Trace fossils from the Lower Jurassic Ciechocinek Formation, SW Poland

Paulina LEONOWICZ

Institute of Geology, University of Warsaw, ul. Żwirki i Wigury 93, PL-02089 Warszawa, Poland;
e-mail: Paulina.Leonowicz@uw.edu.pl

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ABSTRACT: Mud-silt deposits of the Lower Jurassic Ciechocinek Formation from the Częstochowa-Wieluń region are characterized by a low diversity ichnofossil association, which includes the ichnogenera *Planolites*, *Palaeophycus*, *Helminthopsis*, *Gyrochorte*, *Protovirgularia* and *Spongeliomorpha* as well as some unidentified pascichnia. This association points to deposition in a low-energy brackish environment with poorly oxygenated sediments. Changes of seafloor oxygenation, influenced by periodical bottom currents, resulted in various bioturbation intensities, which range from none to high.

INTRODUCTION

During the Early Jurassic the territory of Poland was situated in a marginal part of the extensive, epicontinental Central European Basin (Fig. 1: A), which was particularly sensitive to sea-level fluctuations, causing frequent displacements of the shoreline and changes of sedimentary environment. The Ciechocinek Formation marks the maximum extent of marine sedimentation in Poland, related by Dadlez (1969) and Pieńkowski (2004) to the Early Toarcian transgression, which is recorded in the whole Central European Sea. Fauna in these deposits is uncommon and of low diversity. It includes phyllopods, ostracods, scarce foraminifers and occasional fragments of bivalves, gastropods and fish teeth (Kopik and Marcinkiewicz 1997; Kopik 1998). The lack of typical marine fauna indicates that the transgression did not cause the development of normal-marine conditions in the Polish Basin. Such a conclusion is also confirmed by analysis of the dinoflagellate assemblage (Barski and Leonowicz 2002) and geochemical study of siderites (Leonowicz 2007). In the absence of body fossils, trace fossils are the most useful tool in environmental interpretations. They are quite common in the Ciechocinek Formation and include *Diplocraterion parallelum* Torell as well as some other non-identified fodinichnia, repichnia, domichnia and cubichnia (Pieńkowski 1988, 2004). However, more detailed analysis of the ichnofossil association was not carried out till now.

The purpose of this paper is to analyse the trace fossil association from the Ciechocinek Formation deposits in the Częstochowa – Wieluń region (Fig. 1: B) in order to determine bottom conditions in the sedimentary basin. Observations of the type and distribution of trace fossils were made in successions cropping out in two clay-pits, which belong to the “Cerpol-Kozłowice” Enterprise and “Boroszów” Brickyard, as well as during examination of cores from 16 boreholes drilled by the Polish Geological Institute. Fresh, unpolished surfaces of rocks were observed. In order to reco-

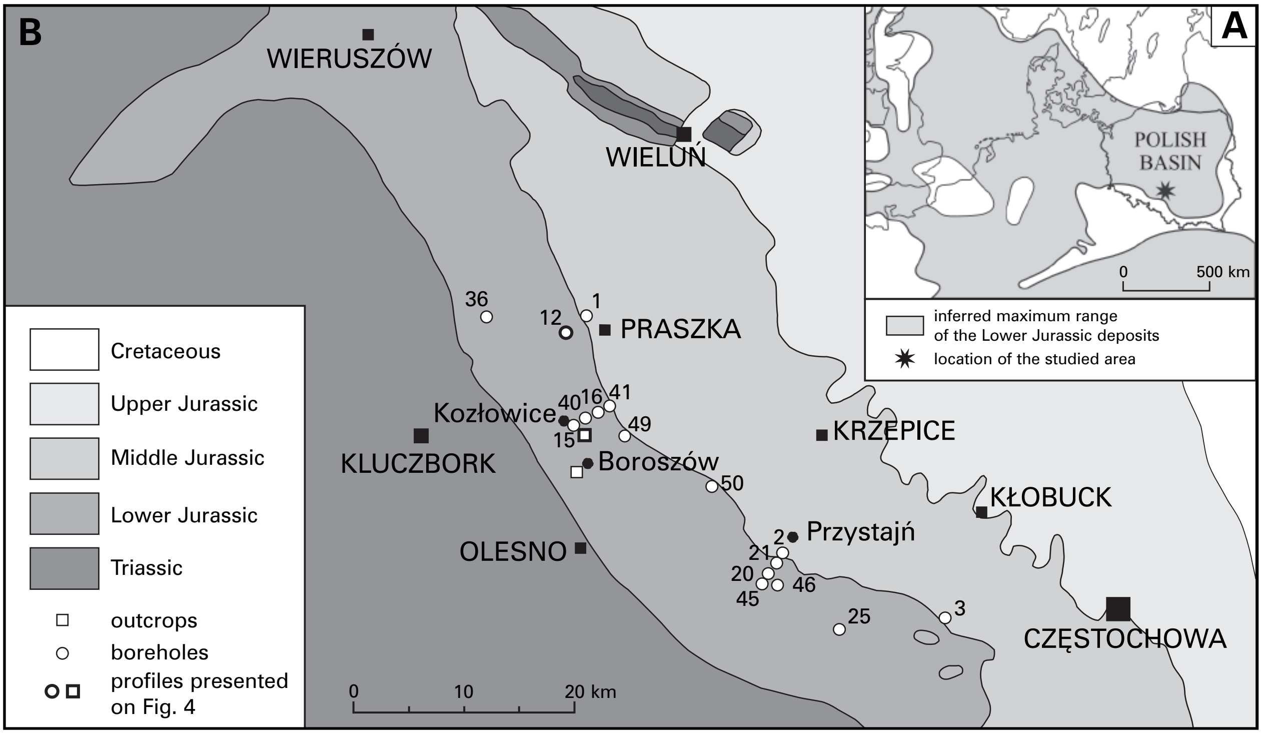

Fig. 1. Location of the studied area: A – Polish Basin as a part of the Central European Basin in the Early Jurassic time (after Pieńkowski 2004); B – location of studied profiles on a geological sketch-map of the Częstochowa-Wieluń region.

gnize the fabric of massive deposits, thin sections, made from well consolidated mudstones and siltstones, were examined under the microscope.

GEOLOGICAL SETTING

The Ciechocinek Formation represents a mud-silt succession (Fig. 2) consisting of poorly consolidated, grey, olive and willow-green mudstones and siltstones with lenses and subordinate intercalations of sands and sandstones (Teofilak-Maliszewska 1967, 1968; Leonowicz 2005). Up to several centimeter thick lenses and intercalations of siderite as well as small siderite and pyrite concretions are common. In all types of deposits fine plant detritus as well as larger, several centimeter long wood fragments occur.

In the area studied the Ciechocinek Formation overlies sand-mud deposits of the Blanowice Formation and is overlain by the similarly developed Borucice Formation (Fig. 3), both of alluvial and lacustrine origin (Pieńkowski 2004). Depending on the section, boundaries between formations are distinct, confined by erosional surfaces or gradual, marking continuous changes of sedimentary environment. Based on dinoflagellate cysts, the deposits of the Ciechocinek Formation were dated to the Margaritatus – Tenuicostatum zones (Barski and Leonowicz 2002). Pieńkowski (2004) placed it within the Lower Toarcian, on the basis of sequence stratigraphy correlation and the results of macrospore analysis by Marcinkiewicz (1957, 1960, 1964, 1971). He noted there one find of *Diplocraterion* (Nowa Wieś 12 borehole) and some, locally common, non-identified trace fossils of fodinichnia and repichnia.

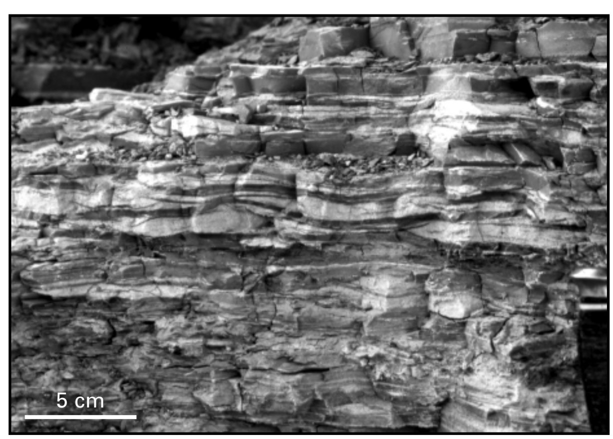

Fig. 2. Deposits of the Ciechocinek Formation from the Kozłowice clay-pit: intercalations of massive muds, lenticular-bedded muds and interlaid mud-sand heteroliths.

ICHNOLOGY OF THE CIECHOCINEK FORMATION

Trace fossil association is not diverse and includes *Planolites*, *Palaeophycus*, *Helminthopsis*, *Gyrochorte*, *Protovirgularia* and *Spongeliomorpha* as well as many small, undetermined trace fossils, most probably of the pascichnia category. Trace fossils are preserved in mud-silt deposits as endichnia and in sandstone lenses as hypichnia. Thicker, poorly consolidated sandy layers are devoid of bioturbational structures.

Planolites isp. (Fig. 5: A-F)

DESCRIPTION: Unlined and unbranched, straight, curved or tortuous trace fossils, cylindrical or elliptical in cross-section, usually from fraction to 2 mm in diameter, variably oriented to the bedding. Less common are thicker forms, reaching up to 7 mm in diameter, usually horizontal or subhorizontal and gently curved. Filling of burrows is structureless, differing in grain size and/or colour from the host rock, locally pyritized. *Planolites* is preserved as full relief in mud-silt deposits or on sole surfaces of sandstones.

REMARKS: The size and curvature suggest that most of the specimens observed should be assigned to *Planolites montanus* Richter (Fig. 5: C, D, F). Larger forms may belong to *Planolites beverleyensis* Billings (Fig. 5: E). *Planolites* is common in all types of the Ciechocinek Formation deposit. It is referred to vermiform deposit-feeders, mainly polychaetes, producing active backfilling (Pemberton and Frey 1982). *Planolites* is a facies-crossing, eurybathic form, known from shallow marine and deep-marine flysch deposits as well as from fresh-water environments (*e.g.* Książkiewicz 1977; Pieńkowski 1985; Bjerstedt 1987; Beynon and Pemberton 1992; Pemberton and Wightman 1992; Buatois and Mángano 1998; Fürsich 1998).

Palaeophycus isp. (Fig. 5: G)

DESCRIPTION: Straight or gently curved, predominantly horizontally oriented, unbranched, smooth or rarely faintly ornamented cylindrical trace fossils up to 10 mm in diameter, slightly flattened in cross-section. Filling structureless, of the same lithology as the host rock. Preserved on sole surfaces of sandstones.

REMARKS: The lack of thick lining and distinct ornamentation suggests that most of the specimens observed represent *Palaeophycus tubularis* Hall. *Palaeophycus* is less common than *Planolites* in deposits of the Ciechocinek Formation; however, in the Kozłowice outcrop numerous specimens occur. It is interpreted as the result of passive filling of polychaete burrows (Pemberton and Frey 1982). It is a facies-crossing, eurybathic form, known from deep-marine flysch and brackish-marine deposits as well as from the fresh-water environments

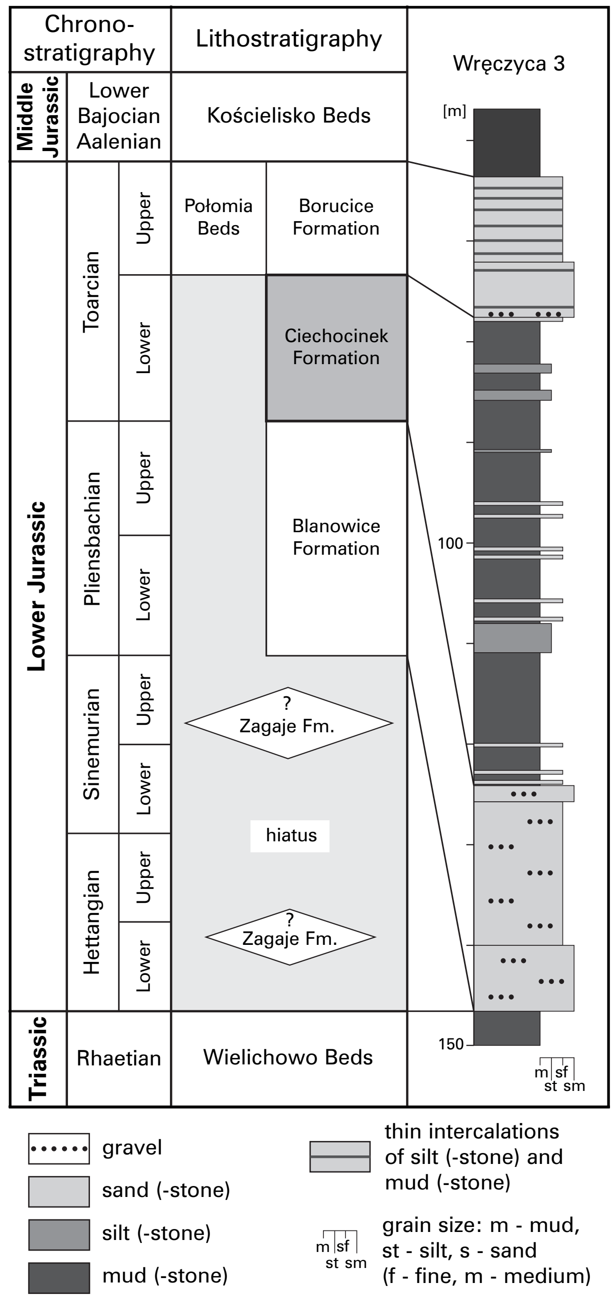

Fig. 3. Lithostratigraphy of the Lower Jurassic in the Cracow-Silesian region (after Kopik 1998; Pieńkowski 2004; Deczkowski and Daniec 1981) and the representative lithological profile of the borehole Wręczyca 3 (after Leonowicz 2007).

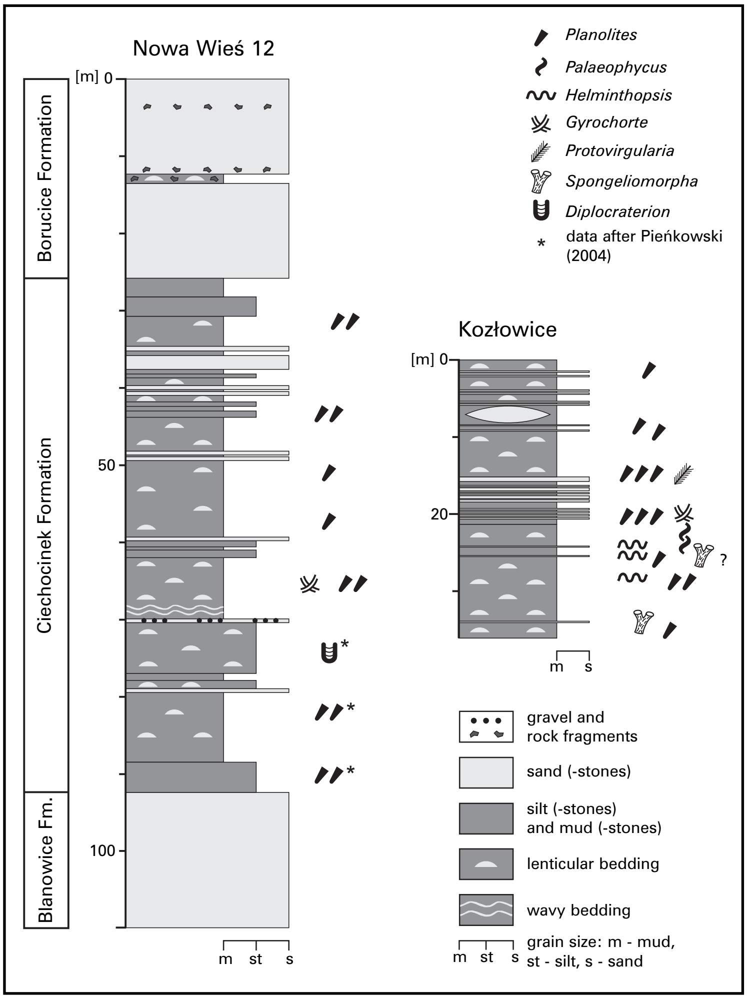

Fig. 4. Distribution of trace fossils in two representative sections of the Ciechocinek Fm. Simplified lithostratigraphical division is marked, in which the Ciechocinek Fm. includes deposits originated in transitional marine/continental environments.

(*e.g.* Książkiewicz 1977; Pieńkowski 1985; Bjerstedt 1987; Beynon and Pemberton 1992; Pemberton and Wightman 1992; Buatois and Mángano 1998).

Helminthopsis isp. (Fig. 6: A, B)

DESCRIPTION: Simple, unbranched, horizontal cylinders, 2 mm in diameter, slightly flattened in cross-section, sinuous or irregularly meandering. Filling is structureless and of the same lithology as the host rock. They occur on sole surfaces of sandstones or on parting planes in muds.

REMARKS: Only a few specimens were observed in the Kozłowice outcrop. It is interpreted as a grazing trail (Pemberton *et al.* 2001) or feeding burrow (Wetzel and Bromley 1996), produced at shallow depth in sediment by polychaetes and priapulids. *Helminthopsis* is a facies-crossing, eurybathic form, known from deep-marine flysch to brackish-marine deposits as well as from the fresh-water environments (*e.g.* Książkiewicz 1977; Bjerstedt 1987; Beynon and Pemberton 1992; Buatois and Mángano 1998).

Gyrochorte isp. (Fig. 6: E, F)

DESCRIPTION: Winding, horizontal, double ridge separated by a median groove. The surface of ridges is smooth or has an indistinct, plaited structure, composed of biserially arranged, obliquely aligned pads of sediment. The ridges are curved or gently meandering; they do not branch and often cross themselves. The width of trace fossils changes along their axis and generally does not exceed 4 mm. *Gyrochorte* is preserved as epirelief in sandstones and mudstones.

REMARKS: Only single specimens were observed in the Kozłowice outcrop and Nowa Wieś 12 borehole. *Gyrochorte* is interpreted as a result of active digging in sediment of deposit-feeding worm-like animal, probably an annelid (Heinberg 1973; Gibert and Benner 2002). The trace maker was probably an opportunistic animal, colonizing newly deposited storm sediment. *Gyrochorte* is known from nearshore and shallow marine environments, marking a broad range of environmental conditions from hypersaline to hyposaline (*e.g.* Hallam 1970; Heinberg 1973; Heinberg and Birkelund 1984; Fürsich 1998; Gibert and Benner 2002).

Protovirgularia isp. (Fig. 6: C)

DESCRIPTION: Small, straight, horizontal, bilobate trace fossil, about 3 mm wide, comprising two symmetric, obliquely striated belts separated by an indistinct median ridge. Preserved on sole surface of a small sandstone lens.

REMARKS: Only one specimen was found in the Kozłowice outcrop. *Protovirgularia* is a repichnion form, ascribed to the activity of bivalves, which crawled by the rhythmic action of a foot (Seilacher and Seilacher 1994). It is known from

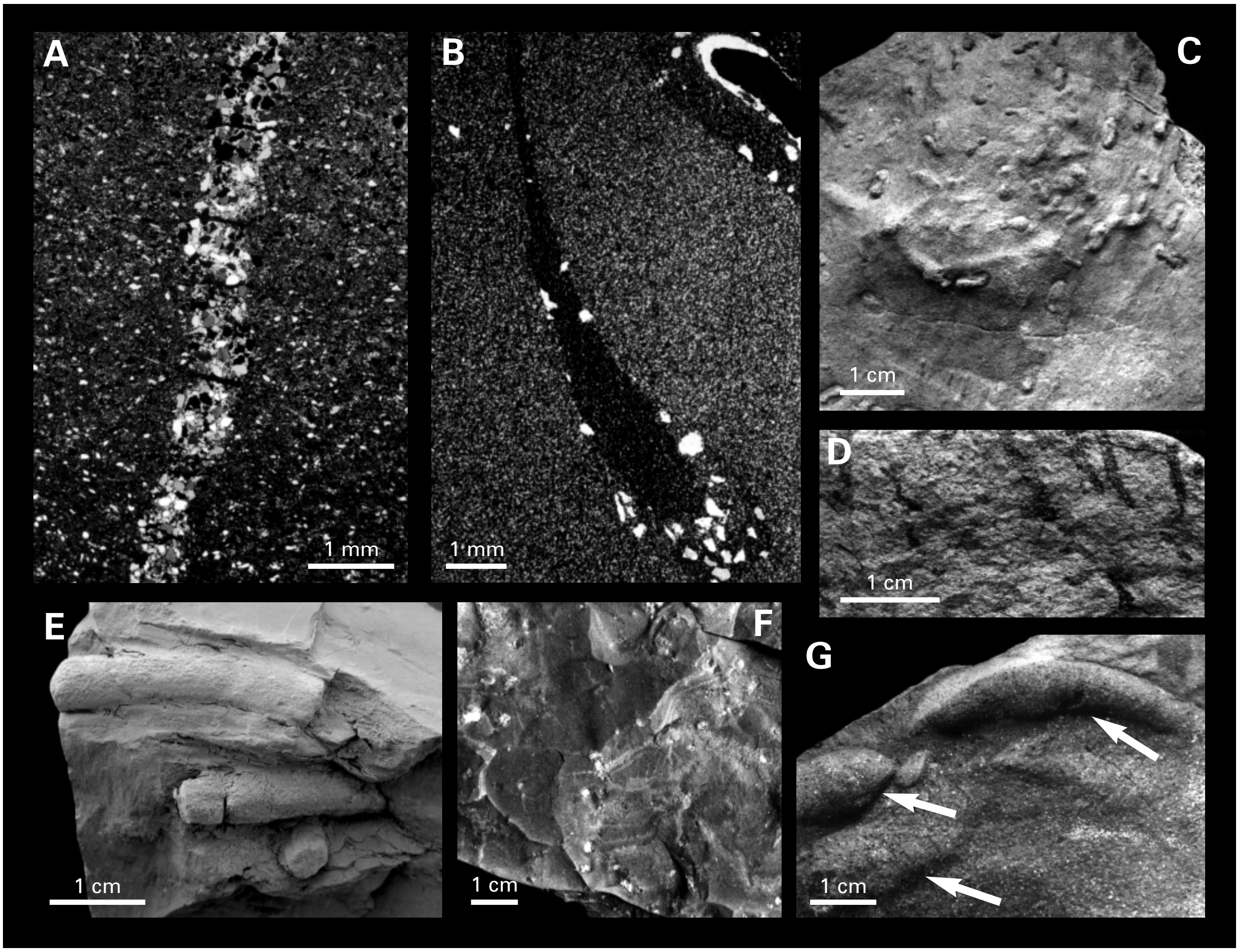

Fig. 5. Trace fossils from the Ciechocinek Formation: A-F – *Planolites*: A – small tunnel filled with a coarser material in a sideritic silty mudstone, microphotograph, crossed nicols; B – small tunnel filled with a darker material in a sideritic mudstone, microphotograph, one nicol; C – *Planolites montanus* preserved on a sole surface of sandstone lens; D – tunnels of *Planolites montanus* filled with a darker material in a massive siltstone; E – *Planolites beverleyensis* filled with fine-grained sandstone and preserved as endichnia in a mud; F – cross-section of thin *Planolites montanus* filled with a light grey, fine sand; G – *Palaeophycus tubularis* (arrows) preserved on a sole surface of sandstone lens. A-C, E, G – Kozłowice outcrop; D – Wichrów 50 borehole; F – Przystajń 25 borehole.

both marine and fresh-water deposits (*e.g.* Goldring *et al.* 2005; Uchman 1998).

Spongeliomorpha isp. (Fig. 6: D, G, H)

DESCRIPTION: Horizontal and subhorizontal, branching tunnels, up to 25 mm thick, cylindrical or elliptical in cross-section, displaying elongated striation on exterior of burrow casts. Branches are Y-shaped, usually enlarged at points of bifurcation. Striation approximately longitudinal, only on the side surfaces oblique. Burrows are filled with fine-grained, light grey sand, commonly pyritized. They occur mainly as endichnia in dark grey mudstones; only one problematic specimen occurred on the sole surface of sandstone.

REMARKS: *Spongeliomorpha* was found only in the Kozłowice outcrop, in the lower part of the succession, where it occurs in two highly bioturbated horizons (Fig. 6: D), each of them a few centimetres thick. *Spongeliomorpha* is interpreted as the domicile of crustaceans – crabs and shrimps (Frey *et al.* 1984) – which dig in a firm, semiconsolidated substrate. Such behaviour is typical of the Glossifungites ichnofacies. The striation consists of casts of scratch marks, produced by locomotory organs of the tracemaking animals. *Spongeliomorpha* is a facies-crossing form, noted from shallow and deep-marine deposits as well as from the fresh-water environments (Frey *et al.* 1984; Frey and Pemberton 1984; Buatois and Mángano 1998; Uchman 1998).

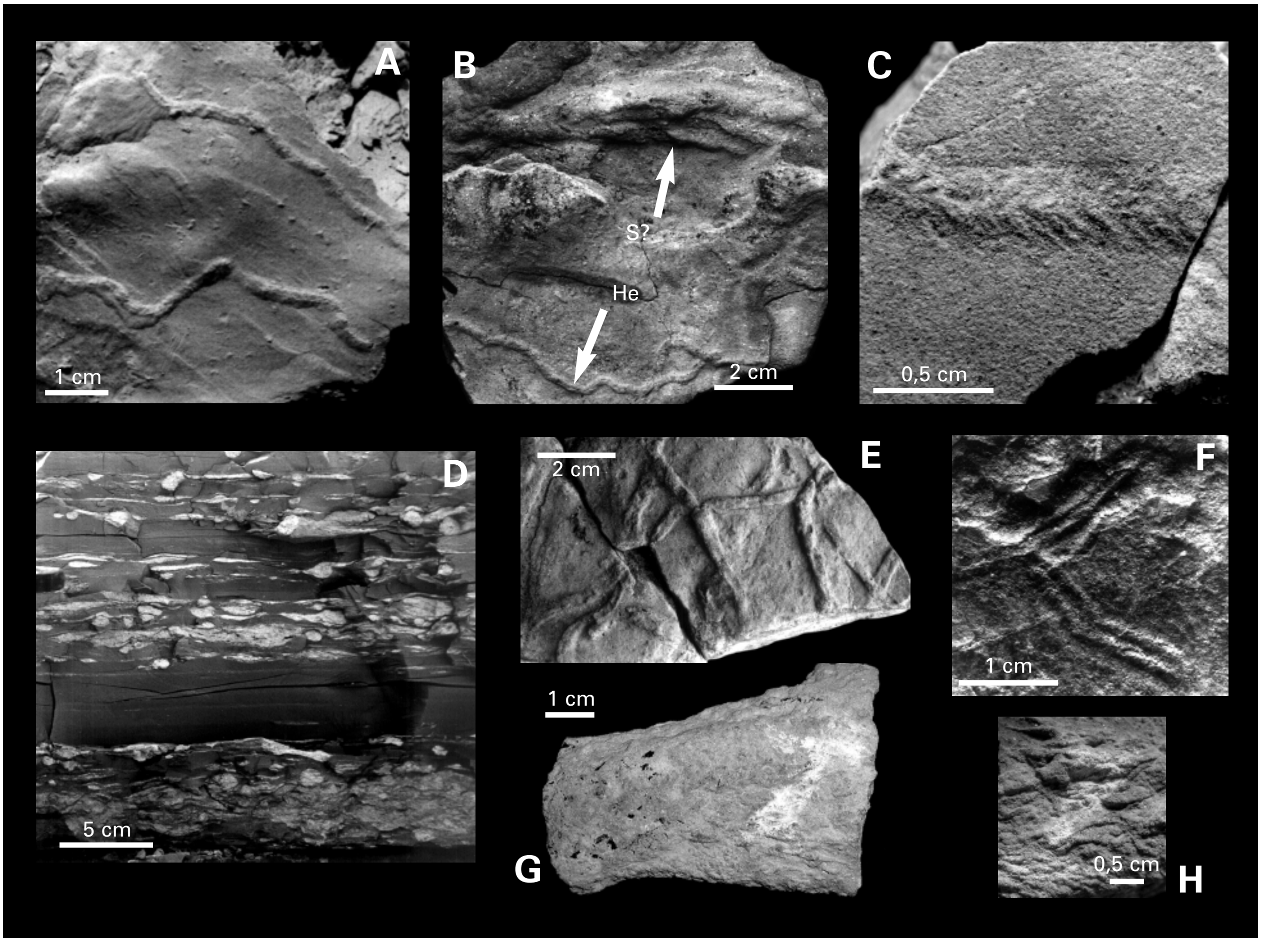

Fig. 6. Trace fossils from the Ciechocinek Formation: A – *Helminthopsis* on a parting plane in mudstone; B – *Helminthopsis* (He) and *Spongeliomorpha?* (S?) on a sole surface of sandstone bed; C – small *Protovirgularia* on a sole surface of a sandstone lens; D – two highly bioturbated horizons with *Spongeliomorpha* burrows from the Kozłowice outcrop; E, F – *Gyrochorte* on the upper surfaces of sandstones; G, H – *Spongeliomorpha*: G – close-up view of tunnel filling; H – scratch marks (detail from G). A-E, G, H – Kozłowice outcrop; F – Nowa Wieś 12 borehole.

In the Ciechocinek Formation many other, non-identified pascichnial traces fossils occur. They were observed on sole surfaces of sandstones as well as in thin sections from sideritic mudstones and siltstones.

CHARACTERISTICS OF ICHNOFOSSIL ASSOCIATION

The trace fossil association from the Ciechocinek Formation is of low diversity and dominated by simple forms of non-specialized deposit-feeders. The most common is *Planolites* isp., which occurs in almost whole succession, accompanied by some non-identified pascichnia. In some cores *Planolites* is the only ichnofossil observed. Other trace fossils are less common and are concentrated in the lower half of succession (Fig. 4). In many intervals, diminution of ichnofossil size, common for *Planolites*, is a characteristic feature. In these parts of succession, which are devoid of other trace fossils, *Planolites* is often less than 1 mm thick.

The degree of bioturbation ranges usually from low to moderate (BI = 1-3 in the scale after Taylor and Goldring 1993) (Fig. 7), the bedding boundaries are distinct and primary sedimentary structures well preserved. In such deposits intensively or completely bioturbated (Fig. 7: D) intercalations occur as well as layers devoid of bioturbational structures, with undisturbed lamination (Fig. 7: A).

PALAEOENVIRONMENTAL INTERPRETATION

The trace fossil association, restricted to a few facies-crossing ichnotaxa, does not bring substantial information about the salinity of basin water. The finding of *Diplocraterion* (Pieńkowski 1988, 2004) and *Gyrochorte* as well as the lack of ichnofossils characteristic only of fresh-water deposits, such as *Scoyenia* or traces of insect activity, point to the marine character of the water. Other features, such as the lack of shelled organisms, reduced diversity of the ichnofossil association with simultaneous high population density, largely consisting of the single ichnogenus (*Planolites*), the prevalence of infauna producing simple structures, as well as frequent size reduction, are characteristic of a brackish water environments (Howard and Frey 1973; Pemberton and Wightman 1992; Pemberton *et al.* 2001).

In the lower half of the succession the ichnofossil association is more diverse and includes *Diplocraterion parallelum* and *Gyrochorte* (Fig. 4). It can be inferred that these deposits mark increased water salinity, resulting from the transgression. Noteworthy is the presence of two highly bioturbated horizons with *Spongeliomorpha* in the Kozłowice outcrop (Fig. 4). The occurrence of trace fossils characteristic of the Glossifungites ichnofacies marks an episode of firmground formation, which is usually associated with reduced sediment input and erosional exhumation of compacted substrate (Pemberton *et al.* 2001). Therefore, horizons with *Spongeliomorpha* could point to a transgressional impulse following a short episode of regression. The same episode could be marked by a thin layer of coarse grained sandstone and gravel, occurring in the lower part of the Nowa Wieś 12 borehole (Fig. 4). However, such a regional event should be pronounced throughout the basin, whereas other profiles are devoid of convincing evidence of sea level change. Thus, it is more likely that the firmground formation and the short-lived supply of coarser material in sections mentioned was linked with local changes of bottom circulation.

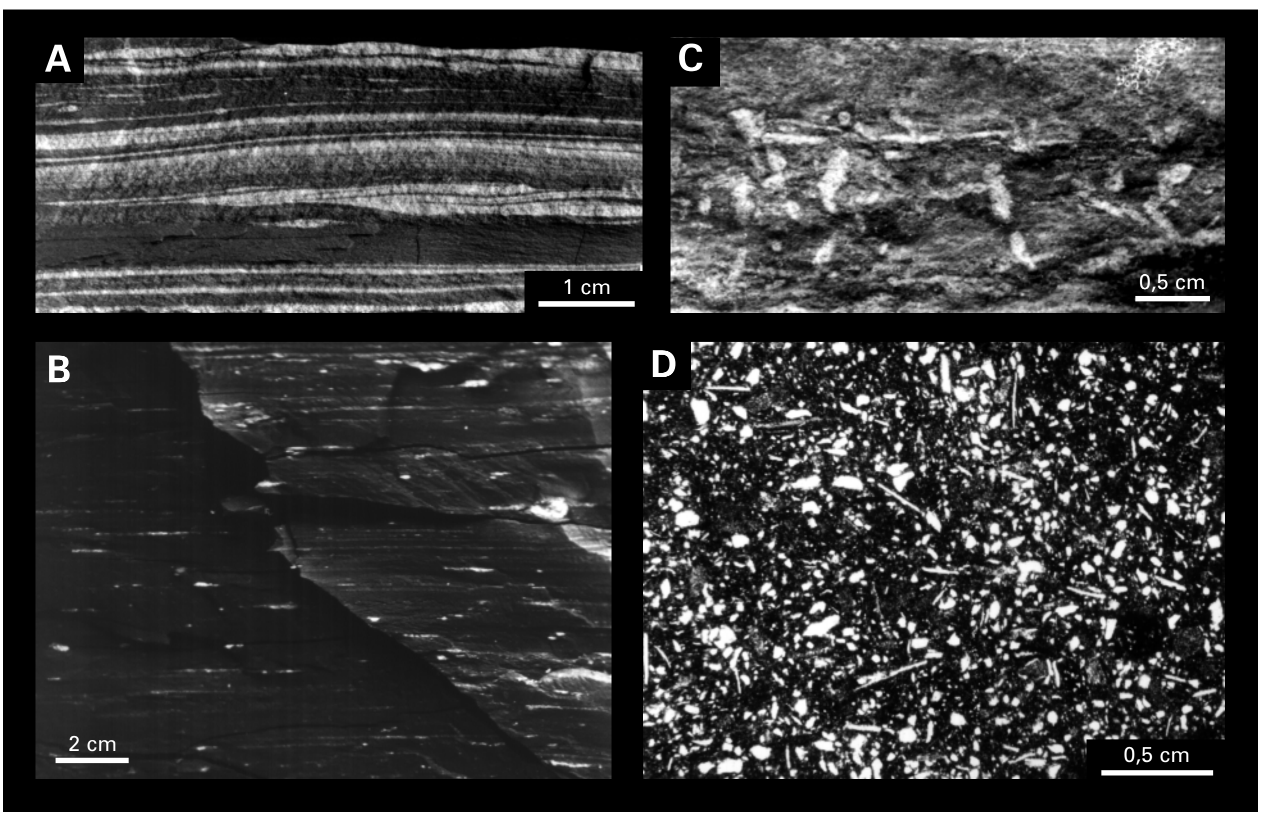

Fig. 7. Bioturbation degrees in the Ciechocinek Formation deposits: A – non-bioturbated mud with undisturbed lamination; B – sparsely bioturbated mud; C – moderately bioturbated massive siltstone; D – completely bioturbated clayey silt; microphotograph of massive deposit devoid of macroscopically detectable bioturbational structures (one nicol). All photographs show cross-sections of beds. A, B, D – Kozłowice outcrop; C - Wichrów 50 borehole.

In the upper half of the succession, the diversity of the trace fossil suite is lower, and almost only *Planolites* occurs. In the uppermost part of the succession the phyllopod *Estheria* sp., typical of brackish environments, also occurs (Wręczyca 3 and Przystajń 20 boreholes). These deposits marks a falling in salinity related to regression.

The ichnofossil association does not contain ichnotaxa diagnostic of Seilacher's ichnofacies; however, it reveals many similarities to the Cruziana ichnofacies (Seilacher 1967). The muddy-silty character of the deposits, dominance of deposit-feeders, occurrence of pascichnia, domichnia and repichnia structures as well as the prevalence of horizontal and subhorizontal orientations of burrows – these features are typical of the Cruziana ichnofacies, known from estuary, lagoon, bay, tidal flat and continental shelf deposits (Seilacher 1967; Frey and Pemberton 1984). Generally, it points to shallow marine, moderate to low-energy environments, situated between the fair-weather and storm wave base.

The predominant low to moderate density of trace fossils indicates that conditions in the bottom sediment were generally moderately favourable for benthic fauna, due to the lowered water salinity and possibly low oxygenation of sediment. Bottom conditions changed irregularly from place to place and from time to time resulting in the formation of strongly bioturbated and non-bioturbated intercalations. Apart from salinity, benthic life is influenced by a number of factors, from which the most important is oxygenation of the seafloor and benthic food availability. As deposits of the Ciechocinek Formation are generally rich in organic matter, fluctuation of seafloor oxygenation was the most probable reason for changeable conditions. Deposition of the Ciechocinek Formation originated predominantly as a result of quiet deposition from suspension, interrupted periodically by storm-generated offshore currents as well as long-lasting turbidity currents of low density, linked with seasonal changes in river discharge and displacements of river mouths (Leonowicz 2002). In such conditions the bottom water, as well as the organic-rich bottom sediment, could stay poorly oxygenated, and the benthic animal community was restricted to taxa adapted to inhabit oxygen-depleted environments. Deposits with the low diversity *Planolites* association, characterized by reduced burrow size, resemble partly the *Planolites* association from the Lower Cretaceous Grand Rapids Formation, which was interpreted as reflecting reducing or anoxic conditions developed in a restricted setting (Beynon and Pemberton 1992). The prevalence of reducing conditions in sediments analyzed is advocated by the presence of early diagenetic pyrite as well as the common siderite mineralization in muds (Leonowicz 2005). In places where the bottom water was stagnant and sediment enriched in organic matter, anoxic conditions could develop, resulting in non-bioturbated levels. Episodes of bottom current activity could improve oxygenation of the sea-floor and lead to formation of highly bioturbated levels.

SUMMARY

- The mud-silt deposits of the Ciechocinek Formation contain a low diversity trace fossil association, which includes *Planolites*, *Palaeophycus*, *Helminthopsis*, *Gyrochorte*, *Protovirgularia* and *Spongeliomorpha* as well as many small, unidentified pascichnia. The occurrence of marine trace fossils *Diplocraterion* and *Gyrochorte* indicates that this suite represents an impoverished marine association.
- The diversity of the ichnofossil association and the intensity of bioturbation were affected by the salinity of basin water and oxygenation of bottom sediment. Benthic food availability was not decisive, as deposits of the Ciechocinek Formation are generally rich in organic matter.
- Low-salinity water resulted in a decrease in trace fossil diversity, represented mainly by simple burrows of non-specialized deposit-feeders. These are, however, quite abundant in some parts of the succession. The highest salinity and the maximum of marine transgression fall into the lower half of the succession.
- The degree of bioturbation depended, most probably, on the oxygenation of the seafloor, which changed with time, resulting in intercalations of high and low bioturbated deposits with non-bioturbated muds. The bottom sediment was mainly poorly oxygenated due to the low energy of sedimentary environment and the high content of organic matter. Episodes of increased oxygenation are related to the activity of bottom currents generated by storms, seasonal changes in river discharge and displacements of river mouths.

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REFERENCES:

Barski M. and Leonowicz P. 2002. Cysty Dinoflagellata z odsłonięć liasu w Kozłowicach i Boroszowie (Wyżyna Woźnicko-Wieluńska) [Dinoflagellates of Lower Jurassic outcrops at Kozłowice and Boroszów (southern Poland)] (in Polish with English summary). *Przegląd Geologiczny*, **50**, 5: 411-414.

Beynon B. M. and Pemberton S. G. 1992. Ichnological signature of a brackish water deposit: an example from the Lower Cretaceous Grand Rapids Formation, Cold Lake oil sands area, Alberta. *In*: S. G. Pemberton (*Ed.*), Applications of Ichnology to Petroleum Exploration, A Core Workshop Society of Economic Paleontologists and Mineralogists, Core Workshop Notes, 17: 199-221.

Bjerstedt T. W. 1987. Latest Devonian - earliest Mississippian nearshore trace-fossil assemblages from West Virginia, Pennsylvania, and Maryland. *Journal of Paleontology*, **61**, 5: 865–889.

Buatois L. A. and Mángano M. G. 1998. Trace fossil analysis of lacustrine facies and basins. *Palaeogeography, Palaeoclimatology, Palaeoecology*, **140**: 367-382.

Dadlez R. 1969. Stratigraphy of the Lias in Western Poland (in Polish with English summary). *Prace Instytutu Geologicznego*, **57**: 1-92.

Deczkowski Z. and Daniec J. 1981. Rudy żelaza. *In*: L. Wielgomas (*Ed.*) Surowce Mineralne Województwa Częstochowskiego, 102-115. Wydawnictwa Geologiczne. Warszawa.

Frey R. W., Curran H. A. and Pemberton S. G. 1984. Tracemaking activities of crabs and their environmental significance: the ichnogenus *Psilonichnus*. *Journal of Paleontology*, **58**, 2: 333-350.

Frey R. W. and Pemberton S. G. 1984. Trace fossil facies models. *In*: R. G. Walker (*Ed.*), Facies Models, 2nd ed., 189-207. Geoscience Canada, Reprint Series 1.

Fürsich F. T. 1998. Environmental distribution of trace fossils in the Jurassic of Kachh (Western India). *Facies*, **39**: 243-272.

Gibert J. M. and Benner J. S. 2002. The trace fossil *Gyrochorte*: ethology and paleoecology. *Revista Española de Paleontología*, **17**, 1: 1-12.

Goldring R., Pollard J. E. and Radley J. D. 2005. Trace fossils and pseudofossils from the Wealden strata (non-marine Lower Cretaceous) of southern England. *Cretaceous Research*, **26**: 665-685.

Hallam A. 1970. *Gyrochorte* and other trace fossils in the Forest Marble (Bathonian) of Dorset, England. *In*: T. P. Crimes and J. C. Harper (*Eds*), Trace Fossils, 189-200. *Geological Journal Special Issue*, 3.

Heinberg C. 1973. The internal structure of the trace fossils *Gyrochorte* and *Curvolithus*. *Lethaia*, **6**, 3: 228-238.

Heinberg C. and Birkelund T. 1984. Trace-fossil assemblages and basin evolution of the Vardekløft Formation (Middle Jurassic, central East Greenland). *Journal of Paleontology*, **58**, 2: 362-397.

Howard J. D. and Frey R. W. 1973. Characteristic physical and biogenic sedimentary structures in Georgia estuaries. *American Association of Petroleum Geologists Bulletin*, **57**, 7: 1169-1184.

Kopik J. 1998. Lower and Middle Jurassic of the north-eastern margin of the Upper Silesian Coal Basin (in Polish with English summary). *Biuletyn Państwowego Instytutu Geologicznego*, **378**: 67-129.

Kopik J. and Marcinkiewicz T. 1997. Jura dolna: Biostratygrafia. *In*: S. Marek and M. Pajchlowa (*Eds*), The epicontinental Permian and Mesozoic in Poland (in Polish with English summary). *Prace Państwowego Instytutu Geologicznego*, **153**: 196-205.

Książkiewicz M. 1977. Trace fossils in the flysch of the Polish Carpathians. *Palaeontologia Polonica*, **36**: 1-208.

Leonowicz P. 2002. Litofacje i środowisko sedymentacji tzw. warstw ciechocińskich (lias) na obszarze częstochowsko-wieluńskim. Ph. D. Thesis. Archiwum Uniwersytetu Warszawskiego. (In Polish)

Leonowicz P. 2005. The Ciechocinek Formation (Lower Jurassic) of SW Poland: petrology of green clastic rocks. *Geological Quarterly*, **49**, 3: 317-330.

Leonowicz P. 2007. Origin of siderites from the Lower Jurassic Ciechocinek Formation from SW Poland. *Geological Quarterly*, **51**, 1: 67-78.

Marcinkiewicz T. 1957. Megaspores of the Lias from Praszka, Zawiercie and Święty Krzyż Mountains (in Polish with English summary). *Kwartalnik Geologiczny*, **1**, 2: 299-302.

Marcinkiewicz T. 1960. Megaspore analysis of Jurassic sediments near Gorzów Śląski-Praszka (Cracow-Wieluń region) (in Polish with English summary). *Kwartalnik Geologiczny*, **4**, 3: 713-733.

Marcinkiewicz T. 1964. The stratigraphy of the Lower Jurassic in the Mechowo IG-1 borehole on the basis of megaspore research (in Polish with English summary). *Biuletyn Instytutu Geologicznego*, **189**: 57-60.

Marcinkiewicz T. 1971. The stratigraphy of the Rhaetian and Lias in Poland based on megaspore investigations (in Polish with English summary). *Prace Instytutu Geologicznego*, **65**: 1-58.

Pemberton S. G. and Frey R. W. 1982. Trace fossil nomenclature and the *Planolites - Palaeophycus* dilemma. *Journal of Paleontology*, **56**, 4: 843-881.

Pemberton S. G. and Wightman D. M. 1992. Ichnological characteristics of brackish water deposits. *Society of Economic Paleontologists and Mineralogists Core Workshop*, **17**: 141-167.

Pemberton S. G., Spila M., Pulham A. J., Saunders T., MacEachern J. A., Robbins D. and Sinclair I. K. 2001. Ichnology and sedimentology of shallow to marginal marine systems: Ben Nevis and Avalon Reservoirs, Jeanne d'Arc Basin. *Geological Association of Canada, Short Course Notes*, **15**: 1-343.

Pieńkowski G. 1985. Early Liassic trace fossil assemblages from the Holy Cross Mountains, Poland: their distribution in continental and marginal marine environments. *In*: H. A. Curran (*Ed.*), Biogenic structures: their use in interpreting depositional environments. *Society of Economic Paleontologists and Mineralogists Special Publication*, **35**: 37-51.

Pieńkowski G. 1988. Facies analysis of the Upper Triassic and Liassic of the Cracow-Wieluń Upland and prospects for occurrence of clay deposits (in Polish with English summary). *Przegląd Geologiczny*, **36**, 8: 494-456.

Pieńkowski G. 2004. The epicontinental Lower Jurassic of Poland. *Polish Geological Institute Special Papers*, **12**: 1-154.

Seilacher A. 1967. Bathymetry of trace fossils. *Marine Geology*, **5**: 413-428.

Seilacher A. and Seilacher E. 1994. Bivalvian trace fossils: a lesson from actuopaleontology. *Courier Forschung Senckenberg*, **169**: 5-15.

Taylor A. and Goldring R. 1993. Description and analysis of bioturbation and ichnofabric. *Journal of the Geological Society (London)*, **150**: 141-148.

Teofilak-Maliszewska A. 1967. The petrography of the Liassic deposits in the Polish Lowland Area (in Polish with English summary). *Biuletyn Instytutu Geologicznego*, **207**: 67-144.

Teofilak-Maliszewska A. 1968. Petrography of Liassic deposits in the northern margin of the Świętokrzyskie Mountains (in Polish with English summary). *Biuletyn Instytutu Geologicznego*, **216**: 107-190.

Uchman A. 1998. Taxonomy and ethology of flysch trace fossils: revision of the Marian Książkiewicz collection and studies of complementary material. *Annales Societatis Geologorum Poloniae*, **68**, 2-3: 105-218.

Wetzel A. and Bromley R.G. 1996. Re-evaluation of the ichnogenus *Helminthopsis* – a new look at the type material. *Paleontology*, **39**, 1: 1-19.