

New Data on Palynostratigraphy of the Lipovtsy Formation in the Razdol'naya Coal Basin (Southern Primorye)

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Abstract—Palynological samples, plant megafossils, and fossil wood taken from the upper Lipovtsy Subformation (Porechye open-pit coal mine in the Il'ichevka coalfield, Razdol'naya River Basin, southern Primorye), as well as coal samples for determining coal-forming plants from dispersed cuticles are analyzed. The taxonomic composition of the identified palynomorphs from the coals and interstratal clastic sediments indicates the Aptian age of host deposits. The palynological spectra from the lower humic–rhabdopissite coal seam are dominated by Gleicheniaceae and Cyatheaceae accompanied by Dicksoniaceae and *Ginkgocycadophytus*. In the palynological spectra from the upper coal seam, the share of Gleicheniaceae substantially decreases, though they remain dominant; simultaneously, single angiosperm pollen grains appear in them. The spectra from the clastic rocks are dominated by Polypodiaceae and Cyatheaceae. The taxonomical composition of the gymnosperms is relatively diverse, although their abundance is low. The share of angiosperms increases with respect to both their diversity and abundance. The angiosperm pollen, found for the first time in the Aptian deposits of the Razdol'naya River Basin, provides grounds to assume that these plants appeared earlier than previously thought (early Albian). The coal-forming plants of the Il'ichevka coalfield are determined.

Keywords: spore-pollen spectra, fossil plants, Lower Cretaceous, Aptian, Il'ichevka coalfield, Razdol'naya coal Basin, Primorye

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INTRODUCTION

The Razdol'naya coal Basin is located in the southwestern part of southern Primorye, where it occupies a spacious region from the Amur Bay coast to the middle reaches of the Razdol'naya River. It is approximately 5000 km² in size (Fig. 1).

The Basin and its framing structures are composed of Paleozoic, Mesozoic, and Cenozoic sedimentary, magmatic, and metamorphic rock complexes. Of them, the most widespread rocks are basalts, which occupy approximately half of the region. The coaliferous freshwater terrestrial deposits of the Razdol'naya Basin were attributed to the Nikan Group (regional stage) in [13]. Subsequently, they were estimated to be Barreman–Albian in age on the basis of fossil plants [5, 14, 22, 27] and molluscan assemblages [6]. Palynological data support this conclusion [1, 5].

In the northern part of the Razdol'naya Basin, the Lower Cretaceous deposits (Nikan Group) rest with the erosional surface upon Ordovician and Late Permian granitoids being overlain by Neogene and Quaternary sedimentary sequences. The group is subdivided into three formations: Ussuri (lower), Lipovtsy (middle), and Galenka (upper). Krassilov [10] was the

first to propose these stratigraphic units. The northern part of the Basin hosts the Lipovtsy, Il'ichevka, and Konstantinovka coalfields.

Initially, the coaliferous productive formations of the Basin were considered to be Jurassic in age. Subsequently, Kryshtofovich [13], who studied the Lipovtsy mine, established their Early Cretaceous age on the basis of abundant plant remains. He was the first to define a special type of liptobiolith coals and propose the term “rhabdopissites” for them.

We have carried out for the first time geological and biostratigraphic studies in the recently implemented Porechye open-pit coal mine (44°06'12.7" N, 131°30'3.7" E), one of the areas of the Il'ichevka coalfield [18]. The open-pit coal mine is located in the Slavyanka, Krest'yanka, and Sinelovka river Basins, where it contacts in the east along the large normal fault (amplitude 500 m) the Lipovtsy coalfield; its western boundary coincides with the meridional Boguslavka fault [24].

Like in the Lipovtsy coalfield, the coal-bearing potential of the Il'ichevka coalfield is provided by Lower Cretaceous sequences united into three formations: Ussuri, Lipovtsy, and Galenka. The Lipovtsy

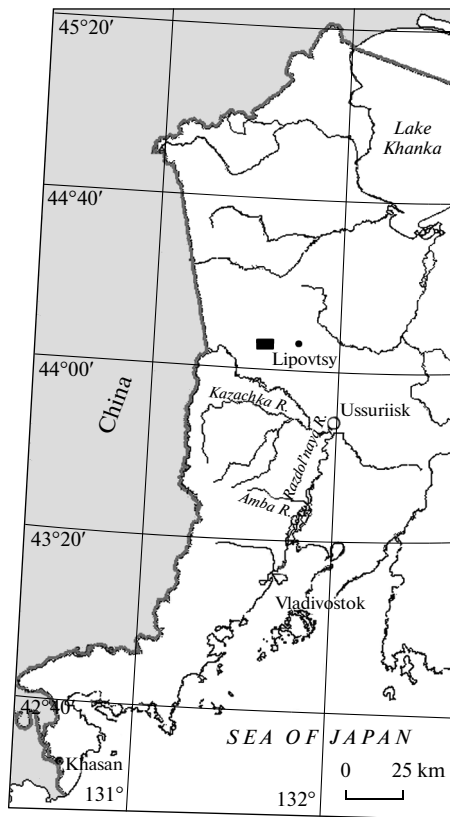


Fig. 1. Location of the Porechye open-pit coal mine of the Il'ichevka coalfield, Razdol'naya Basin, southern Primorye.

Formation is subdivided into two subformations: the lower unproductive and upper coaliferous. The unproductive subformation (up to 440 m thick) is composed of inequigranular sandstones and conglomerates. The upper coaliferous subformation (up to 200 m thick), composed of sandstones and siltstones, contains two productive hard coal seams (Rabochii and Verkhni), which are characterized by complex structure and represented by humic, rhabdopissite–humic, and rhabdopissite coals. Like the Lipovtsy coals, their counterparts from the Il'ichevka coalfield represent a valuable raw material for the chemical industry [24, 26].

The geological structure of the Il'ichevka coalfield is still poorly studied: only two small areas are explored for coal. For this reason, for our geological and paleobotanical research (Figs. 2, 3) we have chosen a new area of the coalfield exposed in the Porechye open-pit coal mine [3, 18].

MATERIALS AND METHODS

During fieldworks in 2013, we described the section, sampled fossil plant remains, and took samples for the palynological analysis. Some results of these investigations are published in [18]. Additional sampling of plant remains and rocks for palynological analysis from the coals and interstratal sediments was carried out in 2014. This work presents the obtained new data.



Fig. 2. Lower part of the Porechye open-pit coal mine section.



Fig. 3. Upper part of the Porechye open-pit coal mine section.

The samples for palynological analysis were subjected to preliminary treatment in line with the standard maceration technique [21].

The microscopic investigation of pollen and spores, as well as plant macrofossil remains, was conducted under an Axio-Scop-40 light microscope equipped with an AxioCamHR (Carl Zeiss design) in the laboratory of electron microscopy at the Institute of Biology and Pedology.

The permanent preparations in the gelatin–glycerin preserving agent and thin sections are stored in collection room of laboratory of Paleobotany of the Institute of Biology and Soil Science (collections nos. 181 and 32, respectively).

GEOLOGICAL STRUCTURE AND PALEOBOTANICAL CHARACTERISTICS

The following section is observable in the Porechye open-pit coal mine from the base upward (Fig. 4):

(1) Coal with 5–6 intercalations of light gray silty mudstones 3–50 cm thick (the thickest two in the middle of the coal seam). The coal is composed of a mixture of humic and rhabdopissite varieties with small resin rods 0.5–1.0 mm in diameter at the bedding planes of the latter variety. The intercalations of detrital rocks are represented by tuffaceous silty mudstones locally grading along the strike into tuffstones or tuffs. They are composed of poorly sorted angular (frequently acute-angled) clasts of acid plagioclase (elongated laths) and more isometric quartz. Some

clasts are represented by basic–intermediate volcanics and biotite flakes. The volcanic glass is brown, frequently highly altered. The rock is characterized by thin horizontal and horizontal–wavy bedding (emphasized by the orientation of the fragments and thin lenses of carbonaceous matter) and is slightly silicified (thin section description A.I. Malinovskii). The bedding planes demonstrate abundant variably coalified plant detritus. The upper part of the bed from tuffaceous silty mudstones yielded plant remains: *Equisetites* sp., *Lycopodites* sp., *Gleicheniopsis suifunensis* Krassil., *Gleichenites zippei* (Corda) Sew., *Polypodites polysorus* Pryn., *Cladophlebis frigida* (Heer) Sew., *Nilssoniopteris rhitidorachis* (Krysht.) Krassil., *Pseudotorelia* sp., *Cephalotaxus ussuriensis* Krassil., *Athrotaxites berryi* Bell., *Elatides* cf. *curvifolia* (Dunk.) Nath. The coal is composed of remains of *Mirovia orientalis* (Nosova) Nosova and *Pseudotorelia* sp. in its lower part and fragments of *Araucariodendron heterophyllum* Krassil., *A. cf. angustifolium* Krassil., *Tomharisia* cf. *florinii* Krassil., *Nilssoniopteris rhitidorachis*, and undeterminable bennettites. The thickness is 7 m.

(2) Sandstone, light, yellowish gray, uniform, locally gravely and with small well-rounded pebbles. The thickness is 20 m.

(3) Coal, humic–rhabdopissite, with intercalations of gray silty mudstones. It is composed of fragments of *Araucariodendron heterophyllum* and *Athrotaxites berryi*. The thickness is 1–2 m.

(4) Sandstone, light, yellowish gray to brown, gravely with small pebbles at the base. The thickness is 7–10 m.

(5) Silty mudstone, gray with slight greenish tint, uniform. The thickness is 1.5 m.

(6) Mudstone, brownish yellow, uniform, locally with small coal lenses in the uppermost part of the bed. The thickness is 0.15–0.30 m.

(7) Sandstone, light, yellowish gray. The thickness is 7 m.

(8) Silty mudstones, with intercalations of coal (up to 20 cm thick) in the upper part. The coals are composed of remains of Miroviaceae and bennettites (*Anomozamites* sp., *Nilssoniopteris rhitidorachis*, *N. prynadae* Samyl., *Nilssoniopteris* sp.) and undeterminable angiosperms. The thickness is 1.5–2.0 m.

Higher in the section, the sandstone beds and coal seams become thinner, while the share of silty mudstones increases (more than 3 m). The section is terminated by vitrocrytaloclastic tuffstones with coarse psammitic pyroclastics (locally up to lapilli size). The tuffstones contain fossil wood of conifers close to recent representatives of the subfamilies Sequoioideae, Taiwanioideae, and Taxodioideae from the family Cupressaceae (cf. *Taxodioxylon* sp.). The apparent thickness of the tuffstones is <0.5 m.

RESULTS AND DISCUSSION

The section of the Porechye open-pit coal mine begins with a thick (up to 7 m) coal seam of the upper Lipovtsy Subformation. Previous palynological studies [18] have revealed that the palynological spectra from the upper rhabdopissite coal, as well as from its underlying and overlying mudstones (samples SPP-21–SPP-23, SPP-28), include angiosperm pollen. This observation, extremely important for understanding the evolution of the angiosperms, stimulated us to pay special attention to the rocks constituting the interval of 25–50 m of the section under consideration.

The performed analysis made it possible to reveal the taxonomic composition of the palynospectra in samples SPP-16, K-2, K-4, K-5, K-8, K-9, and SPP-33; to trace the ratios between the main palynomorph groups; and to characterize the palynospectra from the coals and clastic rocks (Fig. 1, table, Plates 1, 2).

The palynological spectrum in sample SPP-16 from dark gray siltstone with thin coal lenses is dominated by spores produced by ferns close to the Gleicheniaceae (*Gleicheniidites laetus*, *G. senonicus*, *G. carinatus*, and *Plicifera delicata*), constituting together 35.9% of the total assemblage. The subdominant taxa are represented by ferns close to Cyatheaceae and Dicksoniaceae: *Cyathidites minor*, *C. australis*, *Leiotriletes* spp. (up to 27.2% in sum), *Laevigatosporites ovatus*, and *L. ovoideus* (up to 8.3% in sum). Gymnosperm pollen (28.6%) is represented by

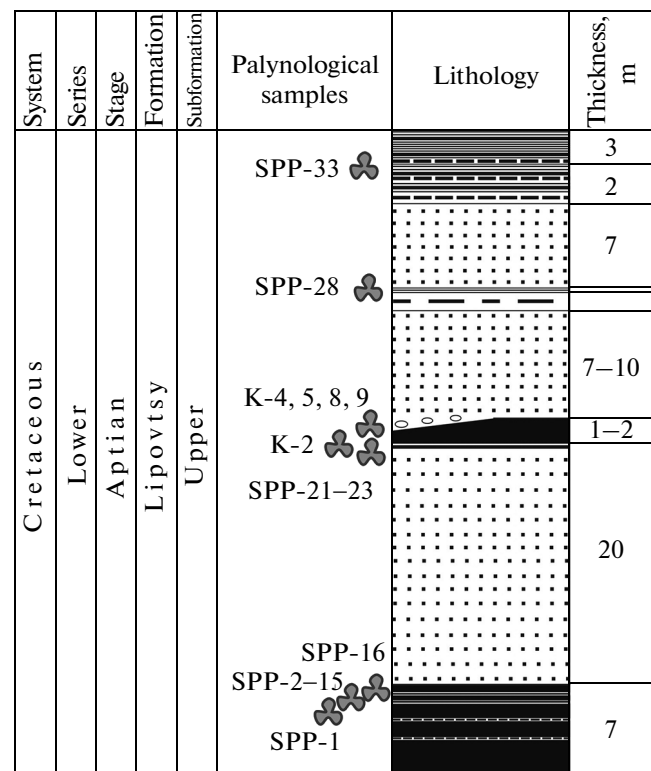


Fig. 4. Schematic geological section of the Porechye open-pit coal mine.

the following taxa: *Ginkgocycadophytus* sp., *Alisporites bilateralis*, *Cedripites parvisaccatus*, *Araucariacidites australis*, *Taxodiaceapollenites hiatus*, and *Classopollis classoides*.

The rhabdopissite coal (sample K-2) yielded a spore–pollen spectrum dominated by spores (62.2%) having affinity with: Gleicheniaceae (*Gleicheniidites laetus*, *G. senonicus* (28.3% together)), Cyatheaceae (*Cyathidites minor* (11.7%), *C. australis* (3.3%)), and smooth trilete *Leiotriletes* spp. (13.9%). They are accompanied by rare *Osmundacidites nicanicus* (1.7%) and *Stereisporites stereoides* (1.1%). Gymnosperm pollen (36.7% in total) is represented by *Ginkgocycadophytus* sp. (15.6%), *Taxodiaceapollenites hiatus* (12.2%), *Podozamites* spp. (2.2%), *Classopollis classoides* (1.7%), *Araucariacidites australis* (0.6%), and the first appearing angiosperms *Tricolpites* sp. and *Clavatipollenites hughesii* (1.1%).

The spore–pollen spectrum from the dark gray siltstone (sample K-4) contains dominant spores close to Athyriaceae *Laevigatosporites ovatus*, *L. ovoideus* (up to 35.4% in sum) and subdominant Cyatheaceae and Dicksoniaceae: *Cyathidites minor* and *C. australis*, *Leiotriletes* spp. (19.5%). The spectrum includes also rare grains of *Concavissimisporites asper* (7%), *Gleicheniidites laetus* (4.5%), *G. senonicus* (1.9%), *Stereisporites stereoides* (1%), and *Rouseisporites reticulatus* (1%). Gymnosperm pollen is represented by *Ginkgo-*

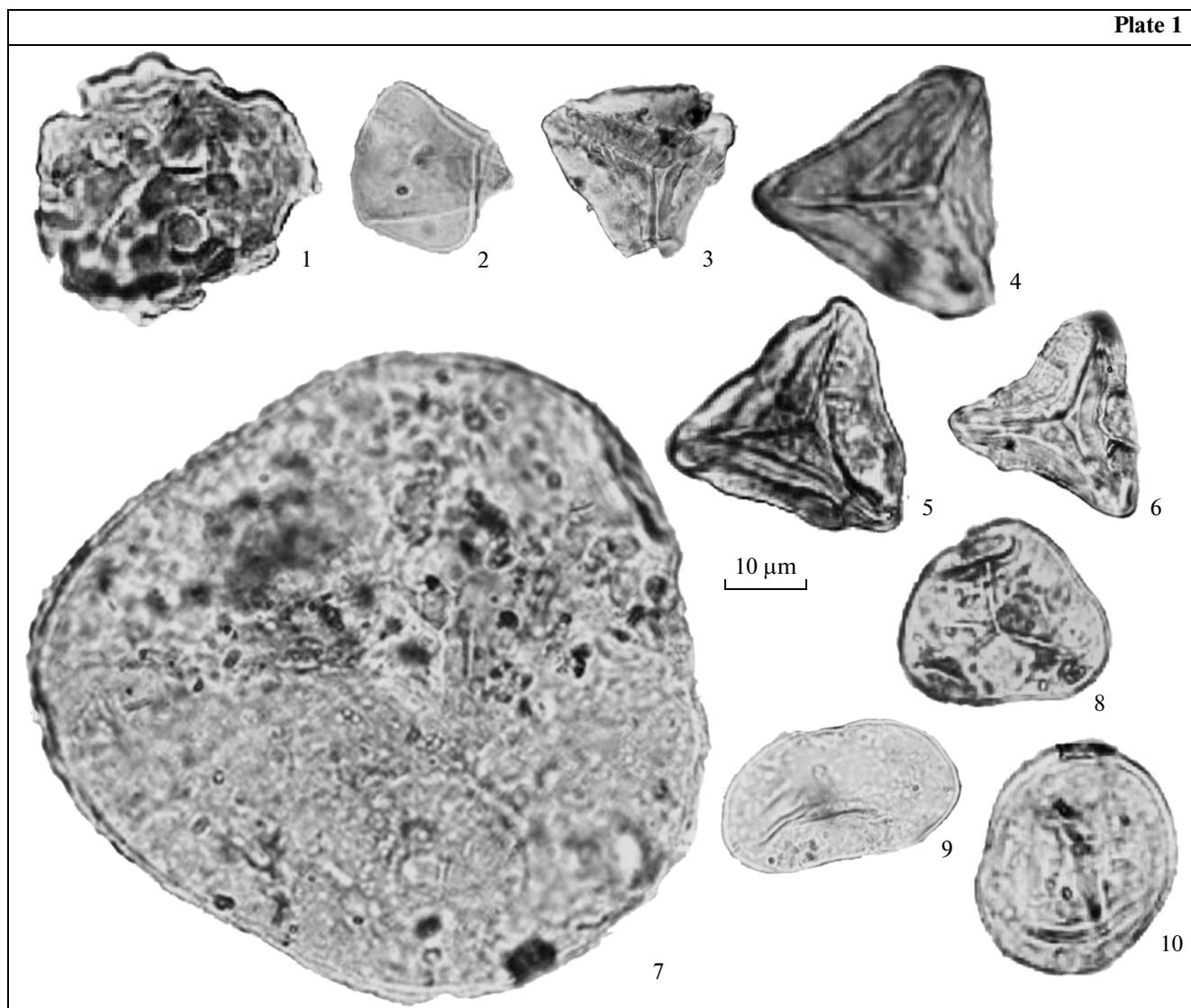


Plate 1. Pteridophytes spores, Porechye open-pit coal mine, Il'ichevka coalfield, Razdol'naya Basin, southern Primorye, Lipovtsy Formation, collection no. 181 (IBSS FEB RAS, Vladivostok).

(1) *Leptolepidites verrucatus*, SPP-22; (2) *Cyathidites minor*, SPP-28; (3) *Gleicheniidites carinatus*, SPP-28; (4, 5) *G. senonicus* SPP-22, SPP-28; (6) *G. laetus*, K-4; (7) *Concavissimisporites asper*, K-4; (8) *G. junctus*, SPP-22; (9) *Laevigatosporites ovatus*, SPP-22; (10) *L. ovoideus*, SPP-22.

cycadophytus sp. (10.9%), *Taxodiaceapollenites hiatus* (4.5%), *Araucariacidites australis* (1.6%), *Podocarpidites ellipticus* (1.3%), *Cedripites parvisaccatus* (1.3%), *Eucommiidites troedsonii* (1.3%), *Classopollis classoides* (1%), and *Piceapollenites variabiliformis* (0.6%).

The spore–pollen spectrum from the mudstones (sample K-5) is dominated by ferns (77.6%) close to Gleicheniaceae *Gleicheniidites laetus*, *G. senonicus*, *G. carinatus* (up to 26.3%); Cyatheaceae *Cyathidites minor*, *C. australis* (up to 22.4%); Dicksoniaceae *Leiotriletes* spp. (up to 19%); Athyriaceae *Laevigatosporites ovatus* (up to 7.4%); and Schizaeaceae *Concavissimisporites asper* (up to 1.5%). Gymnosperms are represented by *Ginkgocycadophytus* sp.,

Taxodiaceapollenites hiatus, *Classopollis classoides*, *Podozamites* sp., *Podocarpidites multesimus*, *Araucariacidites australis*, and bisaccate Coniferales (grains deformed, air sacs indistinctly differentiated) constituting in sum up to 26%. The share of angiosperm pollen represented by *Tricolpites* sp. and *Quercus sparsus* is 3.8%.

The spore–pollen spectrum from the carbonaceous siltstone with plant detritus (sample K-8) is also dominated by spores of ferns *Cyathidites minor* (20.65%), *Laevigatosporites ovatus* (11.8%), *L. ovoideus* (2.7%), *Gleicheniidites laetus* (10.3%), *G. senonicus* (6.5%), *Leiotriletes* spp. (8.4%), and *Concavissimisporites asper* (4.6%). Gymnosperms include

Plate 2

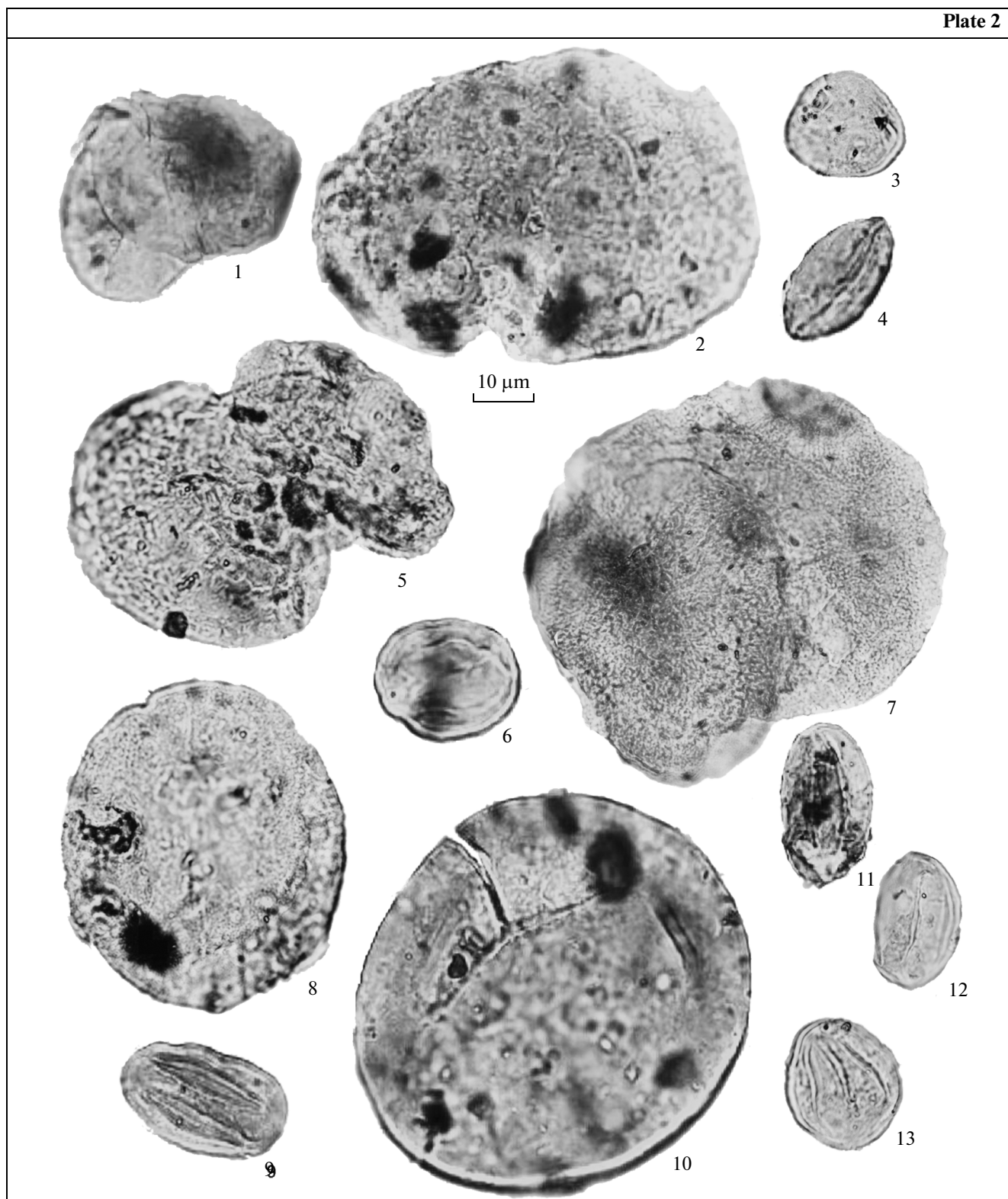


Plate 2. Gymnosperm and angiosperm pollen, Porechye open-pit coal mine, Il'ichevka coalfield, Razdol'naya Basin, southern Primorye, Lipovtsy Formation, collection no. 181 (IBSS FEB RAS, Vladivostok).

(1) *Cedruspollenites parvisaccatus*, SPP-22; (2) *Piceapollenites variabiliformis*, SPP-22; (3) *Taxodiaceapollenites hiatus*, K-4; (4) *Ginkgocycadophytus* spp., SPP-28; (5) *Podocarpidites ellipticus*, K-4; (6) *Classopolis classoides*, SPP-22; (7) *Alisporites bilateralis*, SPP-2; (8) *Araucariacidites australis*, K-4; (9) *Eucommiidites troedsonii*, SPP-22; (10) *Podozamites* spp., SPP-22; (11–13) *Tricolpites* spp., SPP-28, K-4.

Taxonomic composition (%) of spore—pollen spectra (Porechye open-pit coal mine, Razdol'naya River Basin)

Taxa	SPP-1 Rhabdopissite,	Carbonaceous mudstone, SPP-2	Light gray tuffaceous mudstone, SPP-3	Bright coal, SPP-4	Gray mudstone with coal lenses, SPP-5	Gray mudstone with coal lenses, SPP-7	Bright coal, SPP-8	Bright coal, SPP-9	Tuffaceous mudstone with plant remains, SPP-10a	Gray siltstone with coal lenses, SPP-14	Gray siltstone, SPP-15	Dark gray siltstone with thin coal lenses, SPP-16	Rhabdopissite, K-2	Dark gray siltstone, K-4	Mudstone, K-5	Carbonaceous siltstone with plant detritus, K-8	Rhabdopissite, K-9	Dark gray mudstone with coal lenses, SPP-21	Dark gray mudstone with coal lenses, SPP-22	Bright coal, SPP-23	Carbonaceous mudstone, SPP-28	Light gray mudstone, SPP-33
<i>Stereisporites stereooides</i>		2.8	1.2		1.5	0.8			1.6	1.5			1.1	1				1.69			1.21	
<i>Foveosporites cenomanicus</i>					1.2																	
<i>Leptolepidites verrucatus</i>					0.8																1.21	
<i>Retiriletes subrotundus</i>				1.2	1.2																1.613	
<i>Concavisporites junctus</i>					0.4				0.8									0.34				
<i>Osmundacidites nitcanicus</i>	1.3	2.2		2.3						0.4			1.7				1.4	0.68		2.3		1.6
<i>Gleicheniidites laetus</i>	21	19.4	24	29	8.8	6.1	22	22	12.4	11.7	11	17.8	18	5	10	10.3	20	5.07	5.83	11	22.18	6.4
<i>G. carinatus</i>				4.2						2.3	2.1	2.8			3		2.4					
<i>G. circiniidites</i>	5.7	7.8	6.9	8	2	3.8	5.8	6.7	1.2	2.3	3						5.3					
<i>G. senonicus</i>	33	22.8	29	28	10	6.1	24	30	8.8	9.4	11	12	10	2	14	6.5	23	4.73	3.4	13	6.048	4.3
<i>Plicifera delicata</i>										2.6	3	3.3						1.01	3.4		3.226	
<i>Cicatricosisporites multicostatus</i>					1	0.4												0.68	1.46		2.419	2.7
<i>C. dorogensis</i>																						1.1
<i>Appendicisporites tricuspidatus</i>									0.8									0.68	1.46		1.613	
<i>Trilobosporites mirabilis</i>									1.2													

Spores

Table. (Contd.)

Taxa	Rhabdopissite, SPP-1	Carbonaceous mudstone, SPP-2	Light gray tuffaceous mudstone, SPP-3	Bright coal, SPP-4	Gray mudstone with coal lenses, SPP-5	Gray mudstone with coal lenses, SPP-7	Bright coal, SPP-8	Bright coal, SPP-9	Tuffaceous mudstone with plant remains, SPP-10a	Gray siltstone with coal lenses, SPP-14	Gray siltstone, SPP-15	Dark gray siltstone with thin coal lenses, SPP-16	Rhabdopissite, K-2	Dark gray siltstone, K-4	Mudstone, K-5	Carbonaceous siltstone with plant detritus, K-8	Rhabdopissite, K-9	Dark gray mudstone with coal lenses, SPP-21	Dark gray mudstone with coal lenses, SPP-22	Bright coal, SPP-23	Carbonaceous mudstone, SPP-28	Light gray mudstone, SPP-33	
	<i>Concavissimisporites asper</i>	0.8			1.5	1.5			0.8				2.2	7	2	4.6							
	<i>Pilosporites echinatus</i>				1				0.8														
	<i>Klukisporites variegatus</i>					0.4																	
	<i>Rouseisporites radiatus</i>																						
	<i>R. reticulatus</i>													1									1.1
	<i>Laevigatosporites ovatus</i>	2.6	1.7	2.4	0.8	2.9	8.8		4	1.5	2.1	5		30	7	11.8	1	11.8	16	4.5	5.645	9.6	
	<i>L. ovoideus</i>					1	2.7		1.6	0.8	0.8	3.3		5		2.7	1	2.7	7.28		1.21	2.7	
	<i>Leioiriletes</i> spp.	11	8.9	13	9.6	18	17	10	14	13.2	24.9	23	13.3	14	8	20	8.4	11	14.2	16.5	20	8.871	12.3
	<i>Cyathidites minor</i>	14	13.3	12	7.7	13	13	18	7.8	21.2	12.1	14	10.6	12	8	19	20.6	11	10.8	8.25	16	7.258	14.4
	<i>C. australis</i>		1.7	1.2	1.2	6	2.7	3.3	2.2	1.6	1.9	3	3.3	3.3	4	3		3.8	2.7	1.46	3.8	1.21	5.9
	Gymnosperms																						
	<i>Ginkgocycadophytus</i> spp.	10	9.4	6.1	5.8	18	17	13	13	10.4	14	15	8.4	16	11	10	12.6	13	27.4	16	17	16.94	12.3
	<i>Podocarpidites multesimus</i>									2.8						1							
<i>P. ellipticus</i>														1									
<i>Alisporites bilateralis</i>									0.8	1.1	0.8	1.7							1.94				2.2

Table. (Contd.)

Taxa	Rhabdopissite, SPP-1	Carbonaceous mudstone, SPP-2	Light gray tuffaceous mudstone, SPP-3	Bright coal, SPP-4	Gray mudstone with coal lenses, SPP-5	Gray mudstone with coal lenses, SPP-7	Bright coal, SPP-8	Bright coal, SPP-9	Tuffaceous mudstone with plant remains, SPP-10a	Gray siltstone with coal lenses, SPP-14	Gray siltstone, SPP-15	Dark gray siltstone with thin coal lenses, SPP-16	Rhabdopissite, K-2	Dark gray siltstone, K-4	Mudstone, K-5	Carbonaceous siltstone with plant detritus, K-8	Rhabdopissite, K-9	Dark gray mudstone with coal lenses, SPP-21	Dark gray mudstone with coal lenses, SPP-22	Bright coal, SPP-23	Carbonaceous mudstone, SPP-28	Light gray mudstone, SPP-33
<i>Piceapollenites variabiliformis</i>														1		1.1	3.3					
<i>Cedruspollenites parvisaccatus</i>										0.4	0.8	1.2		1		1.1						
Coniferales		1.7				1.9			4	1.5	3	5.6	4.4	4	4	4.2		1.01	2.43	2.3	2.822	3.2
<i>Araucariacidites australis</i>					1	0.8			0.8	1.9	1.7	2.2	0.6	2	1	2.3		1.35	1.94		1.613	1.6
<i>Taxodiaceapollenites hiatus</i>	2.6	6.1	1.6	2.7	11	9.6	5	3.3	8.4	7.9	5.1	6.7	12	5	4	6.5	3.3	8.45	5.83	9.1	5.242	9
<i>Podozamites</i> spp.													2.2		1							
<i>Classopollis classoides</i>		2.2	0.8		3.9	2.3			2	1.12	0.8	2.8	1.7	1	1	1.9	1.4	0.68	1.46			1.1
<i>Eucommiidites troedsonii</i>					2	2.7			0.8	0.8				1		2.7		1.01	0.97		1.613	2.1
Angiosperms																						
<i>Clavatipollenites hughesii</i>													1.1									
<i>Tricolpites micromunus</i>																			0.49		1.21	
<i>T. vulgaris</i>																		2.37	3.4		4.435	
<i>T. variabilis</i>																						2.1
<i>Tricolpites</i> spp.													1.1	3		1.9		0.68	0.49	0.8	0.806	2.7
<i>Quercites sparsus</i>														1								
<i>Retitricolpites georgiensis</i>																0.8					0.403	1.6

Ginkgocycadophytus sp. (12.6%), *Taxodiaceapollenites hiatus* (6.5%), *Eucommiidites troedsonii* (2.7%), *Araucariacidites australis* (2.3%), *Classopollis classoides* (1.9%), *Piceapollenites variabiliformis* (1.1%), and *Cedripites parvisaccatus* (1.1%). Pollen of angiosperms *Tricolpites* sp. and *Retitricolpites georgiensis* is rare, constituting less than 3%.

The spore–pollen spectrum from the upper rhabdopissite layer (sample K-9) is characterized by the dominant role of spores close to Gleicheniaceae: *Gleicheniidites laetus*, *G. senonicus*, *G. carinatus*, *G. circiniidites* in sum constituting 49.8%. They are accompanied by smooth spores *Cyathidites minor*, *C. australis*, *Leiotriletes* spp. (25.3% in total). The share of gymnosperms is low (21.4%) with *Ginkgocycadophytus* sp. being dominant (13.4%). Pollen close to the Pinaceae and Taxodiaceae is represented by *Piceapollenites variabiliformis* (3.3%) and *Taxodiaceapollenites hiatus* (3.3%), respectively. The content of Cheirolepidiaceae (*Classopollis classoides*) is extremely low (up to 1.4%).

In the spore–pollen spectrum from light gray mudstone (sample SPP-33), the dominant role belongs to spores (62.1%): *Cyathidites minor*, *C. australis*, *Leiotriletes* spp., *Gleicheniidites laetus*, *G. senonicus*, *G. carinatus*, *Laevigatosporites ovatus*, *L. ovoideus*, *Cicatricosisporites multicostatus*, *C. dorogensis*, *Rouseisporites reticulatus*, *Osmundacidites nicanicus*. Gymnosperm pollen constituting in sum 31.5% is represented by *Ginkgocycadophytus* sp., *Taxodiaceapollenites hiatus*, *Eucommiidites troedsonii*, *Araucariacidites australis*, *Classopollis classoides*, and *Alisporites bilateralis*. The share of angiosperms is low (up to 6.4% in sum). They include *Tricolpites vulgaris*, *Tricolpites* sp., and *Retitricolpites georgiensis*.

Angiosperm pollen is found in samples SPP-21–SPP-23, SPP-33, K-2, K-5, and K-8 taken from the basal and uppermost parts of the upper rhabdopissite coal seam. First in the section the rare tricolpate pollen *Tricolpites* sp., *T. vulgaris*, and *T. micromunus* appears; its number in the spectra SPP-21, 22 is from 3 to 4.5%. It has been found in the dark gray mudstones underlying the upper rhabdopissite bed. The coal seam contains the first appearing pollen of *Clavatiipollenites hughesii* in addition to *Tricolpites* sp. with its abundance decreasing to 1–2%. In the palynospectra of samples SPP-28 and SPP-33 from the mudstones of the sequence overlying the coal seam, the diversity and abundance of angiosperm pollen slightly increases owing to the appearance of *Tricolpites vulgaris* and *Retitricolpites georgiensis* (up to 7%). Together with them the dispersed cuticles were revealed, whose structure is similar to those of platanoids which could be one of producers of tricolpate pollen.

In Primorye, angiosperm remains have been found in Aptian–Abian sequences: leaves of monocotyledonous *Pandanophyllum ahnertii* Krysht. [14]; fruit *Onoana nicanica* Krassil. from the Lipovtsy Formation

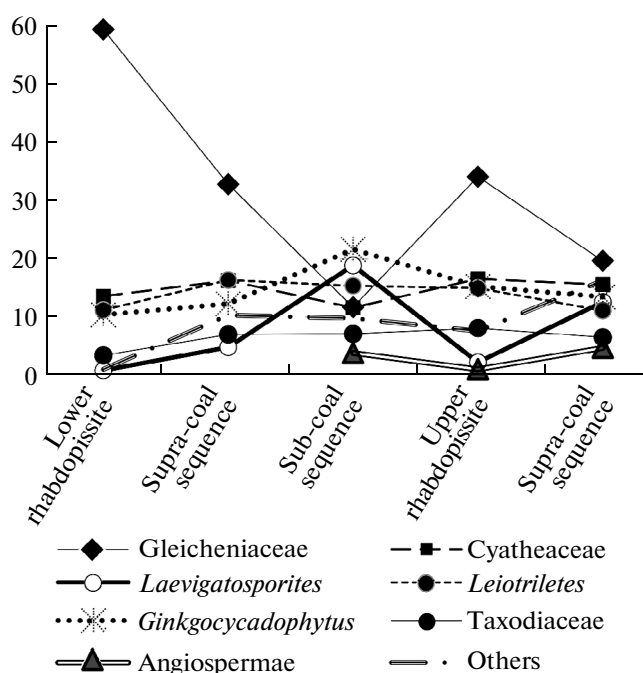


Fig. 5. Proportions of main spores and pollen groups in spectra from the lower and upper rhabdopissite coal seams and supra- and sub-coal clastic intercalations.

of the Razdol'naya Basin [10]; leaves of the ranunculoid morphotype belonging to *Achaenocarpites capitellatus* Krassil. et Volynets, *Ternariocarpites floribundus* Krassil. et Volynets from the Frentsevo Formation [30]; and *Aralia lucifera* Krysht. from the Kangauz Formation of the Partizansk Basin [7, 10, 14].

On the basis of palynological data, the first appearance of undoubtedly angiosperm pollen in the Razdol'naya Basin was previously noted in early Albian palynospectra from the lower part of the Galenka Formation in [15].

Such an important biotic event of the Cretaceous period, as the appearance of the most advanced group of the plant world in the territories adjacent to Razdol'naya River Basin of Primorye, occurred much earlier. In the Partizansk Basin, *Tricolpites* sp., *Asteropollis asteroides* Hedl. et Norr. are known from the upper Aptian Saryi Suchan Subformation, while *Tricolpites* sp., *Asteropollis asteroides*, and *Cyclusphaera psilata* Volh. et Sepul. are recorded in the lower Albian Severnyi Suchan Formation [15, 20].

In addition to the above-mentioned finds, the oldest angiosperms are also reported from the Albian deposits of the southern Russian Far East (Iorek Formation overlying coaliferous deposits in the Bureya Basin; lower part of the marine Ai Formation on Sakhalin [15]).

Information on the pollen of the first angiosperms *Clavatiipollenites hughesii*, *C. incisus* Chlon., *Asteropollenites asteroides*, and *Tricolpites* sp. from the Barre-

mian–Aptian sequences of the Transbaikalian region is available in [4]. *Retinocolpites* sp. is found in the Barremian–Aptian Nishihiro Formation of southeastern Japan [31]. *Clavatipollenites* sp. and *Tricolpopollenites* sp. are recorded in the coeval Yimin Formation in the northeastern part of Heilongjiang Province of China [32] and *Clavatipollenites hughesii* is found in the Barremian–Aptian Longpan Formation (Anchow Basin, North Korea) [29].

Khlonova assumed that the tricolpate, monosulcate, and anasulcate types of angiosperm pollen characterize ancestral forms [25]. Our finds indicate that precisely these morphotypes appear first in the geological record of eastern Asia.

It is most likely that the last higher plant taxon appeared in the eastern part of the Asian continent in the Barremian–Aptian. In the Razdol'naya Basin, this period was marked by wide development of marshy landscapes with highly productive plant communities. They yielded much phytomass into sediments, which was transformed subsequently during diagenesis into coals. Swamp communities represented conservative and balanced coenoses [16, 17]. In such mesophytic coenoses, the deficiency in free ecological niches played an important role as a depressant of evolutionary processes and their destruction eliminated the main inhibiting agents and provided conditions favorable for the development of some biocenose members such as, for example, angiosperms. In the opinion of Krassilov [11, 12], being anthracophobes, early angiosperms avoided swampy communities; angiosperms at the time of their first appearance inhabited disturbed biotopes such as alluvium, volcanic substrate, and others. This exploratory strategy, as well as its more advanced reproductive system, determined the survival and high-degree adaptation of this plant group.

No angiosperm remains were previously known in the Aptian sections of the Razdol'naya Basin, which is probably explained by the wide development of peat-forming overwetted environments at that time. In the section of the Porechye open-pit coal mine, the lower thick coal seam is terminated with a member of alternating coal and ash layers. In all probability, volcano eruptions, which repeatedly covered the river valley with ash, were responsible for the formation of stress conditions for plants and animals and even destruction of usual habitat settings. In such situations, plants with an exploratory ecological strategy, combining a high fundamental tolerance with wide dispersion ability, gained an advantage over others (for example angiosperms and gleicheniaceus ferns).

The oldest representatives of the Gleicheniaceae are known to exist from the Carboniferous Period. After the almost total extinction at the Permian–Triassic, the family started gradually restoring its diversity and abundance in the Middle Triassic boundary, culminating in the Early Cretaceous. By the Paleogene, they became practically extinct in Eurasia [2, 33].

The peak of their morphological diversity and prevalence in the plant communities of Europe and Asia corresponded to the middle–late Aptian [1, 8, 15, 19, 23]. It is conceivable that the dominant role of gleicheniaceus ferns (their recent representatives are heliophilous and hydrophilous forms [9]) through such a spacious region is explained by some environmental changes.

CONCLUSIONS

Study of the palynomorphs from the coal seams and interstratal clastic sediments in the Porechye open-pit coal mine of the Il'ichevka coalfield (Razdol'naya Basin) has provided additional information on their spore–pollen spectra. The analysis of the taxonomic composition of the spores and pollen has made it possible to characterize their spectra and define the dominant and subdominant species in sediments of different genesis.

For example, the palynospectra from the lower humic–rhabdopissite coal seam are dominated by Gleicheniaceae and Cyathaceae accompanied by Dicksoniaceae and *Ginkgoocycadophytus*. In the palynospectra from the upper rhabdopissite coal seam, the dominant role belongs to pteridophytes, while the share of Gleicheniaceae notably decreases. The main feature of the spectra is the appearance of single pollen grains of angiosperms in them. In the palynospectra from the clastic rocks, Gleicheniaceae loss its dominant position and give way to Polypodiaceae accompanied by diverse Cyathaceae. The taxonomic diversity of the gymnosperms remains relatively high although their abundance is insignificant. The share of angiosperms increases both with respect to their diversity and abundance. Our finds confirm that the tricolpate, monosulcate, and anasulcate types of angiosperm pollen were the first to appear in the geological record of eastern Asia.

The clastic deposits of the open-pit coal mine yielded impressions of fossil plants and remains of coniferous wood. Palynological and epidermal–cuticular analyses of them revealed the composition of the coal-forming plants both in productive and thin coal seams.

Comparison of the taxonomic compositions of the palynospectra from the Porechye open-pit coal mine and the previously known assemblages from the Lipovtsy coalfield has made it possible to estimate the accumulation period of the coaliferous subformation of the Lipovtsy Formation in the open-pit coal mine as corresponding to the Aptian age [28]. The angiosperm pollen, first found in the Aptian sediments of the Razdol'naya Basin, provides grounds to assume that this plant group appeared earlier than was thought previously (early Albian).

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