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Arthropod trackways, "*Diplichnites*" *triassicus* (LINCK, 1943), from the Lower Triassic (Buntsandstein) fluvial deposits of the Holy Cross Mts, Central Poland

ABSTRACT: Arthropod trackways of possibly notostracan origin, determined as "*Diplichnites*" *triassicus* (LINCK, 1943), are described from the Buntsandstein (Lower Triassic) fluvial deposits exposed at Stryczowice on the north-eastern margin of the Holy Cross Mountains, Central Poland. These trackways form an almost monotypic ichnocoenose preserved on the sole surfaces of sandstone beds, interpreted as crevasse-splay deposits. In contrast to other "*Diplichnites*" *triassicus* ichnocoenoses, the trackways have been left by animals moving generally down-current.

INTRODUCTION

Trace fossils, both of vertebrate and invertebrate origin, have recently been described from the Lower Triassic Buntsandstein deposits of the Holy Cross Mts, Central Poland (FUGLEWICZ & *al.* 1990, GRADZIŃSKI & UCHMAN 1994). The present contribution supplements these papers, giving a description and environmental interpretation of the arthropod trackways, formally attributed to the ichnospecies "*Diplichnites*" *triassicus* (LINCK, 1943).

GEOLOGIC SETTING

The described trackways come from a small quarry situated at a hill south of Stryczowice, a village south-west of Ostrowiec Świętokrzyski at the north-eastern margin of the Holy Cross Mountains (Text-fig. 1*A-C*; for detailed location *see* MADER & BARCZUK 1985, Fig. 5, outcrop *32*). A sequence of red-violet sandstones and mudstones exposed at that quarry (Text-fig. 1*D*) is assigned to the Labirynthodontidae Beds of the Middle Buntsandstein in the local lithostratigraphic scheme; chronostratigraphically, they correspond pro-

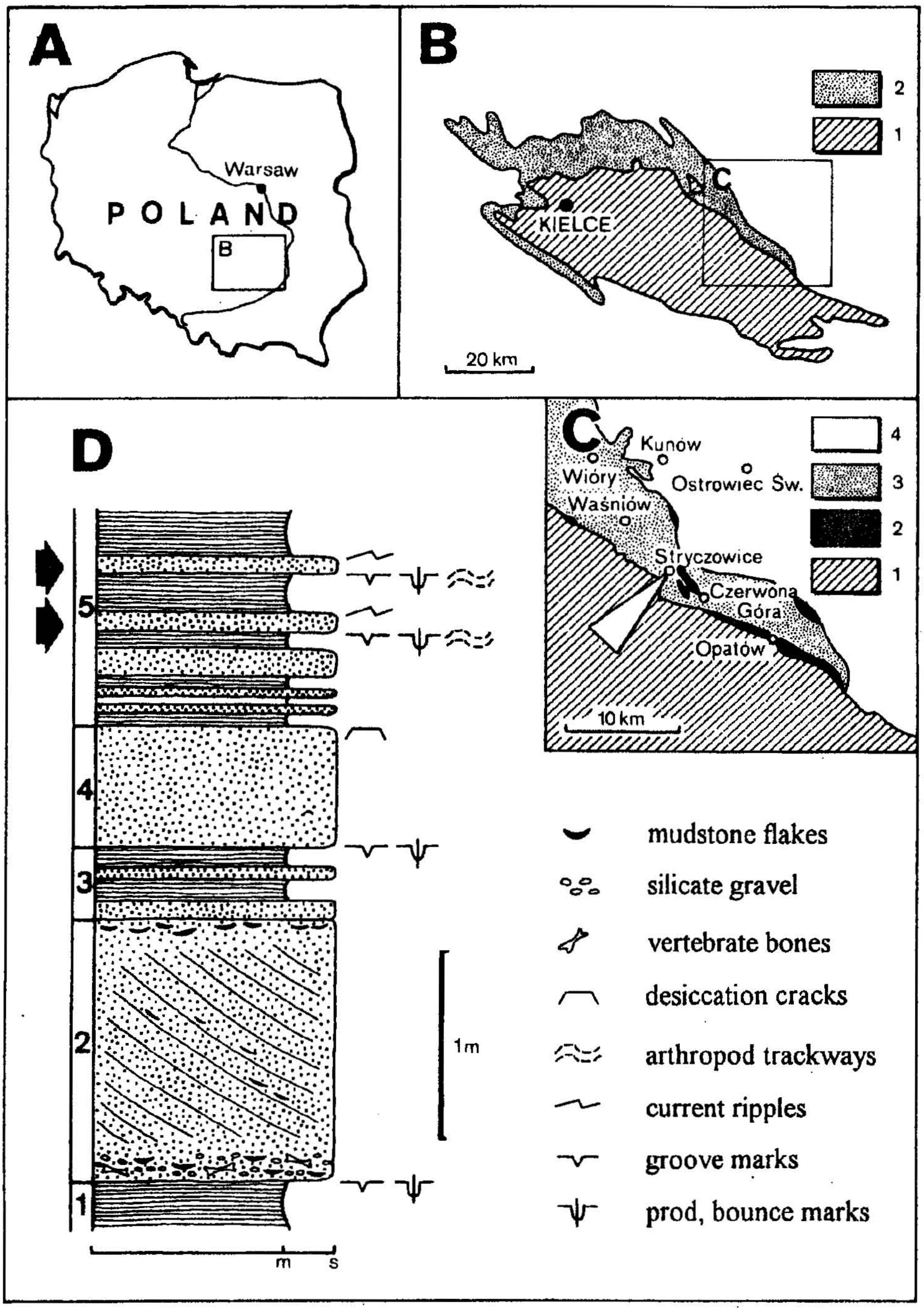


Fig. 1

Geologic setting of the studied sequence, exposed at the Stryczowice quarry

(for explanation *see* the opposite page)

bably to the Scythian Stage of the Lower Triassic (for detailed data on stratigraphy *see* SENKOWICZOWA & ŚLĄCZKA 1962, MADER & BARCZUK 1985, MADER & RDZANEK 1985, FUGLEWICZ & *al.* 1990).

DEPOSITIONAL ENVIRONMENT

The Labirynthodontidae Beds are thought to have been deposited in channels and floodplains of a moderately to weakly braided river system (MADER & RDZANEK 1985, FUGLEWICZ & *al.* 1990). The deposits exposed at the Stryczowice quarry form a cyclothem typical of such a system (Text-fig. 1*D*). The massive cross-bedded sandstone layer with basal conglomerate containing the admixture of reptilian and amphibian (labirynthodont) bones (unit *2* in Text-fig. 1*D*) represents the main channel deposit. Higher up in the profile there lie intercalating mudstone and sandstone layers (units *3-5* in Text-fig. 1*D*) which represent a floodplain environment. The mudstone layers were formed by slow accumulation of suspension-load fine matter in standing water of ponds and lakes. The sandstones show sedimentary structures indicative of a high-energy current flow (groove, prod, and bounce marks on their soles, linguoid ripples on tops). They represent crevasse-splay deposits that reflect a rapid introduction of sand into the floodplain area during periodic floods. The arthropod trackways occur on sole surfaces of two thin layers of fine-grained sandstone which, taking into account their position in the profile (unit *5* in Fig. 1*D*), may be interpreted as distal crevasse-splay deposits.

SYSTEMATIC ICHNOLOGY

Ichnogenus "*Diplichnites*" DAWSON, 1873

REMARKS: The diagnosis of the ichnogenus *Diplichnites* DAWSON, 1873, has been subject of controversy reflecting different approaches of particular Authors to the nomenclature of trace fossils (SEILACHER 1955; HÄNTZSCHEL 1975; BRIGGS & *al.* 1979, BROMLEY & ASGAARD 1979; POLLARD

Fig. 1 (*see the opposite page*)

A — Territory of Poland; rectangled is the area of the Holy Cross Mts (presented in *B*)

B — General map of the Holy Cross Mts, to show the occurrence of Paleozoic (1) and Buntsandstein (2) deposits; quadrangled is the area presented in *C*

C — Geologic map of the north-eastern margin of the Holy Cross Mts; 1 — Variscan basement, 2 — continental mass-flow conglomerates, traditionally regarded as Zechstein, 3 — Buntsandstein, 4 — younger deposists (*redrawn from* MADER & BARCZUK 1985, Fig. 2); arrowed is the Stryczowice quarry

D — Lithological section exposed at the Stryczowice quarry; m — mudstones, s — sandstones (for further explanations *see* text); arrowed are the occurrence sites of the studied trackways "*Diplichnites*" *triassicus* (LINCK, 1943)

1985; WALTER & GEITSCH 1988; BROMLEY 1990; PICKERILL 1992, 1994). Since the landmark paper of SEILACHER (1955), this ichnogenus was widely applied to denote trilobite walking traces (*e.g.* RADWAŃSKI & RONIEWICZ 1963, CRIMES 1970, ORŁOWSKI 1992). More recently, however, some Authors strongly argue for the narrower definition of this ichnogenus and for its restriction only to myriapod walking traces (*e.g.* BRIGGS & *al.* 1979, WALTER & GEITSCH 1988). The present Authors declare for a broad conception of this ichnogenus based on solely morphological criteria, following the suggestions of BROMLEY & ASGAARD (1979), BROMLEY (1990), and PICKERILL (1992, 1994). The studied trackways fall well within the limits of such a broadly understood ichnogenus *Diplichnites* DAWSON, 1873. However, as a formal revision of the ichnogenus has yet to be given, the present Authors are content with provisional ichnogeneric assignment of the investigated traces.

"*Diplichnites*" *triassicus* (LINCK, 1943)
(Pls 1-4)

1943. *Merostomichnites triassicus*, n. sp.; O. LINCK, pp. 22-24, Pl. 1, Fig. 3; Pl. 2, Fig. 2.

?1962. Arthropod tracks; H. SENKOWICZOWA & A. ŚLĄCZKA, p. 324, Pl. 21, Fig. 4.

1963. *Merostomichnites triassicus* LINCK, 1943; A. SEILACHER, p. 88, Fig. 7.

1972. *Merostomichnites triassicus* LINCK, 1943; R.G. BROMLEY & U. ASGAARD, p. 13.

1979. *Diplichnites triassicus* (LINCK, 1943); R.G. BROMLEY & U. ASGAARD, p. 64, Fig. 16E-F, Fig. 18.

1983. *Acripes sittichenbachis*, n. ichnospec.; H. WALTER, pp. 148-49, Pl. 1, Figs 2-3; Pl. 2, Fig. 3.

1985. *Acripes* [*Merostomichnites*] *triassicus* (LINCK, 1943); J. POLLARD, pp. 276-280, Fig. 6a-c.

1986. *Acripes sellensi*, n. ichnospec.; H. WALTER, p. 6, Pl. 2, Figs 1-4.

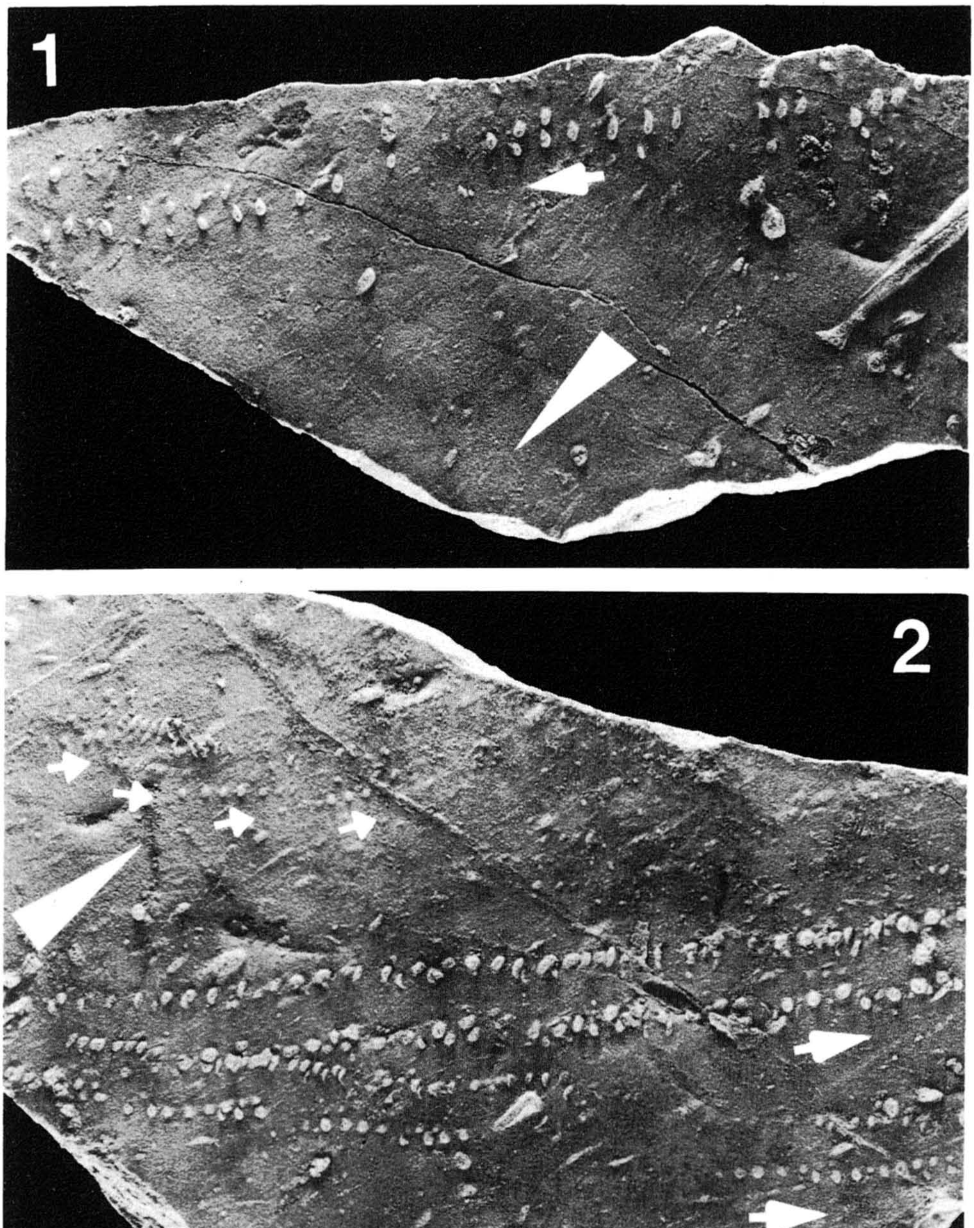
1992. *Diplichnites triassicus* (LINCK, 1943); R. PICKERILL, p. 23, Fig. 3A.

MATERIAL: 19 trackways from the Labirynthodontidae Beds; Middle Buntsandstein, Lower Triassic, locality Stryczowice south-west of Ostrowiec Świętokrzyski, Holy Cross Mountains, Central Poland.

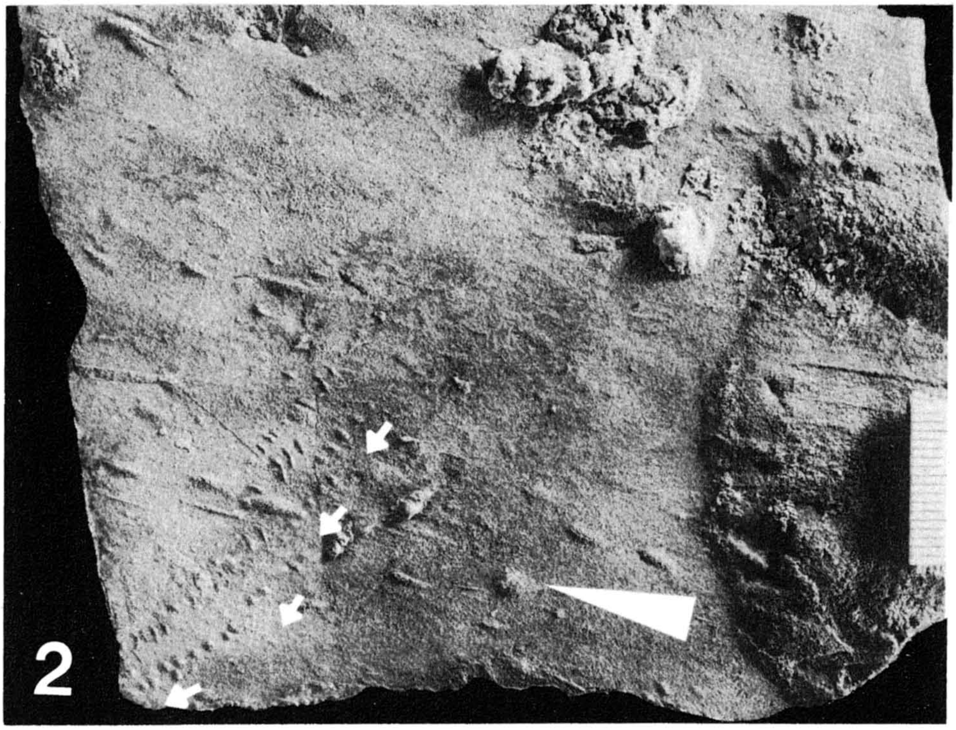
DESCRIPTION: The trackways are preserved as positive hypichnia on the sole surfaces of sandstone layers. The preserved length of the longest specimen is 250 mm; the external width ranges from 7 to 11 mm. The trackways consist of two paralell rows of tracks (individual footprints), and usually have straight or slightly sinuous course. Some trackways (Pl. 2, Fig. 2; Pl. 3, Fig. 2) are discontinuous and break up into distinct segments, somewhat differing in orientation and consisting each of two *en echelon* series per 5-7 tracks. The depth of track imprinting, both between and within trackways varies considerably. Some trackways are very distinct and sharp, others are weaker, vanishing even completely in places. In some cases (the lower trackway in Pl. 4) only one track row is visible. The morphology of tracks is variable, even within one trackway: they may be oval, ellipsoidal, crescentic, or comma-shaped. The tracks belonging to the last three categories are normal or slightly oblique to the axis of the trackway. The spacing between tracks in a row is also variable, reaching maximally 4 mm. Sometimes tracks are very closely spaced and overlapping each other (especially the specimens presented in Pl. 2, Fig. 2).

PLATE 1

Trackways "*Diplichnites*" *triassicus* (LINCK, 1943) left by presumably notostracan arthropods moving down-current; bigger arrow indicates the current direction, smaller arrows indicate movement direction of the arthropods; nat. size

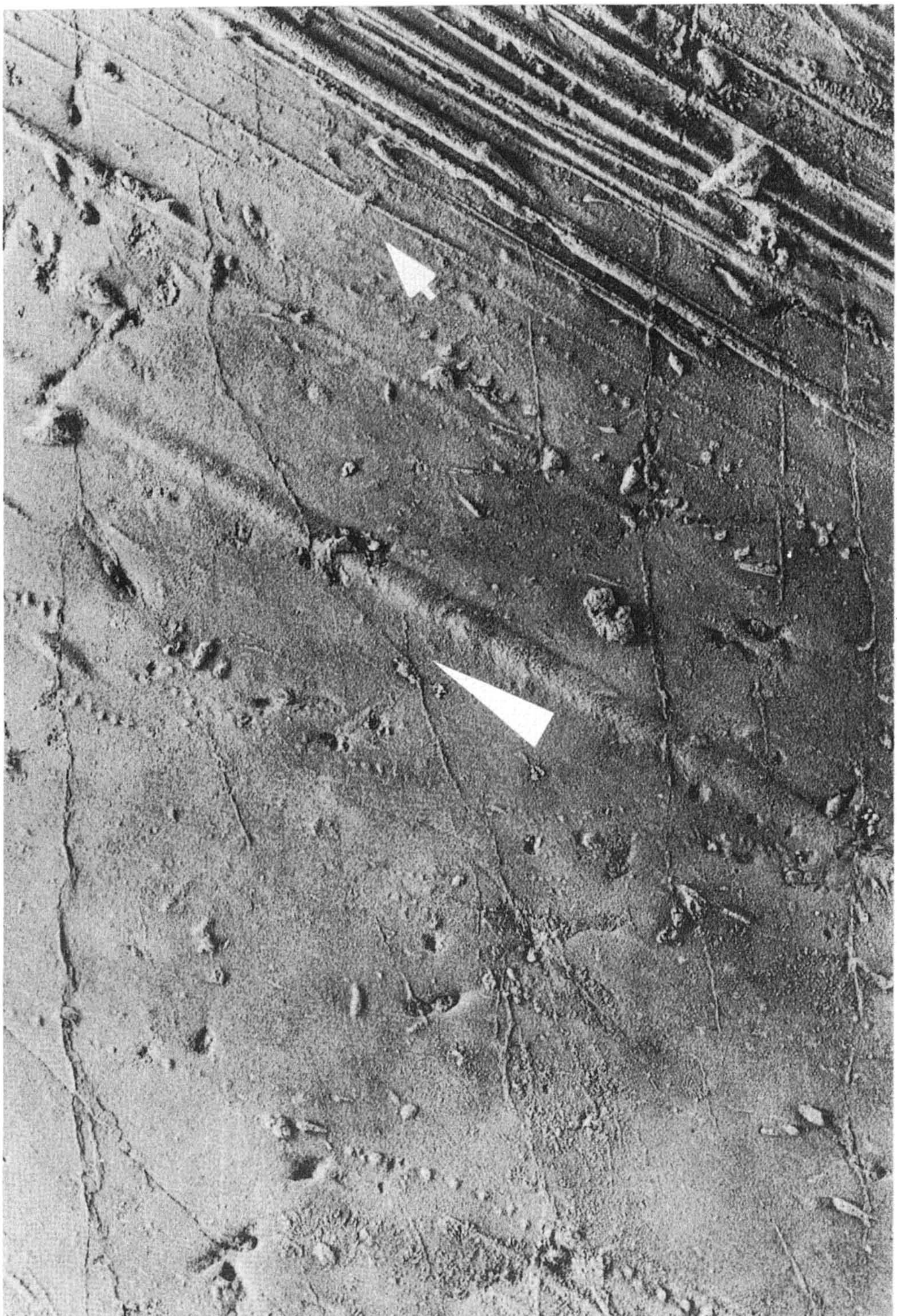


1-2 — Trackways "*Diplichnites*" *triassicus* (LINCK, 1943) made by presumably notostracan arthropods moving obliquely to the current direction; bigger arrows indicate the current direction, medium and smaller arrows indicate the movement direction of the athropods; nat. size



1 — Trackway "*Diplichnites*" *triassicus* (Linck, 1943) composed of oval tracks (movement direction undeterminable); nat. size

2 — Trackway "*Diplichnites*" *triassicus* (Linck, 1943) roughly perpendicular to the current (explanation of arrows as in Pl. 2); the down-current end of a broad groove cast is visible at right; slightly enlarged



REMARKS: The morphology of the trackways is consistent with the description and illustrations of the type material from the Buntsandstein of Schwarzwald presented by LINCK (1943).

The trackways *Acripes sittichenbachis* WALTER, 1983, and *Acripes sellensi* WALTER, 1986, from the Rotliegendes and the Buntsandstein of Germany, respectively, fall well within the variability range of "*Diplichnites*" *triassicus* (LINCK, 1943).

Due to a poor quality of the photograph it is not clear if the specimen from the studied locality Stryczowice, illustrated by SENKOWICZOWA & ŚLĄCZKA (1962, Pl. 21, Fig. 4), is conspecific with "*Diplichnites*" *triassicus* (LINCK, 1943).

PRODUCERS OF THE TRACKWAYS

The trackways "*Diplichnites*" *triassicus* (LINCK, 1943) are commonly regarded as arthropod walking traces. They are known from alluvial deposits of Late Paleozoic and Triassic age (*see* POLLARD 1985 for a comprehensive review). The size of trackways and their morphology, particularly the occurrence of natural cycles composed maximally of 9 tracks (usually less), as well as environmental evaluation of deposits yielding these ichnofossils, testify for notostracan branchiopods, similar to *Triops*, as their most probable producers (LINCK 1943, SEILACHER 1963, BROMLEY & ASGAARD 1979, POLLARD 1985).

The traces produced by recent *Triops*, reared in aquarium, show very similar morphology (TRUSHEIM 1931, Fig. 2). The only difference is the absence of imprints of fulcra and antennae in the fossil trackways. This may be explained in two ways: 1) these elements might have been too delicate to leave the traces in natural conditions (LINCK 1943); 2) as most of the fossil trackways seem to represent undertracks (*sensu* GOLDRING & SEILACHER 1971), rather than truly surficial traces, the absence of antennae and fulcra imprints can be explained by the undertrack fallout — imprints of such elements are usually not preserved in udertracks, as convicingly demonstrated by GOLDRING & SEILACHER (1971) for the horseshoe crab trackways. Further experiments with modern *Triops* are needed to resolve this question.

Recent tadpole shrimps live in fresh and brackish water environments, commonly in extremely shallow, ephemeral lakes and ponds with clear water and muddy bottom (TASCH 1969, POLLARD 1985). Young specimens rest on the bottom sediment or burrow; adults rest and walk on the bottom or swim. The same behavior may be ascribed to the Triassic forms (POLLARD 1985).

PLATE 4

Poorly preserved trackways "*Diplichnites*" *triassicus* (LINCK, 1943), associated with groove marks and chevron marks (in the center of the photo); bigger arrow indicates the current direction; movement direction of the arthropods is recognized only in one case (*smaller arrow*); nat. size

REMARKS ON THE ICHNOCOENOSE

The ichnocoenose preserved on the sole surfaces of thin sandstone layers in the Stryczowice quarry is almost monotypic. Besides possibly notostracan trackways "*Diplichnites*" *triassicus* (LINCK, 1943), only a single trace attributable to the activity of another animal has been found. It is very similar to the unnamed trace from continental Triassic deposits of Germany illustrated by SEILACHER (1955, Fig. 5-31) and interpreted as a bivalve locomotion trail. There are no resting or burrowing traces of arthropods within the Stryczowice ichnocoenose, although such traces are frequently associated with walking traces in other Triassic localities (SEILACHER 1963; BROMLEY & ASGAARD 1972, 1978; POLLARD 1985).

The preservation of both organic and inorganic traces on sole surfaces of sandstone layers was possible due to a lithological contrast between the sandstones and underlying mudstones. Some trackways may be strictly exogenic in origin, *i.e.* formed by arthropods walking just on the top surface of a mud layer. However, it is more likely that the arthropod traces are very shallow undertracks, formed at the mud surface which was already covered by an extremely thin sand cover. The variability in the distinctness of particular parts of some trackways, sometimes manifested by the presence of one track row only, can be best explained by the undertrack fallout principle, as suggested for similar case by ANDERSON (1975, Fig. 3).

A good preservation of the trackways and associated inorganic marks may be ascribed to the presence of a cohesive microbial mat on the upper surface of the mud layer (its presence is suggested by ruffling associated with some groove marks, *see* Pl. 4). Such mats are known to favor the preservation of tracks and markings in various environments (*e.g.* SEILACHER & *al.* 1985). In the case of recent trackways of *Triops*, the most distinct traces were also gained on the mud surface covered with a thin algal/diatomaceous film (TRUSHEIM 1931).

The association of the possibly notostracan walking traces with various directional mechanical marks in the Stryczowice ichnocoenose provokes a question: were the arthropods moving up- or down-current? The strong rheotaxy is reported for recent tadpole shrimps, which face upstream both during burrowing in the sediment or walking; the same was concluded for fossil forms basing on the orientation of their traces, "*Diplichnites*" *triassicus* including (*see* BROMLEY & ASGAARD 1972, 1979; POLLARD 1985 *and* references therein).

The walking direction of the arthropods can be deduced from the morphology of individual tracks. According to POLLARD (1985), the concave sides of crescentic or comma-shaped appendage tracks are oriented towards the locomotion direction of the trace producers. This is also consistent with observations of TRUSHEIM (1931, Fig. 2). One may note, however, that in the case of some studied trackways which are composed of oval tracks (Pl. 3, Fig. 1; Pl. 4), the locomotion direction of their producers cannot be determined.

The flow direction is indicated by the orientation of prod, bounce and chevron marks (*see* Pl. 4), on the sole surfaces of sandstones. Current ripples on the tops of layers indicate approximately the same direction.

The comparison of the data gained from the trackways and the inorganic directional marks leads to a somewhat unexpected conclusion that, in the case of the studied ichnotope, the notostracans followed generally the current flow direction (Pls 1-2 and 4). No traces of animals moving decidedly against the current have been recognized. Some arthropods walked almost exactly along the current (Pls 1 and 4), whereas the course of others was more or less oblique to the current (Pl. 2, Figs 1-2). In the later case, however, the maximal angle between the current and the trace-maker directions was less than 45°.

In one case only, the trackway was left by the animal moving in a direction approximately perpendicular to the current (Pl. 3, Fig. 2). This trackway is clearly disrupted into distinct offset track-series laterally shifted to one another. Such a morphology reflects probably the "skipping" rather than continuous movement of an animal which struggled against the side current.

As far as it is known, the occurrence of trackways of animals walking generally down-current distinguishes the Stryczowice ichnocoenose from all other "*Diplichnites*" *triassicus* assemblages, in which trackways show rheotactic or random orientation. The explanation lies probably in a unique nature of the Stryczowice ichnocoenose. While the other "*Diplichnites*" *triassicus* assemblages are time-averaged and record the normal life activity of the notostracans (including resting and burrowing), the trackway-bearing sole surfaces of the crevasse sandstones in the Stryczowice quarry represent "fossil snapshots", freezing the notostracan activities during very brief time intervals. The trackways were left during the first phase of a flood, under high-velocity flow conditions. Most likely, the current flow was strong enough to force arthropods to move generally in a down-current direction. Analogical walking traces of trilobites, "pushed" by a back-side current, have been described and illustrated by SEILACHER (1960, Fig. 13B) from the famous Devonian Hunsrückschiefer of Germany.

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TROPY "*Diplichnites*" *triassicus* (LINCK, 1943) Z PSTREGO PIASKOWCA GÓR ŚWIĘTOKRZYSKICH

(Streszczenie)

Przedmiotem pracy jest opis i interpretacja ekologiczna tropów stawonogów znalezionych w rzecznych osadach środkowego pstrego piaskowca (warstwy labiryntodontowe) w Stryczowicach koło Opatowa na północno-wschodnim obrzeżeniu Gór Świętokrzyskich (*patrz* fig. 1). Rozważane tropy (*patrz* pl. 1-4), utworzone zapewne przez skorupiaki z rzędu przekopnic (Notostraca), zostały formalnie zaliczone do ichnogatunku "*Diplichnites*" *triassicus* (LINCK, 1943). Tropy te występują na spągowych powierzchniach warstw piaskowców, zinterpretowanych jako dystalne osady glifów krewasowych. W odróżnieniu od innych stanowisk ichnogatunku, w których tropy wykazują reotaksję lub bezładną orientację, tropy ze Stryczowic zostały pozostawione przez zwierzęta poruszające się na ogół zgodnie z kierunkiem prądu.
