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Early Jurassic flora from South Primorye, Far East, Russia

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Abstract

A unique Early Jurassic flora from the Schitukhe Formation of South Primorye, Russia is further studied, with newly collected materials. The flora is composed of over 50 taxa. It is dominated by ferns (Dipteridaceae, Marattiaceae, etc.), cycads (*Pterophyllum*, *Nilssonia*, *Ctenis*, *Taeniopteris*, etc.), conifers (*Cycadocarpidium*, *Podozamites*, etc.), and other seasonally deciduous gymnosperms (Czekanowskiales, Ginkgoales, etc.), showing a special flora living in an ecotone zone between the Palaeofloristic realms of Siberian Flora and Euro-Sinian Flora in the East Asia during the early Early Jurassic. The flora is compared with its coeval floras from China and Japan. A new species *Cycadocarpidium pacificum* n. sp. is reported. The age of the Schitukhe flora is constrained by the marine mollusca fossils yielded in the sandwich marine beds of the Schitukhe Formation, as the Hettangian–Sinemurian.

Keywords: Early Jurassic; Flora; Schitukhe Formation; Ecotone zone; South Primorye (Russia)

1. Introduction

The fossil plants from the Schitukhe Formation (i.e., Schitukhe flora) in the Petrovka (formerly Schitukhe) and Litovka (formerly Sibichuan) river basins of southeastern Primorye, Far East Russia were first collected in the 20th century by N.A. Belyavsky, V.D. Prynada, and B.I. Vassilev (Konovalova and Markevich, 2004), and studied primarily by S.A. Shorokhova, V.A. Krassilov, and later by E.B. Volynets, S.A. Shorokhova, and E.N. Salyukova (Krassilov and Shorokhova, 1973; Volynets, 2008; Volynets and Shorokhova, 2010; Salyukova et al., 2013).

In some localities the phytofossils were found together with brackish water bivalves among which *Anodontophora*, *Modiolus*, *Meleagrinella*, *Cardinia*, *Myophoria*, and *Palaeopharus* indicate the Early Liassic age (by L.D. Kiparisova's opinion), and the ammonites *Franciceras* and *Caloceras* indicating the Hettangian–early Sinemurian age (Konovalova and Markevich, 2004).

Krassilov and Shorokhova (1973) revealed the main taxa of the flora from the Petrovka River Basin including *Marattiopsis hoerensis* (Shimper) Thomas, *Phlebopteris angustiloba* (Presl) Hirmer et Hoerhammer, *Nilssonia acuminata* (Presl) Goeppert, *Pterophyllum* cf. *subaequale* Hartz, and considered the age of the flora as the Early Liassic. The fossil-bearing strata mentioned above were outlined by B.I. Vassilev in 1961 as an independent stratigraphic unit, Schitukhe Formation, after the name of the river (Konovalova and Markevich, 2004).

This paper is aiming at the further and detailed study of the Schitukhe flora with its further collections and updated analysis, as well the comparisons with its coeval floras from the adjacent regions, particularly China and Japan.

2. Materials

The studied Early Jurassic plants of the Schitukhe Formation in southeastern Primorye were collected through the years by Shorokhova (1959–1989) and Krassilov (1968–1969) in the Petrovka and Litovka river basins (Fig. 1). They are represented by the impression of stems, leaves, leafy shoots, cones, cone

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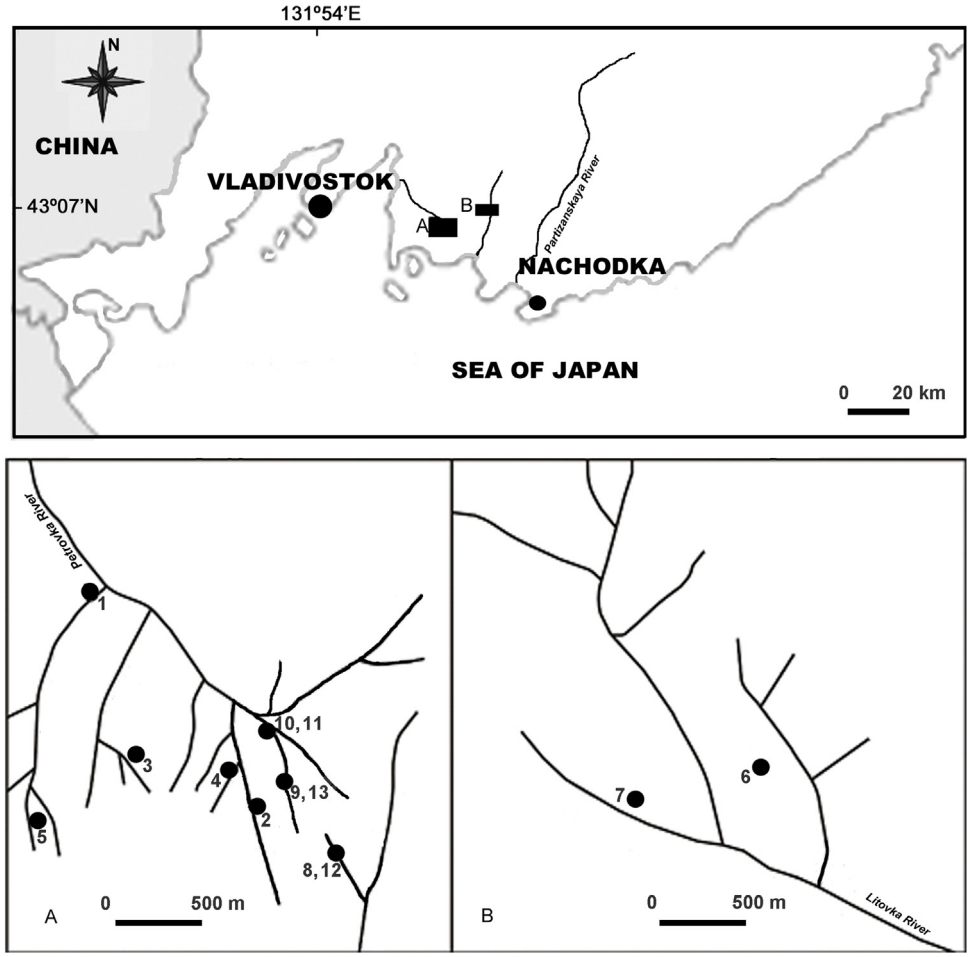

Fig. 1. Localities of Early Jurassic plants on South Primorye; A – the Petrovka River Basin; B – the Litovka River Basin.

scales, and separated strobili. These materials have acceptable consistency, and are photographed by the authors with Canon PowerShot G-14 and Canon PowerShot S120, as well as with the help of Digital USB Microscope OITEZ DP-M16. All the fossils are housed in the Laboratory of Palaeobotany of Federal Scientific Center of Biodiversity of the East Asian Terrestrial Biota, Far East Branch of the Russian Academy of Sciences (FSC Biodiversity FEB RAS), under the number Sh–5.

The plant fossil-bearing Schitukhe Formation is composed mainly of siltstones, fine and medium-grained sandstones, and coal siltstones, with rare layers of conglomerates. Its thickness is 300–330 m. The formation unconformably overlying the siltstones of the Lower–Middle Triassic Shimeuza Bed that yields the Olenekian–Anisian bivalves and ammonites (Zakharov et al., 2005); and underlain in conformably by sandstone strata of conceivably the Pliensbachian–early Toarcian age (Konovalova and Markevich, 2004; Zakharov et al., 2009; Salyukova et al., 2013). The Schitukhe Formation is divided into two subformations. Most of the plant fossils and marine bivalve (*Modiolus* and *Cardinia*) and ammonoid fossils (*Franciceras* and *Caloceras*) were collected from the lower subformation (ca. 200–280 m thick). Fewer plants (including *Phlebopteris*, *Clathropteris*, with a few *Coniopteris*) of this flora were collected from the upper subformation (ca. 100–210 m thick) which is also sandwiched with marine beds yielding bivalve fossils represented by *Leda rostralis* Lamarck, showing the Early Jurassic age (Konovalova and Markevich, 2004; Salyukova et al., 2013).

3. Floral composition

The Schitukhe flora is composed of over 50 taxa, mainly as follows: Equisetales – *Neocalamites hoerensis* (Schimper) Halle, *Neocalamites* sp., *Equisetites muensteri* Sternberg, *Equisetites* sp.; ferns – *Marattiopsis hoerensis* (Schimper) Thomas, *Phlebopteris angustiloba* (Presl) Hirmer et Hoerhammer, *Clathropteris elegans* Oishi, *Dictyophyllum* sp., *Thaumatopteris elongata* Oishi, *Thaumatopteris* sp., *Hausmannia* sp., *Todites* sp., *Osmundopsis nipponica* Kimura et Tsujii, *Coniopteris* sp., *Cladophlebis scoresbiensis* Harris, *C.* ex gr. *denticulata* (Brongniart) Fontaine, *C.* ex gr. *haiburnensis* (Lindley et Hutton) Brongniart, *C. nebbensis* (Brongniart) Nathorst, *C. asiatica* Chow et Yeh, *Cladophlebis* spp.; Caytoniales – *Sagenopteris* cf. *undulata* Halle; Bennettitales – *Pterophyllum subaequale* Hartz emend. Pott et McLoughlin; Cycadales – *Ctenis sulcicaulis* (Phillips) Ward, *C. yamanarii* Kawasaki, *Ctenis* sp., *Nilssonia acuminata* (Presl) Goeppert, *N. spinosa* Krassilov; Cycadophytes uncertain in systematic position – *Taeniopteris lanceolata* Oishi, *Taeniopteris* sp.; Ginkgoales – *Ginkgoites* ex

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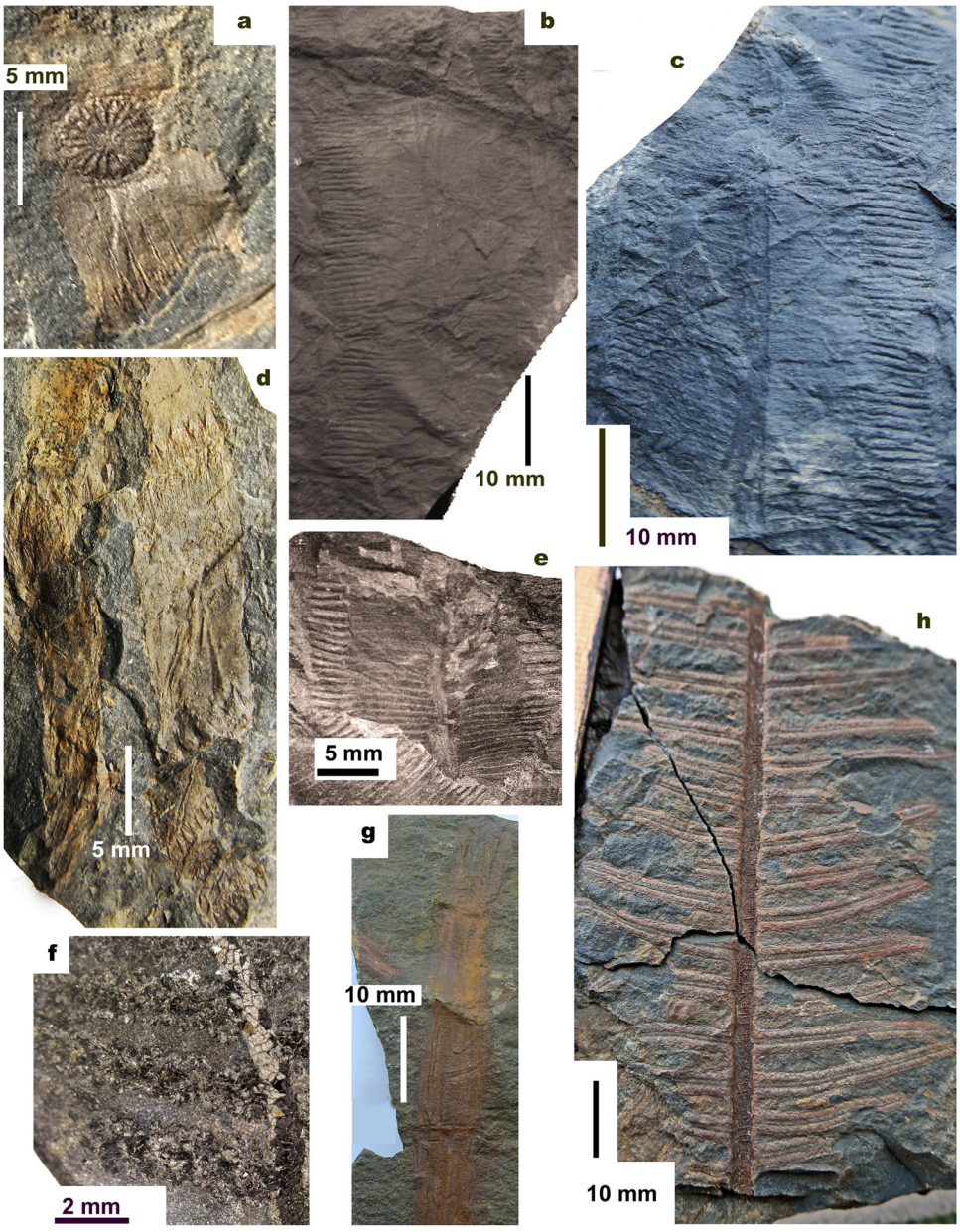

Fig. 2. Horsetails and ferns of the Schitukhe Floral Assemblage. (a) *Equisetites* sp., a fragment of slice through the nodal diaphragm and stem, Sh–5-3. (b, c, e) *Marattiopsis hoerensis* (Schimper) Thomas, fragments of linear leaves with typical venation, Sh–5-4, Sh–5-5, Sh–5-6. (d) *Equisetites muensterii* Sternberg, fragments of stems, bearing teeth-like leaves on node and private small diaphragms, Sh–5-8. (f) *Osmundopsis nipponica* Kimura et Tsujii, enlargement from Fig. 4a showing a fragment of fertile pinnules with the cluster of sporangia, Sh–5-8. (g) *Neocalamitaes* sp., stem with three nodes, Sh–5-9. (h) *Phlebopteris angustiloba* (Presl) Hirmer et Hoerhammer, a fragment of a large sterile frond with typical venation in pinnules, Sh–5-10.

gr. *muensterianus* (Presl) Krassilov et Schorchova, *Ginkgoites* spp.; Czekanowskiales – *Czekanowskia* ex gr. *rigida* Heer, *Phoenicopsis* ex gr. *angustifolia* Heer; Coniferales – *Cycadocarpidium pacificum* n. sp., *Cycadocarpidium* spp., *Podozamites latifolius* (Schenk) Kryshtofovich et Prynada, *P.* ex gr. *lanceolatus* (Lindley et Hutton) Schimper, *Podozamites schenkii* Heer, *Podozamites* spp., *Pityophyllum* ex gr. *nordenskioldii* Heer, *Elatocladus* spp.; and the taxa uncertain in systematic position – *Linguifolium* sp., *Carpolithes minor* Prynada, *Carpolithes* sp., and *Strobilites* sp. (Figs. 2–10).

The Equisetales *Equsetites muensteri* and *Neocalamites hoerensis* are typical for Late Triassic and Early Jurassic floras of Eurasia (Harris, 1926, 1937; Krassilov and Shorokhova, 1973; Li et al., 1988; Sun, 1993; Shorokhova et al., 2008, 2009; Sun et al., 2010).

Among the ferns, Marattiaceae *Marattiopsis hoerensis* is characteristic for the *Thaumatopteris* Zone of European Liassic flora (Harris, 1926, 1961), and its comparable *M. asiatica* Kawasaki occurs in the Early Jurassic of South Palaeofloristic Province in China (Li, 1995), as well as in Japan (Kimura and Tsujii, 1980b). The Osmundaceae *Osmundopsis nipponica* and *Todites* sp. are similar to the taxa described from Early Jurassic flora of Kuruma Group in Japan (Kimura and Tsujii, 1980b), as well as to *O. plectrophora* Harris from *Thaumatopteris* Zone

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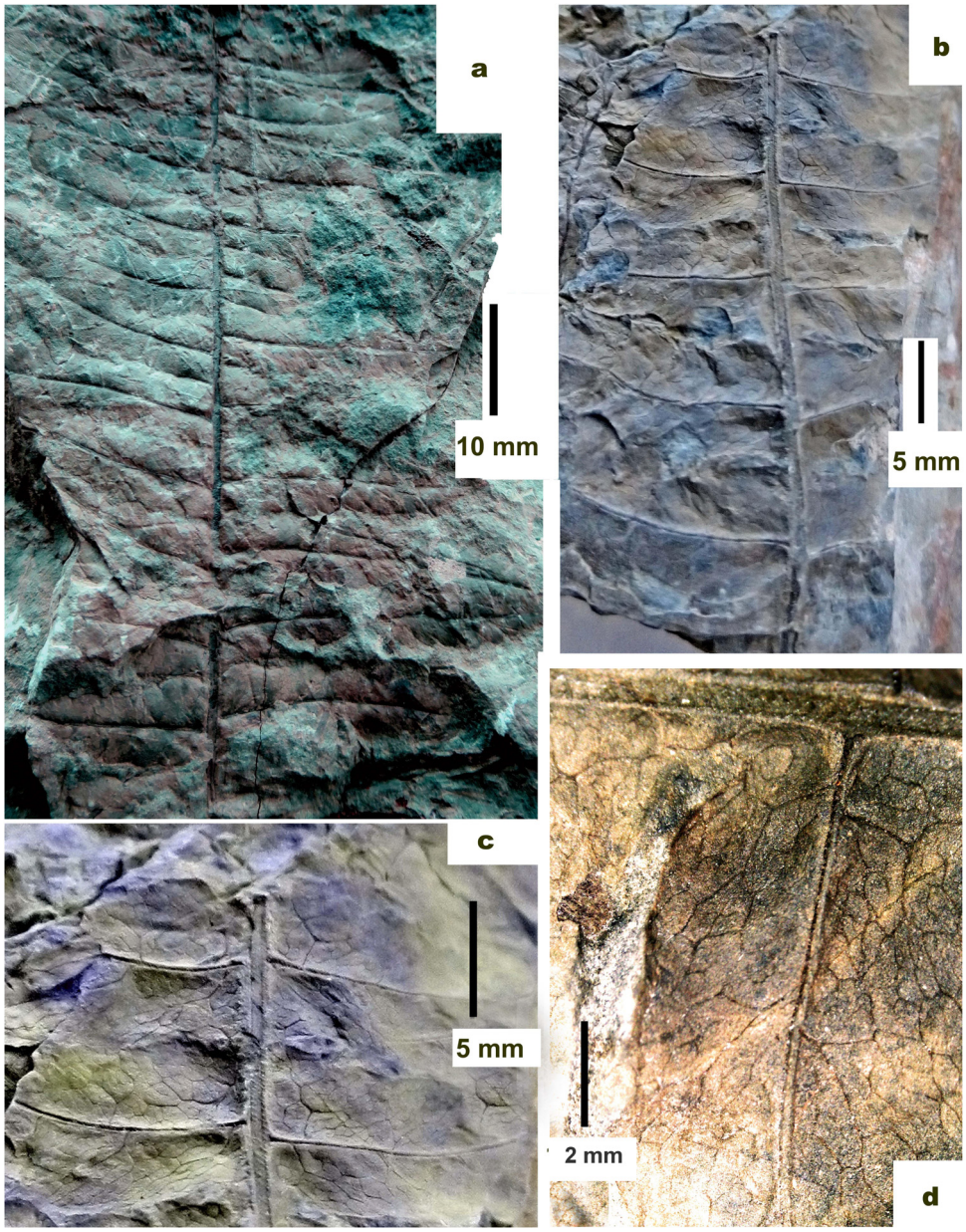

Fig. 3. *Thaumatopteris elongata* Oishi from Schitukhe Floral Assemblage. (a) Almost a whole, large, sterile segmented leaf, Sh–5-26. (b) Incomplete sterile segmented leaf, showing venation in it, Sh–5-27. (c) Enlargement from of the upper part of (b). (d) Segment from of the lower (left) part of (c), showing polygonal meshes in pinnules with entire margin.

of Greenland (Harris, 1937). The Matoniaceae representative, only *Phlebopteris angustiloba*, is characterestic in the *Thaumatopteris* Zone of Europe and Greenland (Harris, 1926). The Dipteridaceae is represented by *Clathropteris elegans*, *Dictyophyllum* sp., *Thaumatopteris elongata*, *Thaumatopteris* sp., and *Hausmannia* sp., among which *Clathropteris elegans* is rare in occurrence but was presented in Rhaetian–Liassic floras of Japan and China (Oishi, 1940; Li, 1995). *Dictyophyllum* and *Thaumatopteris* are sporadic in this flora, and the former is common in the Norian floras in Primorye of Russia and Northeast China (Sun, 1993; Shorokhova et al., 2008, 2009); while the latter is common for the Early Jurassic floras of Japan (Oishi, 1932; Kimura and Tsujii, 1980a, 1980b). Their rare presence is also reported in Early Jurassic Flora of the Northern and Southern palaeofloristic provinces of China (Sze, 1956; Chen et al., 1980; Zhou and Li, 1980; Zhou, 1983; Li, 1995; Deng et al., 2000). It should be emphasized that in this flora we recognized the Dicksoniaceae taxon (only *Coniopteris* sp.) though it is extremely rare in occurrence. This taxon is one of the indicators for the Early Jurassic flora's *Neocalamites–Cladophlebis* assemblage in the Northern Palaeofloristic Province of China (Li et al., 1988) and the flora from the Kuruma Group of Japan (Kimura and Tsujii, 1980a, 1980b, 1981). *Cladophlebis* (incertae sedis of ferns) is abundant in this flora, of which *C. scoresbiensis* was found both in the Greenlandic *Lepidopteris* Zone of the Rhaetian age (Harris, 1926) and the Assemblage of *Neocalamites–Cladophlebis* in the Northern Palaeofloristic Province of China of the Hettangian–Toarcian age (Li et al.,

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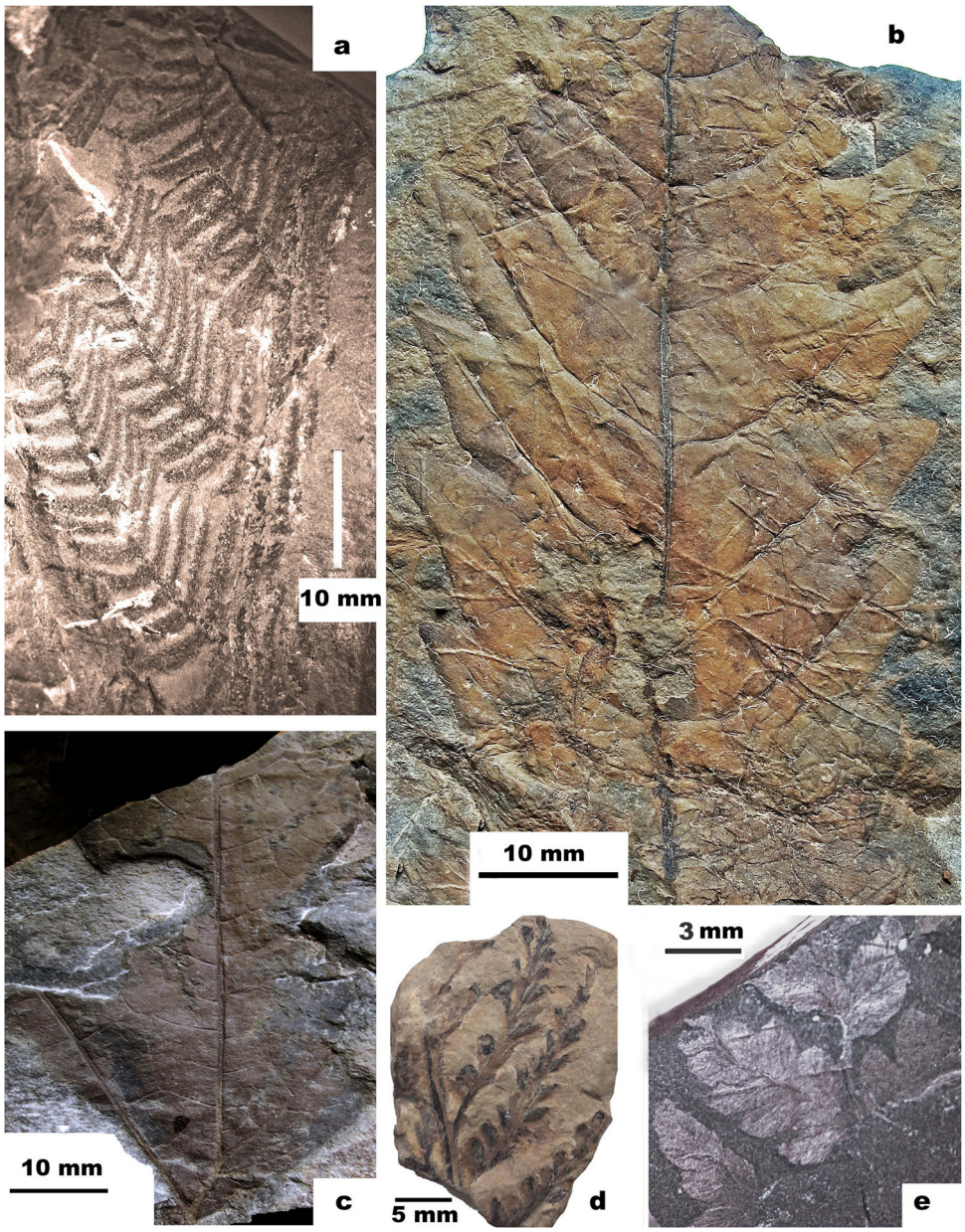

Fig. 4. Ferns of the Schitukhe Floral Assemblage. (a) *Osmundopsis nipponica* Kimura et Tsujii, ɑ part of the fertile fronds, Sh–5-8. (b) *Clathropteris elegans* Oishi, large, segmented leaf of a fern with typical venation, Sh–5-11. (c) *Dictyophyllum* sp., a fragment of middle part of a large leaf, Sh–5-12. (d, e) *Coniopteris* sp.; (d) fertile frond, Sh–5-13; (e) sterile frond, Sh–5-14.

1988; Li, 1995). *C.* ex gr. *haiburnensis* is also abundant in this flora, and is characteristic for Liassic–Early Doggerian in Europe (Harris, 1961), as well as for the Early Jurassic *Neocalamites–Cladophlebis* flora in the Northeast China (Li, 1995). Some other taxa of *Cladophlebis*, e.g., *C.* ex gr. *denticulata*, *C. nebbensis*, were common in the Late Triassic and Early Jurassic floras of Eurasia (Harris, 1926, 1961; Sze et al., 1963; Sun, 1993; Li, 1995; Deng et al., 2017).

The Gymnosperms are very abundant in this flora, represented mainly by Caytoniales, Bennettitales, Cycadales, Ginkgoales, Czekanowskiales, and Coniferales. The Caytoniales is characterized by *Sagenopteris undulata* which is characteristic for the *Lepidopteris* Zone (Rhaetian) in Sweden (Harris, 1926). Bennettitalean taxon (only *Pterophyllum subaequale* revealed) is similar to those described from Liassic *Thaumatopteris* Zone of Greenland (Harris, 1937, 1969; Pott and McLoughlin, 2009). The Cycadales is mainly represented by *Ctenis* and *Nilssonia*, in which *Ctenis sulcicaulis* is very similar to the specimens from Liassic of Yorkshire described by Harris (1937, 1964); *C. yamanarii* is similar to those from the Late Triassic Dadong Group in Korea (Kawasaki, 1925, 1926, 1939; Kimura and Kim, 1984a, 1984b; Kim, 1993) and with *C. kaneharae* from Early Jurassic of Japan (Oishi, 1940; Kimura and Tsujii, 1983). *Nilssonia acuminata* is numerous in this flora, and this species was described by Schenk (1867a, 1867b) from the Liassic of Franconia (Germany), and also recorded in the Late Triassic and Early Jurassic floras of China and Japan (Oishi, 1932; Li, 1995). *N. spinosa* is known in this

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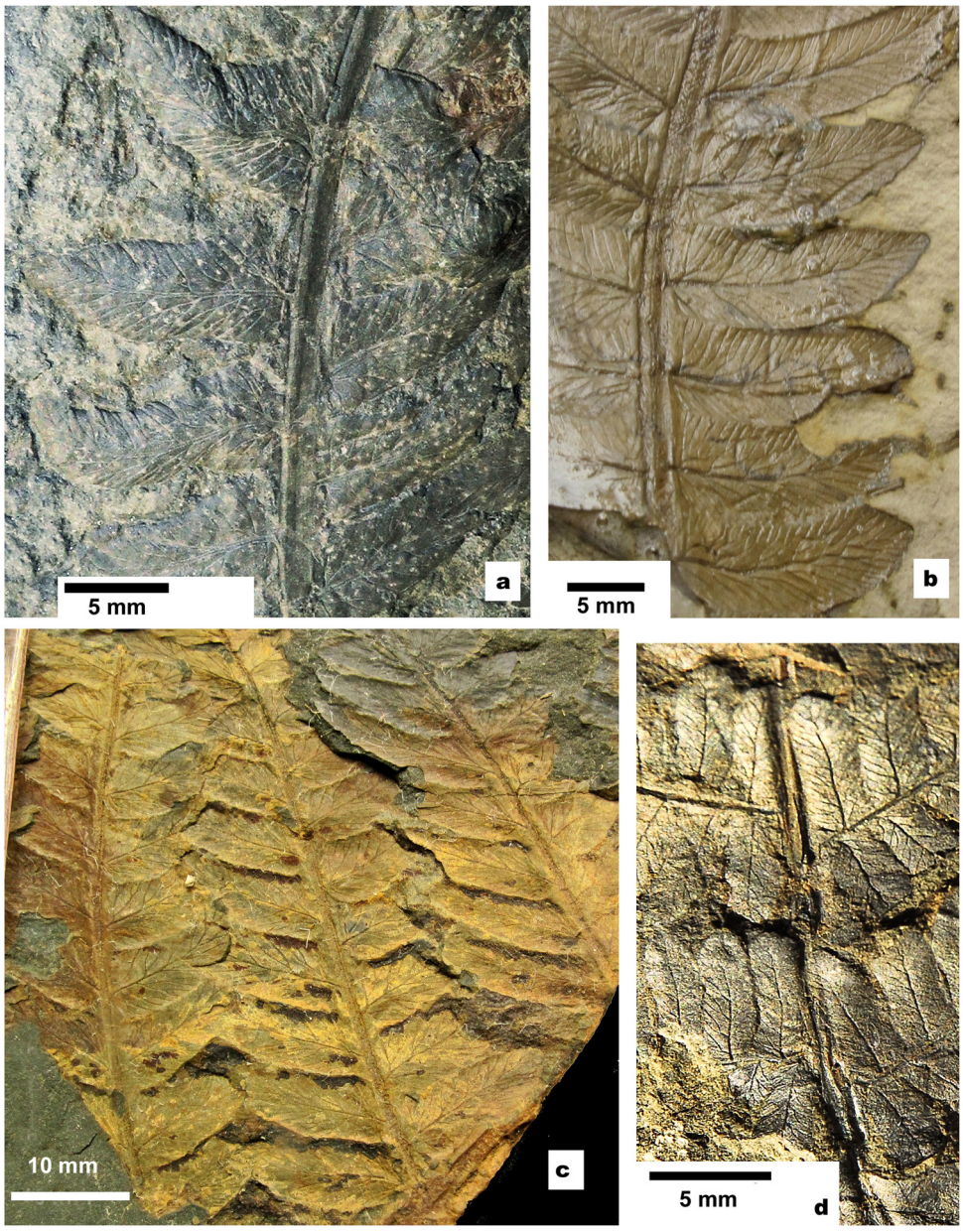

Fig. 5. Ferns of the Schitukhe Floral Assemblage. (a–c) *Cladophlebis* ex gr. *haiburnensis* (Lindley et Hutton) Brongniart; (a, b) part of sterile frond with venation in pinnules, Sh–5-15, Sh–5-16; (c) fragment of a large frond, Sh–5-17. (d) *Cladophlebis denticulata* (Brongniart) Fontaine, fragment of a frond with venation, Sh–5-18.

flora, too. The cycadophytes of uncertain systematic position include *Taeniopteris lanceolata* with linear or linear-lanceolate leaves, recorded in the Rhaetian in Japan (Oishi, 1932) and of the Early Jurassic in the Northern Palaeofloristic Province of China (Li, 1995).

The Ginkgoales is mainly represented by *Ginkgoites*, in which *G*. ex gr. *muensterianus* is similar to the Liassic *Ginkgo muensterianus* (Schenk, 1867a, 1867b). The Czekanowskialean *Phoenicopsis* ex gr. *angustifolia* and *Czekanowskia* ex gr. *rigida* have been recorded in a longer geological range (Late Triassic–Cretaceous) and are typical for the Northern Eurasian Mesozoic floras.

As to conifers, the genera *Podozamites*, *Cycadocarpidium*, *Pityophyllum*, and *Elatocladus* are identified, in which the leafy shoots of *Podozamites schenkii* are similar to those of Rhaetian–Liassic floras of Europe (Harris, 1926), Japan (Kimura, 1959a, 1959b) and China (Sun, 1993; Li, 1995); *P. latifolius* is common in the Late Triassic and Early Jurassic floras in Bavaria (Schenk, 1867a, 1867b) and in the Late Triassic flora of South Primorye (Shorokhova et al., 2009); and *P.* ex gr. *lanceolatus* is also very common in the Jurassic records of Eurasia (Harris, 1926; Kimura, 1959a, 1959b; Li, 1995). It should be also emphasized that the abundance of the female reproductive organ *Cycadocarpidium* is most characteristic for this flora. Besides the Late Triassic, *Cycadocarpidium* have been also recorded in the Liassic of Issyk-Kul, Central Asia (Genkina, 1966), and the Early Jurassic floras of Daolengshan and Xiaomeigou in Gansu (Li, 1995), Hongqi (Yang and Sun, 1985) and Shasonggang of Jilin (Sun et al., 2003) in the Northern Palaeofloristic Province of China. The megastrobili

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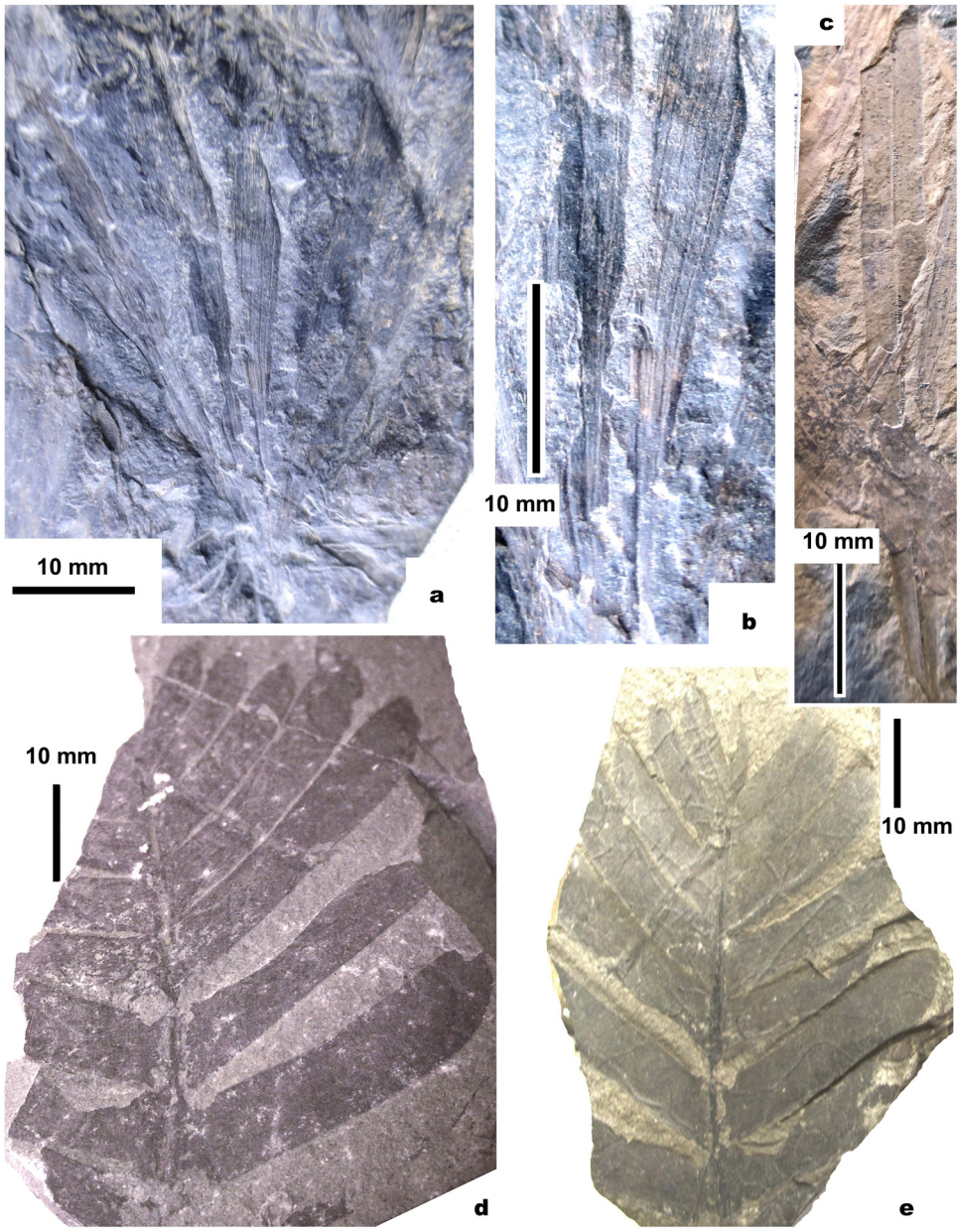

Fig. 6. Gymnospermaleans of the Schitukhe Floral Assemblage. (a, b) *Phoenicopsis* ex gr. *angustifolia* Heer; (a) a bunch of leaves on brachyblast, Sh–5-19; (b) enlargement from (a), showing venation in leaves. (c) *Pityophyllum* ex gr. *nordenskioldii* Heer, wide isolated leaf, Sh–5-20. (d, e) *Ctenis yamanarii* Kawasaki, segmented leaves with venation in it, Sh–5-20, Sh–5-21.

of *Cycadocarpidium* with *C. pacificum* n. sp., are new findings in the authors' present study, which is similar to *C. ovatum* Kon'no from the Upper Triassic of Japan (Kon'no, 1961). The other conifers, e.g., *Pityophyllum* and *Elatocladus*, commonly occurred in the Mesozoic; while the isolated leaves of *Linguifolium* were described from the Late Triassic–Early Jurassic floras of Southern Hemisphere (Anderson and Anderson, 1989; Holmes et al., 2010).

In sum, for the composition of the Schitukhe flora, the ferns (34%) and conifers (22%) are dominate, cycadophytes (16%) is subdominant, which are accompanied by horsetails (8%), plants in unclear systematic position (8%), ginkgoaleans (6%), czekanowskialeans (4%), and caytonialeans (2%).

4. Comparisons with coeval floras of China and Japan

Vakhrameev (1964, 1988) had divided the two Palaeofloristic realms (i.e., the Siberian and Euro-Sinian realms) in Eurasia with the Early Jurassic age. According to this division, the Early Jurassic Schitukhe flora of South Primorye is located in the boundary region between the East Asian Palaeofloristic province of the Euro-Sinian Realm, and the southeastern Siberian Realm in Eurasia. Thus, it is interesting that the Schitukhe flora studied in this paper has both floristic characters of the Siberian and Euro-Sinian realms.

In comparisons to China, the Jurassic Flora of China was divided into the Northern and Southern palaeofloristic

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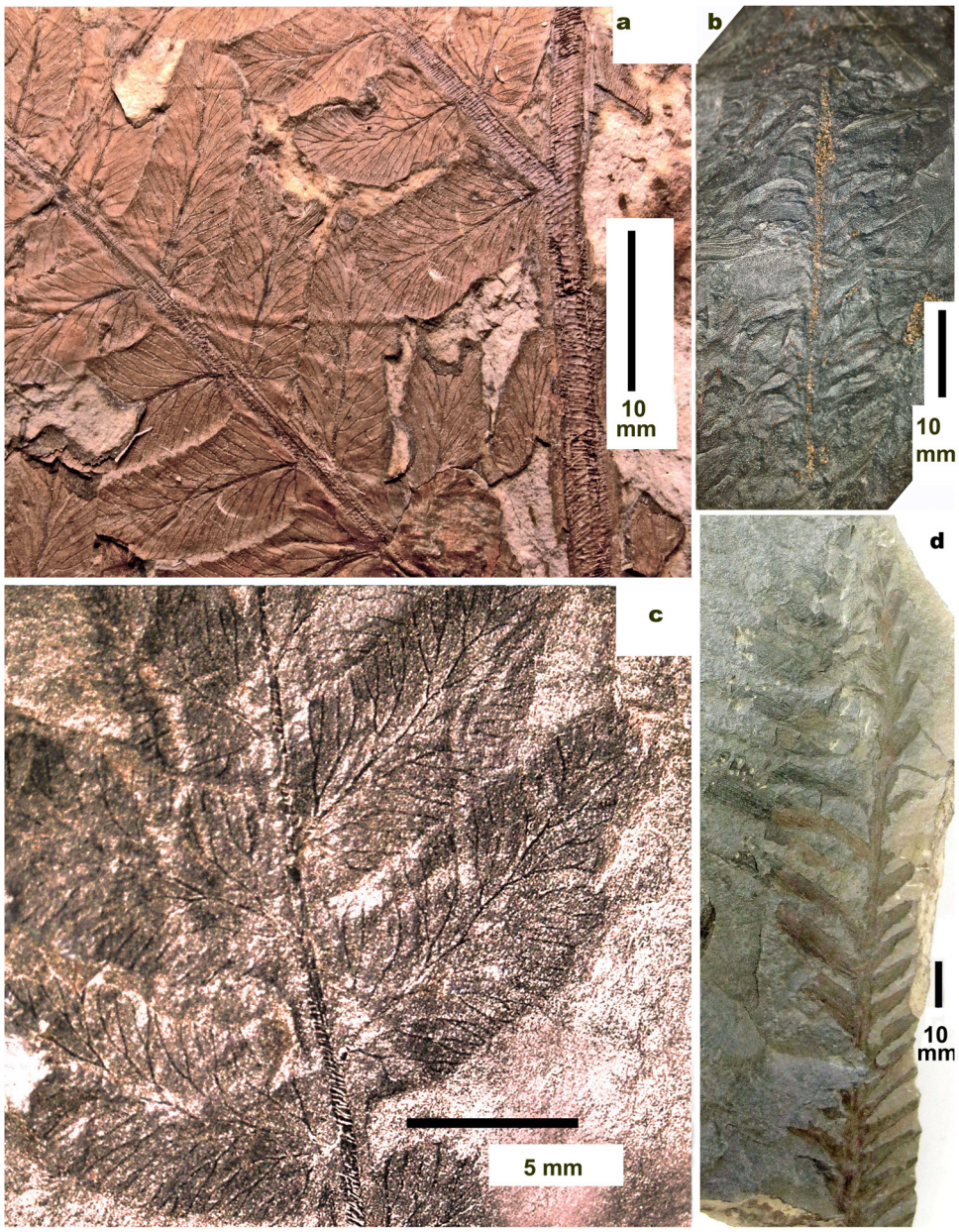

Fig. 7. Ferns and gymnospermaleans of the Schitukhe Floral Assemblage. (a, c) *Cladophlebis asiatica* Chow et Yeh, middle part of a frond, showing thick rachis and pinnule form, Sh–5-22, Sh–5-24. (b) *Elatocladus* sp., foliage shoot, Sh–5-23. (d) *Ctenis sulcicaulis* (Phillips) Ward, incomplete fragment of a large pinnate leaf, Sh–5-25.

provinces (Zhou, 1984; Li, 1995). The Early Jurassic flora in the Northern Province is represented by the assemblage of *Neocalamites–Cladophlebis* (*Neocalamites–Marattiopsis*) with the Hettangian–Toarian age, and the Middle Jurassic flora is represented by the assemblage of *Coniopteris–Phoenicopsis* (*Coniopteris–Raphaelia*) (Li et al., 1988; Li, 1995). The assemblage of *Neocalamites–Cladophlebis* was studied in detail in the Qaidam Basin of Qinghai and Lanzhou area of Gansu in Northwest China (Li et al., 1988), as well as in the Junggar Basin of Xinjiang (Li et al., 1988; Chen, 1995; Li, 1995; Deng et al., 2000; Sun et al., 2010), Inner Mongolia of China (Wang, 1984; Deng et al., 2017), West Hill of Beijing (Chen et al., 1984), Beipiao of Liaoning (Mi et al., 1980, 1996), and Shasonggang and Yihe of Jilin (Sun et al., 2003, 2010a, 2010b), etc.

The assemblage of *Neocalamites–Cladophlebis* in the northern China includes three subassemblages (beds): a) early – Xiaomeigou subassemblage (*Zamites* bed, Hettangian–Sinemurian), b) middle – Houshaoshan subassemblage (*Cladophlebis* bed, Pliensbachian), and c) late – Tianshuigou subassemblage (*Hausmannia* bed, Toarician). In comparison, the Schitukhe flora and the *Neocalamites–Cladophlebis* assemblage have a lot of common taxa, such as *Neocalamites* (*N. hoerensis*, *N. carrerei*), *Equisetites*, *Todites*, *Clathropteris elegans*, *Hausmannia*, *Cladophlebis* (*C. denticulata*, *C. nebbensis*, *C. haiburnensis*,

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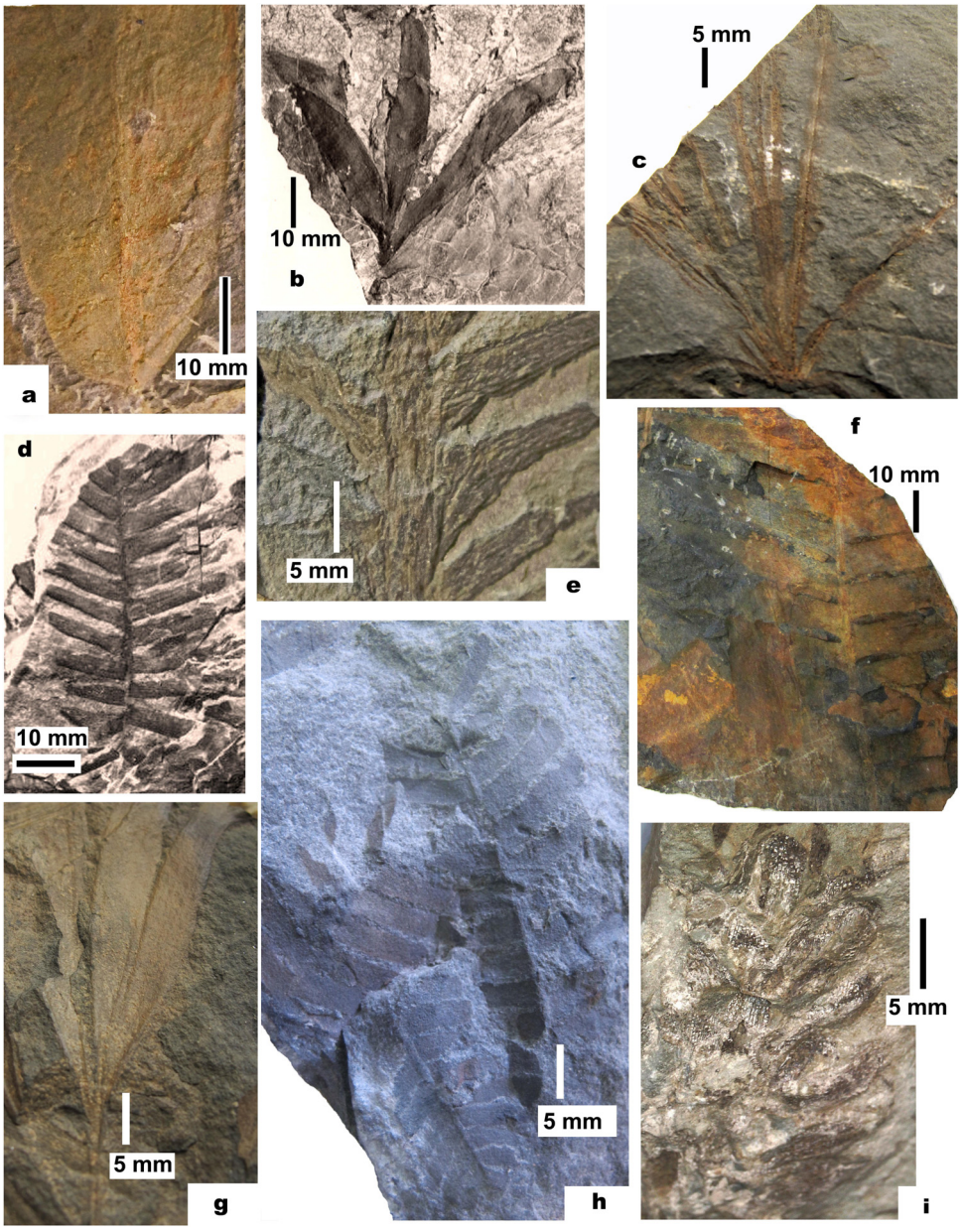

Fig. 8. Gymnospermaleans of the Schitukhe Floral Assemblage. (a) *Linguifolium* sp., incomplete linear-lanceolate leaf, Sh–5-28. (b, g) *Ginkgoites* spp.; (b) a leaf, Sh–5-29; (g) fragment of leaf, Sh–5-30. (c) *Czekanowskia* ex gr. *rigida* Heer, linear leaves, Sh–5-31. (d) *Pterophyllum subaequale* Hartz emend. Pott et McLoughlin, leaf and pinnae, Sh–5-32. (e) *Ctenis sulcicaulis* (Phillips) Ward, incomplete fragment of a large pinnate leaf, showing venation in segments, Sh–5-33. (f, h) *Nilssonia acuminata* (Presl) Goeppert, fragments of segmented leaves, Sh–5-34, Sh–5-35. (i) *Cycadocarpidium pacificum* Volynets et Sun n. sp., female cone, cylindrical in form, with freely spaced seed scale complexes, Sh–5-36.

C. asiatica), *Ctenis*, *Ginkgoites*, *Czekanowskia*, *Phoenicopsis*, *Pityophyllum nordenskioldii*, *Elatocladus*, *Podozamites* and *Cycadocarpidium*. The difference lies mainly in that the assemblage of *Neocalamites–Cladophlebis* of China has no *Coniopteris* and Cycadophytes in the early subassemblage, and the three thermophilic taxa *Phlebopteris*, *Marattiopsis* and *Thaumatopteris*, mainly shown in the Xinjiang and Inner Mongolia of China (Li, 1995) and Jilin (Sun et al., 2010b).

In the Northeast China, the Early Jurassic flora from Yihe of eastern Jilin, which is not so far from the South Primorye, has 35 species of 22 genera (Sun et al., 2008, 2010a, 2010b), and is somewhat similar to the Schitukhe flora in floral composition. The two floras have many common taxa, e.g., *Equisetites*, *Neocalamites* (*N. hoerrensis*), *Marattiopsis* (*M. hoerensis*), *Coniopteris*, *Clathropteris* (*C. elegans* = *C. obovata* Oishi), *Cladophlebis*, *Pterophyllum*, *Nilssonia*, *Ctenis*, *Taeniopteris*, *Phoenicopsis*, *Podozamites*, etc. Particularly, both the floras have some dipteridaceous ferns, and cycadophytes (e.g., *Pterophyllum* and *Ctenis*), but the difference is in the absence of *Cycadocarpidium* in the Yihe flora. The Early Jurassic Shansonggan flora from the Shansonggan in middle Jilin has 37 species of 22 genera, among which there are many common taxa to those of the Schitukhe flora, such as *Neocalamites hoerensis*, *Cladophlebis asiatica*, *Czekanowskia* ex

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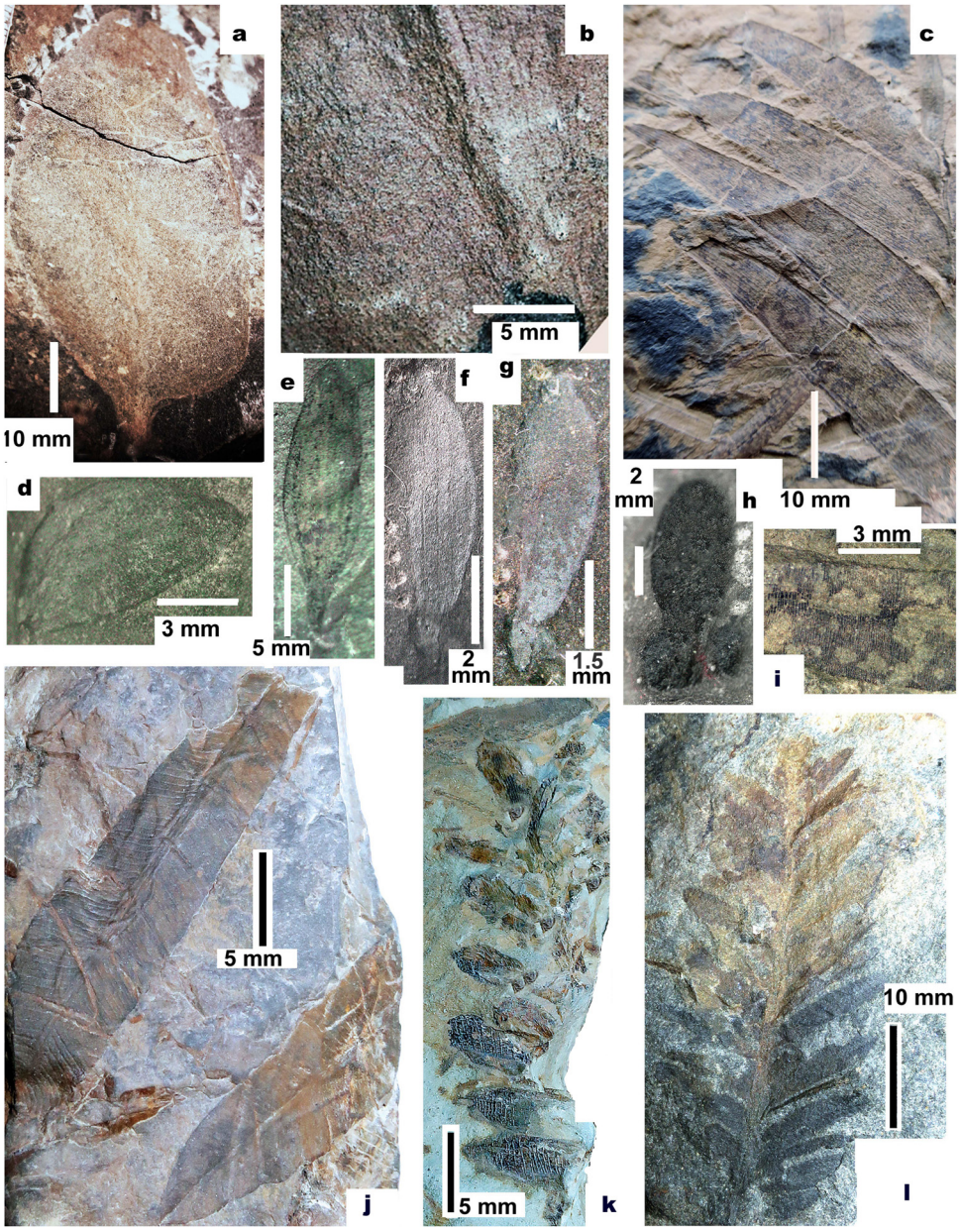

Fig. 9. Gymnospermaleans of the Schitukhe Floral Assemblage. (a, b) *Linguifolium* sp.; (a) complete leaf with petiole, Sh–5-37; (b) middle part of leaf with (a), showing venation. (c) *Podozamites latifolius* (Schenk) Kryshtofovich et Prynada, incomplite foliage shoot, Sh–5-38. (d) *Cycadocarpidium* sp. 1, bract scale mainly with 7–8 veins and petiole, Sh–5-40. (e, f) *Cycadocarpidium* sp. 2, bract scale with 5 veins and petiole, Sh–5-41, Sh–5-42. (g) *Cycadocarpidium* sp. 3, seed scale complex, Sh–5-43. (h) *Cycadocarpidium* sp. 4, seed scale complexs, Sh–5-44. (i) *Pityophyllum* sp., fragment of leaf with venation, Sh–5-45. (j) *Taeniopteris lanceolata* Oishi, two linear leaves with venation, Sh–5-46. (k) *Cycadocarpidium pacificum* Volynets et Sun n. sp., paratype, the upper part of the friable cylindrical cone with seed scales complexes, Sh–5-10-2a. (l) *Elatocladus* sp., foliage shoot, Sh–5-39.

gr. *rigida*, *Phoenicopsis* ex gr. *angustifolia*, *Pityophyllum* ex gr. *nordenskioeldii* and *Podozamites* ex gr. *lanceolatus*; as well as a lot of comparable taxa, such as *Ginkgoites marginatus* (Nathorst) Florin (*G.* ex gr. *muensterianus*), *Ctenis angustiloba* Mi et Sun (*C. sulcicaulis*), *Cladophlebis ingens* Harris (*C. scoresbiensis*), etc. The characters of the two floras both have *Coniopteris* and *Cycadocarpidium*. The difference is mainly in the absence of dipteridaceous ferns, and *Marattiopsis*, *Phlebopteris* in the Shansonggan flora. Another Early Jurassic flora that may be comparable, is the Beipiao flora in western Liaoning (Mi et al., 1980, 1996). The flora has over 60 taxa, and is most diverse in ferns, such as *Marattiopsis hoerensis*, *M. muensteri* (Goeppert) Schimper, *Todites denticulata* (Brongniart) Krasser, *T. williamsonii* (Brongniart) Seward, *Hausmannia ussuriensis* Kryshtofovich, *Taumatopteris pusilla* (Nathorst) Oishi et Yamasita, *Clathropteris meniscioides* (Brongniart) Brongniart, *Cladophlebis* spp.; and accompanied by *Ginkgo huttoni* (Sternberg) Heer, *G. digitata* (Brongniart) Heer, various cycadophytes (e.g., *Nilssonia*), and conifer *Podozamites*. Compared to the Schitukhe flora, the two floras have more common taxa, particularly the ferns (*Marattiopsis hoerensis*, *Todites denticulata*, *Dictyophyllum*, *Clathropteris*, *Hausmannia*, *Coniopteris*,

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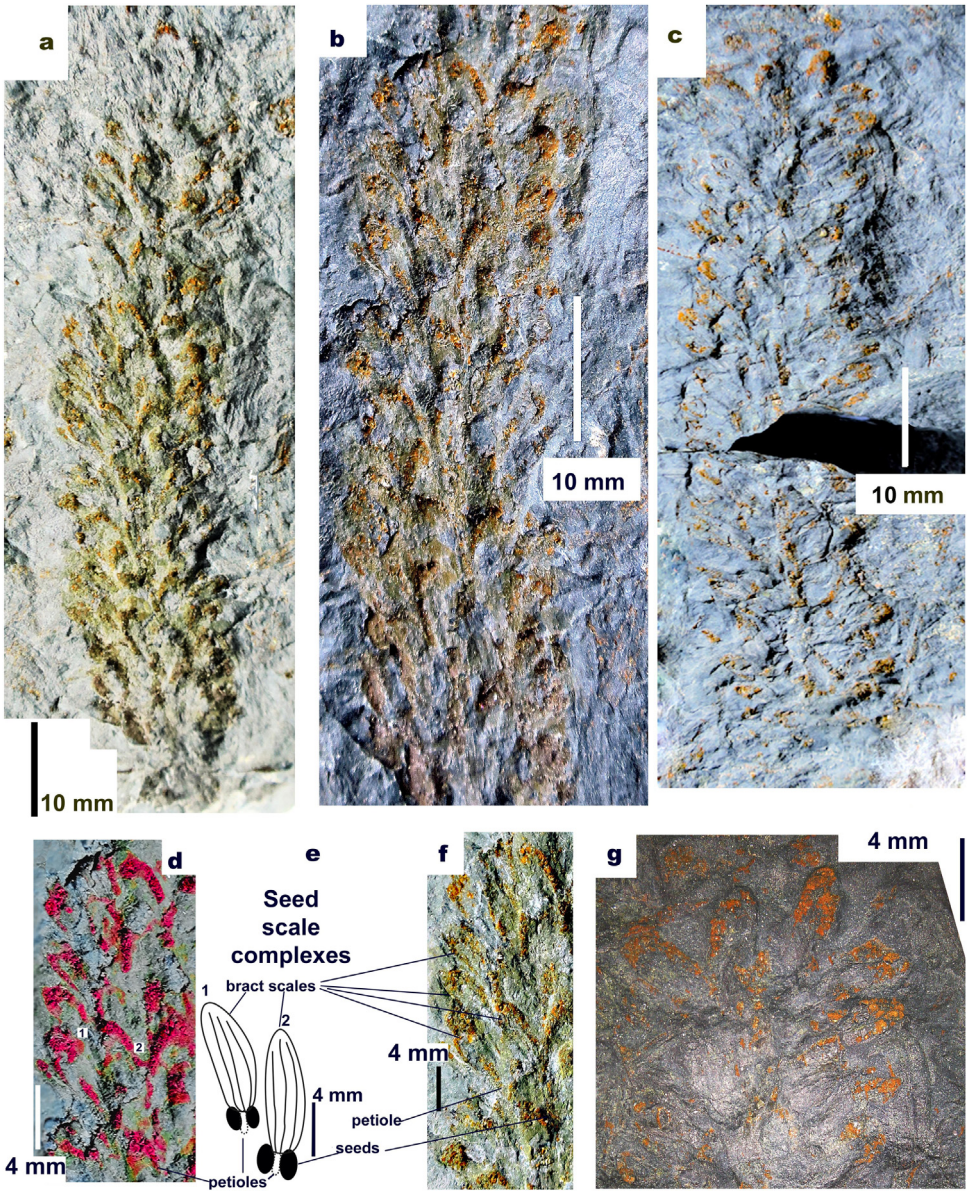

Fig. 10. *Cycadocarpidium pacificum* Volynets et Sun n. sp. (a) Holotype, female cone with closely spaced seed scaly complexes, Sh–5-6-2. (b) Incomplete counterpart from (a), the female cone, Sh–5-6-1. (c) Incomplete specimen, the female cone with closely spaced seed scaly complexes, Sh–5-6-3. (d) The enlargement middle part of the holotype (a), with clearly represented seed scale complexes. (e) Linear drawing of seed scaly complexes of (d). (f) The left side of the middle part of (b), with seed scaly complexes. (g) The upper part of the cone (c), with strongly pronounced seed scaly complexes.

Cladophlebis), and the gymnospermous *Ginkgoites* (*Ginkgo*), *Nilssonia*, *Podozamites*, etc. However, in the Beipiao flora the czekanowskialeans and conifer *Cycadocarpidium* have not found.

In the Southern Palaeofloristic Region of China, the Early Jurassic flora was well-studied in middle Hunan, with the marine bivalve fossils well documented in age (Zhou, 1984; Li, 1995), and Xiangxi (Hsiangchi) of western Hubei (Wu et al., 1980). The flora in Hunan is represented by the assemblage of *Marattiopsis–Otozamites* which is divided into three subassemblages: a) early – Pianjiachong subassemblage (Hettangian), b) middle – Dakouba subassemblage (Sinemurian), and c) late – Fengjiachong subassemblage (Pliensbachian–Toarician). In Xiangxi (Hsiangchi) of western Hubei, the Early Jurassic flora only contains the late (Pliensbachian–Toarician) subassemblage, named as of *Todites princips–Ptilophyllum* (Sze et al., 1963; Wu et al., 1980; Li, 1995). Some other related studies of the Early Jurassic flora in this Region have been also done in the northeastern Sichuan (Ye et al., 1986; Wang et al., 2010).

Taxonomically, the Schitukhe flora has more common or similar taxa to those of the early assemblage of *Marattiopsis–Otozamites*, particularly in the dipteridaceous and marattiaceous ferns and cycadophytes. The common or similar taxa include *Neocalamites hoerensis* (*N. carrerei* Zeiller), *Marratiopsis hoerensis* (*M. muensteri* (Goeppert) Schimper), *Dictyophyllum* sp., *Clathropteris elegans* (*C. meniscioides* (Brongniart) Brongniart), *Phlebopteris*, *Cladophlebis scoresbiensis* (*C. raciborskii* Zeiller), *C denticulata*, *Sagenopteris*,

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Nilssonia acuminata, *Pterophyllum subaequale* (*P. aequale* Brongniart), *Pityophyllum* ex gr. *nordenskioldii*, *Podozamites* (*Lindleycladus*) *lanceolatus*, as well as some elements of the fern *Coniopteris*. However, the main differences are in that the Early Jurassic floral assemblage of the South China has abundant thermophilic *Otozamites* which has not been found in the Schitukhe flora. Seasonally deciduous czekanowskialeans (*Czekanowskia*, *Phoenicopsis*, etc.), and ginkgoaleans were absent in the *Marattiopsis–Otozamites* assemblage. In addition, in the late assemblage (*Todites princips–Ptilophyllum* subassemblage, Pliensbachian–Toarician), especially in the Xiangxi (Hsiangchi) of Hubei (Wu et al., 1980), there are abundant *Ptilophyllum* in the floral composition, while this cycadophytes taxon has not been found in the Schitukhe flora from Russia.

In Japan, which is within the East Asian Palaeofloristic province of the Euro-Sinian Realm in the Early Jurassic according to the division of Vakhrameev (1964, 1988), the Early Jurassic plants were mainly studied from the Iwamuro Formation (or the lower part of the Kuruma Group) (Kimura, 1959a, 1959c), and the Nishinakayama Formation of the lower part of Toyora Group (Kimura et al., 1988).

In the Iwamuro Formation (or the lower part of the Kuruma Group), the flora is mainly composed of *Equisetites iwamuroensis* Kimura, *E.* sp., *Neocalamites hoerensis*, *Dictyophyllum* sp., *Clathropteris* sp., *Thaumatopteris elongata*, *T. nipponica* Oishi, *Hausmannia* sp., *Cladophlebis rachborskii* Zeiller, *C. haiburensis*, *Coniopteris* sp., *Pterophyllum propinquum* Goeppert, *Nilssonia brevis* Brongniart, *N. orientalis* Heer, *Otozamites fujimotoi* Kimura, *Ctenis* sp., *Ginkgoites digitata* (Brongniart) Seward, *Czekanowskia rigida*, *Phoenicopsis* sp., *Brachyphyllum* ex gr. *expansum* (Sternberg) Seward, *Podozamites lanceolatus*, *Swedenborgia cryptomerioides* Nathorst, *Taeniopteris* sp., etc. (Oishi, 1940; Kimura, 1959a, 1959c; Kimura and Tsujii, 1980a; Kimura and Ohana, 1990). Combined with marine fossils (*Corbicula kurumensis*, *Bakevellia magnissima*, and *Astarte* sp.), the age of the Iwamuro Formation is considered as Lower Liassic (Kimura, 1959a). The taxonomic composition of the Iwamuro flora is quite similar with the Schitukhe flora, particularly in the occurrence of the abundant *Thaumatopteris* and a few of *Coniopteris*. The floral assemblage of the Nishinakayama Formation, the lower part of the Toyora Group, is represented by the ferns – *Gleichenites*?, *Marattiopsis*, *Phlebopteris*, *Sphenopteris*; cycadophytes – *Otozamites*, *Zamites*, *Pseudoctenis*; conifers – *Brachyphyllum*, *Araucarites*, *Cupressinocladus*, *Geinitzia*, *Elatides*, etc. (Kimura et al., 1986; Kimura and Ohana, 1987a, 1987b, 1990). This flora is comparable to the present Schitukhe flora in composition characters. The age of the Nishinakayama Formation is dated by the ammonite fossils as the Pliensbachian–Toarcian (Hirano, 1971, 1973).

Thus, only the Early Jurassic flora of Iwamuro Formation in Japan is comparable with the Schitukhe flora. Among the floras the common taxa include *Equisetites*, *Neocalamites*, *Marattiopsis* (*Marattia*), *Phlebopteris*, *Coniopteris*, *Clathropteris*, *Dictyophyllum*, *Thaumatopteris* (*T. elongata*), *Hausmannia*, *Cladophtebis*, *Pterophyllum*, *Ctenis*, *Nilssonia*, *Taeniopteris*, *Ginkgoites* (*Ginkgo*), *Czekanowskia*, *Phoenicopsis*, *Podozamites*, etc. The dominance of ferns and a variety of cycadophytes, ginkgoales and conifers and the participation of czekanowskiales determines the similarity of the comparable floras. However, in the Japanese Early Jurassic floras there is no *Cycadocarpidium*, while the Schitukhe flora has no *Otozamites*, *Swedenborgia*, which might indicate that the Schitukhe flora is somewhat earlier than the above two Japanese floras although they all fall in the age of the Early Jurassic.

5. Discussion

A detailed study of the Early Jurassic flora from the Schitukhe Formation in South Primorye, Russia is made by the authors. The flora is composed of over 50 taxa dominated by ferns (Dipteridaceae, Matoniaceae, Marattiaceae, etc.), cycads (*Pterophyllum*, *Nilssonia*, *Ctenis*, *Taeniopteris*, etc.), and seasonally deciduous conifers (*Cycadocarpidium–Podozamites*, etc.), Czekanowskiales, and Ginkgoales, showing a mixed flora with floral characters of both the Siberian and Euro-Sinian Palaeofloristic realms in the East Asia during the earliest Early Jurassic.

Paleoclimatically, the Early Jurassic floras in the Siberian Palaeofloristic Realm is considered to be under the moderate-warm climate with well-pronounced seasonality. The main representatives consist of dipteridaceous, matoniaceous and marattiaceous ferns (*Clathropteris*, *Huasmannia*, *Phlebopteris*, *Marattiopsis*), cycadaleans (*Nilssonia*, etc.) and bennettitaleans (*Pterophyllum*, etc.), all showing a warm ant some humid climates; and ginkgoaleans (*Ginkgoites*, etc.), czekanowskialeans (*Czekanowskia*, *Phoenicopsis*) and seasonally deciduous conifers (Pinaceae, Cycadocarpidaceae), indicating a moderate-warm and seasonal change in the paleoclimates. The abundant undergrowth herbaceous ferns represented mainly by *Cladophlebis*, and the horsetails (*Neocalamites*, *Equisetites*), imply the climates were more or less moist during the flora living in the paleoenvironment. However, in the Euro-Sinian Palaeofloristic Realm in the Early Jurassic, the abundance of the thermophilic and hydrophilic bennettitaleans, cycadaleans, dipteridaceous and other ferns, shows the subtropic or tropic-subtropic climate during the time. In addition some evergreen conifers with scaly-leaves (Cheirolepidiaceae/Cupressaceae), as well as *Araucarites* and *Elatocladus* (*Elatides*) imply a hot and likely arid climates during the time. According to the floral composition, the Schitukhe flora is considered living under a moderate-warm climate with some seasonal changes.

Paleophytogeographically, in the Late Triassic and Early Jurassic, the floras in Europe, Greenland, and Southern Sweden were in the Euro-Sinian Palaeofloristic Realm. Harris (1937, 1961) proposed two phytostratigraphical zones: the *Lepidopteris* Zone (Rhaetian) and *Thaumatopteris* Zone (Liassic). On the boundary of the Triassic–Jurassic, the appearance of *Thaumatopteris brauniana* (Popp) Schweitzwer evidence of Early Liassic, with the disappearance of the Rhaetian species *Lepidopteris ottonis* (Göppert) Schimper, which is a phytostratigraphic reference for the continental Hettangian–Sinemurian deposits in dating. In the Early Jurassic Schitukhe flora of South Primorye, the taxa characterizing the *Thaumatopteris*

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Zone (Liassic) include *Maratiopsis hoerensis*, *Phlebopteris angustiloba*, *Thaumatopteris* spp., *Nilssonia acuminata*, *Pterophyllum subaequale*, *Ginkgoites* ex gr. *muensterianus*, as well as some species of *Cladophlebis* (*C.* ex gr. *haiburnensis* = *C. ingnes* Harris), which were also shown in the Early Jurassic floras of Germany, Poland, Hungary, Romania (Harris, 1937; Weber, 1968; Vakhrameev, 1988; Popa et al., 2003; Pott and McLoughlin, 2009; Barbacka et al., 2014), though the above taxa typically occurred in the Euro-Sinian Palaeofloristic Realm. However, the Schitukhe flora has also many typical taxa of the Siberian Palaeofloristic Realm, such as the abundant deciduous gymnosperms represented by the Czekanowskiales (*Czekanowskia*, *Phoenicopsis*), Ginkgoales (*Ginkgoites*, etc.), and a lot of Pinaceae (*Pityophyllun*, etc.), etc. The floral characters clearly indicate that the Schitukhe flora of South Primorye is a mixed flora living in the ecotone zone between the Palaeofloristic realms Siberian Flora and Euro-Sinian Flora during the early Early Jurassic. The similar examples have been recorded along the boundary of the two above realms, such as the Early Jurassic Flora from Zagaji and Ostrowiec formations (lower Hettangian–Sinemurian) in Ostrowiec–Swietokrzyski area of Poland, has nearly equivalent floral composition to the Schitukhe flora (Barbacka et al., 2014). The Polish flora has common taxa with the Schitukhe flora, such as *Neocalamites* (*N. hoerensis*), *Todites*, *Thaumatopteris*, *Phlebopteris* (*P. angustiloba*), *Coniopteris*, *Cladophlebis* (*C. nebbensis*), *Ginkgoites*, *Czekanowskia*, *Phoenicopsis*, and *Podozamites.* However, in the Early Jurassic Polish Flora, some local taxa are found, e.g., *Pachypteris*, *Pseudotorellia*, *Brachyphyllum*, and *Desmiophyllum*, while no *Cycadocarpidium*, Cycadophytes, Caytoniales, or Pinaceae were found, which is different from the Schitukhe flora. Despite these differences, it can be assumed that the Early Jurassic Flora from the Ostrowiec–Swietokrzyski of Poland is also under the ecotonic conditions. Similar examples are also occurred in southern border area of the Siberian Palaeofloristic Realm, such as the Early Jurassic Daqingshan flora of Inner Mongolia, China (Wang, 1984; Li, 1995); the Early Jurassic Yihe and Shasonggang floras of Jilin, China (Sun et al., 2003, 2010a, 2010b); the Early Jurassic Kaktui floral assemblage (flora, formerly as the Rhaetian in age) from Issyk-Kul Lake area in Kyrgyz (Genkina, 1966); and the Hettangian–Sinemurian floras of Darvaz Range (Western Pamir), in the south slope of the Gissar Range, Tashkutan, from Tanaka River Basin (Vakhrameev, 1988).

Thus it appears clear that there was an ecotone zone along which many mixed floras between the Siberian and Euro-Sinian Palaeofloristic realms developed during the Early Jurassic. The influence of the Siberian Palaeofloristic Realm on the border floras of the Euro-Sinian Realm is clearly manifested by the frequent occurrence of ginkgoaleans, czekanowskialeans, and ancient pinaceous, creating a transitional (ecoton) zone between them. The Schitukhe flora of South Primorye could be as one of the most significant points for the Early Jurassic phytogeographical study in the East Asia.

Comparing in detail with the coeval floras of Primorye, China and Japan, we came to the conclusion that the Schitukhe flora has similarities with the Early Jurassic floras of China (e.g., the Shansonggang flora, Yihe flora, Beipiao flora, and the flora from the lower–middle Guanyintan Formation of Hunan), in particular, it appears to be more similar to the Yihe flora of Jilin, China. The Schitukhe flora is also similar to the Early Jurassic floras of the Iwamuro Formation (or the lower Kuruma Group) and the Nishinakayama Formation in Japan, but differs in having *Cycadocarpidium*, with no *Otozamites*, etc., which might indicate that the Schitukhe flora is somewhat older than the Japanese flora from Nishinakayama Formation.

On the basis of floral characters, combined with the marine fossil evidence and the biostratigraphic correlations to those of Japan and China, the age of the Schitukhe flora appears to be the earlier Early Jurassic, probably the Hettangian–Sinemurian age.

It should be noted that taxa of the family Dicksoniaceae rarely appear for the first time in the Hettangian–Sinemurian assemblages of the North and South provinces of China, of Ostrowiec–Swietokrzyski area of Poland, as well as in the Gissar and Darvaz ranges of Central Asia. In addition, fern *Thaumatopteris* in the early Jurassic floristic assemblages of Eurasia is phytostratigraphic a bench mark for the Hettangian–Sinemurian.

6. Conclusion

A detailed study, with newly added materials, of the Early Jurassic flora from the Schitukhe Formation in the Petrovka River Basin of South Primorye, Russia is made by the authors. The flora is composed of over 50 taxa dominated by ferns (Dipteridaceae, Matoniaceae, Marattiaceae, etc.) and conifers (Cycadocarpidiaceae, Pinaceae, etc.), subdominated by cycads (*Pterophyllum*, *Ctenis*, *Nilssonia*, etc.), and accompanied by horsetails (*Equisetites*, *Neocalamites*), seed-ferns (Caytonialeans), and seasonally deciduous Czekanowskiales and Ginkgoales in a small amount. From the floristic comparisons with the coeval floras of China and Japan, the Schitukhe flora has shown clearly to be the Early Jurassic flora. Moreover, combined with marine fossil evidence (Zakharov et al., 2009), the Schitukhe flora can be constrained as the Hettangian to the early Sinemurian in age.

The abundance of ferns (*Marattiopsis*, *Phlebopteris*, *Clathropteris*, *Dictyophyllum*, *Thaumatopteris*, *Hausmannia*, *Todites*, *Osmundopsis*) and cycadophytes (*Pterophyllum subaequale*, *Ctenis sulcicaulis*, *C. yamanarii*, *Nilssonia spinosa*) in the Schitukhe flora indicates that the flora was developed under a subtropical or subtropical to warm temperate climates, with humid conditions in general in the early Jurassic time. The elements of ginkgoaleans, czekanowskialeans and deciduous conifers in the floral composition, indicate that the climates were with seasonal changes, as usually occurred in the warm-temperate region.

Paleophytogeographically, compared with the coeval floras of the Early Jurassic, particularly with those of China and Japan, the Schitukhe flora has both the floristic characters of the Early Jurassic Siberian and Euro-Sinian Palaeofloristic realms, which implies that the flora was perhaps living in an ecotone zone, as a mixed flora, between the Siberian and Euro-Sinian Palae-

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ofloristic realms during the Early Jurassic. The influence of the Siberian Palaeofloristic Realm to the flora is clearly manifested by the occurrence of the deciduous gymnosperms such as ginkgoaleans, czekanowskialeans, and pinaceous conifers. The Schitukhe flora of South Primorye could be as one of the most significant points for the Early Jurassic paleophytogeographical study in the East Asia.

7. Systematic description of new species

Coniferales

Cycadocarpidiaceae

Cycadocarpidium Nathorst, 1886

Cycadocarpidium pacificum Volynets et Sun n. sp.

(Figs. 8i, 9 k, 10)

Etymology: The specific name comes from the geographical position of the fossil locality on the coastal Pacific Ocean.

Holotype: Sh–5-6-2 (Fig. 10a, d, e).

Paratype: Sh–5-10-2a (Fig. 9k).

Repository: Laboratory of Palaeobotany of Federal Scientific Center of Biodiversity of the East Asian Terrestrial Biota, Far East Branch of the Russian Academy of Sciences.

Type locality: The holotype from Litovka River Basin of South Primorye, Russia; the paratype from Petrovka River Basin of South Primorye, Russia.

Type stratum: Schitukhe Formation; Lower Jurassic.

Diagnosis: Female cone, nearly cylindrical in form. Cone axis thin, arranged spirally by many seed scale complexes with a short stalk for each. Bract scales linear-oblong in form, mainly with 3 veins. Seed scale complex having 2 small seeds for each, oval-rounded in shape, and 0.5–1 mm in size. Seed scales not clear seen.

Description: Cone nearly cylindrical in form, 4–4.5 cm in length by ca.1.5 cm in diameter. Cone axis thin, about 1.0–1.4 mm thick, arranged spirally by many seed scale complex with a short stalk for each. Bract scales linear-oblong in form, small, 4–7 mm long by 1.2–2.3 mm wide, with 3 veins in general. Seed scale complex, with a short stalk, having 2 small seeds for each, oval-rounded in shape, and 0.5–1 mm in size. Seed scales not clear seen. Seven cone specimens preserved and showing the upper and middle parts of the loose cones.

Remarks: The new specimens are characterized by the whole cone with complete morphological features for the female reproductive organs *Cycadocarpidium.* Morphologically, the described new specimens are similar to the cone material of *Cycadocarpidium ovatum* Kon'no from the Upper Triassic of Japan (Kon'no, 1961). However, the Japanese species has the cones of larger size, with a long petiole in seed scale complex with a friable arrangement on the axis. A few similar megastrobili were also reported from the Upper Triassic of Donbass (Russia) (Stanislavsky, 1976), and Japan (Kon'no, 1961), but the differences are more contrast in the seed scale complex.

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