A plant-root system in the Lower Devonian of the Holy Cross Mountains, Poland

Piotr Szrek[a], Sylwester Salwa[a] and Grzegorz Niedźwiedzki[b]

[a] Polish Geological Institute – National Research Institute, 4 Rakowiecka Street, 00-975, Warszawa, Poland; piotr.szrek@pgi.gov.pl
[b] Department of Organismal Biology, Evolutionary Biology Centre, Uppsala University, Norbyvägen 18A, 752 36 Uppsala, Sweden

Received 16 July 2014, accepted 15 October 2014

Abstract. The depositional environment of the Lower Devonian of the Holy Cross Mountains has only been studied and interpreted in part, particularly for the lower portion of the profile. Recent fieldwork findings suggest a considerable change with regard to earlier hypotheses. Apart from the sedimentological observations that indicate marginal marine and very shallow-water conditions, horizons with plant-root traces and layers interpreted as palaeosols showing different stages of pedogenesis have been documented. The presence of palaeosols in some areas of the Holy Cross Mountains is the first direct evidence for the existence of terrestrial conditions during the Lower Devonian in this area. This plant-root system is one of the oldest fossil records ever described globally.

Key words: Lower Devonian, vascular plants, roots, Holy Cross Mountains, Poland.

INTRODUCTION

The Holy Cross Mountains are the only place in Poland where almost the entire sequence of Palaeozoic strata accessible for investigation is exposed. During the Early Devonian, the Holy Cross Mountains area was positioned at the southern shelf of Laurussia. Palaeontological data for this time in the Holy Cross Mountains are mainly represented by the body fossils and ichnofossils of invertebrates (Szulczewski & Porębski 2008), as well as vertebrates (e.g., Kulczycki 1960; Tarlo 1964; Szrek et al. 2014). Rare references to plant remains have been made by a few authors (e.g., Czarnocki 1936; Kowalczewski 1971; Tarnowska 1976; field observations of the so-called rests of plants) and miospores have been identified during stratigraphic investigations (Fijałkowska-Mader & Malec 2011). In this study we present the first description of vascular plant roots discovered within the siliciclastic deposits, which suggest the occurrence of terrestrial conditions during the Early Devonian.

GEOLOGICAL SETTING

The studied sediments belong to the Haliszka Formation, an informal unit distinguished by Tarnowska (1976). The age of the analysed section within the Haliszka Formation was determined based on miospores and correlation with other sections in the locality studied as upper Pragian–lower Emsian (*Verrucosisporites polygonalis–Diabolisporites wetteldorfensis* zones; Turnau & Tarnowska 1997; Fijałkowska-Mader & Malec 2011). In fact, many authors have suggested that the siliciclastic deposits partly represent the Old Red continental sediments, however, to date no accurate evidence supporting a terrestrial origin of the Lower Devonian deposits has been put forward or suggested.

MATERIAL AND METHODS

During the fieldwork conducted in 2013 we investigated a poorly known site near Kostomłoty Village in the northeastern part of the Kielce region in the Holy Cross Mountains (Fig. 1A). This locality is a natural exposure formed by a linear group of rocks, showing a profile of about 10 m in thickness (Fig. 1B). This succession contains several thick, fine-grained sandstone beds including erosional channels with conglomerate infillings (Fig. 1B). There are also several erosional surfaces marked by an iron association coatings in the profile.

The specimens figured are housed in the collection of the Geological Museum of the Polish Geological Institute – National Research Institute, Warszawa (collection Muz. PGI 1755.II).

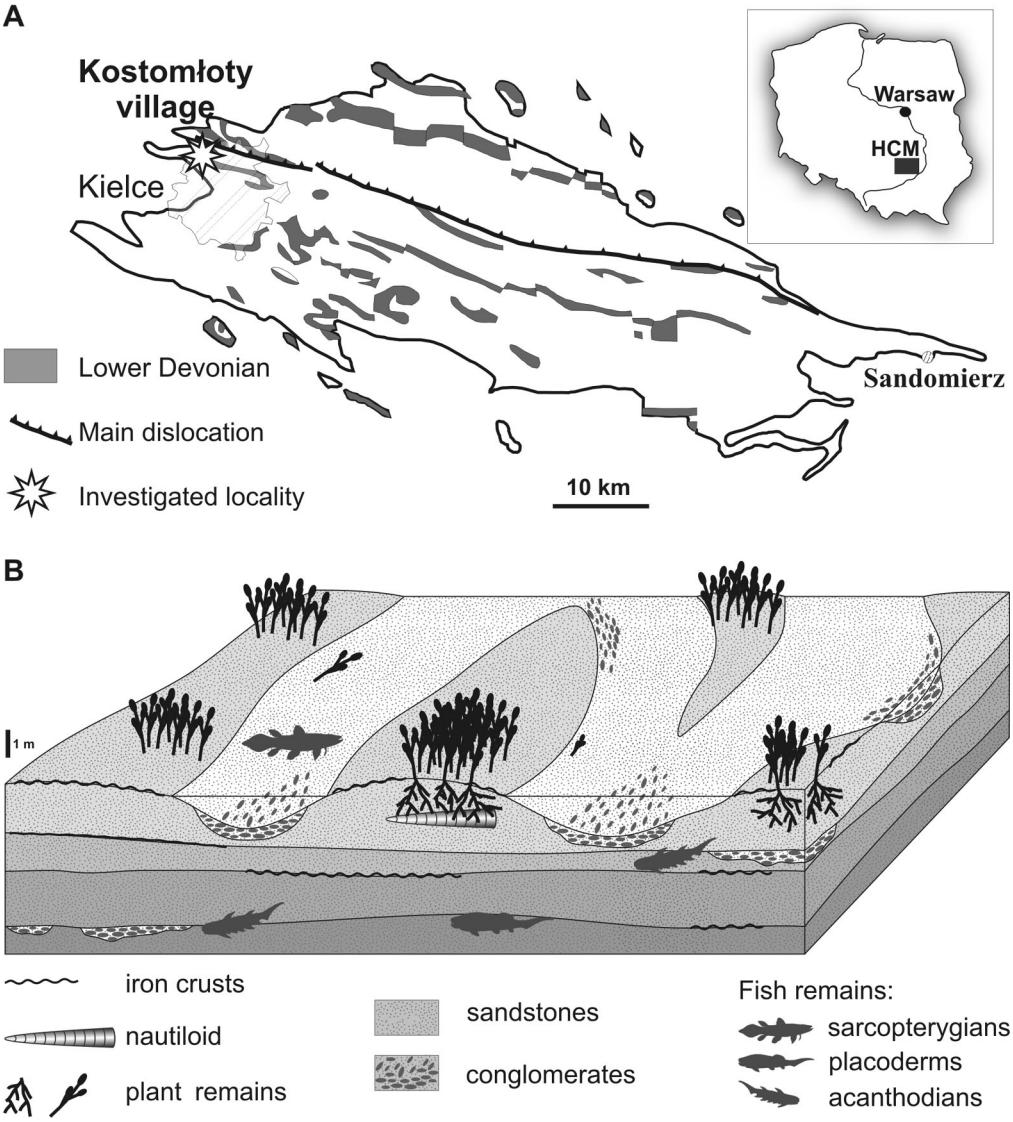

Fig. 1. A, location of Kostomłoty in the Holy Cross Mountains (HCM), Central Poland (after Kowalczewski 1971, fig. 1 – modified); **B**, block diagram showing the investigated profile near Kostomłoty.

DESCRIPTION

In the upper part of the profile we found exclusively well-preserved vascular plant-root traces (Fig. 2A–E). They are preserved as empty spaces, left after the removal of plant-root tissues. The root forms are quite diverse, ranging from straight to twisting and nearly vertical in most cases, but they also penetrate the rock in a horizontal or nearly horizontal direction. They are oval in the transversal section. Some individuals attain 20 mm (Fig. 2A) in diameter but usually they do not exceed 10 mm (Fig. B–D). The axial length varies from a few centimetres to 50 cm. The entire root system is about 1 m long and is characterized by horse tail-like parts. Almost all the roots are marked with iron association crusts (Fig. 2A–E) and occur in extremely high density (Fig. 2B). Some of the roots have overgrown the others, indicating a multiseasonal growth (Fig. 2B, D). They are definitely distinguished from animal traces: the diameter monitored along particular axes is changeable and secondary branches are usually smaller in diameter than their primates.

The same horizon contains other fossil remains that belong to vertebrates. They are represented by unde-

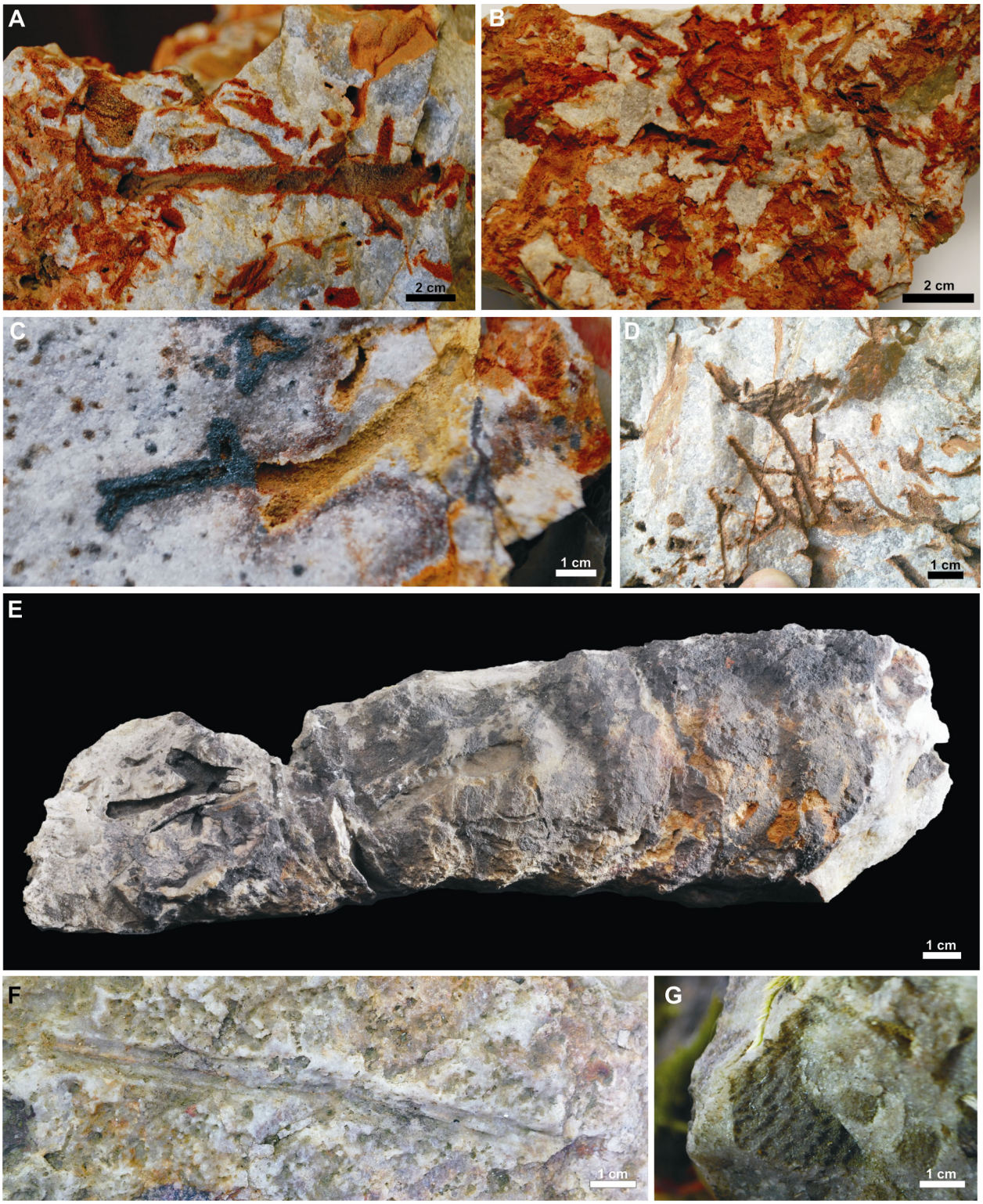

Fig. 2. Fossil remains collected in the locality. **A**, part of a thick root specimen (collection No. Muz. PGI 1755.II.220); **B**, **C**, close up of some small individuals of roots (collection No. Muz. PGI 1755.II.221); **D**, an example of roots crossing each other (collection No. Muz. PGI 1755.II.222); **E**, nautiloid shell covered by roots (collection No. Muz. PGI 1755.II.223); **F**, acanthodian fin spine (specimen in the field); **G**, fragment of placoderm plate (specimen in the field).

termined placoderms, acanthodians and sarcopterygians (Fig. 2F, G). Those remains are very rare and poorly preserved as natural moulds like root traces. A very peculiar specimen of a nautiloid phragmocone was found close to the root-bearing surface (Figs 1B, 2E). It is covered by root traces and was subjected to pedogenic conditions, because some of the roots overgrow the shell which is covered by an iron crust. Similar phenomena were described by Retallack et al. (2009).

Root traces from the Holy Cross Mountains are larger and more complex than previously postulated for land vascular plants in Early Devonian time (Kenrick & Crane 1997). They correspond to similar occurrences of land vascular plants from Quebec described by Elick et al. (1998) but have more diversified architecture and larger dimensions. They are also larger than other equivalents of the Lower Devonian in age occurrences, known from the literature (see Elick et al. 1998; Raven & Edwards 2001; Hao et al. 2010). Their origin characters indicate a multiseasonal vegetation that must have occurred on elevated marginal marine sediments. To date there is no evidence regarding the size of the aerial parts of these plants but based on the proportions (root/shoot ratio; Mokany et al. 2006), it is likely that they reached more than 1 m in height.

CONCLUSIONS

The described plant-root system is the first direct evidence that some areas of the Holy Cross Mountains were controlled by terrestrial conditions during the Early Devonian. The plant roots analysed herein also constitute the oldest evidence of the existence of large roots ever described. This also casts a new light on the terrestrialization processes at the beginning of the Devonian period (Retallack 2011) and makes a new contribution to the general knowledge in this field. Further studies will be conducted with regard to the precise dating of these deposits based on zircon, sedimentological analysis and palaeobiological studies of the rich invertebrate trace fossils and vertebrate remains from plant-root-bearing deposits.

Acknowledgements. We would like to thank Oive Tinn (Department of Geology, University of Tartu) and Kathleen Histon (Varese, Italy) for their valuable reviews. Polish Geological Institute – National Research Institute funded our fieldworks (internal funds). This paper is a contribution to IGCP Project 591.

REFERENCES

Czarnocki, J. 1936. Review of stratigraphy and paleogeography of the Lower Devonian of the Holy Cross Mountains. *Sprawozdania Państwowego Instytutu Geologicznego*, **7**, 129–200 [in Polish and German].

Elick, J. M., Driese, S. G. & Mora, C. I. 1998. Very large plant and root traces from the Early to Middle Devonian: implications for early terrestrial ecosystems and atmospheric p(CO_2). *Geology*, **26**, 143–146.

Fijałkowska-Mader, A. & Malec, J. 2011. Biostratigraphy of the Emsian to Eifelian in the Holy Cross Mountains (Poland). *Geological Quarterly*, **55**, 109–138.

Hao, S., Xue, J., Guo, D. & Wang, D. 2010. Earliest rooting system and root : shoot ratio from a new *Zosterophyllum* plant. *New Phytologist*, **185**, 217–225.

Kenrick, K. & Crane, P. R. 1997. The origin and early evolution of land plants. *Nature*, **389**, 33–39.

Kowalczewski, Z. 1971. Main geological problems in the Świętokrzyskie Mts. *Kwartalnik Geologiczny*, **15**, 263–283 [in Polish, with English summary].

Kulczycki, J. 1960. *Porolepis* (Crossopterygii) from the Lower Devonian of the Holy Cross Mountains. *Acta Palaeontologica Polonica*, **5**, 65–103.

Mokany, K., Raison, R. J. & Prokushkin, A. S. 2006. Critical analysis of root : shoot ratios in terrestrial biomes. *Global Change Biology*, **12**, 84–96.

Raven, J. A. & Edwards, D. 2001. Roots: evolutionary origins and biogeochemical significance. *Journal of Experimental Botany*, **52**, 381–401.

Retallack, G. J. 2011. Woodland hypothesis for Devonian evolution of tetrapods. *Journal of Geology*, **119**, 235–258.

Retallack, G. J., Hunt, R. R. & White, T. E. 2009. Devonian palaeosols and tetrapod habitats in Pennsylvania. *Journal of the Geological Society, London*, **166**, 1143–1156.

Szrek, P., Niedźwiedzki, G. & Dec, M. 2014. Storm origin of bone-bearing beds in the Lower Devonian placoderm sandstone from Podłazie Hill (Holy Cross Mountains, central Poland). *Geological Quarterly*, **58**, 795–806.

Szulczewski, M. & Porębski, S. 2008. Stop 1–Bukowa Góra, Lower Devonian. In *Ichnological Sites of Poland. The Holy Cross Mountains and the Carpathian Flysch. The Second International Congress on Ichnology. Cracow, Poland, August 2–September 8, 2008. The Pre-Congress and Post-Congress Field Trip Guidebook* (Pieńkowski, G. & Uchman, A., eds), pp. 18–37. Warszawa.

Tarlo, L. B. 1964. Psammosteiformes (Agnatha) – a review with descriptions of new material from the Lower Devonian of Poland. I – general part. *Palaeontologia Polonica*, **13**, 1–135.

Tarnowska, M. 1976. Lithological correlation of the Lower Devonian in the eastern part of the Holy Cross Mountains. *Biuletyn Instytutu Geologicznego*, **296**, 75–115 [in Polish, with English summary].

Turnau, E. & Tarnowska, M. 1997. Obecność zigenu (pragu) i emsu koło Kielc [Presence of the Siegenian (Pragian) and Emsian near Kielce]. *Posiedzenia Naukowe Państwowego Instytutu Geologicznego*, **53**, 154–155 [in Polish].