In situ preserved equisetophyte stems in the Upper Bajocian Parkinsoni Zone (Middle Jurassic) of the Northern Caucasus (Russia)

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Serge V. Naugolnykh and Vasily V. Mitta

Abstract

This paper focuses on the first record of equisetophyte stems preserved *in situ* in the dark siltstones of the Djangura Formation of the Late Bajocian (Middle Jurassic) age in the Bolshoi Zelenchuk River Basin (Zelenchuk district of the Karachaevo-Cherkessk Republic, Northern Caucasus, Russia). The stems are long and narrow, with long internodes, vertically orientated in growth upright position. The outer surface of the stems bears thin, prolonged ribs. There are well-formed diaphragms at the stem nodes. The diaphragms are covered with fine radial striations. The stems possess a central internal cavity of subcylindrical shape. The sedimentary conditions of forming the layer with equisetophyte stems can be interpreted as tidal plain or littoral.

Keywords: Middle Jurassic, equisetophytes, Equisetaceae, *Neocalamites*, *Equisetites*, Northern Caucasus, Upper Bajocian, palaeoecology.

1. Introduction

The palaeoecological significance of fossil equisetophytes is related to their stable environmental preferences, allowing the use of these plants as markers of certain palaeoenvironments. Most of the ancient and recent equisetophytes were and still are inhabitants of near-shore humid environments. Moreover, many equisetophytes can be regarded as pioneering plants which are adapted to fast colonization of clastic substrates under stressed ecological conditions. This is why the equisetophytes s. l. can be considered as a useful tool for general palaeoecological reconstructions, especially if these plants are preserved *in situ* (Taylor et al. 2009; Thomas 2014).

This paper is devoted to the first record of equisetophytes preserved *in situ* in the Middle Jurassic Djangura Formation (Besnosov 1967) of the Northern Caucasus. The exact stratigraphic position of this find is based on the rich marine fauna (including those found at the same level). This observation is helpful for a palaeogeographic reconstruction of that region for the Late Bajocian.

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2. Material

The material described was collected by one of the present authors (VM) during the field seasons in 2015–2016, which were aimed for studying of the Upper Member of the Djangura Formation (Besnosov 1967) outcropping in the Kuban River Basin (Zelenchuk District of the Karachaevo-Cherkessk Republic of Russia, Northern Caucasus; Fig. 1). This member is represented by clastic terrigeneous deposits, e.g., clays, siltstones, alevrolites, with siderite concretions forming layer-like aggregations. All layers strike at 5–7º towards North to North-East. The general sedimentary environment was related to a deep to shallow shelf with low hydrodynamic conditions (Besnosov & Mitta 1993).

The specimens described and discussed in the present paper come from the locality No. 25. The section is disposed on the left bank of the Kyafar River, 1.8 km upstream from its mouth (Figs. 1, 2). The length of the section is ca. 150 m. The dense grey and dark-grey clays and siltstones with siderite concretions, 5–7 cm in diameter, containing ammonites: *Parkinsonia* ex gr. *djanelidzei* Kakhadze, a single *Rarecostites donezianus* (Borissjak), and numerous *Dinolytoceras zhivagoi* Besnosov. The ammonites most commonly are represented by fragmentary preserved casts. Small belemnite rostra (*Megateuthis* sp.) and rare bivalves (*Entolium* sp.) were also found in this section. The subvertically preserved stems of equisetophytes have been recorded in the upper part of the section, one meter above the level with ammonites. The general thickness of the deposits outcropping in the section is more than five meters.

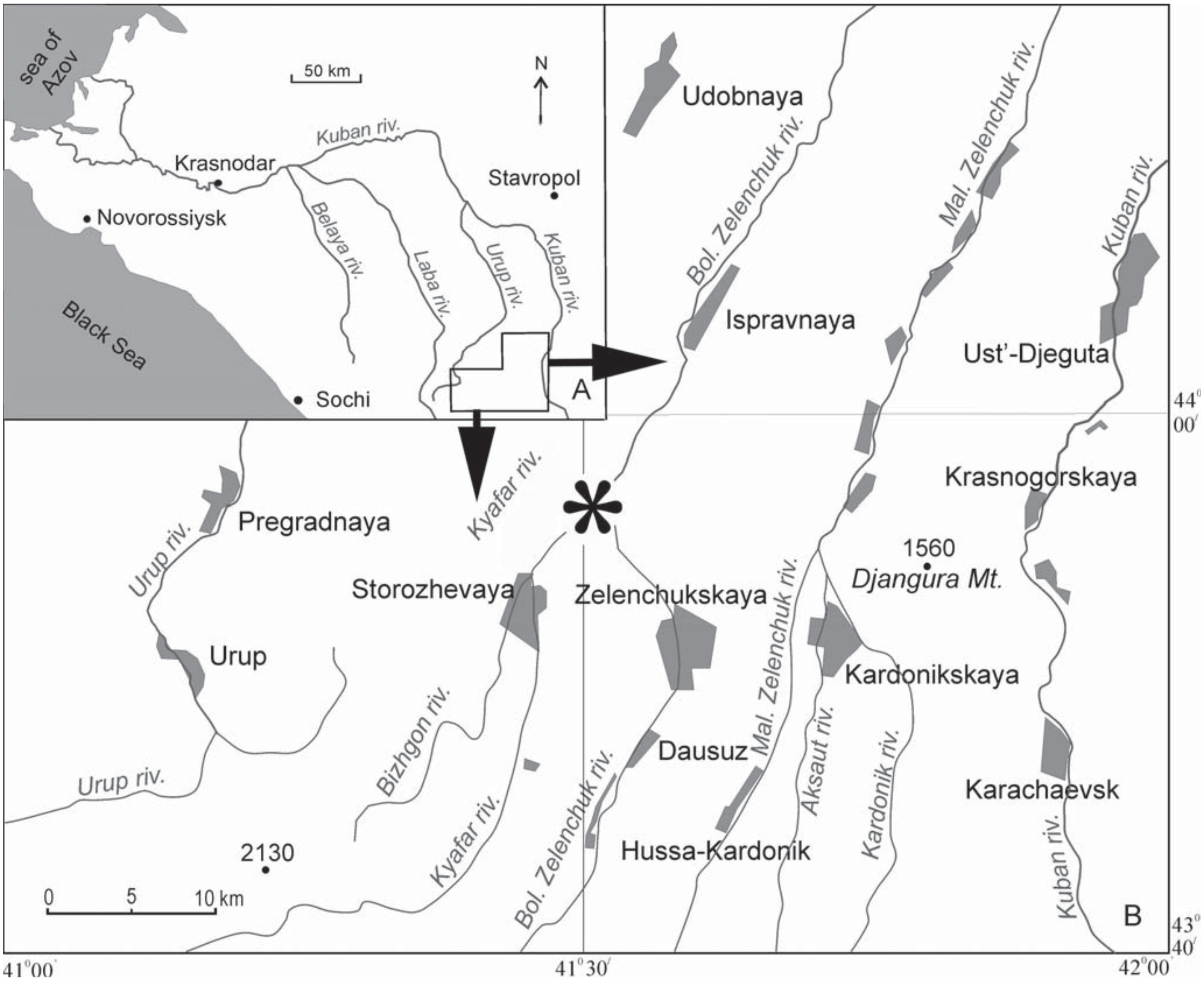

Fig. 1. Geographical position of locality No. 25 (marked by an asterisk). **A:** General map; **B:** detailed map.

Without any doubt the clays with the equisetophyte macrofossils can be assigned to the Parkinsonia parkinsoni Chronozone of the Late Bajocian. Older deposits of Bajocian age crop out along both banks of the Kyafar River upstream of the locality No. 25. The equivalents of the standard subdivisions of the Upper Substage, e.g. the lower subzone of the Parkinsonia parkinsoni Zone and the Garantiana garantiana and Strenoceras niortense zones occur upstream, up to the Storozhevaya village (Mitta & Sherstyukov 2014; Mitta & Schweigert 2016). The Lower Bajocian outcrops upstream of the Storozhevaya village on the Kyafar River banks and its incomings just above the water level. The Lower Bathonian rocks, which are time-equivalent to the Zigzagiceras zigzag Chronozone, can be observed downstream of the Kyafar River mouth along the banks of the Bolshoy Zelenchuk River (Mitta 2015).

The deposits observed in the section No. 25 belong to the middle part of the Parkinsoni Zone and are described as the Beds with *Parkinsonia djanelidzei* (Mitta et al. 2017, in press), probably corresponding to the lowest part the Truellei Subzone of the Standard Time Scale).

The material studied is stored in the Geological Institute of Russian Academy of Sciences (GIN RAS), Moscow, under the collection numbers 4914/29–4914/33.

3. Observations

The material includes two well-preserved stems (Figs. 3A–C, 4A, B, E), both with basal parts, and seven fragments of stems preserved in different extent. The best preserved stem fragment is 94 mm long and 17 mm wide.

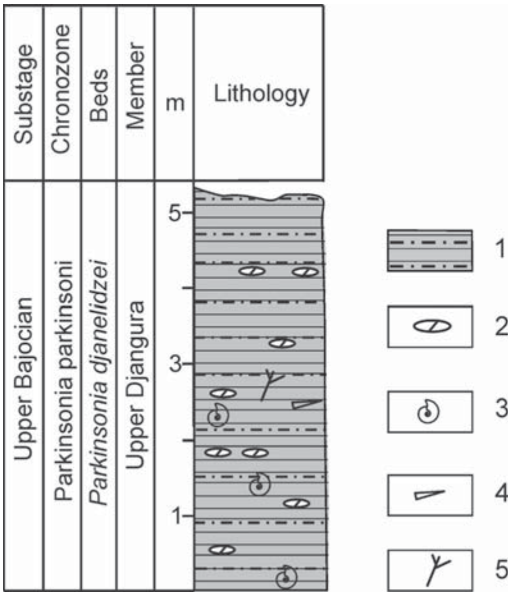

Fig. 2. Section of locality No. 25. Middle Jurassic, Upper Bajocian; the middle part of the Parkinsonia parkinsoni Zone, Beds with *Parkinsonia djanelidzei*. Karachaevo-Cherkessk Republic, Russia; Zelenchuk District, Kyafar River. Legend: 1 – clays and siltstones; 2 – concretions; 3 – ammonite shells; 4 – belemnite rostra; 5 – equisetophyte stems, preserved *in situ*.

The second well-preserved fragment is 87 mm long and 11 to 20 mm wide. The widest part of the stem occurs towards its upper (distal) part, so the stem width is gradually decreasing towards the stem base. Judging from the general shape of the stem fragments we can suppose that the whole length of the plant was not less than 300 mm.

The shape of the stems is more or less cylindrical, with conical to rounded basal parts (Fig. 4D). The superficial surface of the stems is rather smooth, but actually it bears very fine prolonged ribs (Fig. 4D, E). The nodes are very indistinct. Only one stem fragment shows two nodes and one complete internode (specimen GIN 4914/30). The length of the internode is 89 mm, and the width of the prolonged ribs is 0.3 mm. There is one unclear evidence (weakly preserved lateral branch scar) that the main vertical stem had lateral branches of smaller size, which were attached to the node line along the main axis.

Two fragments of stem, which are broken in nodes, clearly show nodal diaphragms typical of all representatives of equisetophytes. The diaphragms bear a fine radial striation (Fig. 4A, B). All the specimens in the collection have a distinct inner cavity, cylindrical in shape (Fig. 4C, E), which is also characteristic for all representatives of equisetophytes. The cavity is filled with secondary minerals (mostly calcite).

The field observations (Fig. 3C) showed that the stems were attached to subhorizontal stolons or rhizomes, but these rhizomes are represented by relatively short fragments. This can be explained by the horizontal rhizomes as results of a fragmentation process, which is typical of the vegetative reproduction mode of equisetophytes. One lateral branch, which has been deformed, is observed in the basal part of the stem (Fig. 3A, B).

Although the features of the fossils are relatively poor, the general habit and the morphological details allow us to suggest that these remains belonged to an equisetophyte closely related to the genera *Equisetites* Sternberg or *Neocalamites* Halle, and on this basis the Kyafar plants can be preliminarily attributed to the family Equisetaceae.

Concerning the *in situ* preservation of the stems and rhizomes of the Kyafar equisetophytes, it is obvious that these plants started their life on the bottom of a very shallow basin near zero depth or on the littoral, but after that they were submerged and buried by slow but permanent sedimentation of clastic material (Fig. 5, S).

4. Discussion

Stems of equisetophytes preserved *in situ* in palaeosoils or FPS-profiles (abbreviation made after "fossil-palaeo-soil" term) as well as in the more or less common sediments, are recorded from different deposits, mostly representing near-shore or shallow-water environments (e.g., Watson & Batten 1990; Kelber & Van Konijnenburg-Van Cittert 1998; Tverdokhlebov 2004; Appleton et al. 2011; Thomas 2014).

A specific feature of the Kyafar equisetophytes is their very long and relatively narrow internode, but this morphological character is also reported for some other equisetophytes beginning from the Permian up to the Recent. For instance, similar exceptionally long internodes are typical of *Neocalamites tubulatus* Naugolnykh from the Upper Permian of the northern part of Russia (Naugolnykh 2009, figs. 3, 5). The stems of the Kyafar equisetophytes have many features in common with some species of the genus *Equisetites* Sternberg (sensu lato) from the Middle Jurassic of Turkmenistan. For example, the Kyafar equisetophytes are similar to *Equisetites ketovae* Burakova in having very long internodes and a smooth to finely ribbed surface of the stems (Burakova 1960, pl. 14, fig. 1), and they are especially similar to underground organs (stolones or rhizomes) of this species (Burakova 1960, fig. 3), which were misinterpreted by that author as "roots" (Burakova 1960). Very fine ribs as well as long internodes and the shape of the node diaphragms of the Kyafar equisetophytes are similar to the Middle Triassic equisetophyte described as *Zonulamites nymboidensis* Holmes from Australia (Holmes 2000; especially specimens illustrated on

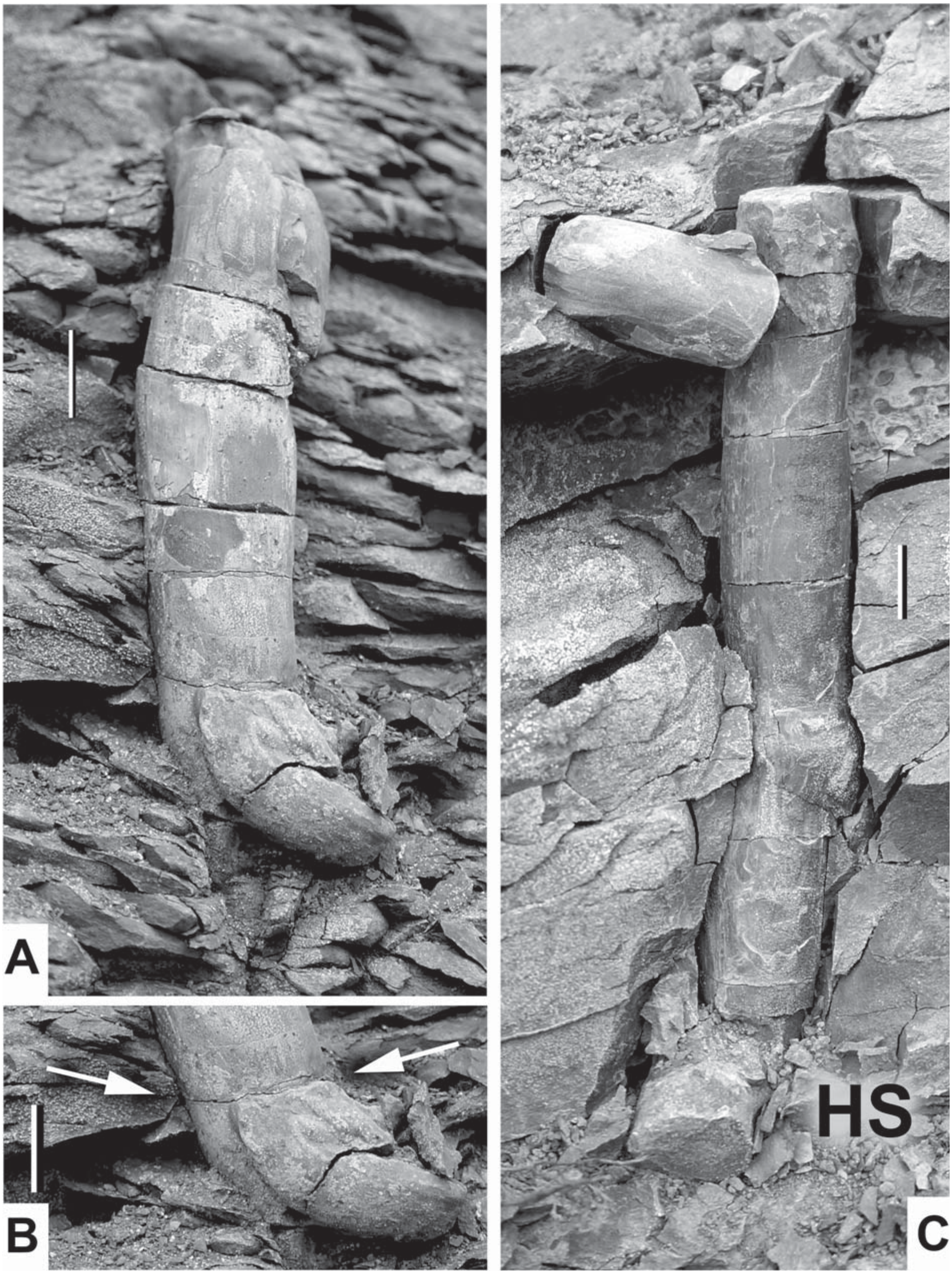

Fig. 3. A–C: The equisetophyte stems preserved *in situ*, field photographs. Scale bars equal 10 mm. Abbreviation: HS – horizontal stolon (rhizome). The node is marked by arrows in Fig. 3B.

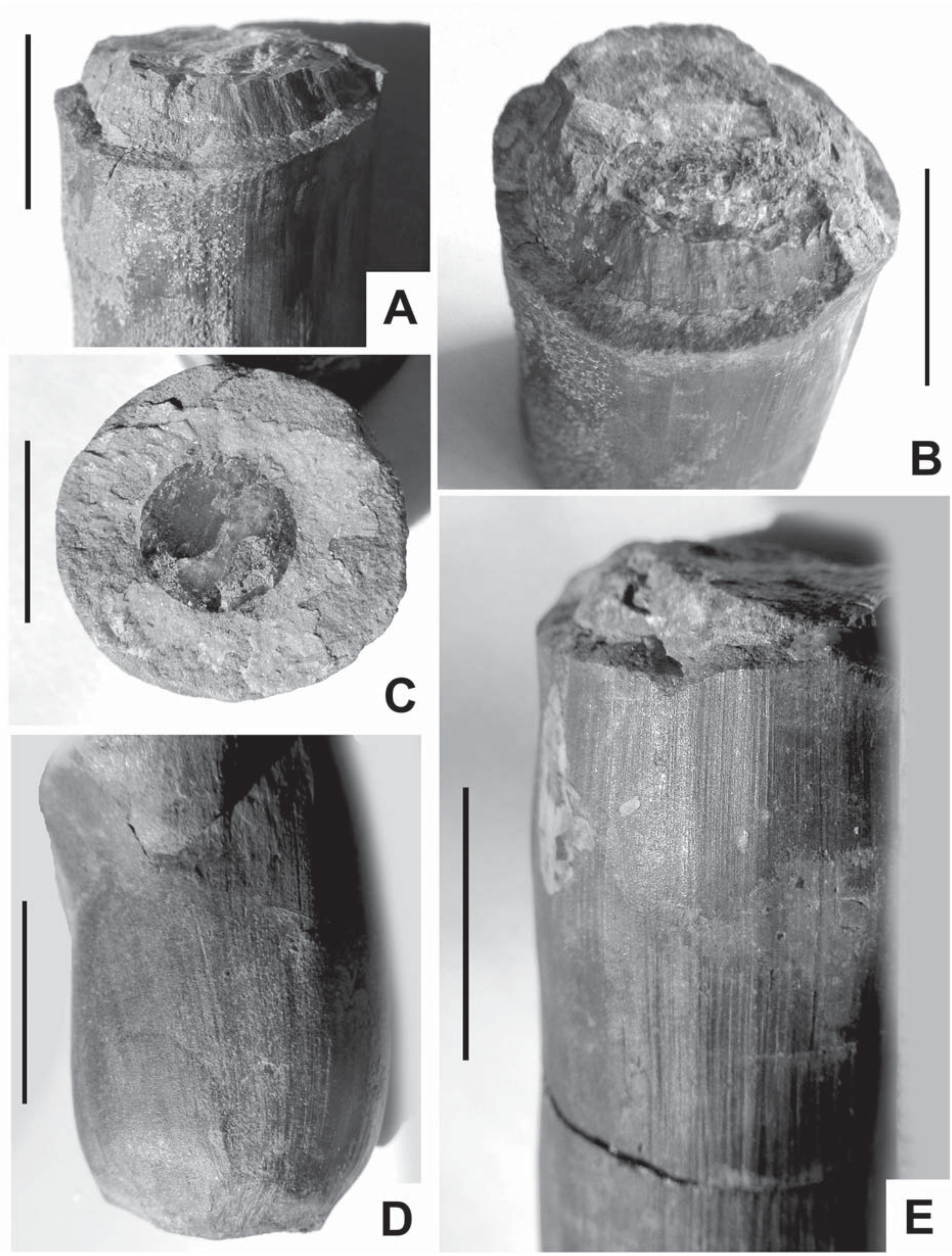

Fig. 4. The equisetophyte stems preserved *in situ*. **A, B:** Nodal part with the well-discernible diaphragm, specimen GIN RAS No. 4914/30; **C:** cross section with the distinct central cavity filled with secondary minerals, specimen GIN RAS No. 4914/33; **D:** basal part of rounded shape, specimen GIN RAS No. 4914/32; **E:** longitudinal ribs covering outer surface of the stem, specimen GIN RAS No. 4914/30. Scale bars equal 10 mm.

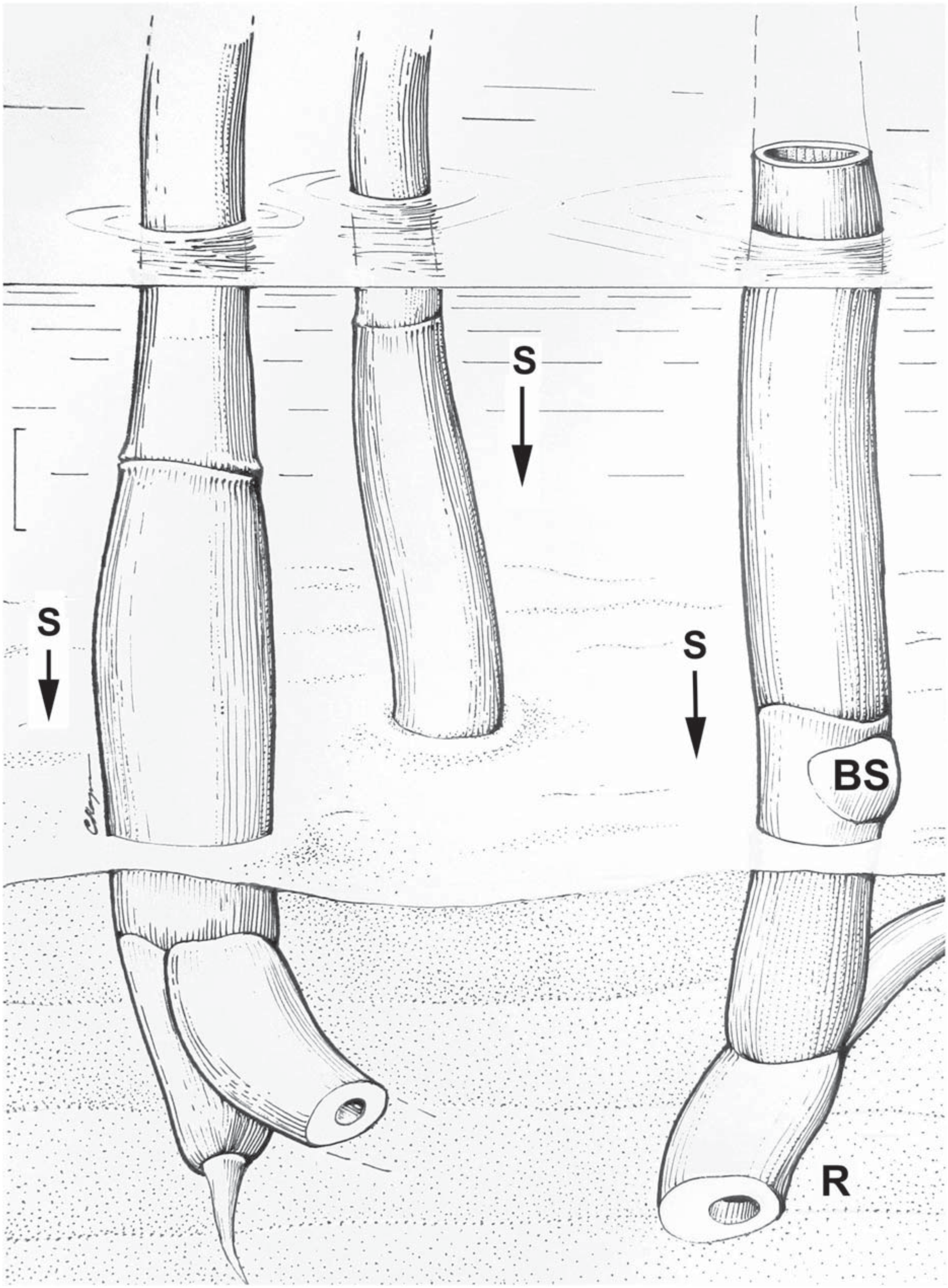

Fig. 5. Morphological interpretation of the fossils studied (see Figs. 3, 4) and the environmental conditions of growing of the Kyafar equisetophytes. Scale bar equals 10 mm. Abbreviations: BS – branch scar; R – rhizome; S – direction of sedimentation.

his figure 6A, C, E, F), which, according to our viewpoint, can be assigned to the genus *Equisetites* s. l. as well.

The evolutionary history of the equisetophytes s. str. (e.g., the family Equisetaceae) now can be traced back as deep as to the Carboniferous and Permian (DiMichele et al. 2005; Naugolnykh 2009; Yang et al. 2011; Singh et al. 2011). The direct phylogenetic predecessors of Equisetaceae are representatives of the family Tchernoviaceae, which is characteristic for the Carboniferous and Permian of Angaraland (Meyen 1971; Meyen & Menshikova 1983; Naugolnykh 2002, 2004). Equisetophytes s. l. closely related to Tchernoviaceae are also recorded from the Permian of the Southern Hemisphere, e.g., Gondwanaland (Holmes 1996; Duran et al. 1997; Escapa & Cuneo 2005; Cuneo & Escapa 2006).

During their evolution equisetophytes show a strict adaptation for growing in near-shore environments (Taylor et al. 2009). The new find of *in situ* stems of equisetophytes in the Middle Jurassic of the Kyafar locality is in good agreement with that tendency and strongly supports the possibility of using equisetophytes as important ecological markers of wet environments.

In evolutionary terms, the genus *Equisetum* was in stasis at least from the Paleocene (McIver & Basinger 1989), or even from earlier times (Gould 1968; Watson & Batten 1990; Markovich 1993). Most probably this stasis was corresponding with constant ecological preferences of the equisetophytes as more or less permanent hydro- or hygrophils.

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