ślady stóp w pobliżu stanowiska z jajami. Jaja elipsoidalne zostały przeniesione przez prąd wodny związany z powodzią i złożone na wtórnym złożu w pobliżu kulistych jaj zauropodów. Osady tej samej i następnych powodzi przykryły jaja, które obumarły i nie uległy wykluciu. Po rozkładzie ich miękkich części i wypełnieniu wnętrza osadem mulistym na drodze infiltracji, procesy diagenetyczne doprowadziły najpierw do lokalnej sylifikacji wewnątrz struktur,

a potem do stopniowego rozpuszczenia skorupek oraz ich podstawienia infiltrującymi minerałami ilastymi. Po etapie głębszego pogrzebania struktur nastąpił proces syderytyzacji. Stosunkowo niedawno, w trzeciorzędzie, syderyt utlenił się do wodorotlenków i tlenków żelaza.

Znalezisko to jest pierwszym odkryciem struktur jajowych dinozaurów w Polsce i drugim odkryciem tych struktur na świecie w utworach dolnojurajskich. Niniejszy artykuł może się przyczynić do podjęcia dyskusji na temat silnie zmienionych jaj i kryteriów, jakie powinny kierować interpretacją i oznaczaniem struktur jajowych dinozaurów.

Zupełnie odrębnym problemem jest ochrona tego unikatowego stanowiska, które jest niszczone przez przygodnych poszukiwaczy gagatu. W tym celu konieczne jest skuteczniejsze egzekwowanie obowiązującego prawa, a także jak najszybsze zabezpieczenie i opracowanie najcenniejszego materiału naukowego znajdującego się w odsłonięciu.

EXPLANATIONS OF PLATES

PLATE I

Fig. 1. General view (in 1986) of the Sołtyków outcrop showing different fluvial facies: fp — mudstones, claystones and coals of the flood plain/oxbow lake subfacies with numerous paleosol levels; ch — main fluvial channels, sandstones with large-scale trough bedding, transport directions from the north to the south dominate; cr — crevasse splay channels, transport directions approximately perpendicular to the "main" channel directions. Fan-shaped crevasse splay deposits dominate in the bottom of the outcrop, when dinosaur nest and many footprints have been found

Ogólny widok odsłonięcia w Sołtykowie (1986 r.) ukazujący różne facje rzeczne: fp — mułowce, iłowce i węgle subfacji równi zalewowej i starorzeczy z licznymi poziomami paleoglebowymi; ch — „główny" kanał rzeczny, piaskowce z warstwowaniami rynnowymi dużej skali, przeważają kierunki transportu z północy na południe; cr — kanały glifów krewasowych, kierunki transportu w przybliżeniu prostopadłe do kierunku „głównego" kanału. Osady glifów krewasowych wachlarzowatego kształtu występują w spągu odsłonięcia, gdzie znaleziono gniazdo i liczne tropy dinozaurów

Fig. 2. Dinosaur nest in the crevasse splay deposits. Three spherical egg structures are visible (inset). Arrows indicate current directions: subordinate (thin arrow) and major one (thick arrow). North is on the right side of the photograph

Gniazdo dinozaurów w utworach glifów krewasowych. Widoczne są trzy sferoidalne struktury jajowe (w ramce). Strzałki oznaczają kierunki transportu: cienka strzałka — kierunek podrzędny, gruba strzałka — kierunek główny. Północ jest z prawej strony fotografii

PLATE II

Fig. 1. Large theropod footprint *Kayentapus soltykovensis* (after G. Gierliński, 1994). This track was left by the large carnivorous dinosaur, *Dilophosaurus* sp. Photo G. Gierliński

Ślad stopy dużego teropoda *Kayentapus soltykovensis* (według G. Gierlińskiego, 1994). Ten ślad został pozostawiony przez dużego drapieżnego dinozaura, *Dilophosaurus* sp. Fot. G. Gierliński

Fig. 2. Early ornitishian footprint *Anomoepus* sp. (after G. Gierliński, 1995). Coll. and photo — G. Gierliński

Ślad wczesnego dinozaura ptasiomiednicznego *Anomoepus* sp. (według G. Gierlińskiego, 1995). Kolekcja i fotografia — G. Gierliński

Fig. 3. Early sauropod footprint *Parabrontopodus* sp. found in the next layer and in the same place where the dinosaur nest have been found. Comparison with other sauropod footprints found nearby indicates that this footprint was left by a juvenile sauropod. Coll. and det. — G. Pieńkowski

Trop wczesnego zauropoda *Parabrontopodus* sp. znaleziony w nadległej ławicy w tym samym miejscu, w którym zostało znalezione gniazdo dinozaurów. Porównanie z innymi tropami dinozaurów odkrytymi w pobliżu wskazuje, że trop ten został pozostawiony przez młodego osobnika. Kolekcja i oznaczenie — G. Pieńkowski

Fig. 4. Some fossils, trace fossils and sedimentary structures occurring in the crevasse splay deposits in the Sołtyków outcrop: p — drifted plant fossils (left — *Equisetites* sp., right — unidentified coniferous plant); r — vertical sections of plant roots; L — *Lockeia* sp. (bivalve resting track); d — desiccation cracks filled by sand. Vertical structure represents a groove cast. Lower surface of the sandstone layer

Niektóre skamieniałości, skamieniałości śladowe i struktury sedymentacyjne występujące w osadach glifów krewasowych w Sołtykowie: p — szczątki napławionej flory (po lewej — *Equisetites* sp., po prawej — niezidentyfikowany fragment rośliny szpilkowej); r — pionowe przekroje korzeni roślin; L — *Lockeia* sp. (ślady postoju małży); d — wypełnienia szczelin z wysychania. Pionowa struktura to hieroglif prądowy wleczeniowy. Dolna powierzchnia ławicy piaskowca

PLATE III

Fig. 1. Fragment of the sandstone bed covering the nest from the top. The hollows correspond to the underlying egg structures, in one hollow (A) part of the clayey-ferruginous infilling is still visible. Note the partly preserved rim-shaped nest of spherical egg structures and scattered ellipsoid egg structures. The chip-like clayey plates occur on the structures and around them

Fragment warstwy piaskowca przykrywającego od góry gniazdo dinozaurów. Wgłębienia w osadzie odpowiadają niżejległym strukturom jajowym; w jednym wgłębieniu (A) wciąż widoczny jest fragment ilasto-żelazistego wypełnienia struktury. Kuliste jaja ułożone w kształcie segmentu pierścienia, podczas gdy struktury elipsoidalne są chaotycznie rozrzucone w osadzie. Na strukturach i wokół nich występują drobne płytki ilaste

Fig. 2. Sketch corresponding to the Fig. 1, explaining the arrangements of the egg structures. Note two generations of the structures and the regularity of the spherical structures within the rim. Arrow indicates the local current direction

Szkic dotyczący fig. 1, wyjaśniający ułożenie struktur jajowych. Widoczne są ich dwie generacje oraz regularne kształty jaj tworzących strukturę pierścieniową. Strzałka wskazuje lokalny kierunek prądu

Fig. 3. The same bed in the cross-section, along the longitudinal crack visible in Fig. 1. Note cross-bedding lamine coating the spherical egg structures. Current direction is from the left to the right of the photograph

Ta sama warstwa w przekroju poprzecznym wzdłuż widocznego na fig. 1 podłużnego pęknięcia. Widoczne warstwowanie przekątne, które obleka kuliste struktury jajowe. Kierunek prądu od lewej do prawej strony fotografii

Fig. 4. Burrows inside the upper part of the structure j (arrows). Note that infilling of this part of the structure is sandy, i.e. it is coarser than clayey infilling of the other structures. It could significantly change the oxygen conditions in the sediment

Jamki żerowiskowe w górnej części struktury j (strzałki). Widoczne jest wypełnienie piaszczyste tej części struktury, a więc bardziej gruboziarniste niż ilasto-mułowe wypełnienia innych struktur. Mogło to znacznie zmienić warunki tlenowe w osadzie

Fig. 5. Clayey-ferruginous infilling of the egg structure i, revealing tiny, cylindrical, flattened structures (arrowed), covered with a dark matter. Black arrow points to the spot where the sample for the SEM investigations was taken from (see Text-figs. 6–9)

Ilasto-żelaziste wypełnienie struktury jajowej i, w którym zachowane są niewielkie, cylindryczne, spłaszczone struktury (strzałki), pokryte ciemną substancją. Ciemna strzałka oznacza miejsce, z którego pobrano próbkę do badań w mikroskopie elektronowym SEM (porównaj fig. tekstowe 6–9)

Fig. 1

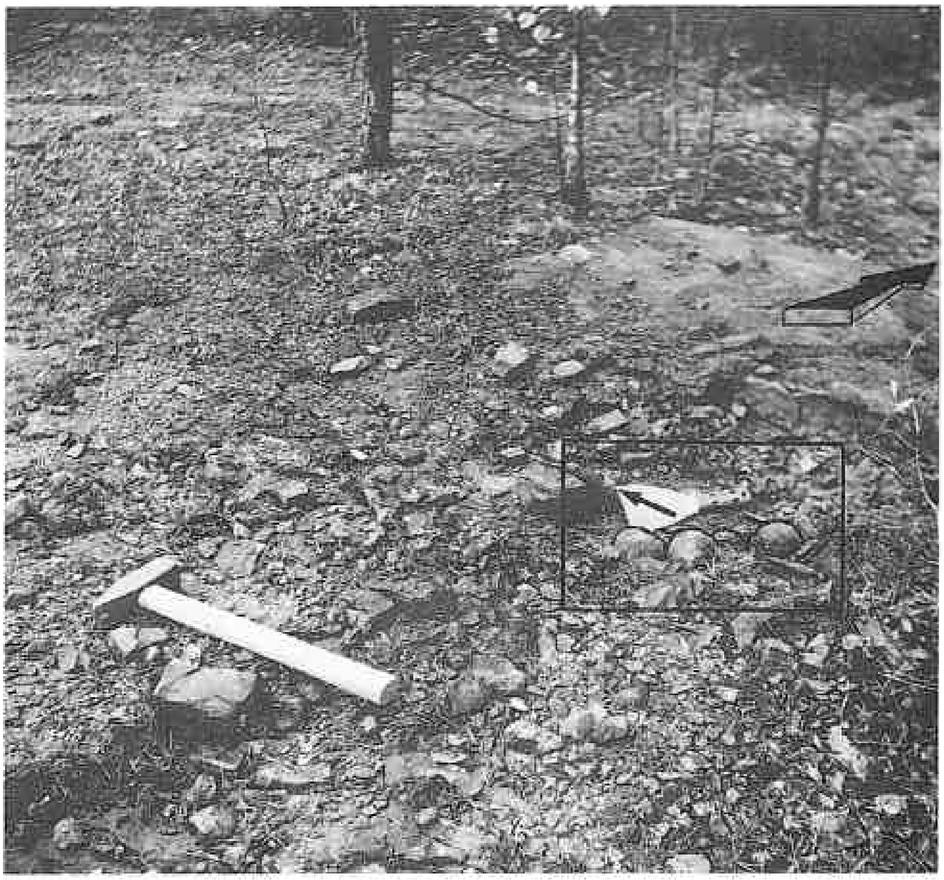
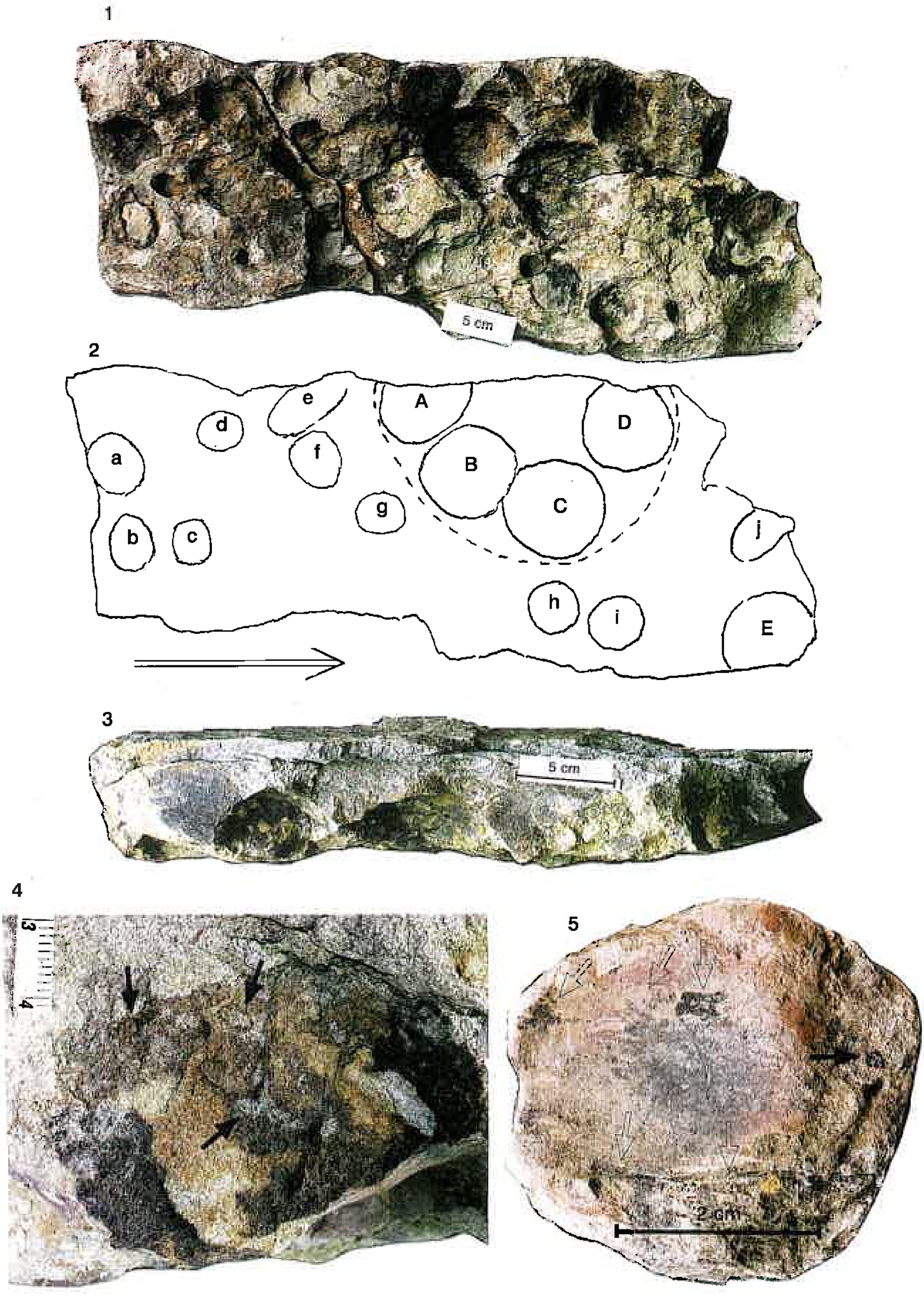


Fig. 2

Grzegorz PIEŃKOWSKI — Dinosaur nesting ground from the Early Jurassic fluvial deposits, Holy Cross Mountains (Poland)

Grzegorz PIEŃKOWSKI — Dinosaur nesting ground from the Early Jurassic fluvial deposits, Holy Cross Mountains (Poland)



Grzegorz PIEŃKOWSKI — Dinosaur nesting ground from the Early Jurassic fluvial deposits, Holy Cross Mountains (Poland)