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Early Cretaceous flora from coal-bearing strata of Markovsky Peninsula in South Primorye, Russia

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Abstract: The Early Cretaceous flora from the coal-bearing strata (Ussuri and Lipovtsy formations) in the Markovsky peninsula of South Primorye, Far East Russia, is reported in some detail in this paper. The flora containing over 80 species of about 50 genera can be divided into two assemblages. The paleofloristic characteristics and the comparisons of this flora with its coeval floras from the adjacent region of the eastern Heilongjiang of Northeast China, indicate the flora and its coal-bearing strata of the Markovsky peninsula can be compared to those of the Chengzihe and Muling formations of the Jixi area of Heilongjiang, representing probably the late Barremian and Aptian age, respectively.

Key words: Early Cretaceous; flora; Ussuri Formation; Lipovtsy Formation; Barremian-Aptian; Markovsky peninsula; South Primorye; Russia

Introduction

The history of the research on the fossil plants from the Markovsky peninsula of South Primorye, Russia, has been over a century. Ivanov (1889) first collected the fossil plants which study was involved by Swedish paleobotanist Halle (1921) who considered these plants similar to the Wealden flora of Europe. Since 1910 Kryshtofovich (1916) had studied this flora, and identified two different aged floras, including the Mongugai flora (Triassic) and Nikan flora (Jurassic–Cretaceous) (Kryshtofovich, 1919). Prynada (1937, 1939; Kryshtofovich & Prynada, 1932) and Stempel (1924) also involved the phytostratigraphic research of this area. Since 1960s, Krassilov has made an enormous achievement to the study of Early Cretaceous flora and stratigraphy of South Primorye (Krassilov, 1967), including those of this peninsula (Fig. 1). Krassilov (1967) divided the Cretaceous strata into the Ussuri Formation (Barremian), Lipovtsy Formation (Aptian), Galenka Formation (Albian) and Korkino Group (Cenomanian). The first two formations are coal-bearing in nature which yield abundant fossil plants. For the recent years, Volynets (2003, 2005, 2006, 2009, 2010) has done more research on this Early Cretaceous floras and stratigraphy in this area, and obtained more plant fossils and related geological information from the Firsov cape and Markovsky peninsula. Some other advances in the concerned research have been gained also (Markevich, 1995; Markevich *et al.*, 2000; Bugdaeva *et al.*, 2004, 2006; Krassilov & Volynets,

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2008). In this paper the authors concentrate on the introduction of the recent advances in study of the flora from the coal-bearing strata (i. e. the Ussuri Formation and Lipovtsy Formation) in this peninsula.

2 Material and method

The Early Cretaceous plants of the Markovsky peninsula were mainly collected in the coastal outcrops on the Brazhnikov Bay area, but the most numerous finds are on the Klikov cape and near the Sokol Bay. Up to know, there have been over 1000 specimens of fossils collected, which is favorable for the present research. The research work was based on the collections of fossil plants from the coal-bearing strata at 21 localities (Fig. 1), including 8 sites from the Ussuri Formation (101, 102, 109-113, Barremian), and 13 from the Lipovtsy Formation (26, 26/1-7, 27, 27/1, 28, Aptian). Referred this research, there are 3 localities from the Galenka Formation (38-40, lower-middle Albian). The specimens of the fossil plants are composed of leaves, leafy shoots, seeds and fossil woods. Many of the specimens were subjected in chemical processing for cuticular study. However, there are only some compression specimens which can be used for anatomical study due to their poor preservations of cuticles.

The recent collections of the fossil plants at the Markovsky peninsula were mainly done by Volynets for the last several years, and by Kovaleva in summer 2011. All the specimens are stored in the Laboratory of Paleobotany of the Institute of Biology and Soil Science, FEB RAS in Vladivostok.

3 Stratigraphy and flora

The Lower Cretaceous coal-bearing strata in the Markovsky peninsula are distributed in the southern extension of the Razdol'naya Basin, represented by the Ussuri Formation and Lipovtsy Formation (Krassilov, 1967; Volynets, 2008, 2009, 2010) (Fig. 2). The most complete section studied in downstream of the Bogataya River and continues along the eastern coast of Amur Bay (Burde, 1961; Evlanov, 1962). Both the coal-bearing Ussuri and Lipovtsy Formations yield abundant fossil plants.

Ussuri Formation (K_1us)

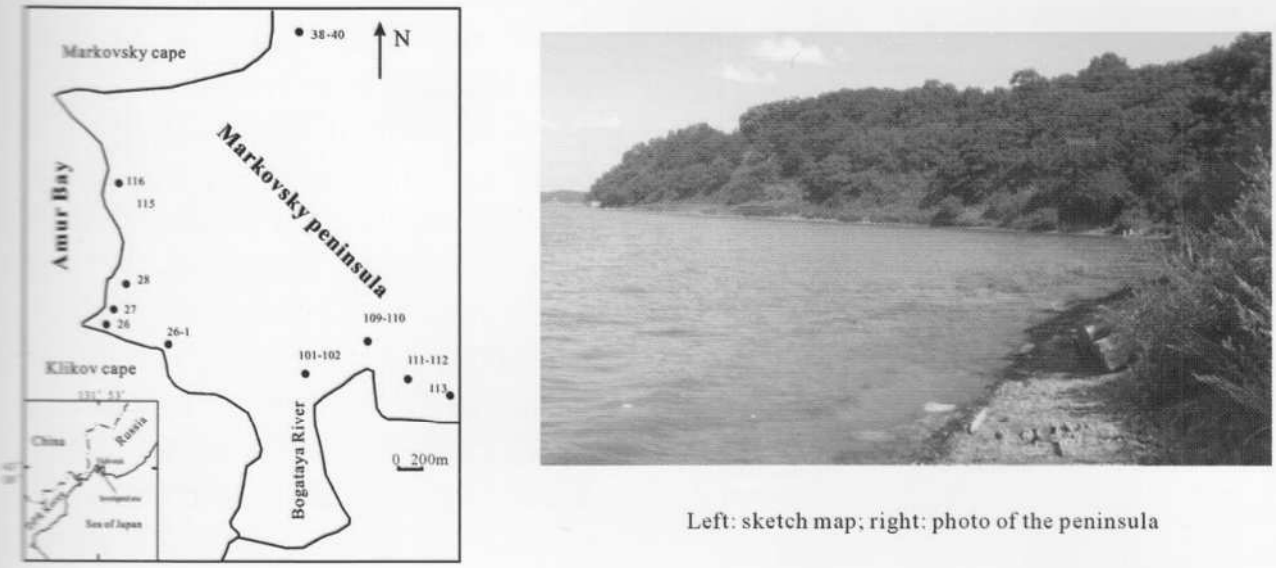
This Ussuri Formation (76 m in total thickness) consists mainly of cross-bedded fine and medium-grained sandstone and siltstone with elements of coal-bearing layers. The basal part of the Formation (1.5 m thick) begins with the fine-grained sandstone (Volynets, 2009), yielding *Onychiopsis psilotoides* (Stok. et Webb) Ward, *Coniopteris burejensis* (Zal.) Sew., *Lycopodites prynadae* Krass. and *Podozamites* sp. In the lower part of the section have also been found: *Cladophlebis* sp., *Podocarpus nicanicus* Krass., *Pseudolarix dorofeevii* Samyl., *Pityostrobus* sp., *Podozamites ex* gr. *lanceolatus* (Lindl. et Hutt.) Braun, etc. In the middle and upper parts of the Formation, the mudstone, fine-grained sandstone with thin-bedded siltstones, we found fossil plants: *Equisetites* sp., *Coniopteris burejensis* (Zal.) Sew., *Coniopteris* sp., *Onychiopsis psilotoides* (Stokes et Webb) Ward, *Adiantopteris yuasensis* (Yok.) Krass., *Podocarpus nicanicus* Krass., *Pseudolarix dorofeevii* Samyl., *Pityostrobus* sp., *Podozamites ex* gr. *lanceolatus* (L. et H.) Braun.

The above plant fossils of the Ussuri Formation are characterized by the *Ruffordia-Elatides* assemblage which was considered Barremian age (Krassilov, 1967), and probably the late Barremian or late Barremian-early Aptian in age, considered by the present authors.

Lipovtsy Formation (K_1lp)

The basal part (40 m thick) of the Lipovtsy Formation consists of cross-bedded thick layer of sandstone and layers of gravel-stone, with fossil woods. Rising up, there are sandstone, siltstone, carbonate mudstones, and coals. The carbonate mudstones and coals are 22 m thick. Fossil ferns were found here, e,g, *Onychiopsis* sp., *Coniopteris* sp., and *Cladophlebis* sp.

The middle part (57.5 m thick) of the Formation begins with the first most thick (0.4 m) layer of coal and carbonate mudstone (0.2 m) (Fig. 3). Then the deposits rise up with the cross-bedded fine-



Left: sketch map; right: photo of the peninsula

Fig. 1 Geographical positions of the fossil localities

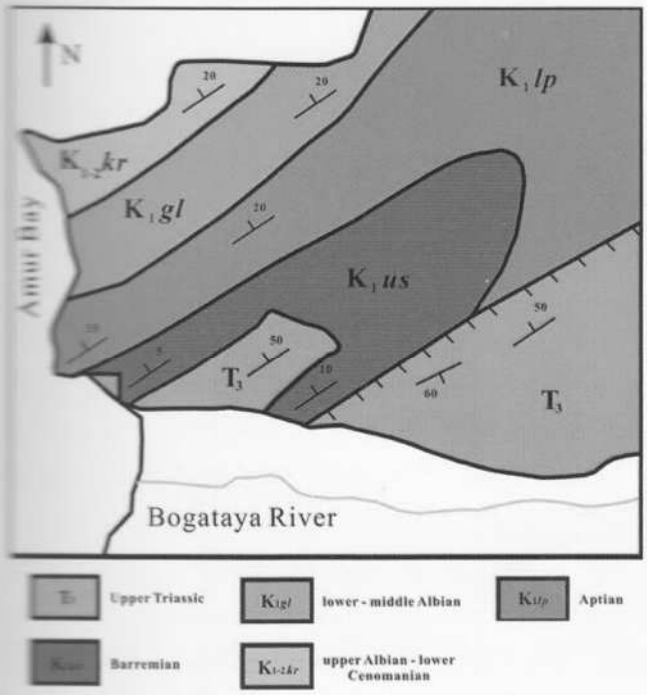


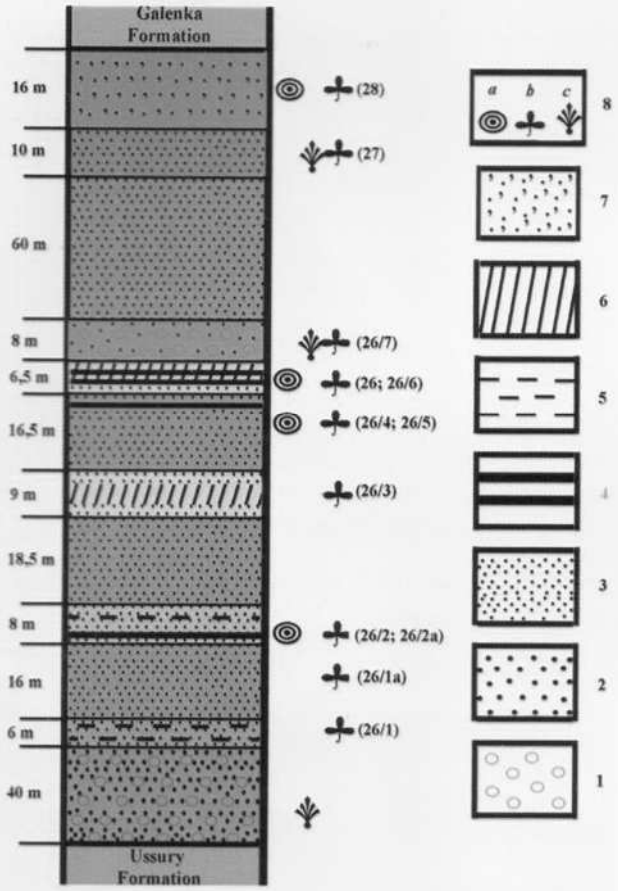
Fig. 2 Cretaceous deposits in the Markovsky peninsula

grained sandstone and grit-stone, and the carbonate mudstone and coals, where were found the fossil plants (locality 26): *Cladophlebis frigida* (Heer) Sew., *Nilssonia* ex gr. *orientalis* Heer and *Athrotaxopsis expansa* Font. In fine-grained sandstone are found tuffs and calcareous concretions, from which identified a few multi-chambered foraminifera and radiolarian nucleus. In this part some wood fossils are

Fig. 3 Coal-bearing beds of Lipovtsy Formation

also found, including *Xenoxylon latiporosum* (Cramer) Gothan and *Xenoxylon hopeiense* Chang (Afonin, 2008).

The upper part of the Formation (86.5 m thick) begins with layer of the dense fine-grained sandstones and tuffs. Then this section rises up mainly the medium-grained sandstone, siltstone with mudstone, carbonate mudstone and coals, and in sandstones also found calcareous concretions. Here (localities 27, 28) the plant fossils collected include: *Lycopodites nicanicus* Krass., *Equisetites* sp., *Onychiopsis psilotoides* (Stokes et Webb) Ward., *Cycadites sulcatus* Krysht. et Pryn., *Nilssonia* ex gr. *orientalis Heer*,



1 - conglomerate; 2 - gritstone; 3 - fine - and middle-grained sandstone; 4 - coal; 5 - mudstone;6 - siltstone; 7 - sandstone with tuff; 8 - (*a*) calcareous concretions; fossil plants (*b*) and woods (*c*).

Fig. 4 Sketch column of Lipovtsy Formation and fossil-bearing beds

Araucariodendron heterophyllum Krass., *Elatides asiatica* (Yok.) Krassilov and other taxa (Volynets, 2010).

Total thickness of the Lipovtsy Formation is 213 m (Fig. 4). The above plant fossils of this Formation are characterized by *Cycadites-Athrotaxopsis* assemblage which is considered the Aptian age (Krassilov, 1967; Volynets, 2009, 2010), and probably the middle-late Aptian.

The overlying deposits of the Lipovtsy Formation is the Galenka Formation (K_1gl, 105m thick) which is filled with tuffs, aged in the lower-middle Albian.

4 Comparison of the flora with its coeval floras from Northeast China

The Early Cretaceous coal-bearing strata and flora from the Markovsky peninsula are quite similar to their coeval coal-bearing strata and the flora from the eastern Heilongjiang Province of Northeast China where is adjacent to the Primorye, Russia.

In the eastern Heilongjiang of China, the Lower Cretaceous coal-bearing strata are represented by the Jixi Group which is mainly composed of the Chengzihe Formation (including Didao Formation in the lowest part) and the Muling Formation (Zheng & Zhang, 1982, 1983; Sun *et al.*, 1992, 1995, 2000; Sun & Dilcher, 2002; Yang, 2003). The flora of the coal-bearing Chengzihe Formation and Muling Formation of Heilongjiang can be comparative with the flora from the Ussuri and Lipovtsy Formations of the Markovsky peninsula, respectively. There are many common taxa occurred in both the Russian and Chinese two floras, such as: *Coniopteris* ex gr. *arctica* (Pryn.) Samylina, *Coniopteris burejensis* (Zal.) Seward, *Adiantopteris sewardii* (Yabe) Vassilevskaja, *Onychiopsis psilotoides* (Stokes et Webb) Ward, *Ruffordia goeppertii* (Dunk.) Seward, *Cladophlebis frigida* (Heer) Seward, *Polypodites polysorus* Prynada, *Acanthopteris onychioides* (Vassil. et K.-M.) Zhang(= *Birisia onychioides* (Vassilevsk. et K.-M.) Samylina), *Pterophyllum burejense* Prynada, *Nilssonia sinensis* Yabe et Oishi(= *Nilssonia* ex gr. *brongniartii* (Mant.) Dunker), *Ginkgo* sp., *Athrotaxites berryi* Bell, *Sphenolepis kurriana* (Dunker) Schenk (= *Athrotaxopsis expansa* Font.), *Podozamites lanceolatus* (Lindl. et Hutt.) Schenk, *Elatocladus submanchurica* Yabe et Oishi (= *Elatides asiatica* (Yok.) Krassilov), etc. Besides, many taxa can be comparable each other, such as *Thallites*, *Ginkgo*, *Pityostrobus*, *Pityolepis*, *Pityophyllum*, etc. On the other hand, the stratigraphic sequences of the coal-bearing strata from the Chinese and Russian two localities are very similar in characters.

Although the floras of the Jixi Group of Heilongjiang were considered some earlier in age, e. g. the Chengzihe Formation as late Hauterivian – early Barremian (Sun & Dilcher, 2002), and the Muling Formation as the late Barremian –early Aptian (Sun *et al.*, 1995), the marine bivalves fossils from the

Chengzihe Formation has been considered as Aptian age (Sha *et al.*, 2009). On the other hand, the dinoflagellates fossils of the Chengzihe Formation, which were regarded as the main evidence for dating (Sun *et al.*, 1992, 1995; Sun & Dilcher, 2002), were considered as younger age by Russian paleozoologist Konovalov (in communications). Therefore, the authors consider the floras of the coal-bearing Chengzihe Formation and Muling Formation of Heilongjiang, China can be compared with those of the Ussuri and Lipovtsy Formations of the Markovsky peninsula, Russia, and their ages might be as the late Barremian (or to early Aptian) and Aptian, respectively.

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