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Comparison of Early Jurassic flora from South Primorye of Russia with its main coeval floras of China

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Abstract: The Early Jurassic flora, with over 42 species of 26 genera and documented in age by sandwiched marine beds, from the Lower Jurassic Schitukhe Formation of South Primorye, Russia, is further reported. The flora is dominated by cycadophytes, ferns and conifers, with some of ginkgoales and czekanowskiales in composition, and characterized by occurrence of *Cycadocarpidium*, with very rare *Coniopteris*. A comparison of this flora with its coeval Early Jurassic floras of China is discussed, and the Russian flora is considered as the early assemblage of Early Jurassic flora, and more similar to the Early Jurassic floras from the Shansonggang and Yihe formations of Jilin, Beipiao Formation of Liaoning, and lower-middle Guanyintan Formation of Hunan in China.
Key words: Early Jurassic; Schitukhe flora; South Primorye; Russia; China

1 Introduction

The Mesozoic of Primorye Region of Far East Russia is rich in remnants of plants and mollusks. A. N. Krishtofovich had first studied the Mesozoic flora from this region, and considered all the floras as the Jurassic age (Kryshtofovich, 1910). Later, he specified that some of them belonged to the Triassic (e.g. Mongugai flora), and others to Cretaceous (e.g. Nikan flora), with no Jurassic (Kryshtofovich, 1921). However, since 1950s, some geologists (e.g. N. A. Belyaevskii, B. I. Vasil'ev) found several locations yielding the Jurassic floras such as in the Litovka and Petrovka river basins (Geology USSA, 1969). The plant-bearing beds were intercalated the mollusk-bearing beds, yielding *Modiola*, *Cardinia*, *Myophori*, and *Palaeopharus*, etc. allocated in an independent Schitukhe Formation (Triassic and Jurassic..., 2004). Besides, in 1963, L. S. Baklanova found ammonites in this formation, identified by J. Krymgoltsa as *Franciceras* and *Caloceras*, showing the typical Hettangian stage. Later research work includes those of S. A. Shorokhova, V. A. Krassilov, and E. B. Volynets (Krassilov & Shorokhova, 1973; Volynets, 2008; Volynets & Shorokhova, 2010; Zakharov *et al.*, 2009) who have indicated the flora from the Litovka and Petrovka river basins aged in the Early Jurassic, also.

2 Geological Setting

The Schitukhe Formation was established in Petrovka and Litovka river basins of South Primorye, Russia in 1962 by B. D. Chemeris (Geology USSA, 1969; Triassic and Jurassic..., 2004). The forma-

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tion is composed of siltstone, finely-medium grained sandstone with rare interbedded conglomerates and carbonaceous siltstone, yielding remains of bivalves and plants and the formation was divided into the two subformations (Fig. 1).

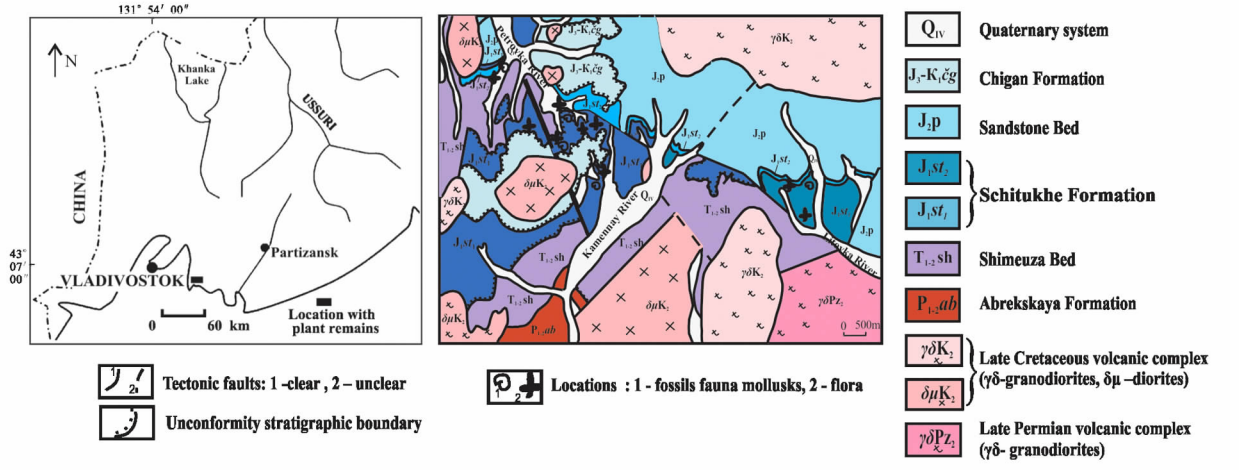

Fig. 1 Geographic location of Schitukhe flora(L) and geological map of the Petrovka River Basin(R)

The lower subformation is represented by sandstone and siltstone of cross and horizontal lenticular bedding, with a lot of plant remains, including *Neocalamites hoerensis* (Schimp.) Halle, *Cladophlebis* ex gr. *haiburnensis* (L. et H) Schimper, *C. scoresbyensis* Harris, *Ginkgoites muensterianus* (Presl.), *Ctenis sulcicaulis* (Phillips) Ward, *Phoenicopsis* ex gr. *angustifolia* Heer, *Czekanovskia* ex gr. *rigida* Heer, *Podozamites* ex gr. *lanceolatus* (L. et H.) Schimper, *Pitiophyllum* ex gr. *nordenskioldii* Heer, etc.; and bivalves *Modiola* and *Cardinia*. The thickness of this deposit is 200-210 m. The upper subformation consists mostly of sorted sandstone (fine – and coarse-grained), siltstone, gravelite and conglomerates. It is more coarse-grained, and the thickness of this deposit is 60 m (Fig. 2). At the base of this subformation, the early Liassic plants *Phlebopteris angustiloba* (Presl.) Hirm. et Hoerh. and *Clathropteris elegans* Oishi were found, and identified by S. A. Shorokhova (Konovalova & Shorokhova, 1990).

In the upper section of the sandstone of bed, A. I. Burago collected the remains of bivalves *Leda rostralis* Lam., *Lima* sp. and *Meleagrinella* sp., and I. I. Tuchkov and L. V. Sibiryakova pointed that *Leda rostralis* Lam. is the typical taxon of the Early Jurassic (Triassic and Jurassic…, 2004).

The more complete collections of plant remains (about 23 species of 19 genera) from the Schitukhe Formation were made by Krassilov & Shorokhova (1973). Shorokhova (1975 *) reported the plants including the typical early Liassic *Marattiopsis hoerensis* (Shimper) Thomas and *Phlebopteris angustiloba* (Presl.) Hammer et Hoerh, and the gymnosperms include *Nilssonia acuminata* (Presl.) Goeppert, *Pterophyllum* cf. *subaequale* Hartz, etc.

The updated collections of the plant remains from this formation has been made by E. B. Volynets, including horsetails (*Equisetites*, *Neocalamites*), ferns (*Cladophlebis*, *Marattiopsis*, *Phlebopteris*, *Clathropteris*, *Hausmannia* and *Todites*), seed-fern caytoniales (*Sagenopteris*), cycadophytes (*Pterophyllum*, *Ctenis*, *Nilssonia* and *Taeniopteris*), ginkgoales (*Ginkgoites*, *Baiera*, *Sphenobaiera*), czekanowskiales (*Czekanowskia*, *Phoenicopsis*) and conifers (*Podozamites*, *Cycadocarpidium*, *Cycadocarpidiostrobus*, *Pityophyllum*, *Elatocladus*), etc. The flora is dominated by cycadophytes, ferns and conifers, in general (Volynets, 2008; Volynets & Shorokhova, 2010; Zakharov *et*

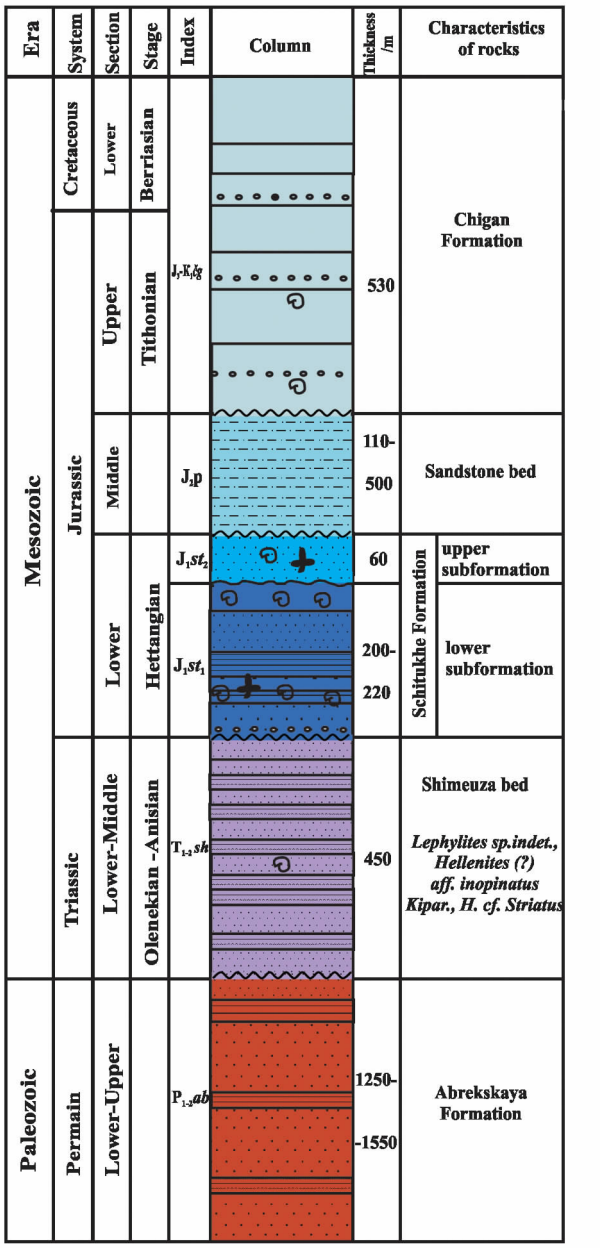

Fig. 2 Synthetic column of stratigraphy of South Primorye, Far East Russia

al., 2009).

3 Material

The material of the plant remains for the present study was collected from 13 localities in the Petrovka and Litovka river basins located in the southeastern Primorye Region (Fig. 1), including those collected by S. A. Shorokhova and V. A. Krassilov during 1968-1978, with assistance of the geologists from the Geological Survey of Primorye Region. The material includes mainly the well-preserved impressions of leaves, leafy shoots and reproductive organs. The collections have been stored in the Institute of Biology and Soil Sciences, Far East Russia in Vladivostok.

4 Composition of Schitukhe flora

The Early Jurassic Schitukhe flora is composed over 42 species belonging to 26 genera (Table 1), including Equisetales (*Equisetites munsterii* Sternb, *E.* sp., *Neocalamites hoerensis* (Schimp.) Halle, *N.* sp.), Filicales (*Marattiopsis hoerensis* (Schimp.) Thomas, *Phlebopteris angustiloba* (Presl) Hirm. et Hoerh., *Clathropteris elegans* Oishi, *Todites* sp., *Hausmannia* sp., *Coniopteris* sp., *Cladophlebis scoresbiensis* Harris, *C.* ex gr. *denticulata* (Brongn.) Font., C. ex gr. *haiburnensis* (L. et H.) Brongn., *C. schituchensis* Schor. (MS), *C. nebbensis* (Brongn.) Nath., *C.* sp.), Caytoniales (*Sagenopteris* cf. *undulata* Ward), Bennettitales (*Pterophyllum* cf. *subaequale* Hartz), Cycadales (*Ctenis sulcicaulis* (Phill.) Ward, *C.* cf. *yokoyamae* Krysht., *Ctenis* sp., *Nilssonia acuminata* (Presl) Goepp., *N. spinosa* Krassilov, *Taeniopteris lanceolata* Oishi, *Taeniopteris* sp.), Ginkgoales (*Ginkgoites* ex gr. *muensterianus* (Presl), *Sphenobaiera huangii* (Sze) Krass.), Czekanowskiales (*Czekanowskia* ex gr. *rigida* Heer, *Phoenicopsis* ex gr. *angustifolia* Heer), Coniferales (*Podozamites schenkii* Heer, *P. latifolius* (Schenk) Krysht. et Pryn., *P.* ex gr. *lanceolatus* (L. et H.) Schimper, *Podozamites* sp., *Cycadocarpidium* sp., *Cycadocarpidiostrobus* sp., *Pityophyllum* ex gr. *nordenskioeldii* Heer, *Elatocladus* sp.), and some unclassified taxa so far (*Carpolithes* sp., *Strobilites* sp., etc.).

From this composition, it is clear to show that the Schitukhe flora is dominated by the cycadophytes (including bennettitales and cycadoales), ferns, and conifers characterized by the occurrence of *Cycadocarpidium* and *Cycadocarpidiostrobus*. The genus *Cycadocarpidium* has usually been found in the Upper Triassic of

Table 1 Main taxa of Early Jurassic Schitukhe flora

No.	Taxa	Abundant	Numerous	Rare	Single
	Equisetales				
1	Equisetites munsterii Sternberg			*	
2	Equisetites sp.		*		
3	Neocalamites hoerensis (Schimp.) Halle	*			
4	Neocalamites sp.			*	
	Filicales				
5	Marattiopsis hoerensis (Schimp.) Thomas	*			
6	Phlebopteris angustiloba (Presl) Hirm. et Hoerham.			*	
7	Clathropteris elegans Oishi				*
8	Todites sp.				*
9	Hausmannia sp.				*
10	Coniopteris sp.				*
11	Cladophlebis scoresbiensis Harris			*	
12	C. ex gr. denticulata (Brongn.) Font.			*	
13	C. ex gr. haiburnensis (Lindl. et Hutt.) Brongnirt	*			
14	C. schituchensis Schorochova (MS)		*		
15	C. nebbensis (Brongn.) Nathorst		*		
16	Cladophlebis sp.			*	
17	Cladophledis sp. 1			*	
18	Cladophledis sp. 2			*	
	Caytoniales				
19	Sagenopteris cf. undulata Ward		*		
	Bennettitales				
20	Pterophyllum cf. subaequale Hartz	*			
	Cycadales				
21	Ctenis sulcicaulis (Phill.) Ward	*			
22	C. cf. yokoyamae Kryshtofovich				*
23	Ctenis sp.				
24	Nilssonia acuminata (Presl) Goeppert			*	
25	N. spinosa Krassilov			*	
26	Taeniopteris lanceolata Oishi			*	
27	Taeniopteris sp.			*	
	Ginkgoales				
28	Ginkgoites ex gr. muensterianus (Presl)	*		*	
29	Sphenobaiera huangii (Sze) Krassilov		*		
	Czekanowskiales				
30	Czekanowskia ex gr. rigida Heer	*			
31	Phoenicopsis ex gr. angustifolia Heer	*			

(**Continued 1**)

No.	Taxa	Abundant	Numerous	Rare	Single
	Coniferales				
32	Podozamites schenkii Heer			*	
33	P. latifolius (Schenk) Krysht. et Prynada				*
34	P. ex gr. lanceolatus (Lindl. et Hutt.) Schimper	*			
35	Podozamites sp.			*	
36	Cycadocarpidium swabii Nath.				*
37	Cycadocarpidiostrobus sp.				*
38	Pityophyllum ex gr. nordenskioeldii Heer		*		
39	Elatocladus sp.			*	
	Plants incertae sedis				
40	Linguifolium sp.			*	
41	Carpolithes minor Pryn.			*	
42	Strobilithes sp.				*

this region and its neighboring areas though it can rarely be found in earlier Jurassic strata (Shorokhova *et al.*, 2009; Sun, 1979, 1993; Oishi, 1932).

The abundance of cycadophytes (*Pterophyllum*, *Ctenis*, *Nilssonia*, etc.) and ferns (*Clathropteris*, *Hausmannia*, *Marattiopsis*, *Phlebopteris*, etc.) in the Schitukhe flora implies that its paleoenvironment would be under a subtropical or nearly subtropical and humid climates during the Early Jurassic. While the occurrence of ginkgoales, czekanowskiales and a deciduous conifer in this flora appears to indicate seasonal changeable features in climates, which usually occurred in the warm-temperate climates. Thus the Early Jurassic Schitukhe flora would be under the subtropical or subtropical to warm-temperate zone in paleoclimate for its growing time in the Early Jurassic.

5 Comparison of Schitukhe flora with some coeval floras of China

The Early Jurassic flora from the Schitukhe Formation of Primorye, Russia shows more similarity with its coeval floras from China.

Paleophytogeographically, the Early Jurassic floras of China have been divided into two floral regions, i. e. the Northern Floristic Region and Southern Floristic Region (Zhou & Li, 1980; Zhou, 1995). The Early Jurassic flora in the "Northern Region" is generally composed of the early assemblage (*Neocalamites-Cladophlebis* assemblage) and late assemblage (*Phlebopteris-Coniopteris* assemblage), represented by those mainly in the Qaidam Basin of Qinghai (Li *et al.*, 1988), Junggar Basin of Xinjiang (Deng *et al.*, 2003; Sun *et al.*, 2010). In the early assemblage of this region, some coniferous taxa, e. g. *Storgaardia* and *Cycadocarpidium*, can be found, while usually no fern *Coniopteris* in occurrence. Some Early Jurassic floras such as the Beipiao flora of western Liaoning, Shansonggang flora and Yihe flora of southeastern Jilin in Northeast China represent this assemblage (Mi *et al.*, 1996; Liu & Mi, 1981; Sun *et al.*, 2003, 2010, 2011).

The Early Jurassic Shansonggang flora from the coal-bearing Shansonggang Formation of Jilin is composed of 37 species of 22 genera including ferns, cycadophytes, ginkgoales, czekanowskiales and conifers (Sun *et al.*, 2003), which mostly similar to the Schitukhe flora of Primorye in composition. However, in the Shansonggang flora, both *Cycadocarpidium* and *Coniopteris* are coexisted though *Coniopteris* is rare in occurrence. The Early Jurassic Yihe flora from the coal-

bearing Yihe Formation in Jilin nearby Linjiang City, consists of over 35 species of 22 genera (Lu & Mi, 1981; Sun *et al.*, 2010, 2011), including the horsetail (*Equisetum*, *Neocalamites*, *Annulariopsis*); ferns (*Marattiopsis*, *Coniopteris*, *Clathropteris Cladophlebis*); cycadophytes (*Pterophyllum*, *Anomozamites*, *Cycadolepis*, *Nilssonia*, *Ctenis*, *Taeniopteris*); ginkgoales (*Ginkgo*, *Baiera*, *Glossophyllum*?), czekanowskiales (*Phoenicopsis*), and conifers (*Podozamites*), which are also similar to those of the Schitukhe flora of Primorye, though in the Yihe flora *Cycadocarpidium* was not found.

Another comparative flora is the Early Jurassic Beipiao flora from the coal-bearing Baipiao Formation in western Liaoning (Mi *et al.*, 1996). This flora consists of over 60 taxa, among which there are abundant ferns (*Marattiopsis hoerensis*, *M. muensteri*, *Todites denticulata*, *T. williamsonii*, *Taumatopteris pusilla*, *Clathropteris meniscioides*, *Cladophlebis*, etc.), ginkgoales (*Ginkgo huttoni*, *G. digilala*, *Sphenobaiera crispifolia*, etc.), cycadophytes (*Nilssonia schmidtii*, *N. tenuicaulis*, etc.), and coniferous (*Podozamites*, etc.), which is also similar to the Schitukhe flora in composition. However, there has been no *Cycadocarpdium* found, so far. General speaking, the Early Jurassic Beipiao flora is more similar with the Schitukhe flora of Primorye.

In the Southern Floristic Region of China, the more detailed study of the Early Jurassic floras has been made by Zhou (1984, 1995) in the Guanyintan Formation of Hunan, South China. Some related studies of the Early Jurassic floras in northeastern Sichuan (Ye *et al.*, 1986) and others (Zhou, 1995). The Early Jurassic floras in this region are divided into three assemblages, including of the early assemblage (Hettangian-Sinemurian), and the late assemblages (Pliesbachian and Toarcian). The early assemblage (*Marattiopsis-Otozamites* assemblage) is represented by those in the lower-middle Guanyintan Formation of Henyang. In this assemblage, there are *Neocalamites*, *Marattiopsis*, abundant *Cladophlebis*, Dipteridacea ferns and cycadophytes, with rare *Coniopteris* in occurrence. In general, this assemblage appears to be similar to the Schitukhe flora of Primorye in floral characters. Regarding the late assemblages (called as *Todites princips-Ptilophyllum* assemblage in total) in this region aged in the Pliesbachian and Toarcian, it appears to be more different from the Schitukhe flora of Russia, especially this assemblage has more *Coniopteris* (Zhou, 1995).

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