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A *Cooksonia*-type flora from the Upper Silurian of the Holy Cross Mountains, Poland

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Silurian land plants from the Holy Cross Mts. are described for the first time. The fossil assemblage occurs in a near-shore, marine, terrigenous deposit of Ludlowian/Pridolian age. It contains *Cooksonia* sp., *Cooksonia*-related species, and some problematical forms. The flora, which needs further study, is of importance to our understanding of early vascular plants and Late Silurian palaeogeography.

Our knowledge of Silurian floras is based on a very sparse collection of fossil sites spanning Asia, Australia, Europe, Northern Africa, and the Americas (Edwards et al. 2001; Edwards and Wellman 2001). There is an extensive microfossil record of spores and other plant fragments (Wellman and Gray 2000) that is augmented at a handful of sites (some 15–20) by the fossilised remains of the plants themselves (Edwards and Wellman 2001). The latter are of exceptional interest because they provide the only direct evidence on the morphology of the earliest land plants. In Europe, Silurian land plants have been described from Wales, England, Ireland, the Czech Republic, and the Ukraine. Some plant remains have been recorded from the Silurian formations of Poland (e.g., Tomczyk 1958; Kozłowski 2000), but these have not been described or illustrated. Here, we report a new mass occurrence of fossil land plants from the Upper Silurian of the Holy Cross Mountains.

All specimens described here are housed in the Institute of Geology of the A. Mickiewicz University in Poznań, Poland, abbreviated IGUAM.

Geological setting

The site of the Silurian land flora is located at the western margin of the Winnica village, about 1.5 km NE of the centre of Nowa Słupia, within the Słupianka river valley, directly below a small waterfall (Fig. 1, GPS 50°52'36''N, 21°06'27''E). A monotonous series of olive-green clay shales, mudstones, and siltstones is exposed at both banks of the valley. The strata dip at about 50° NNE and are intercalated with marly-calcareous horizons, occurring occasionally in lenses.

Formerly, the strata were included within the Upper Rzepin Beds (Filonowicz 1968). In this paper, the authors use a new informal term "the Winnica Mudstone Complex", which will possibly be the basis of a formal litostratigraphic unit in the near future. The Winnica Mudstone Complex is equivalent to the upper part of the Lower Rzepin Beds (*sensu* Czarnocki 1950; Tomczyk 1970), series A of the Rzepin beds (*sensu* Malec 2000), series "2" of the Rzepin beds (*sensu* Kozłowski 2000) and, most probably, also the Lipniczek mudstones (*sensu* Tomczyk 1970). The strata in question reach a thickness of about 100 m, and the succession exposed in the analysed section represents their middle part (Kozłowski, unpublished data). According to Kozłowski (2000), oolithic limestones and calcareous sandstones representing the lowermost member of the Rzepin beds (*sensu* Czarnocki 1936) occur below the Winnica Mudstone Complex. The deposits crop out about 70 meters SSE of the analysed section on arable land and in the north-eastern bank of the Słupianka valley. Grey-red mudstone shales representing the Upper Rzepin Beds, well exposed along the river, overlie the Winnica Mudstone Complex.

Stratigraphical position and paleoenvironment

Index trilobites, occurring rather sparsely within the section, and much more frequently in the overlying and underlying strata, provide evidence on the stratigraphical position of these deposits. The underlying strata contain *Homalonotus knighti, Acastella spinosa, Proetus signatus, Calymene beyerii*, and *Richterarges convexus* (Kozłowski 2000). This assemblage is characteristic of the Upper Siedlce on the East European Platform (see Tomczykowa 1991) and indicates the latest Ludlow (Tomczyk 1990). In the Winnica section, representing the middle part of the Winnica Mudstone Complex, the trilobites *Acastella spinosa*, *Calymene beyerii*, and, in the uppermost part, also *Acastella* cf. *prima* have been found. The presence of the latter species is characteristic of the lowermost Podlasie (Lower Pridoli) of the East European Platform (Tomczykowa 1991; Tomczykowa and Witwicka 1974). Unfortunately, the poor preservation of the specimen does not allow an univocal diagnosis. On the other hand, the Early Podlasie (Early Pridoli) age of the upper part of the Winnica Mudstone Complex is confirmed by the ostracode assemblage (*Amygdalena subclusa*, *Cavellina angulata*, *Clavofabella pomeranica*, *Healdianella magna*?, *Hemisiella sphaericruminata*, *H. loensis*, *Kuresaaria circulata*, *Neodibeyrichia* cf. *bifida*, *Primitiopsis minima*, *P. suaris*?, *Retisacculus semicolonatus*, *Scaldianella simplex*), which was found in the lithological equivalent of the Winnica Mudstone

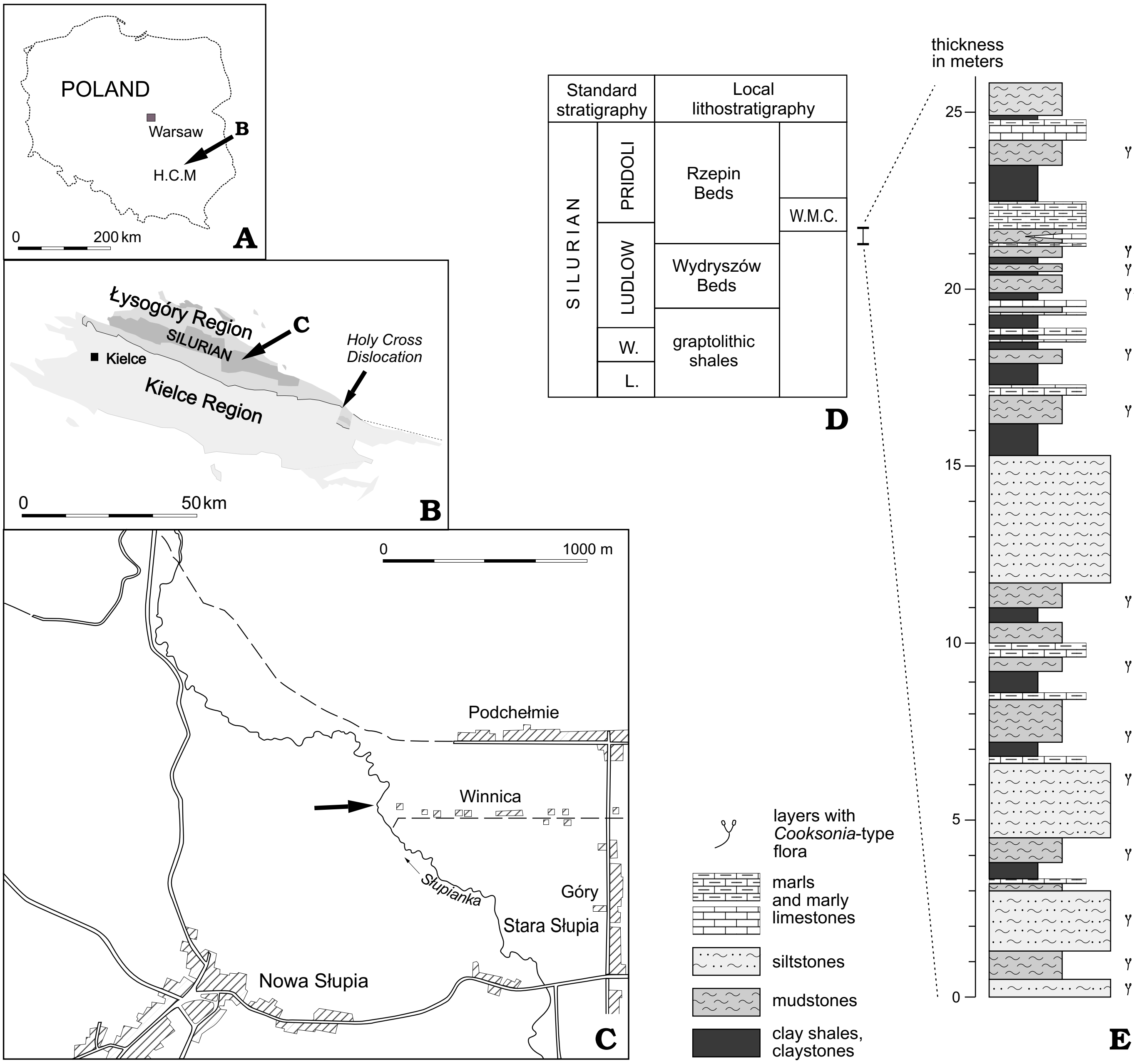

Fig. 1. Geological setting of the described Silurian flora. **A**. Geographical position of the Holy Cross Mountains. **B**. Geological sketch map of the Paleozoic rocks of the Holy Cross Mts. **C**. Geographical position of the described outcrop (arrowed). **D**. Stratigraphical position of the flora-bearing complex. **E**. Geological column of the Winnica Mudstone Complex in the type locality shown in C (after Kozłowski 2000) Abbreviations: H.C.M., Holy Cross Mts., L., Llandovery; W., Wenlock; W.M.C., Winnica Mudstone Complex.

Complex near Rzepin (about 15 km north of Winnica, in the Wydryszów Anticline) (Malec 2000). The deposits occurring above the Winnica Mudstone Complex contain fauna indicative for the Early Podlasie (Early Pridoli), such as *Acaste dayana* or *Leonaspis bidentata* (Tomczykowa 1991; Kozłowski unpublished data). Therefore, the biostratigraphical data indicate a lowermost Pridoli age for the flora.

The clastic deposits forming the Winnica Mudstone Complex contain a very characteristic fossil assemblage, consisting of lingulids, leperditiid ostracods, gastropods, eurypterids, bivalves, fragments of agnathids and rich plant debris (Kozłowski 2000). Together with lithology, there are strong similarities to the British Downtonian, which was deposited in a shallow-water environment (see Antia 1980; Allen 1974; Calef and Hancock 1979). The carbonate layers reveal fauna characteristic for more distal parts of the shelf (i.e., brachiopods, crinoids, trilobites, rugose corals, tabulates, numerous stromatoporoids). Excluding stromatoporoids and tabulates, the fauna is strongly crushed, which might suggest the allochthonous character of most of the bioclasts. According to Kozłowski (2000), both the clastic and carbonate deposits represent back-barrier, periodically brackish environments.

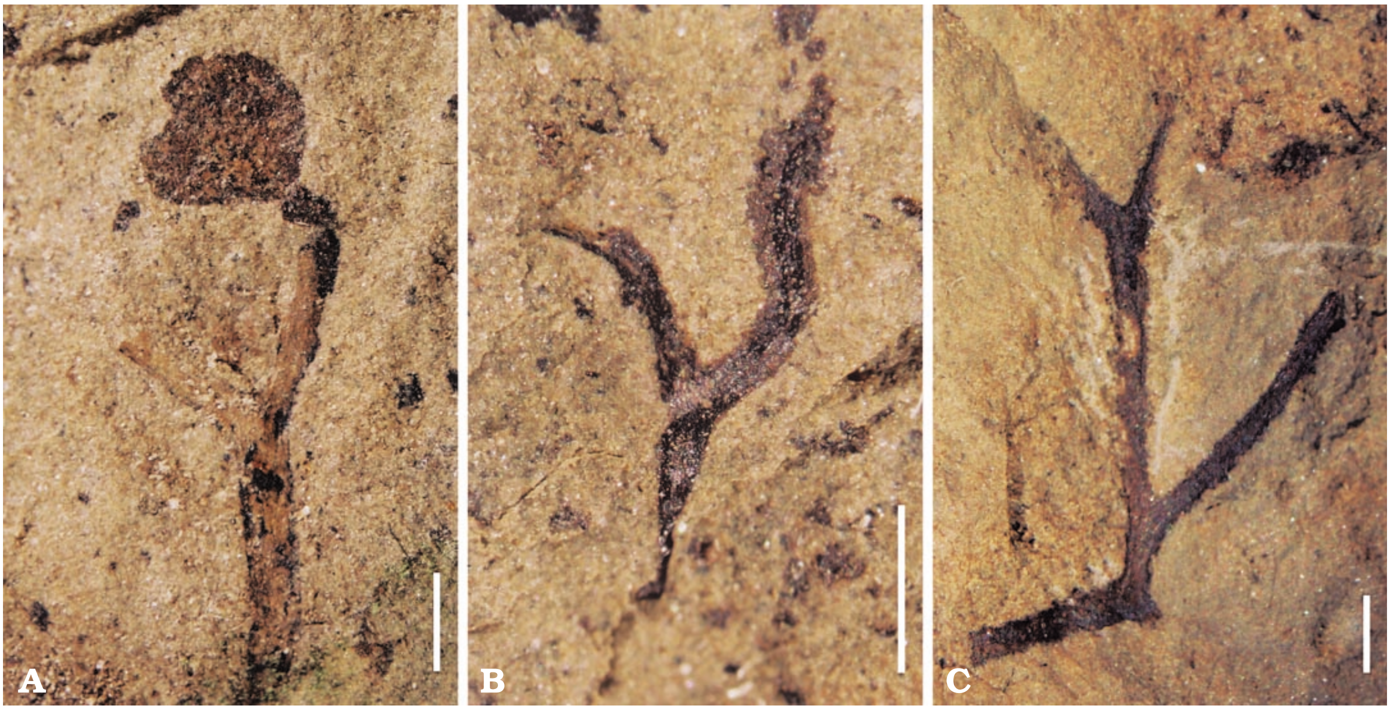

Fig. 2. Examples of land plant fossils from the Winnica section. **A**. *Cooksonia* sp. (IGUAM-0460-01) with preserved sporangium. **B**. Problematical form (IGUAM-0460-02) showing atypical shape of axes. **C**. Problematical form (IGUAM-0460-03) showing considerably different types of branching in its lower part. Scale bars 1 mm.

Description of fossil flora

Fossil plants occur in greatest number in fine-laminated mudstones and siltstones, whereas they are almost absent from shales and limestones. Usually, they are preserved as coalified compressions of highly fragmented axes and isolated sporangia, forming accumulations of plant debris at the top of lamine. Impressions also occur, and these are commonly covered by a thin film of iron or manganese oxides. Secondary mineralization by those oxides also caused the apparent irregularity of axes of some specimens (Fig. 2B, C). Collected material contains about 180 samples. Among these samples, there are only 20 larger specimens that are complete enough to enable an evaluation of the morphology and systematics. One of these is a specimen of the genus *Cooksonia*, which has been found together with some *Cooksonia*-like and problematical forms.

The specimen of *Cooksonia* sp. is shown in Fig. 2A. This is a branched, leafless axis terminated with sporangium. The total length of the specimen is 6.6 mm. The width of its main axis is 0.55 mm, and this increases slightly at the point of branching. Above the bifurcation, the width of axes is about 0.4 mm, and the angle between them is about 70°. The sporangium is oval, its height is somewhat less than its width (1.65 mm and 1.98 mm respectively). The axis terminating in the sporangium is broken, therefore, its orientation is probably not natural. Consequently, both the shape and dimensions of the sporangium could have been altered somewhat during fossilization. Nevertheless, all the features described above conform with the original definition of the genus *Cooksonia* given by Lang (1937) and with other more recent descriptions (e.g., Edwards 1979; Edwards and Rogerson 1979).

Most of the other relatively well preserved specimens show morphological features, which may correspond to the genus *Cooksonia* but none of these bears sporangia. Such sterile axes are conventionally named *Hostinella* (e.g., Edwards et al. 2001). These specimens have slender, naked and bifurcated axes, sometimes with two orders of branching. Their height varies from 3.6 to 8 mm, width of the main axis varies from 0.22 to 1.55 mm, and width of secondary axes is around 0.1 mm. The considerable differences in size range could reflect the ontogenetic stage of a given specimen as well as depend on the order of branching, however, at present, collected material does not permit to solve this problem.

Problematical forms differ from the specimens described above in considerably lower angle of branching (about 40°), unusual shape of axes which is unknown in *Cooksonia* (Fig. 2B), or in considerably different types of branching (Fig. 2C), which can be referred to some problematical *Hostinella* forms described from the Silurian of Bolivia (Edwards et al. 2001). At present, it is not possible to say whether these represent original morphological features of the plants or come from post-mortem alteration of plant remains.

Conclusions

- Upper Silurian sediments from the Holy Cross Mts (Poland) contain *Cooksonia*-like fossils. The range of morphological variation, as well as their mass occurrence, augurs well for further studies which may bring new data about the oldest vascular plants.

- The Winnica Mudstone Complex was deposited at the Ludlow/Pridoli boundary, the evidence of which is based on a trilobite and ostracode fauna. The age of the plant remains falls within the well-known stratigraphic range of the genus *Cooksonia*.
- The flora-bearing beds represent a marine, near-shore environment, and this is typical for other *Cooksonia* assemblages of Late Silurian age.
- Most probably, the plant remains come from islands which surrounded the sedimentary basin of the Holy Cross Mts. from its south-western margin in the Late Silurian times. Further studies should give a better understanding of the Silurian palaeogeography of Europe, and provide a better explanation of the relationships between Silurian land plants coming from isolated localities.

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