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The trace fossil *Asthenopodichnium lithuanicum* isp. nov. from Late Neogene brown-coal deposits, Lithuania

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A new freshwater ichnospecies of *Asthenopodichnium* Thenius, *A. lithuanicum*, is distinguished by its pouch-like shape with a J-shaped limb that is distinctly wider than the remaining part of the pouch. It was produced in a stiffground at the top of a mineral-rich brown-coal layer of Neogene age by a suspension feeder forming pouch-like domichnial cavities. Mayfly larvae may perhaps be considered as candidates for its tracemaker. Other arthropods (amphipods, isopods) are also possibilities. The brown-coal layer was exposed during the Neogene by river erosion, was colonized by the tracemaker (locally two colonization events took place) and in the Pliocene covered by distal crevasse and river channel sands.

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INTRODUCTION

Organic-rich deposits such as coal, lignite, wood (xylite) or gyttja are rarely a substrate for burrowing or boring organisms in aquatic environments, the action of which is recorded as trace fossils. Literature on this topic is very scarce. Philipp and Wehrli (1936) and Schenk (1937) described borings of marine bivalves (*Teredolites*) in lignites from Neogene brown-coal deposits in Germany. Similarly, Bromley *et al.* (1984) described the marine wood boring *Teredolites clavatus* Leymerie from the top surface of a coal layer in the Late Cretaceous Horseshoe Formation, Alberta, Canada. More data concerns bivalve borings in wood in marine environments. These are ascribed to the ichnogenus *Teredolites* (e.g., Kelly and Bromley, 1984; Savrda *et al.*, 1993). Less well known are marine borings in wood produced by amphipods (*Limnoria*) and isopod crustaceans (Bromley, 1970, p. 66, and references therein) or other organisms (Bann *et al*., 2005). To our knowledge trace fossils in brown coal or gyttja in non-marine aquatic environments have not been reported until now. Very little is known about borings in wood in fresh waters. Thenius (1979) described the ichnogenus and ichnospecies *Asthenopodichnium xylobiontum* from Late Neogene wood in Austria and referred it to borings of mayfly larvae.

Some pouch-like trace fossils have been discovered at the top of a mineral-rich brown-coal layer in Neogene brown-coal bog-lake and fluvial deposits at Anykščiai, Northeastern Lithuania (Fig. 1). Given the scarcity of information on burrows and borings in freshwater environments in organic-rich deposits, they are interesting and potentially increase our knowledge on this topic. Their description and interpretation are the main aim of this paper. Some of thse deposit illustrated are housed in the Institute of Geological Sciences of the Jagiellonian University (collection prefix 198P).

GEOLOGICAL SETTING

Neogene deposits, occurring in isolated patches in the valleys of the Šventoji River and its tributaries, Northeastern Lithuania, were discovered by Dalinkevičius (1933), who ascribed them to a Tertiary brown-coal formation (see also Dalinkevičius, 1960). Their micoflora and palaeocarpology were investigated

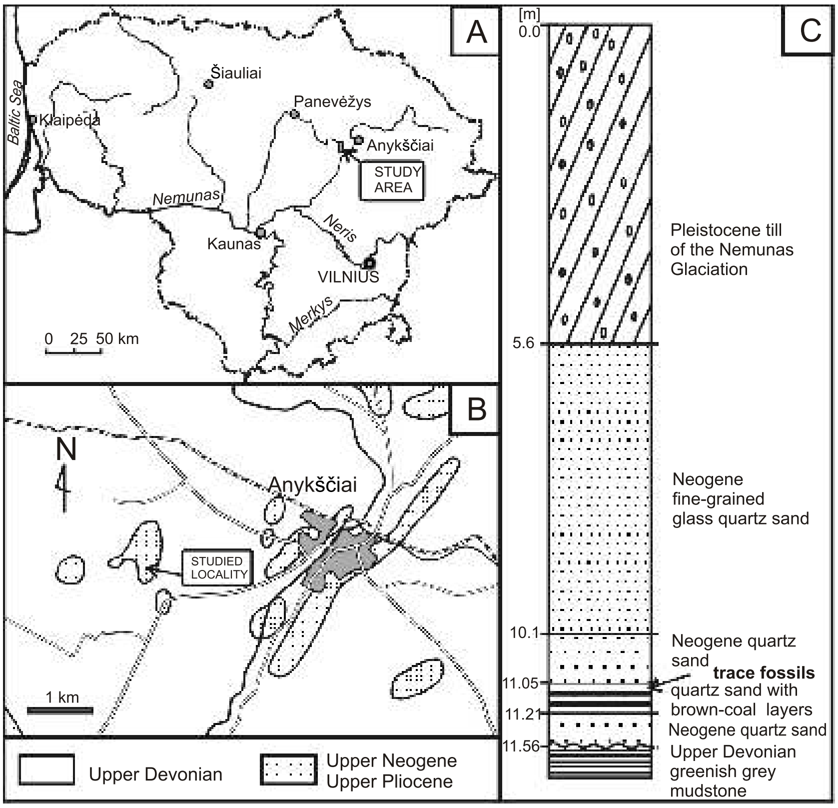

Fig. 1. Location maps and a general section of the sand pit at the locality studied; the detailed map is without Quaternary deposits (based on the *Geological Map* 1: 200 000 by Šliaupa *et al*., 2000)

A — location of studied area in Lithuania; **B** — location of the studied section; **C** — lithostratigraphic column of the studied section and location of the trace fossil bearing horizon

by Vienožinskienė (1960), Kondratienė (1971), Riškienė (1971) and Khomutova in Vaitiekūnas and Khomutova (1972). The lower part of the Lithuanian Neogene contains mainly bog-lake facies and is ascribed to the Miocene, whereas the upper, more widely distributed fluvial part — to the Middle and Upper Pliocene (Vaitiekūnas, 1977). The Pliocene deposits at Daumantai in the Šventoji River valley were distinguished as intermediate between the Neogene and the Pleistocene, and were related to (Gaigalas, 1987) the Anykščiai Regional Stage *sensu* Kondratienė (1971). Baltakis (1966) and Katinas (1971, 1994) studied the Neogene of Lithuania and of the Semba peninsula. For general information on the Lithuanian Neogene see also Paškevičius (1994, 1997).

THE LOCALITY STUDIED

The Neogene brown-coal unit investigated crops out 2 km SW of Anykščiai on the northern side of the main road to Kovarskas–Ukmergė (Fig. 1) in a sand pit, in which a very clean, white glass sand is exploited. The deposits studied belong to the East Lithuanian facies area of the Neogene and can be ascribed to the Pliocene. The sand is 4.5 to 6 m thick, fine-grained, cross-laminated (Fig. 2A) and covered with Pleistocene boulder clays (tills) of the Middle Lithuanian phase of the Baltic Stadial of Nemunas Glaciation. The Pleistocene rests on an erosive exarational discontinuity. Under the sands, a sequence of less clean, very fine- to medium-grained sands about 2 m thick crop out (Fig. 2B) in the western part of the sand pit. These are intercalated with irregular layers of brown coal and drapes of mudstone and siltstone. The latter form a heterolithic sediment. Below, the top of the Upper Devonian red beds (Šventoji Formation) can be seen in ditches at the bottom of the quarry.

The trace fossils were found at the top of the highest brown-coal layer (Figs. 2C and 3), which is up to 9 cm thick and pinches out to the east. The brown-coal is composed of black or black to dark brown detrital, massive or indistinctly laminated black organic matter, some mineral grains, including mica flake, quartz grains, clay minerals or calcite, well-preserved pieces of wood up to 7 cm long, and flat marcasite concretions, 3–5 mm across, lying along the lamine. Macroscopically, the coal resembles a mineral-rich coal *sensu* Taylor *et al.* (1998). Paškevičius (1997) showed that this is a clarain coal of the friable attritus, heliolithic class. It displays a weakly coalified, fragmental and attritic microstructure, and is composed of tiny heliolitithified stems of bushes and herbaceous plants, and fragments of leaves, wood and bark. A leaf matrix composed of attritus dominates. Laterally, the brown-coal layers are replaced by coaly sand, silt and clay.

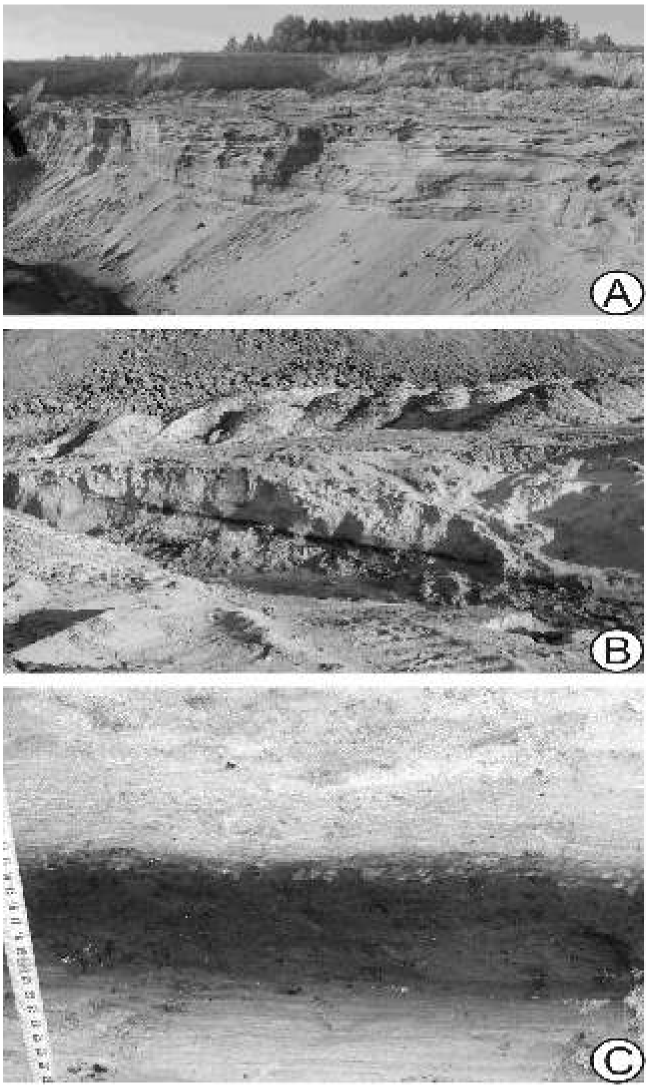

Fig. 2. The locality studied in photographs

A — view of the quarry; **B** — view of the brown-coal deposits with the gyttja layer bearing trace fossils; **C** — *Asthenopodichnium lithuanicum* at the top of the coal layer

The vegetation was of a subtropical type growing on a large alluvial plain. The remains of vegetation were transported by streams and deposited as allochthonous detritus in oxbow lakes as a peaty gyttja or coal. The Pliocene vegetation shows a climatic cooling in comparison to the Miocene. Among the spores and pollen *Pinus silvestris* prevails, comparising up to 70% (10–50% in the Miocene) while the Taxodiaceae decreased to 5% from 45% in the Miocene. Thermophilous plants are rare, but *Quercus*, *Corylus* and *Carpinus* are frequent. *Betula* and *Alnus* prevailed among the boreal tree species.

From a distance the trace fossils are visible as white sand-filled spots, a few mm wide against the dark background of the brown coal. An additional trace fossil (form A) was found in the pieces of wood that occur in the brown-coal layers.

Probably, the cross-bedded sands above the brown-coal layers were deposited in bars of a sandy braided river. The sands in the brown-coal unit originated probably in a meandering or anostomosing river with in a fluvial plain with oxbow lakes or abandoned channels. There is no evidences of marine influence.

TRACE FOSSILS

Ichnogenus *Asthenopodichnium* Thenius 1979
Type ichnospecies *Asthenopodichnium xylobiontum* Thenius 1979

E m e n d e d d i a g n o s i s. — Small, U-shaped spreiten or pouch-like structures in wooden, organic-rich or bone substrates.

R e m a r k s. — Material of the type ichnospecies of *Asthenopodichnium*, *A. xylobiontum* distinguished by Thenius (1979), was discovered in the Late Miocene (Pannonian) deposits of the Vienna Basin (Papp, 1949; Papp and Thenius, 1954; Thenius, 1979). Originally, the ichnogenus *Asthenopodichnium* was diagnosed by Thenius (1979) as "U-shaped spreiten burrows in wood, vertically oriented to the

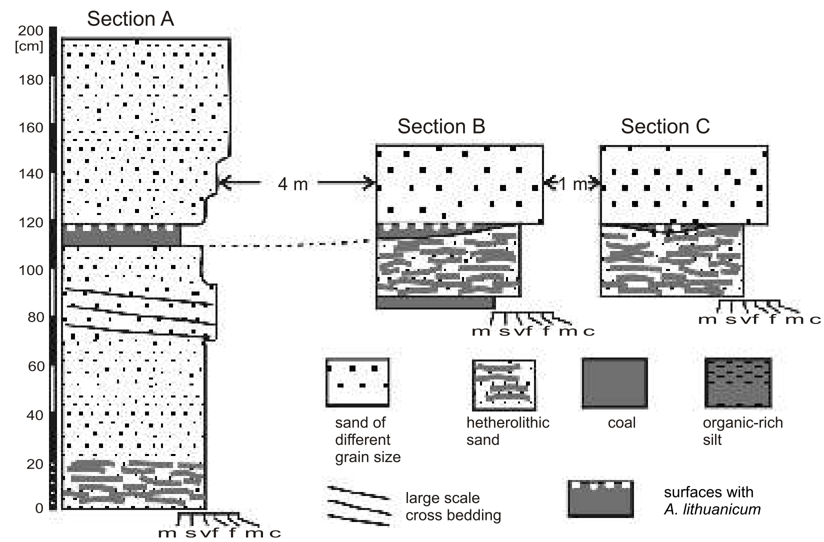

Fig. 3. Detailed section of the Anykščiai brown-coal deposits with the trace fossils

upper side the log". The spreiten, however, are not obvious because even in the type material, the trace fossil appears as a tongue filled with other, non-xylic material and probably is a cast of a spreiten trace fossil, in which limbs and possible spreiten formed a single cavity before casting. Moreover, its occurrence in brown coal and even in organic-rich siltstone enlarges its substrate constraints. For these reasons the diagnosis has been emended.

Bertling *et al*. (2006) considered the major substrate types as ichnotaxobases. In the case of the new, third ichnospecies of *Asthenopodichnium* described in this paper, the boundary between the substrate types is not sharp because of its occurrence in the organic-rich silt. This, however, can be considered as an exception, which does not affect the general rule.

Hitherto, only two ichnospecies of *Asthenopodichnium* Thenius 1979 have been recognized. *A. xylobiontum* Thenius 1979 was diagnosed as "U-shaped spreiten with limbs 1.5–3 mm in diameter and depth (height) up to 20 mm". *A. ossibiontum* Thenius 1988, recognized in mammal bones from the Neogene of the Vienna Basin, Austria, is diagnosed similarly. Thenius (1988) emphasized that its difference from *A. xylobiontum* is based mostly on biological preferences of the tracemaker (wood *versus* bones), though some morphometric differences can also be seen (Figs. 4 and 5).

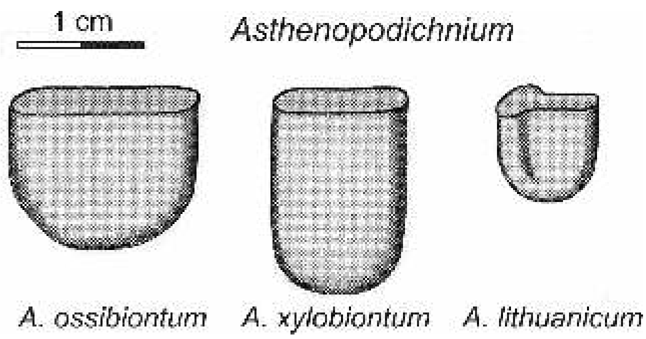

Fig. 4. Morphological models of *Asthenopodichnium* ichnospecies

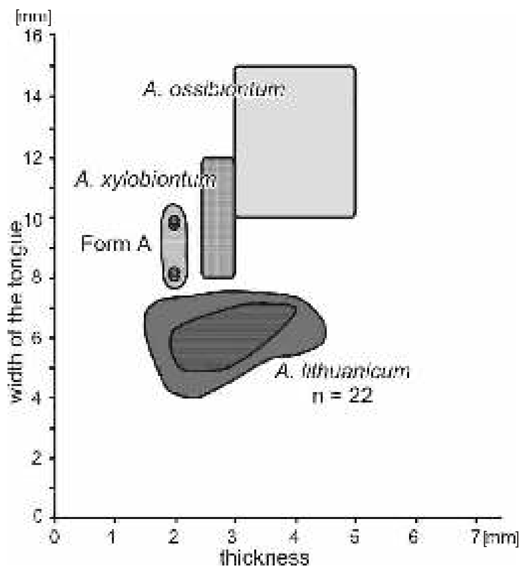

Fig. 5. Thickness and width of *Asthenopodichnium* ichnospecies pouches, form A and lebensspuren discussed in the paper

In general, the barnacle borings *Rogerella* Saint-Seine (1951) and *Zapfella* Saint-Seine (1956) are similar to *Asthenopodichnium* in their overall shape, but these two ichnogenera are found only in lithic marine substrates, primarily in calcareous skeletons (e.g., Bromley, 1970; Häntzschel, 1975). *Diplocraterion luniforme* (Blackenhorn 1916) from the Cretaceous fluvial clastic Hasandong Formation, Korea (Kim and Paik, 1997) displays a similar size and overall shape, but it displays U-shaped limbs and spreiten.

Asthenopodichnium lithuanicum isp. nov.
(Figs. 2C, 4 and 6)

Material and holotype. — 10 small slabs (198P1-5; 198P7-11) with more than 50 trace fossils altogether. The holotype is on the slab 198P1. It is shown in Figure 6A. All the remaining specimens in the slab are co-types.

Diagnosis. — Pouch-like structures in brown coal and rarely in organic-rich siltstones, which display a J-shaped limb that is distinctly wider than the other part of the pouch.

Description. — Small, sand-filled tongues at the top of a brown-coal layer or in pieces of wood. They are oriented vertically at the top of the brown coal. The horizontal cross-section (Fig. 6A) shows that the burrow displays a distinct limb on only one side. Thus, it is a J-shaped rather than U-shaped structure. The limb is distinctly wider than the remaining part of the pouch. The pouches are 4–7.5 mm wide, from 1.5 to 4 mm thick in the limb (Fig. 5), and up to 7.5 mm high (deep). They are scattered on the surface of the brown-coal layer without any preferred orientation but they tend to occur in clusters. Individual burrows are 1–5 mm apart in a cluster. The clusters are located 15–25 mm apart. Individual burrows are rare.

A. lithuanicum occurs in the 2 cm-thick top part of the layer (Figs. 2C, 6B–C). Its top comprises the boundary between the brown coal and the overlying sand or a lamina surface located about 10 mm below the boundary (Fig. 6C). The boundary and lamina surfaces are interpreted as two colonization surfaces.

Remarks. — The trace fossil described fits best the ichnogenus *Asthenopodichnium* because of its overall shape and occurrence in non-lithic substrates. It differs from *A. xylobiontum* and *A. ossibiontum* in the distinct J-shaped limb that is wider than the remaining part of the pouch (Fig. 4).

Form A
(Fig. 7A)

Material. — A xylite (198P6) from the brown-coal layer with a few borings.

Description. — Elongate oval depressions in the surface of a wood fragment. The depressions are 8.5–11 mm

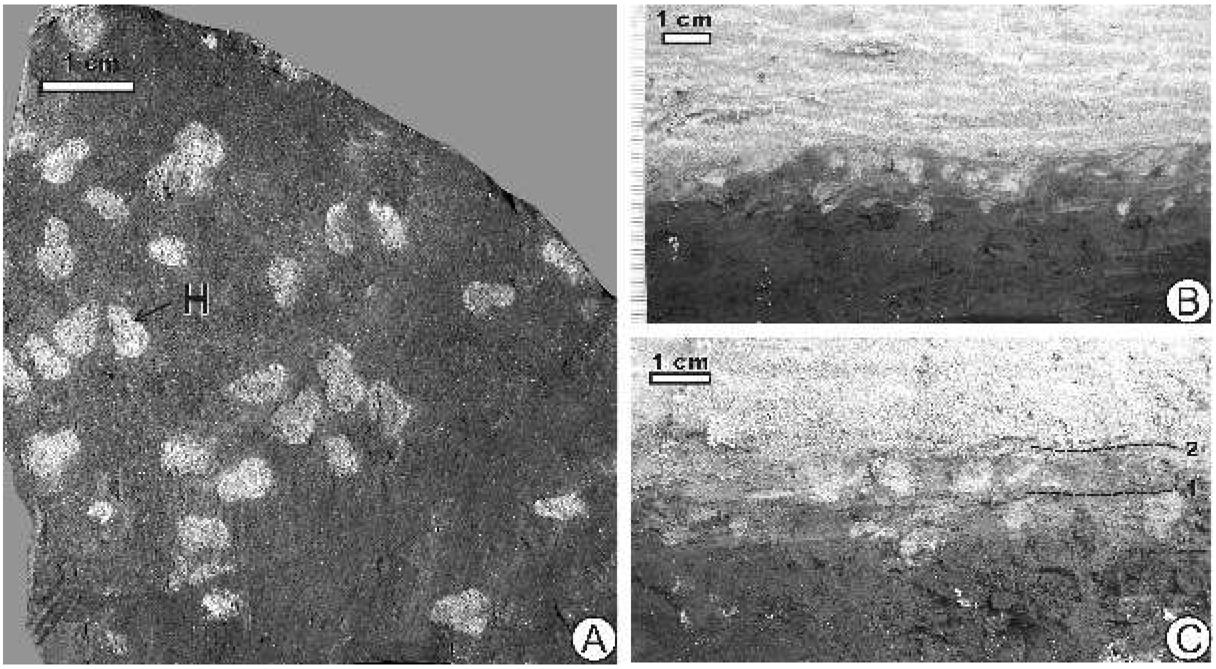

Fig. 6. *Asthenopodichnium lithuanicum* isp. nov.

A — slab 198P1 with the holotype (H); **B** — slightly deformed *A. lithuanicum* at the top of the coal layer; **C** — two colonization surfaces (1 and 2) at the top of the coal layer; field photographs in B and C

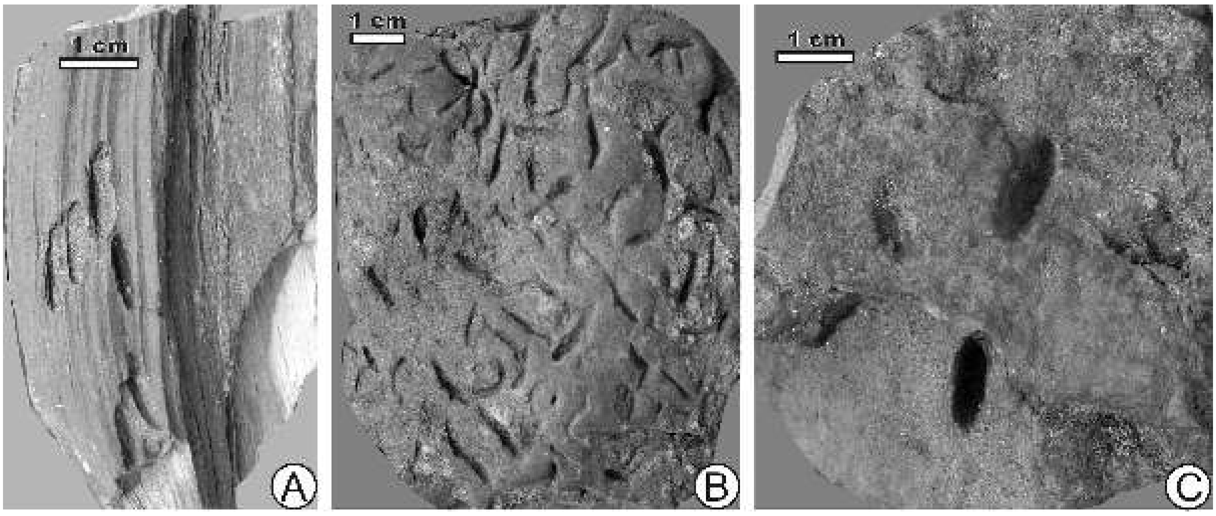

Fig. 7. Form A and lebensspuren related to *Asthenopodichnium*

A — form A in the surface of a piece of wood, 198P6; **B** — lebensspuren type B in the form of elongate depressions in the surface of Pleistocene gyttja exposed in the bottom of the Neris River channel, NW of Vilnius, 198P13; **C** — lebensspuren type C in the form of pouche depressions in the surface of Pleistocene gyttja, 198P12, the same location as in B

long, 1.8–2 mm wide, and up to 2 mm deep. They are oriented parallel or sub-parallel to the wood grains.

Remarks. — The depressions resemble *Asthenopodichnium xylobiontum* Thenius 1979 in their size (Fig. 5) and outline. However, the latter trace fossil is deeper. However, it is not excluded that it is a bottom part of *A. xylobiontum* that remained after erosion of the surface part of the wood.

DISCUSSION

The two ichnospecies of *Asthenopodichnium*, *A. xylobiontum* and *A. ossibiontum*, are borings in a hard substrate. *A. lithuanicum* is a burrow because it occurs in the brown coal and there is no evidence that the grains are cut by the tracemaker.

Moreover, some of the burrows are slightly compactionally deformed (Fig. 6B) showing the substrate was still plastic. The occurrence of burrows and borings within an ichnogenus is not surprising. There are even stranger examples, such as *Gastrochaenolites oelandicus* from the Ordovician of Sweden, which is known both as borings and burrows within the same ichnospecies (Ekdale and Bromley, 2001).

Trace maker identification is an intriguing problem as regards *A. lithuanicum*. Thenius (1979) on the basis of literature and of recent material, referred *Asthenopodichnium xylobiontum* to traces of mayflies of the family Polymitarcidae = Ephoronidae (e.g., *Tortopus*, *Asthenopus*, *Povilla*) produced in wood of recent lakes and rivers of Paleotropis, Neotropis and the SE USA. Thenius (1979) included within *A. xylobiontum* elongate depressions preserved in a xylite in Late Tertiary brown coal in NW Germany on the basis of material illustrated by Schenk (1937, fig. 6; also Thenius, 1979, pl. 1, fig. 1). Recent depressions of this type have been found in the bottom of channel of the Neris River (Vilija), NE of Vilnius, Lithuania (lebensspuren type B; Fig. 7B). The depressions are 9–11 mm long, up to 2 mm wide and up to 2 mm, exceptionally 4 mm deep. They occure on the surface of a Pleistocene interglacial gyttja (160–180 ka). Moreover, such depressions have been found in pieces of wood from the Vistula River near Warsaw, Poland (M. Paszkowski, pers. comm.). The surface of the gyttja NW of Vilnius contains also larger depressions (lebensspuren type C; Fig. 7C) with arcuate bottoms, which are 11–12 mm long, 4–5 mm wide, and up to 10 mm deep. All of these can be ascribed to *Asthenopodichnium*-like burrows (in gyttja) or borings (in wood). This excludes mayflies of the family Polymitarcidae, which do not now occur in Europe, except for *Ephoron virgo* (Oliver). *E. virgo*, however, produces larger and deeper burrows with distinct U-shaped limbs (Abel, 1935, fig. 370), up to 80 mm deep (e.g., Stief *et al*., 2004). Other Eurasian mayfly larvae produce distinctly larger and deeper U-shaped burrows (e.g., Russev, 1987; De, 2002). The same observations concern trace fossils attributed to mayflies (Storch, 1926; Fürsich and Mayr, 1981). Therefore, interpretations of pouch-like trace fossils and lebensspuren exclusively as traces of mayfly larvae can be challenged. Unfortunately, an alternative, convincing interpretation cannot be proposed. Pemberton and MacEachern (1992, p. 56) and Pemberton *et al*. (1992, p. 18A; 2001, p. 81, 195) mentioned shallow, "sparse to profuse nonclavate etchings" produced by isopod crustaceans in a freshwater wood substrate, but more detailed characteristics were not provided. Hoffmann and Hering (2000) distinguished facultative xylophagous taxa among freshwater Gastropoda, Trichoptera, Isopoda, Coleoptera, and obligate xylophagous animals among freshwater Diptera, Trichoptra and Coleoptera. Their lebensspuren, however, are unknown. The geometry and location in the section suggest that the tracemaker *A. lithuanicum* was probably a suspension feeder forming domichnial pouch-like depressions as shelters.

A. lithuanicum was formed at the top of peaty gyttja layer (now the brown coal), which probably formed in an oxbow lake. The peaty gyttja was probably exposed by a crevasse initiating the cutting of a new channel in a fluvial plain and entering the oxbow lake. The exposed layer was probably stiff (a stiffground *sensu* Wetzel and Uchman, 1998) as indicated by well-outlined trace fossils, which are only locally slightly compacted. At least two colonization surfaces can be seen (Fig. 6C) in places when the coal is thickest. Probably, after the first colonization, the burrows were filled passively with sand of a distal crevasse. Later, on a thin, about 1 cm-thick layer of peaty gyttja accumulated. After colonization of this thin layer, crevasse and river channel sediments accumulated and filled the burrows.

Asthenopodichnium lithuanicum and related forms have been found only in brown coal, gyttja or wood. This suggests that this trace fossil is a substrate-specific form. Its interpretation as a suspension feeder domichnion, however, makes difficulties in explaining how the tracemaker benefits from the coaly or woody substrate. In comparison to clastic stiff substrates, brown coal or woody substrates are softer and their thermal conductivity is higher. Therefore, production of cavities can be easier in brown coal or wood. Moreover, they give more protection against changes of temperature in a fluvial environment, which can be important for life of the tracemaker.

CONCLUSIONS

1. *Asthenopodichnium lithuanicum* from brown-coal deposits of Neogene age in Lithuania is a new ichnospecies distinguished by its pouch-shape with a J-shaped limb that is distinctly wider than the remaining part of the limb.

2. *A. lithuanicum* occurs at the top of a brown coal layer that was exposed by river action during the Pliocene and was formed in a stiffground.

3. *A. lithuanicum* was produced by a suspension feeder forming pouch-like domichnial cavities. Mayfly larvae may perhaps be considered as candidates for its tracemaker. Other arthropods (amphipods, isopods) are also possibilities.

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