



## The Early Cretaceous Flora of Razdol'naya River Basin (Primorye Region, the Russian Far East)

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Manuscript received: 10.10.2015  
Review completed: 22.10.2015  
Accepted for publication: 25.10.2015  
Published online: 28.10.2015

### ABSTRACT

Study of the Early Cretaceous (the Barremian-Albian) flora of Primorye region was begun by V.A. Krassilov more than 60 years ago. It was a significant contribution to knowledge of the Cretaceous floras of Asia. The most diverse and abundant flora occurs in the Razdolnaya River Basin of the Primorye region. We continue to research this fossil plant assemblage using light and scanning electron microscopy.

**Key words:** fossil flora, Early Cretaceous, Razdol'naya River Basin, Primorye region

### РЕЗЮМЕ

**Бугдаева Е.В., Вольнец Е.Б., Маркевич В.С. Раннемеловая флора Раздольненского бассейна (Приморье, российский Дальний Восток).** Изучение раннемеловой (баррем-альбской) флоры Раздольненского бассейна Приморья было начато В.А. Красильным более 60 лет назад. Это был значительный вклад в познание меловых флор Азии. Наиболее разнообразной и обильной является флора Раздольненского бассейна. Мы продолжаем исследовать ее с помощью светового и сканирующего электронного микроскопов.

**Ключевые слова:** ископаемая флора, ранний мел, Раздольненский бассейн, Приморье

Only a small number of taxa in the Early Cretaceous flora of the Primorye region (the Russian Far East) has received a full-fledged up-to-date treatment. Thus a lot of problems remain unsolved, and current solutions are no more than tentative. Perceptions of the flora have changed gradually, from it being a "Indian-European Flora" to a "Siberian-Canadian Flora". Major evolutionary changes took place in the ferns, conifers and early angiosperms in the Aptian and Albian stages. The Early Cretaceous vegetation of the Primorye region was remarkably conservative, but it changed rapidly during the Albian, related to intensive volcanism, intensification of tectonic processes, climatic deterioration, and extinctions at higher trophic levels. The paleogeographical significance of the Early Cretaceous plants here is still not fully appreciated, and the importance of the fossil record is often obscured by prevailing dogmatic tectonic interpretations.

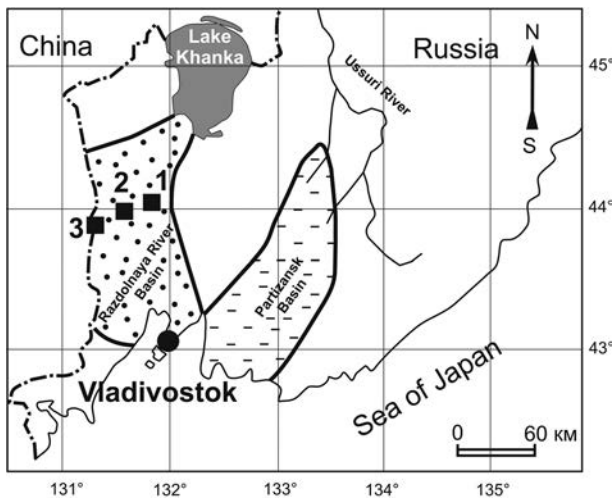
The Early Cretaceous flora of the Primorye region, one of the richest in the world, shows an important stage of the florogenesis of Asia. The uniqueness of the flora was caused by its position at the boundary between the Indo-European and Siberian-Canadian regions.

The first information about finds of these plant remains appeared at the end of the 19th century, but their systematic study was begun by Afrikan Nikolaevich Kryshstofovich at the beginning of the 20th century (Kryshstofovich 1910, 1916, 1919, 1921, 1923). He has revealed two

different floras: an older Mesozoic one was named as the Mongugay flora, and a younger Mesozoic one, the Nikan flora. Consequently discoveries of angiosperms allowed Kryshstofovich to define more precisely the age of the latter assemblage, as the Early Cretaceous (Kryshstofovich 1928, 1929). Later palaeobotanical studies were continued by Prynada (1937, 1939, 1941), Shtempel (1924, 1926, 1960), Vakhrameev (1959), and Samylina (1961), with identifications of new taxa of these Early Cretaceous plants.

In the early 1960s, in the Primorye a talented paleobotanist, stratigrapher and geologist, Valentin Abramovich Krassilov, began his work. Already his first publications showed that an outstanding researcher had appeared in science. In 1965, he defended his thesis on "The Early Cretaceous flora of Southern Primorye and its importance for the stratigraphy", and two years later his monograph was published, the provisions of which have not lost their significance today. This work manifested an amount of studied material and a high level of its comprehension that was revolutionary for those years. One of the first in the field, Krassilov applied the epidermal-cuticular methods which allowed him to reveal new features of the morphology of fossil plant leaves and reproductive organs.

Krassilov devoted a lot of time to research on the flora and stratigraphy of the Razdol'naya River coal basin, located in the southwestern Primorye region (Fig. 1). The sequence of deposits is represented there by the Nikan Group



**Figure 1.** Study localities. 1 – Lipovtsy coalfield, 2 – Ilyichevka coalfield, 3 – Konstantinovskoe coalfield

(Barremian–Albian) and Korkino Group (Albian–Cenomanian). At the suggestion of Krassilov (1965), the first was divided into the Ussuri (Barremian), Lipovtsy (Aptian) and Galenky (Albian) formations. Of greatest interest is the Lipovtsy Formation because of its industrial significance in its coal-bearing deposits (Krassilov 1967).

In the 1960s, Krassilov first studied the extremely diverse (141 species) Early Cretaceous flora of the Razdolnaya River Basin. He described 60 new species, reconstructed the patterns of the vegetation and climate change at that time, and drew a correlation with coeval floras of China, Korea, Japan, and Western Canada (Krassilov 1964a, b, 1965a, b, c, d, 1967). The main conclusions of Krassilov on the flora and stratigraphy of the basin have not lost their relevance today.

Palaeobotanical research on the Razdolnaya River Basin since the 1980s has been continued by Volynets, who, together with geologists of the Primorye Survey of “Primorgeologiya”, collected plant remains extensively. As a result of her study, the taxonomic composition of the floras of the Ussuri, Lipovtsy and Galenky formations and the Korkino Group has been significantly augmented, and the geological age of these stratigraphic units defined more precisely (Volynets 2005, 2006). Additionally, a new species of Miroviaceae was described by Nosova (2001).

In contrast to the palaeobotanical studies, palynological work on the Razdolnaya River Basin began only in the 1960s, and was related to the definition of the age of the Cretaceous strata for the geological mapping of the region (Bolkhovitina & Kotova 1963, Verbitskaya 1965, Shugaevskaya 1962, 1966, 1977). The narrower scope of the application of palynology was broadened by Markevich, who, in addition to the development of palynostratigraphy (palynological zonation), first considered some theoretical issues, such as the problem of the synchronicity of bioevents during the Cretaceous Period, the division of palynozones in East Asia, tracing the appearance events and the morphological evolution of the pollen of flowering plants, the recognition of the rates of evolution of the Cretaceous palynoflora, and hence the palynofloral differentiation in accordance with the climatic and tectonic zones (Markevich 1994, 1995).

In recent years, a detailed study on the plants giving rise to coals of the Lipovtsy, Ilyichevka and Konstantinovka coalfields of the Razdolnaya Basin was begun.

### The Lipovtsy Coalfield

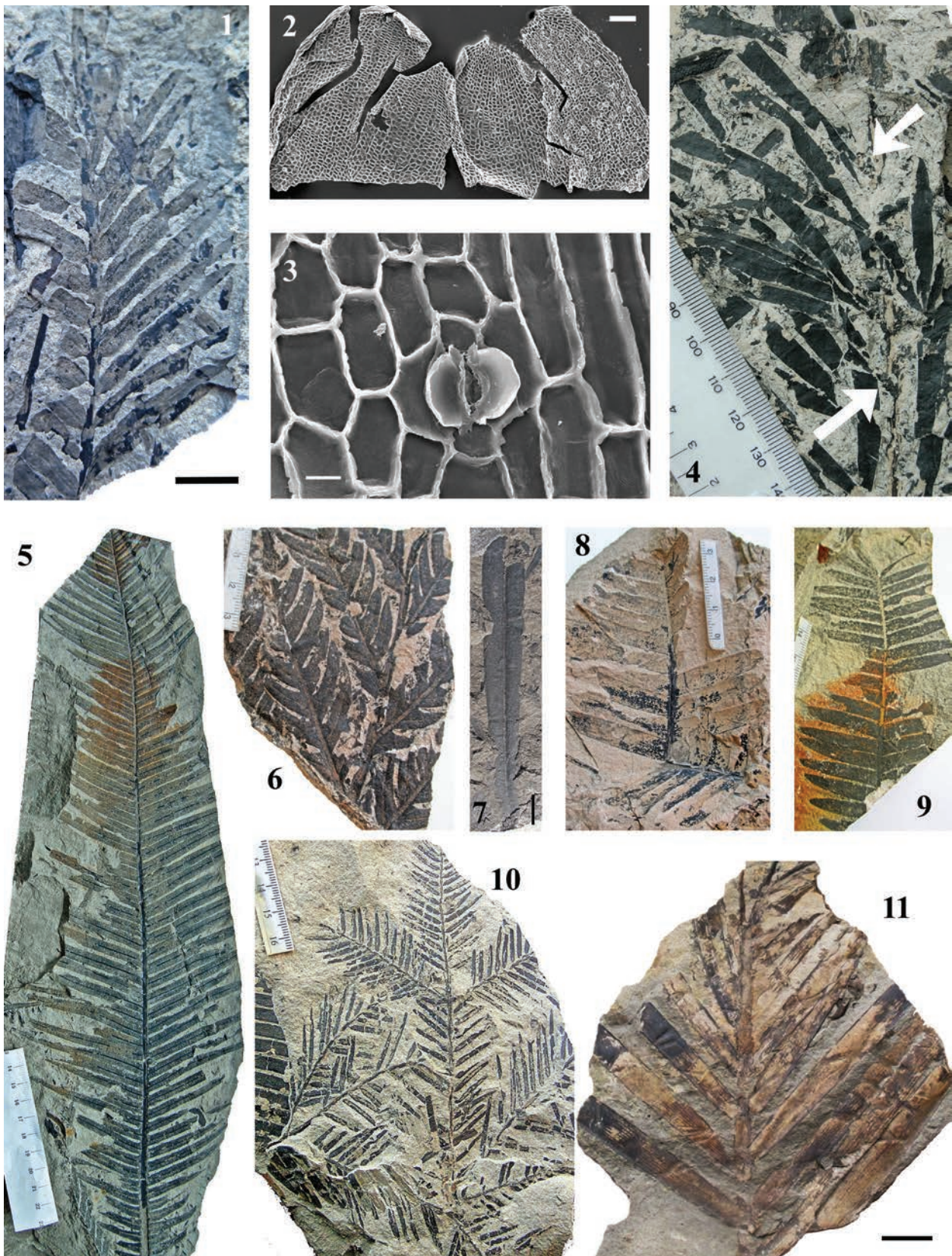
At the beginning of the last century Kryshtofovich worked here. He drew particular attention to “... coal, compact, hard, brownish-black, matte, heavy, filled, or rather more weight consisting of fine needles of resin material penetrating it in all directions, brilliant in the section...” (Kryshtofovich 1928). To this material he allocated a special class of liptobiolith coals – rhabdopissite (from the Greek words *ράβδος* – stick) and *πίσσα* – resin) due to their composition like gum sticks. Also, Kryshtofovich suggested that these sticks “... no other than the resin or gum filling of ducts of trees, conifers or rather – cycadophytes, that probably bennettitaleans...” (ibid). Subsequently, with respect to rhabdopissite-forming plants, palaeobotanists and coal geologists followed the views of Kryshtofovich.

Chemical research on rhabdopissite resin sticks revealed that their parent matter was tannal and resinol resins, different in composition from the resins of conifers (Amosov et al. 1973). Therefore, these could not have been the producers of the Lipovtsy’s liptobioliths.

According to palynological data, the opinion was expressed that the source materials for coals of the Razdolnaya Basin were the remains of conifers, ferns, horsetails, club mosses, cycadaleans, bennettitaleans, ginkgoaleans, and mosses (Verbitskaya et al. 1965). A situation when almost all groups of plants were involved in the formation of coal gives rise to doubt. It should be noted that the composition of palynospectra reflects most the averaged composition of the vegetation in the whole of the drainage basin. Along with this, a complicating factor is the different degree of productivity of anemo-zoophilous plants, as well as the ways that palynomorphs were transported to their place of burial. These factors should be taken into account in the reconstructions of the marsh plant communities, representatives of which formed the coal.

After more than a hundred years there remains the problem that the plants which gave rise to rhabdopissites have not been revealed. The fact of the matter is that palaeobotanists actually have not investigated such phylogenetic rocks as coal. Usually they have collected plant remains from clastic strata (mudstone, siltstone, and sandstone), underlying and overlying the coal seams. It was to the plants found in these interlayers that the coal-forming role was ascribed, whereas terrigenous sedimentation takes place in a completely different environments; the sedimentary material transported from the highlands to the lowlands carried plant fragments. Consequently, the plant taphocoenoses have a mixed type, as in their composition both marsh plants and slope plant communities are represented.

Based on the fact that coal is phylogenetic rock, it was decided to use its bulk maceration. To obtain disperse cuticles the coals dissolved in concentrated nitric acid, washed with distilled water, then exposed to 10 % alkali (KOH) and also washed. Isolated cuticles were mounted into preservative medium of permanent preparations.



**Plate 1** Fig. 1. *Mirovia orientalis* (Nosova) Nosova, Lipovtsy Coalfield, Lipovtsy Formation, scale bar 1 cm; Fig. 2. *Mirovia orientalis*, Lipovtsy Coalfield, Lipovtsy Formation, lower and upper cuticle of upper part of leaf, scale bar 200 µm; Fig. 3. *Mirovia orientalis*, Lipovtsy Coal Field, Lipovtsy Formation, lower cuticle of leaf, stoma, inner view, scale bar 20 µm; Fig. 4. *Pseudotorellia krassilovii* Bugdaeva, Lipovtsy Coalfield, Lipovtsy Formation, white arrows indicate short shoots; Fig. 5. *Nathorstia pectinata* (Goepfert) Krassilov, Lipovtsy Coalfield, Lipovtsy Formation; Fig. 6. *Cladophlebis frigida* (Heer) Seward, Lipovtsy Coal Field, Lipovtsy Formation; Fig. 7. *Nilssoniopteris rbitidorachis* (Kryshtofovich) Krassilov, Lipovtsy Coalfield, Lipovtsy Formation; scale bar 1 cm; Fig. 8. *Pterophyllum sutchanense* Prynada, Lipovtsy Coalfield, Lipovtsy Formation; Fig. 9. *Pterophyllum* aff. *burejense* Prynada, Lipovtsy Coalfield, Lipovtsy Formation; Fig. 10. *Torreya nicanica* Krassilov, Lipovtsy Coalfield, Lipovtsy Formation; Fig. 11. *Zamiophyllum ivanovii* (Kryshtofovich et Prynada) Krassilov, Lipovtsy Coalfield, Lipovtsy Formation, scale bar 1 cm

However, this method has a significant shortcoming. Fern fronds' fine phytollemma do not usually stand the maceration, in which case the information about this group of plants is lost. But palynological data can fill this gap, as spores have thick exine, resistant to chemicals.

Thus, using data on plant macrofossils, spores and pollen, it is possible to define the composition of the coal-forming plants and restore the structure of swamp communities.

It was revealed during the maceration of rhabdopissite from thick productive coal seam "Rabochiy" in Lipovtsy coal mine that the constituent part of coal of is predominantly (almost 100 %) the remains of leaves of *Mirovia orientalis* (Nosova) Nosova (Plate 1, Figs. 1–3) relating to Miroviaceae. In the formation of humic coals of this coalfield a ginkgoaleans played significant role (*Pseudotorellia krassilovii*, Plate 1, Fig. 4). The ferns (such as Cyatheaceae and Gleicheniaceae) also were a part of coal-forming plants.

Krassilov (1967) has collected abundant plant remains from the productive "Rabochiy" coal seam – in all 31 taxa. According to him, the most common plants are ferns *Nathorstia pectinata* (Plate 1, Fig. 5), *Cladophlebis frigida* (Plate 1, Fig. 6), cycadophytes *Nilsoniopteris rithidorachis* (Plate 1, Fig. 7), *Pterophyllum sutschanense* (Plate 1, Fig. 8), *P. aff. burejense* (Plate 1, Fig. 9), *Ctenis yokoyamae*, *C. latiloba*, conifers *Podocarpus harrisi*. We revealed deposits dominated by *Torreya nicanica* (Plate 1, Fig. 10) and *Zamiophyllum ivanovii* (Plate 1, Fig. 11).

The palynospectrum of rhabdopissite from the "Rabochiy" coal seam is characterized by the dominance of bisaccate pollen of such as taxa of the Pinaceae and Podocarpaceae, whereas that relatable to the Taxodiaceae played a lesser role. *Ginkgoecycadophytus* sp. and *Eucommiidites troedsonii* Potonié are of little importance; and the taxonomic diversity of ferns is low. They are represented by mainly by taxa relatable to the Cyatheaceae and Dicksoniaceae and, to a lesser degree, close to the Gleicheniaceae. Representatives of taxa relatable to the Schizaeaceae, Osmundaceae, and Polypodiaceae constitute a small part of the pollen spectrum.

In the deposits we have found in the burials in situ the matoniaceous fern *Nathorstia pectinata*, and the cyatheaceous fern *Alsophbilites nipponensis* (Oishi) Krassil. which produced, respectively, large numbers of spores *Leiotriletes* and *Cyathbidites*, which predominate in the palynospectra.

Based on the study of lithofacies, it has been deduced that the "Rabochiy" coal seam was formed in a period of the maximum peneplanation of the relief, in a vast alluvial valley with lakes, river channels and floodplains under hot and humid climatic conditions (Sharudo 1972). Also, according to this author, the rhabdopissites of the Lipovtsy coalfield accumulated in the littoral zone of a lake.

The coals are enriched by light resin bodies, with extremely comminuted cuticle of leaves, which may indicate a rather long-range transport from the place of growth to the burial site. Almost monospecific burials of miroviaceous leaves are known (Manum et al. 2000, Kirichkova 1985, Gordenko 2004, 2007), which is evidence of the dominant role of these plants in the lowland vegetation. There is no doubt that they have made a significant contribution to the

formation of resinous coal, although it is not yet entirely clear what their role was in the formation of the liptobolites of the Razdolnaya River Basin.

As mentioned above, the palynospectra of the "Rabochiy" coal seam are, besides bisaccate pollen, dominated by spores of Cyatheaceae, Dicksoniaceae, and Gleicheniaceae. Ferns with thin cuticles cannot withstand the chemical maceration of coals, and are absent in residues. But, based on the dominance of these spores in the palynospectra and finds in the coal seam's roof of rosettes and fronds of *Nathorstia pectinata* (Matoniaceae) and *Alsophbilites nipponensis* (Cyatheaceae), we can assume they played a dominant role in the peat formation along the shores of Lake Lipovtsy.

According to our data, the representatives of the Cyatheaceae were the predominant component of palynospectra in the Late Jurassic coals of the Bureya Basin and Early Cretaceous coals of Transbaikalia, the Amur River region and the Primorye region. Beginning with the Berriasian, the Gleicheniaceae intruded into swamp plant communities (Bugdaeva & Markevich 2007); in the Aptian they became the dominant plants. Ginkgoaleans, especially *Pseudotorellia* and *Sphenobaiera*, also supplied material for coal formation (Krassilov 1972, Bugdaeva 1995, 2010). During the Mesozoic, *Pseudotorellia* was a dominant form in wetland plant communities in the Eurasia (Bugdaeva 1999). As elsewhere, the coal-forming plants in the Aptian of Lipovtsy coalfield remained the cyatheaceous and gleicheniaceous ferns, and *Pseudotorellia*, but the Miroviaceae played the main role.

#### Ilyichevka Coalfield (Porechensky quarry)

For the first time, we have conducted a palaeobotanical study of the recently opened Porechensky quarry, in which the coal seams of the Ilyichevka coalfield crop out.

In the Porechensky quarry the section, alternating of light yellowish-gray sandstones and dark grey silty mudstones occur, and several interbedded seams of coal have been studied. The thickness of the coal seams varies from 0.3 to 7 m.

After maceration of coal from all coal beds, the dispersed cuticles were obtained. As a result, we have been able to reveal the taxonomic composition of the plants composing the coal. The residue from the lower thick coal seam consisting of rhabdopissite (7–9 m) is dominated by dispersed cuticles described by Krassilov as representatives of Araucariaceae (*Araucariodendron* cf. *angustifolium* Krassil. and *A. heterophyllum* Krassil.). Rare cuticles of *Pseudotorellia* sp. also occur. Apparently, some of the coal-forming plants were also gleicheniaceous and cyatheaceous ferns, whose spores are prevalent in palynospectrum in this bed. The upper part of this seam consists of thin interbedded siltstone and argillaceous layers (weathered acid volcanic ash) and thin layers of coal. Influx of the clastic material favoured the displacement of plants which were growing along the margins of this swamp. In addition to dispersed cuticles of *Araucariodendron*, the remains of the bennettite *Nilsoniopteris rithidorachis* and conifer *Tombarrisia florinii* Krassil. were discovered. The taxonomic composition of the palynospectrum from the upper part of the lower thick coal seam also shows changes, due to the reducing significance of the Gleicheniaceae, increasing significance of *Leiotriletes*, the ap-

pearance of bisaccate pollen, which in the higher strata [of this section] becomes a ubiquitous participant in the spectra, albeit in small quantities.

The upper productive coal seam (1–2 m thick) is partially composed of rhabdopissite. Identified cuticles mainly belong to the Miroviaceae; the representatives of Cheirolepidiaceae are rare.

The palynospectrum from the mudstone at the bottom of the upper coal seam is characterized by increased taxonomic diversity (the appearance of angiosperms is particularly remarkable) and a change of the dominant taxa: *Ginkgocycadophytus* begins to play a dominant role, and there is a sharp reduction in the significance of the Gleicheniaceae.

The palynospectrum from the upper coal seam is characterized by low taxonomic diversity, dominance by ferns (Gleicheniaceae, Cyatheaceae, *Leiotriletes* – more than 60 %). *Ginkgocycadophytus* frequency is rather high (up 16.7 %); whereas pollen of angiosperms is extremely rare.

In the upper part of section, there is an alternation of fine-grained sandstone, silty mudstones and thin coal layers. The last are composed of remains of Miroviaceae, but with increasingly diverse bennettites *Anomozamites arcticus* Vassil., *Nilssoniopteris rhitidorachis*, *N. prynadae* Samyl., and *Nilssoniopteris* sp. The dispersed cuticles of allegedly angiosperms are extremely rare.

The palynospectrum is dominated by Gleicheniaceae; the importance of the other ferns is very limited. The taxonomic diversity on the palynospectrum is quite high, including by angiosperms.

#### Konstantinovskoe Coalfield (Poltavka mine)

The section at the Poltavka coal mine is geologically similar to the previous one. At the base of the sequence a member with very well-developed coals occurs, including rhabdopissite seams. It is overlain by alternating sandstones, siltstones and thin coal seams.

Coals consists of the following plants: bennettitalean *Nilssoniopteris rhitidorachis*, taxodialean *Athrotaxites orientalis* Deng and Chen, Miroviaceae (*Mirovia* sp.).

#### CONCLUSION

Professor Krassilov so deeply and thoroughly has studied the Early Cretaceous plants of the Razdolnaya River Basin that those who follow can only add some finishing touches to the image of this fossil flora. But he conducted his research in the 1960s, and some problems remain unsolved. For instance, it is necessary to study the cuticles of leaves using scanning and transmission electron microscopy. It is still unknown, what is role was played by plants in the formation of coal, and it is necessary to identify their floral composition, to reveal the structure of the swamp plant communities. Further, the Razdolnaya River Basin is the place of origin of unique resinous coals. Bugdaeva and Markevich revealed that they are composed mainly of Miroviaceae, but the following question remains – how were rhabdopissites formed?

Based on our research we can conclude that in the Aptian the main components of the swamp plant communities were conifers Miroviaceae, Araucariaceae, taxodialeans (*Athrotaxites orientalis*), ginkgoaleans (*Pseudotorellia krassilovi*), bennettites, as well as gleicheniaceous and cyatheaceous ferns. These plants supplied the material for the accumulation of rhabdopissite and rhabdopissite-humic coals in the Razdolnaya River Basin of Southern Primorye.

*xites orientalis*), ginkgoaleans (*Pseudotorellia krassilovi*), bennettites, as well as gleicheniaceous and cyatheaceous ferns. These plants supplied the material for the accumulation of rhabdopissite and rhabdopissite-humic coals in the Razdolnaya River Basin of Southern Primorye.

#### ACKNOWLEDGEMENTS

We, the authors, express our appreciation to Prof. V.A. Krassilov for the happiness brought by his appearance in our lives, for his advices, help, and kindness. We are grateful to Prof. Sun Ge and Dr. W. Wimbledon for corrections in this paper.

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