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The Voznovo Formation: The Reflection of the Early Oligocene Stage in the Geological History of East Sikhote Alin

B. I. Pavlyutkin, I. Yu. Chekryzhev, and T. I. Petrenko

Far East Geological Institute, Far East Division, Russian Academy of Sciences, pr. Stoletiya Vladivostoka 159, Vladivostok, 660022 Russia

E-mail: pavlyutkin@fegi.ru

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Abstract—New data were obtained on the Voznovo Formation, one of the key Tertiary stratigraphic units in East Sikhote Alin. The analysis of macro and microflora in this unit showed that the decision to assign it to the Miocene (*Resolutions*..., 1994) was invalid. The early Oligocene age of the formation is justified. It is shown that the sediments constituting the formation were deposited in a barrier lake. The analysis of the Voznovo taphoflora reveals its mountainous ecotype, which indicates the ancient age of the Sikhote Alin mountainous system. The Voznovo Formation is correlated with other coeval stratigraphic units of the region.

Key words: stratigraphy, early Oligocene, Voznovo Formation, fossil floras, Sikhote Alin.

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INTRODUCTION

Since the mid-1950s, the Nadezhdino Formation distinguished by G.M. Vlasov [10] was traditionally considered as the stratigraphic equivalent of the Oligocene epoch in Primorye. At the same time, the detailed analysis of fossil macro- and microfloral remains from stratotype sections [3, 13, 17, 23] revealed that not only the Nadezhdino but also the overlying Ust–Davydov formations are ascribed to the Eocene. In this connection, the problem concerning the Oligocene's development history in the region is acquiring urgency. In the western Primorye region, the Pavlovsk Horizon with the stratotype section in the Pavlovsk coal field was proposed to characterize the Oligocene epoch [24]. In the eastern, mountainous part of the region, the situation remains uncertain because of the different age interpretations of the *"Engelhardia"* and Voznovo–Amgu floras and their host units. In this work, we propose a solution to this stratigraphic problem for the Sikhote Alin mountainous system.

HISTORICAL REVIEW

The Paleogene–Neogene stratigraphic scale of the Primorye region practically in its present-day form was developed in the mid-1950s [25]. It was based on works by [10, 29, 32], where the main local stratigraphic units for this chronologic interval were proposed. Already at that time, geologists noted substantial differences between the structure of the Paleogene–Neogene complexes in the Sikhote Alin mountainous system, a principal orographic element of the region, and the areas located west of the latter. Nevertheless, unified stratigraphic names accepted for the western Primorye region were applied in some reports of mapping teams and published works on the Sikhote Alin mountainous system. For example, in the Cenozoic Vanchino Depression (the Milogradovka River basin), geologists recognized analogues of the Uglov, Nadezhdino, and Suifun formations, which were first defined in areas located west of Sikhote Alin, i.e., hundreds of kilometers away, where they associate with other sedimentary basins.

At the same time, the original stratigraphic scale of the Paleogen–Neogene deposits was simultaneously being developed for the Sikhote Alin mountainous system. For example, the sequence (100–150 m) of sandstones, siltstones, mudstones, and carbonaceous mudstones with brown coal seams, which was named the Voznovo Formation, was proposed in the 1950s to characterize the Oligocene epoch in this region [9]. This unit is distributed in a limited area in the northeastern segment of the Cenozoic Zerkal'nenskaya Depression in the Svetlyi Creek basin, a left tributary of the Zerkal'naya River (Figs. 1, 2). It was emphasized that the Voznovo Formation is largely underlain by lavas known as the Suvorovo basalts.

It should be noted that the thickness of the Voznovo Formation, which was initially estimated to be up to 150 m [9], appeared to be overestimated. An even higher thickness (up to 326 m) was cited in the subsequent work.[1] In both cases, such an overestimation is

[1] V.V. Marinin et al., *Report on Geological Mapping and Prospecting* (Vladivostok, 1966) [in Russian].

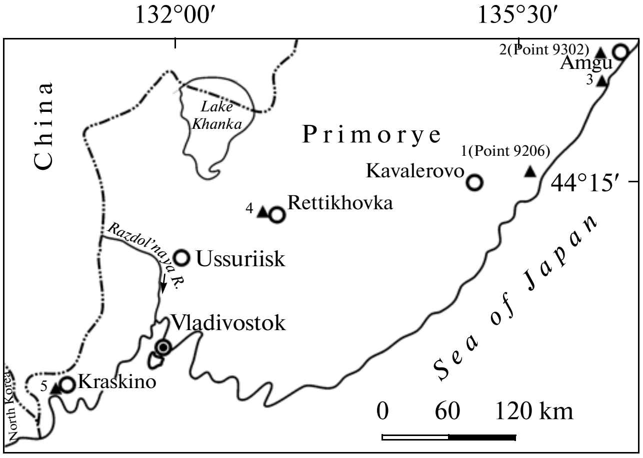

Fig. 1. Type localities of Oligocene floras in the Primorye region.

Floras: (1) Voznovo (Point 9205), (2) Amgu (Point 9302), (3) Klyuch Tikhii,(4) Rettikhovka, (5) Kraskino.

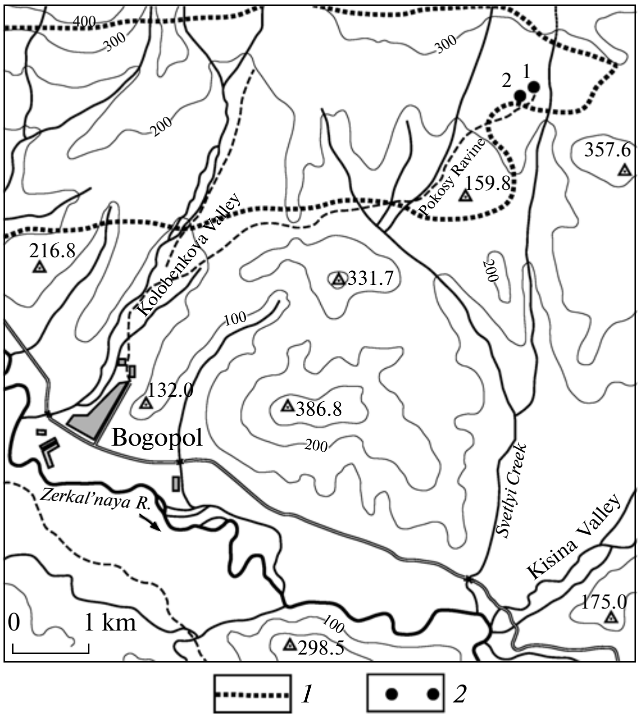

Fig. 2. Location of type sections of the Voznovo Formation.

(*1*) contour of the depression; (*2*) quarries with type sections.

explained by the partial inclusion of older rocks (both the above-mentioned Suvorovo basalts and later defined formations (Tuyanovo, Svetlyi)) into the stratigraphic unit under consideration.

The Voznovo Formation as a local stratigraphic unit was first mentioned in [25], although its characteristics at that time contained no minimally required information for its approval as a valid stratigraphic unit. By the way, such a practice was typical for most local stratigraphic units defined in the 1950s–1960s.

Until the initial 1980s, the Voznovo Formation was considered as an Oligocene stratigraphic unit coeval with the Nadezhdino Formation [26]. However, its stratigraphic position was later revised: the formation was placed at the level of the Bikin regional horizon (lower–middle Miocene) with the possible displacement of the lower boundary to the terminal Oligocene [27]. Work [20] provides the most complete characteristics of the Voznovo Formation and considerations in favor of its age revision. This work presents a series of formation sections based on drilling and mining data. Two of these sections are accompanied by bed-by-bed descriptions, although without indication which of them should be considered as the stratotype one. The maximal thickness of the formation is estimated to be 70 m.

It should be emphasized that the authors of [20] returned to the initial understanding of the geological position of the Voznovo Formation, according to which it rests upon the Suvorovo basalts [9]. At the same time, these basalts were omitted from the Suvorovo Complex and considered (in the stratotype area of the Voznovo Formation) as younger volcanic rocks. Together with the underlying Tertiary sedimentary rocks, they were united into the Svetlyi Formation. In the opinion of the authors [20], the composite Cenozoic section of the Zerkal'nenskaya Depression beyond the distribution area of the Voznovo Formation was supplemented from below by the succession of the Tuyanovo, Suvorovo (basalts), and Tadusha formations.

In connection with the proposed revision of the Voznovo Formation age in its stratotype locality (the Svetlyi Creek basin) [20], it should be emphasized that such a revision was unnecessary. The latter is most likely explained by the cardinal reinterpretation of the whole succession of Paleogene–Neogene sediments in the Primorye region carried out in the 1970s under the influence of the stratigraphic scale developed by that time for neighboring Korea [33]. It should be noted that the invalidity of this scale was subsequently shown primarily by Japanese paleobotanists [39] and then by our data on the Primorye region [21].

MATERIAL

We started the complex study of the Voznovo Formation in 2002. This study was stimulated by the excavation of small quarries for brown coal mining in its stratotype area, which made it possible to recover successions of strata constituting the formation as well as the contacts between them and to obtain representative macro- and microfloral collections for their subsequent study. These collections sampled in collaboration with the geologists V.K. Popov and A.M. Panichev from the Far East Geological Institute and the Pacific Institute of Geography (Far East Division, Russian Academy of Sciences) include over 600 leaf impressions, fruits, and seeds, as well as leafed and leafless shoots. The stratotype section also yielded six representative palynological spectra. In addition, we studied the sediments underlying the Voznovo Formation, which are known as the Svetlyi Formation. The obtained data made it possible to reconstruct the corresponding paleoenvironmental settings and provided grounds for revising the age of the formation and its correlation with other coeval stratigraphic units of the Primorye region.

RESULTS AND INTERPRETATION

According to the Stratigraphic Code [30], the local stratigraphic unit may be accepted as the valid one, i.e., having legal status, primarily after its typifying (selecting its stratotype section). As for the Voznovo Formation, we prefer a new section recovered by quarry no. 1 (point 9206, Fig. 2) as representing its stratotype section. This quarry recovers continuous succession of beds and demonstrates their lateral variations. The main collection of fossil plant remains, as well as samples for the palynological and petrographic studies, was taken precisely from this section. Its coordinates are 44°17′ N and 135°31′ E. The quarry is now abandoned. Below, we give the bed-by-bed description of the section (from the base upward).

(1) Alternating light gray medium-grained sandstones and dark gray carbonaceous siltstones. The thickness is up to... 8 m.

(2) Coal seam consisting of brownish black lusterless coal with lenses of the black lustrous variety and intercalations of brown mudstones and pistachio green intensely altered psammitic tuffs. The thickness is .... 2 m.

(3) Brown to brownish platy siltstones with interbeds of tuffaceous siltstones and moderately preserved macrophytofossils. The thickness is up to............. 5 m.

(4) Brown and light gray silicified opoka-like siltstones with thin intercalations of dark brown mudstones and pistachio green psammitic tuff and well-preserved macrophytofossils. The thickness is up to ....15 m.

(5) Dark brown lumpy intensely fractured siltstones with poorly preserved macrophytofossils. The thickness is up to ....10 m.

The total thickness of the section amounts to 40 m.

The lower boundary of the formation in the quarry was not reached. According to the available drilling data[2], the sandstones of bed (1) rest upon basalts weathered up to the clay state with peculiar brick-red coloration. In the area located 150 m to the northeast, the beds of the Voznovo Formation lean against acid volcanics of the Upper Cretaceous–Paleogene Bogopol Formation.

The section recovered by mined quarry no. 2 located 200 km southwest of the previous one (Fig. 2) is similar to the stratotype section and may be considered as the hypostratotype of the Voznovo Formation.

Its bed-by-bed description is given below (from the base upward).

(1) Coal seam with a bed of ferruginate siltstones (approximately 30 cm) and tonstein (approximately 5 cm). The thickness is ....1.5 m.

(2) Yellow-gray thin-platy siltstones. The thickness is ....1.3 m.

(3) Brown-gray silicified opoka-like siltstones with beds (0.5 m) of their thin-platy varieties and macrophytofossils. The thickness is ....5.0 m.

(4) Brown bedded siltstones, tuffaceous siltstones, sandstones, and tuffstones with two beds of pistachio–yellow decomposed volcanic glass in the upper part of the member, rare macrophytofossils, and diatoms. The thickness is ....7.0 m.

(5) Brown massive tuffstones with a bed (3 cm) of decomposed volcanic glass. The thickness is .....5.2 m.

The integral thickness of the section is ....20 m.

Siltstones and sandstones dominant in both sections and are to a variable extent silicified and belong to the category of semi-lithified and lithified rocks according to the classification accepted in engineering geology. Opoka-like rocks from the main flora-bearing member represent the silty–pelitic cryptogranular variety with rare small inclusions of quartz, feldspars, and micas.

The saturation degree of the rocks constituting the Voznovo Formation with pyroclastic material is low although variable: thin interbeds of tuffaceous siltstones are single. Of higher interest are the lenticular intercalations (5–15 cm thick) of pistachio-yellow acid intensely decomposed tuffs. Under a microscope, it is seen that they are composed of welded curved acicular fragments of acid volcanic glass almost entirely replaced by minerals of the smectite group. The admixture of acid pyrocalstic material in the sediments of the Voznovo Formation reflects the brief episodes of explosive volcanism in the Zerkal'nenskaya Depression or its surrounding structures during the early Oligocene.

The age of the Voznovo Formation and its analogues is the decisive problem for developing the Paleogene–Neogene stratigraphic scale of the Cenozoic depressions in the Sikhote Alin mountainous system. As was noted, the revision of the stratigraphic position of the formation in the terminal 1980s [20], which was subsequently reflected in the Resolutions of the Stratigraphic Meeting [27], was unjustified. We believe that the placement of the Voznovo Formation

[2] Rostovskii, F.I. et al., *Report on Geological Mapping and Prospecting* (Vladivostok, 1965) [in Russian].

in the Miocene level was erroneous and hold the previous viewpoint [9] concerning its Oligocene age.

Our conclusion on the Oligocene age of the Voznovo Formation is based on the analysis of collections of macro- and microfloral remains from the stratotype section and the correlation of this formation with other well-studied stratigraphic units of the Sikhote-Alin mountainous system. Let us primarily consider the peculiar features of the Voznovo macrofloral assemblage.

According to the study of its collections, this flora consists of 90 species belonging to 42 genera and 22 families (Table 1). In addition, the generic and family affinity of four and eight morphotypes, respectively, remains unidentified so far. It should be noted that, inasmuch as different organs of plants are considered, in line with the requirements of the International Botanic Nomenclature Code, as representing autonomous species (although some of them could belong to the same taxon), their real diversity may appear to be lower. This is particularly true of the coniferous plants. It should however be emphasized that the presented table contains exclusions from this rule. For example, *Pseudolarix japonica* Tanai et Onoe is represented in the collection by needles, seeds, and seed scales, whose affiliation to the same plant is unproven. This was accepted a priori by the authors of this species [36], when these requirements were yet invalid.

We present photographs of some fossil macro- and microfloral remains that primarily have certain stratigraphic significance, are very rare in fossil floras, or belong, in our opinion, to new taxa (Figs. 3–5). All of them originate from bed 4 of the stratotype section. Bed 3 is established to contain only leafed *Metasequoia* shoots and coniferous winged seeds, while bed 5 yields numerous remains of *Fagus* leaves, in addition to *Metasequoia* and *Ginkgo* fragments.

Different plant groups are present in the Voznovo flora in highly variable proportions. For example, Equisetales and Filicales are represented by single *Equisetum* and *Adiantum* specimens. On the contrary, gymnosperms prevail in terms of both diversity (45 species) and abundance (up to two-thirds of the assemblage). They are represented by three orders (Ginkgoales, Pinales, and Cupressales) and five families. The genus *Ginkgo* includes a morphotype identified as *Ginkgo* sp., in addition to the common species close to the present-day *G. biloba*. L. *Ginkgo* sp. is characterized by deeply cut leaves, which indicates, in the opinion of some researchers, its belonging to some archaic group of this genus. It should be emphasized that the macro- and microremains of *Ginkgo* characteristic of Early Cenophytic floras are yet unknown among the undoubtedly Neogene floral assemblages of the Primorye region. The youngest sediments, which enclose their rare microremains, characterize the late Oligocene level (Pavlovsk Horizon) in the western part of the region.

The maximal abundance and taxonomic diversity are peculiar of the families Pinaceae (*Abies, Picea, Pseudotsuga, Tsuga, Pseudolarix, Larix, Pinus*) and Taxodiaceae (*Sequoia, Metasequoia, Glyptostrobus, Taxodium, Cunninghamia*); Cupressaceae are less diverse. Some genera are represented by remains of vegetative organs, while others, by productive organs or by both of them. Deciduous shoots of *Metasequoia occidentalis* (Newb.) Chaney are dominant (≈40% of the total abundance); *Metasequoia* female cones and microstrobile bunches are substantially less common. The collection includes needles, cones, and seeds of *Abies, Pinus, Larix, Tsuga,* and *Pseudotsuga*, as well as needles, seeds, seed scales, and fragments of elongated *Pseudolarix* shoots.

The genus *Pseudolarix* is represented by two morphologically distinct species identifiable owing to the remains of winged seeds: *P. japonica* Tanai et Onoe and *P. klimovae* Akhmet. The last species was first described among the Amgu flora of east Sikhote-Alin [4], which was initially considered, similar to the Voznovo flora, as being the Oligocene in age [16] and subsequently referred to the Miocene [28]. Very large needles (up to 8 cm long) with sharp apexes are probably related to *Pseudolarix klimovae* (winged seeds). From the large needles of *Sciadopitys* present in the collection, they differ by their fine texture with transverse wrinkles and poorly-developed middle vein. This representative of the genus *Pseudolarix* is considered in this work as a new species.

The genus *Pinus* in the Voznovo flora is represented by a group of morphotypes with two, three, four, and five needles in a bunch; the three- and five-needled pines are subdivided into forms with short (4–6 cm) and long (10–12 cm) needles, which probably belong to different species. There are also unusual *Pinus* remains with three relatively small but wide lanceolate needles in a bunch, which were never recorded in the Far East Tertiary floras.

Among the Taxodiaceae remains, of interest are fragments of *Cunninghamia protokonishii* Tanai et Onoe leaved shoots. In the Primorye region, the last species is first found in the *"Engelhardia"* flora of the Rettikhovka locality [14].

Flowering plants are dominated by Betulaceae (*Betula, Carpinus, Ostrya, Corylus*) accompanied by subordinate Fagaceae (mostly *Fagus*, single *Quercus*). *Fagus* leaves are relatively abundant in the collection. In the upper layers of the formation, they are distinctly dominant; moreover, this morphotype has no analogues among the known fossils and is classed with a new species.

The interesting finds include bracts (fruit envelopes) of unusual "frightening" appearance, which are identified as belonging to the old extinct Betulaceae group. Similar finds described among *Paleocarpinus* representatives are discovered in Eocene–Oligocene floras from different regions, including Primorye [5].

Table 1. Taxonomic composition of the Voznovo flora (based on leaf and fruit impressions)

Taxa	Locality 9206	
	Samples	Total (Σ)
1	2	3
Family Equisetaceae		
Equisetum sp.-1 (tubers)	269	1
Equisetum sp.-2 (rhizome)	466	1
Family Polypodiaceae		
Adiantum sp.	105	1
Family Ginkgoaceae		
Ginkgo ex gr. *adiantoides* (Ung.) Heer	268, 294, 489, 497 and others	16
Ginkgo sp.	58	1
Family Pinaceae		
Abies sp. (needles)	134*a*	1
Abies sp. (seed)	514	1
Picea kaneharae Tanai et Onoe (seed)	468	1
Picea magna MacGinitie (seed)	326	1
Picea ugoana Huz. (seed)	150, 601 and others	5
Picea sp.-1 (seed)	322	1
Picea sp.-2 (seed scale)	545	1
Picea sp.-3 (leaved shoot)	500, 507	2
Tsuga miyataensis Huz. et Uemura (needles)	165 and others	5
Tsuga sp.-1 (seed)	417	1
Tsuga sp.-2 (cone)	420, 464	2
Pseudotsuga sp. (needles)	254	1
Pseudolarix japonica Tanai et Onoe (needles)	14, 72, 104, 154, 588 and others	20
P. japonica Tanai et Onoe (seed)	11, 107, 152, 205, 524, 614 and others	9
P. japonica Tanai et Onoe (seed scale)	27, 134*a*, 564 and others	11
Pseudolarix klimovae Akhmet. (seed)	113, 518	2
Pseudolarix acuminata Pavlyutkin sp. nov. (needles)	1*a*, 137, 260 (holotype), 479 and others	12
Larix sp.-1 (seed)	202, 211	2
Larix sp.-2 (cone)	49	1
Larix sp.-3 (shoots, including leaved branches)	51, 106, 530 and others	10
Pinus miocenica Tanai	431, 461. 490	3
Pinus ex gr. *trifolia* f. *longa*	1*c*, 2*a*, 10*a*, 437	4
P. ex gr. *trifolia* f. *brevis*	128, 328, 437 and others	7
P. ex gr. *trifolia* f. *lanceolata*	442, 511	2
Pinus ex gr. quadrifolia	64, 71, 180*a*, 260 and others	5
Pinus ex gr. *pentaphylla* f. *brevis*	13, 244, 278, 354, 456, 535 and others	24
P. ex gr. *pentaphylla* f. *longa*	10*a*, 79, 505 and others	6
Pinus sp.-1 (seed)	91, 101, 187, 430 and others	8
Pinus sp.-2 (seed)	28, 178, 248, 454 and others	8
Pinus sp.-3 (seed)	116	1
Pinus sp.-4 (seed)	450, 457	2
Pinus sp.-5 (cone)	99	1
Pinus sp.-6 (densely leaved shoot)	112, 288, 439	3
Family Sciadopityaceae		
Sciadopitys shiragica Huz. (needles)	422, 429	2
Family Taxodiaceae		
Metasequoia occidentalis (Newb.) Chaney (leaved shoots)	74 and others	246
Metasequoia sp.-1 (female cones)	198, 201 and others	5
Metasequoia sp.-2 (microstrobiles)	424, 462	2
Sequoia langsdorfii (Brongn.) Heer (shoots)	7, 142, 153	3
Taxodium dubium (Sternb.) Heer (shoots)	215, 264	3

Table1. (Contd.)

1	2	3
Glyptostrobus europaeus (Brongn.) Heer (shoot)	62, 94, 332, 362 and others	8
Cunninghamia protokonishii Tanai et Onoe	333, 357	2
Family Cupressaceae		
Thuja nipponica Tanai et Onoe (small branches)	36, 82, 92*a*, 526 and others	19
Cupressaceae sp. (shoot with microstrobiles)	379	1
ñFamily Tetracentraceae		
Tetracentron piperoides (Lesq.) Wolfe	19, 20, 146 and others	18
(?) *Trochodendroides* ex gr. *arctica* (Heer) Berry	415	1
Family Hamamelidaceae		
Liquidambar europaea A. Br.	53 (with counter impression)	1
Family Fagaceae		
Fagus voznovica Pavlyutkin sp. nov.	295 (holotype), 360, 369*a*, 395, 406 and others	27
Quercus protoserrata Tanai et Onoe	469	1
Family Betulaceae		
Betula ovalifolia Pavlyutkin sp. nov.	42, 164 (holotype), 181 and others	15
Betula sp.-1	44, 131, 355, 448 and others	12
Betula sp.-2	44, 266, 455 and others	8
Carpinus miocenica Tanai	4, 25, 97, 381 and others	44
Ostrya aequiserrata Pavlyutkin	516, 531 and others	4
Corylus auriculata Klimova	100, 453, 529	3
Corylus cf. *ferrox* Wall	85, 200, 348	3
Palaeocarpinus sikhotealinensis Akhmet. et Manchester	110	1
Family Myricaceae		
Myrica sp.	432	1
Family Flacourtiaceae		
Poliothyrsis sp. (?)	16, 281, 485	3
Family Salicaceae		
Salix sp.	309	1
ñåì. Clethraceae		
Clethra sp.	413	1
Family Ericaceae		
Rhododendron voznovicum Pavlyutkin	236, 493	2
R. bogopolense Pavlyutkin	54	1
R. minosense Huz. et Uemura	261	1
Rhododendron zerkalnense Pavlyutkin sp. nov.	301, 315, 321 (holotype), 609	4
Rhododendron sp.	298	1
Menziesia protopentandra Pavlyutkin	363	1
Menziesia sp. (?)	452	1
Gaultheria primorica Pavlyutkin	356	1
Lyonia voznovica Pavlyutkin	41	1
Arbutus primorica Pavlyutkin	17, 21, 49, 103, 210 and others	12
Ericaceae sp.	473, 542	2
Family Ebenaceae		
Diospiros anomala Pavlyutkin	252	1
Family Rosaceae		
Prunus sp.	129	1
Sorbus lanceolata Tanai et N. Suz.	108	1
Sorbus palaeojaponica Murai	61	
Rubus sp.	572	1
Rosaceae sp.	416	1
Family Fabaceae s. l.		
Leguminosae sp. (bean)	544	1

Table1. (Contd.)

1	2	3
Family Anacardiaceae		
Rhus protoambiqua K. Suz.	445	1
Family Aceraceae		
Acer lebedevii Akhmet. et Schmidt	127, 140	2
Acer cf. *crataegifolium*	75, 293	2
Acer sp.-1	346	1
Acer sp.-2	471	1
Acer sp.-3	384*a* and others	3
Acer sp.-4	375	1
Acer sp.-5	171	1
Acer sp.-6	481	1
Family Hippocastanaceae		
Aesculus sp.	68, 118, 414	3
Plantae insertae sedis		
Carpites sp.-1	94*á*	1
Carpites sp.-2	472*b*, 521	2
Carpites sp.-3	120	1
Dicotylophyllum sp.-1	173	1
Dicotylophyllum sp.-2	222	1
Dicotylophyllum sp.-3	620	1
Phyllites sp.-1	543	1
Phyllites sp.-2 (axis of the *Pseudolarix*? cone)	383*a*	1

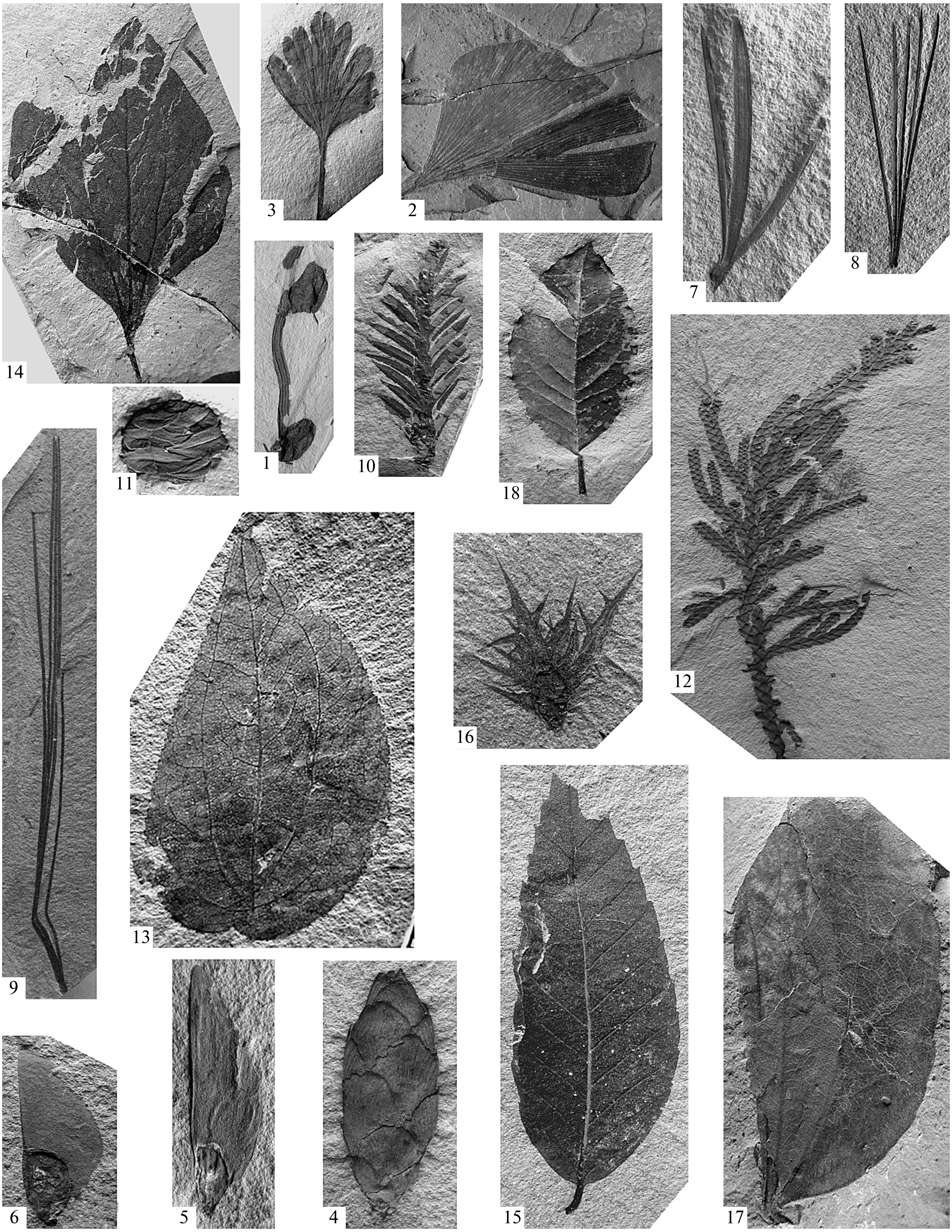
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Fig. 3. Plants of the Voznovo flora. All the images except for those indicated by a special mark are given in their natural size.
(*1*) *Equisetum* sp., 9206/269; (*2*) *Ginkgo* ex gr. *adiantoides* (Ung.) Heer, 9206/497; (*3*) *Ginkgo* sp., 9206/58; (*4*) *Tsuga* sp. (female cone), 9206/464, ×2; (*5*) *Pseudolarix japonica* Tanai et Onoe (seed), 9206/614, ×2; (*6*) *P. klimovae* Akhmet. (seed), 9206/518, ×2.5; (*7*) *Pinus* ex gr. *trifolia* f. *lanceolata*, 9206/442, ×2.5; (*8*) *Pinus* ex. gr. *pentaphylla* f. *brevis*, 9206/535; (*9*) *P.* ex. gr. *pentaphylla* f. *longa*, 9206/505; (*10*) *Cunninghamia protokonishii* Tanai et Onoe, 9206/333; (*11*) *Metasequoia occidentalis* (Newb.) Chaney (female cone), 9206/201, ×1.5; (*12*) *Thuja nipponica* Tanai et Onoe, 9206/526; (*13*) *Tetracentron piperoides* (Lesq.) Wolfe, 9206/19, ×2; (*14*) (?) *Trochodendroides* ex gr. *arctica* (Heer) Berry, 9206/415; (*15*) ***Fagus voznovica* Pavlyutkin sp.nov.**, 9206/295, ×1.5 (holotype); (*16*) *Palaeocarpinus sikhotealinensis* Akhmet. et Manchester (bracts), 9206/110, ×2.5; (*17*) (?) *Poliothyrsis* sp., 9206/281, ×2; (*18*) ***Rhododendron zerkalense* Pavlyutkin sp. nov.**, 9206/321 (holotype).

Single specimens characterize the Hamamelaceae (*Liquidambar*), Miricaceae, Salixaceae (*Salix*), Ebenaceae, Rosaceae (*Sorbus*, *Prunus*, *Rubus*), Leguminaceae, and Aesculaceae families. *Acer* largely represented by impressions of winged seeds (six species) and subordinate leaves are more diverse. The remarkable element of this flora is *Acer lebedevii* Ablaev et Schmidt first described from the Rettikhovka flora.

The unusually wide taxonomic diversity among the flowering plants is characteristic of the Ericaceae family, which is relatively rare in fossil phytoassemblages. This is also true of the Far East Tertiary floras. For example, the relatively well-studied Miocene floral assemblages of the Primorye region are either lacking Ericaceae taxa or their finds are doubtful.

In the Voznovo flora, the Ericaceae family is represented by five genera [22]: *Rhododendron* (*R. minasense* Huz. et Uemura), *R. voznovicum* Pavlyutkin, *R. bogopolense* Pavlyutkin); *Menziesia* (*M. protopentandra* Pavlyutkin); *Lyonia* (*L. voznovica* Pavlyutkin); *Gaultheria* (*G. primorica* Pavlyutkin); and *Arbutus* (*A. primorica* Pavlyutkin). They are accompanied by two *Rhododendron* species (*R. zerkalnensis* sp. nov., *Rhododendron* sp.), *Menziesia* sp., and *Clethra* forms ecologically close to Ericaceae taxa. The genus *Diospyros* (persimmon) represented in the Voznovo flora by the species *D. anomala* Pavlyutkin is more abundant in fossil floras of the Far East.

A remarkable element in the Voznovo flora is the leaf impressions of *Tetracentron piperoides* (Lesq.) Wolfe. *Tetracentron* is a monotype genus represented in the present-day flora by the single species *T. sinense* Oliv., an endemic form in mountainous forests in southwestern China. Impressions of *Tetracentron* leaves are rare in fossil floras; their finds known from Kamchatka, Japan, and Alaska [8, 38, 40] are associated with Eocene floras. The Voznovo collection includes an impression of an incomplete leaf attributed to another monotype genus (*Poliothyrsus* from the family Flacourtiaceae) that also dwells in subtropical mountainous forests of southwestern China. Of interest is a find of a well-preserved leaf conditionally referred to the composite species *Trochodendroides arctica* (Heer) Berry. The Voznovo specimen is represented by the *cocculifolia* form, a principal one for this polymorphic taxon. As is known, its representatives characteristic of the Early Cainophyticum do not cross the lower–upper Oligocene boundary [7].

Summing up the above-mentioned data, we should note that the Voznovo flora is undoubtedly unusual. On the one hand, it is characterized by single representatives of genera that determine the appearance of Eocene floras (*Tetracentron*, (?) *Trochodendroides, Platanus,* ancient *Populus* species, Hamamelaceae, and some other taxa) and, on the other, it demonstrates the distinct abundance and taxonomic diversity of the coniferous, which are rare in known Eocene floras from the Far East localities [1, 2, 8, 37]. At the same time, it differs from the well-studied Neogene type floras of the Primorye region, which span the interval from the initial early Miocene (Sinii Utes flora) to the late Miocene (Ust'–Suifun flora, upper phytolevel). As is known, no Eocene relicts have yet been found in the latter. Thus, the Oligocene age of the Voznovo macroflora and its host sediments seems to be most likely.

It should be added that, according to the data in [20], the phytoassemblage from the lower strata of the Voznovo Formation contains flowering species occurring in the above-mentioned *"Engelhardia"* floras from adjacent regions (Korea, Japan, Primorye, southern Khabarovsk Krai). Among them are *Cocculus* cf. *ezoensis* Tanai, *Cercidiphyllum palaeojaponicum* Endo, *Fothergilla* sp., *Porana macrantha* Heer, *Quercus kryshtofovichii* Klimova, and *Engelhardia koreanica* Oishi. The occurrence of these plants indicates undoubted relations between the Voznovo and *"Engelhardia"* floras. In the Primorye region, the latter are represented by the Kraskino, Rettikhovka, and Klyuch Tikhii floras. The Early Oligocene age of the *"Engelhardia"* floras is proven by Japanese researchers based on the analysis of the macro- and microfaunal assemblages and plant remains and is supported by radioisotopic dating [39].

Let us consider how the inferences drawn from the study of the Voznovo leaf flora correlate with the palynological data on its stratotype section (beds 4 and 5). The taxonomic composition of the Voznovo palynoflora (Table 2) is characterized by diverse sporiferous plants against the background of their low abundance in the spectra. The remarkable feature of this group is the presence of *Gleichenia*, which as yet has never been recorded in Neogene palynofloras of the region under consideration. As a whole, the amount of sporiferous plants in the spectra decreases toward the upper layers of the formation.

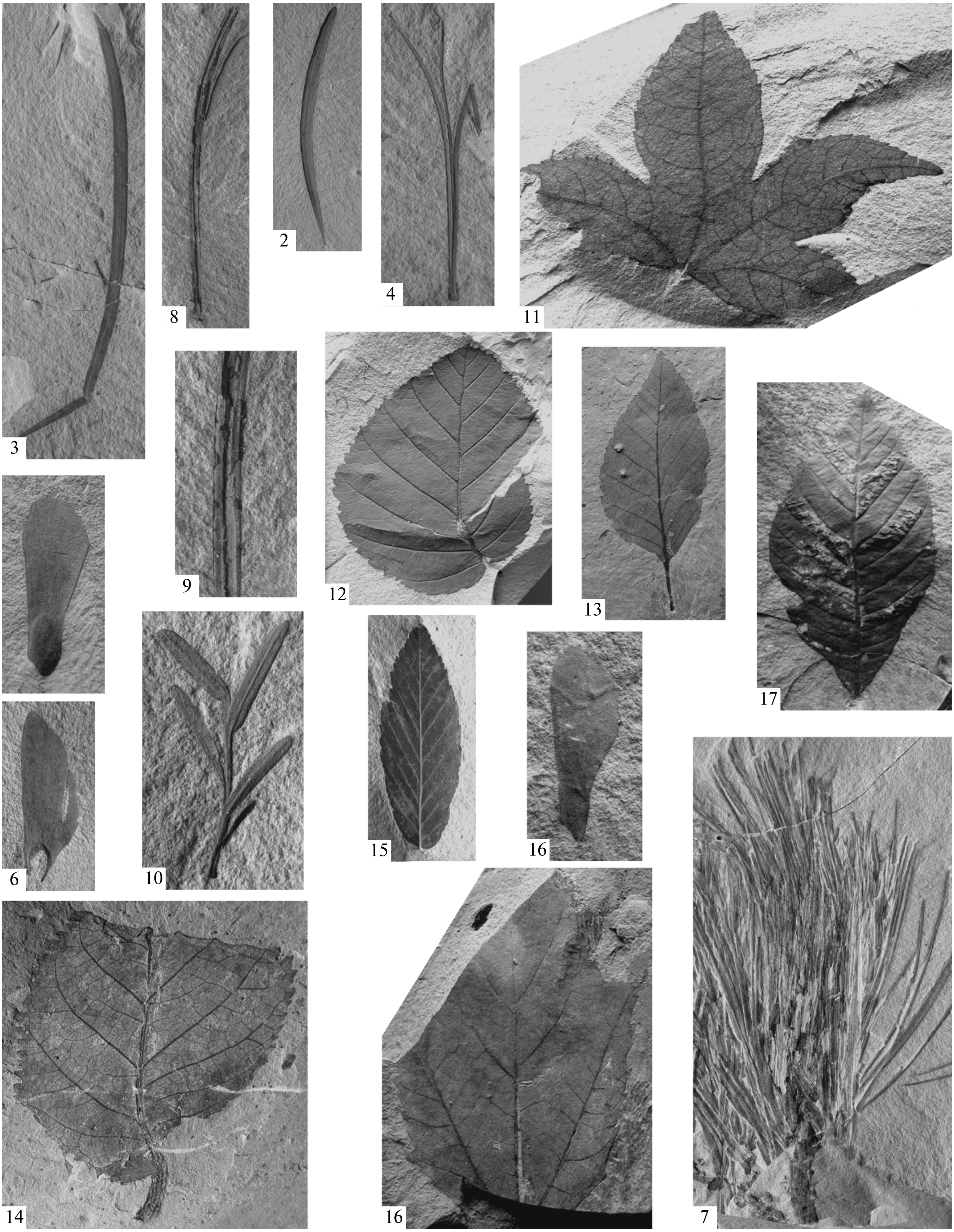
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Fig. 4. Plants of the Voznovo flora.
(*1*) *Picea kaneharai* Tanai et Onoe, 9206/468, ×2; (*2*) *Pseudolarix japonica* Tanai et Onoe (needles), 9206/154; (*3*) ***Pseudolarix acuminata*** **Pavlyutkin sp. nov.**, 9206/260 (holotype); (*4*) *Pinus* ex gr. *trifolia* f. *brevis*, 9206/128; (*5*) *Pinus* sp.-1, 9206/101, ×2.5; (*6*) *Pinus* sp.-2, 9206/178, ×2; (*7*) *Pinus* sp.-6, 9206/439; (*8, 9*) *Sciadopitys* sp., 9206/422, the same (fragment), ×3; (*10*) *Sequoia langsdorfii* (Sternb.) Heer, 9206/142, ×2; (*11*) *Liquidambar europaea* A. Br., 9206/53, ×2; (*12*) ***Betula ovalifolia*** **Pavlyutkin sp. nov.**, 9206/164 (holotype); (*13*) *Betula* sp.-2, 9206/266; (14) *Prunus* sp.,9206/129, ×1.5; (*15*) *Rubus* sp., 9206/572; (*16*) *Acer* cf. *crataegifolium* Siebold et Zucc., 9206/75, ×1.5; (*17*) *Aesculus* sp., 9206/118.

The proportions of gymnosperms and angiosperms show no stable trend: some spectra are dominated, although without a distinct prevalence, by the first of them and others by the second. Of importance is the occurrence (although irregular) of *Ginkgo* and *Araucaria* pollen, since both the genera are unknown in the Miocene floras of the Primorye region, although they permanently occur in Paleogene palynocomplexes. Almost all the spectra demonstrate the presence of *Podocarpus* pollen. Coniferous quantitatively prevail over the Taxodiaceae forms; both families are taxonomically diverse: they include almost all the known genera. The Pinaceae family is dominated by *Pinus* (both subgenera), which are accompanied by southern genera (*Cedrus, Keteleeria*). The taxodiaceae are dominated by pollen of an undeterminable generic affinity (Taxodiaceae gen. indet).

The angiosperm group is dominated by Betulaceae (*Betula, Alnus, Corylus, Carpinus*) and Juglandacae (*Carya, Juglans, Pterocarya*) pollen. One sample contains pollen of *Engelhardia*, a southern representative of the Juglandaceae family permanently occurring in the Paleogene palynofloras of the Primorye region. A remarkable feature of the palynospectra is the occurrence of *Quercus graciliformis* and *Q. conferta*, which are species most likely belonging to southern evergreen oaks from the subgenus *Cyclobalanopsis* also unknown in Miocene palynofloras of the region but permanently observable in Paleogene spectra. Of similar significance for dating the Voznovo palynoflora is the pollen of *Castanopsis, Fothergilla, Corylopsis,* and *Platanus* and from the *Triatriopollenites* and *Plicatopollis* genera. All of them represent components of Paleogene complexes unknown in Miocene palynofloras.

Thus, the data on the palynological spectra from the stratotype section of the Voznovo Formation are quite consistent with the results derived from the study of the leaf flora from the same section: both of them indicate its pre-Neogene age. At the same time, the representativeness of particular plant groups in the macro- and microfloras is frequently different. These discrepancies are typical of these two methods and explained by several factors: the influx of material to burial sites from ecologically different plant groupings (riparine and placore), the different manners of transportation of the objects to the burial sites, the different resistance to burial in sediments, and others. Some discrepancies in the role of particular taxa in the macro- and microfloras from the same beds remain incomprehensible.

By the ithology and fossil phytocomplexes, the Voznovo Formation is correlated with the volcano-sedimentary complex (Granatnenskii Sequence) developed on the eastern megaslope of the Sikhote-Alin mountainous system and composed of opoka-like sandstones and tuffaceous siltstones alternating with basalts (point 9302, Fig. 1). The floral assemblage from the interbasalt beds in the Amgu River basin contains *Ginkgo* ex gr. *adiantoides* (Ung.) Heer and *Podcarpus* sp. (leaves). Similar to the Voznovo flora, the coniferous are dominated by *Metasequoia occidentalis* (Newb.) Chaney (deciduous shoots) accompanied by subordinate *Picea* sp. (winged seeds), *Pseudolarix klimovae* Akhmet. (seed scales and seeds), *Pinus* sp. (seeds), and *Cryptomeria* and *Thuja* (fragments of branches).

The group of flowering plants is similarly dominated by representatives of families that play the leading role in the Voznovo flora: Betulaceae and Ericaceae (*Menziesia*, *Epigaea, Enkianthus, Vaccinium*). They are accompanied by subordinate *Podocarpus* sp., *Cercidiphyllum palaeojaponicum* Endo, *Alnus ezoensis* Tanai, *Fagus antipovii* Heer, *Ribes* sp., *Rubus* sp., *Symplocos* sp., and *Acer palaeoplatanoides* Endo. The similarity between the Amgu and Voznovo floras is distinctly manifested in their taxonomic compositions and the occurrence of single late Eocene relicts and species with a narrow stratigraphic range among the coniferous and flowering plants.

According to [4], the Amgu flora includes numerous coniferous (*Abies, Picea, Larix, Pseudolarix*), Taxodiaceae (*Metasequoia, Glyptostrobus, Cunninghamia*), Cupressaceae (*Thuja*), and Podocarpaceae (*Podocarpus*) forms, as well as leaves, winged seeds, and wood fragments of the genus *Keteleeria* [6]. Klimova [15] described new species of the genera *Corylus* (*C. auriculata* Klimova), *Comptonia* (*C. dentata* Klimova), *Spiraea* (*S. minima* Klimova), and *Ampelopsis* (*A. amgensis* Klimova) in the Amgu flora, in addition to numerous coniferous. The following important point should be emphasized relative to the last species. It includes heterogeneous leaves: one of the specimens figured as *Ampelopsis amgensis* [15; plate 12, Fig. 4] most likely belongs to *"Acer" arcticum* Heer, an archaic species of debatable taxonomic affinity. In our opinion, this point is important, since it is known that this species does not cross the lower–upper Oligocene boundary. It should be noted that Klimova described in the Amgu flora the new species *Platanus aculeata*, which was subsequently found among both early Oli-

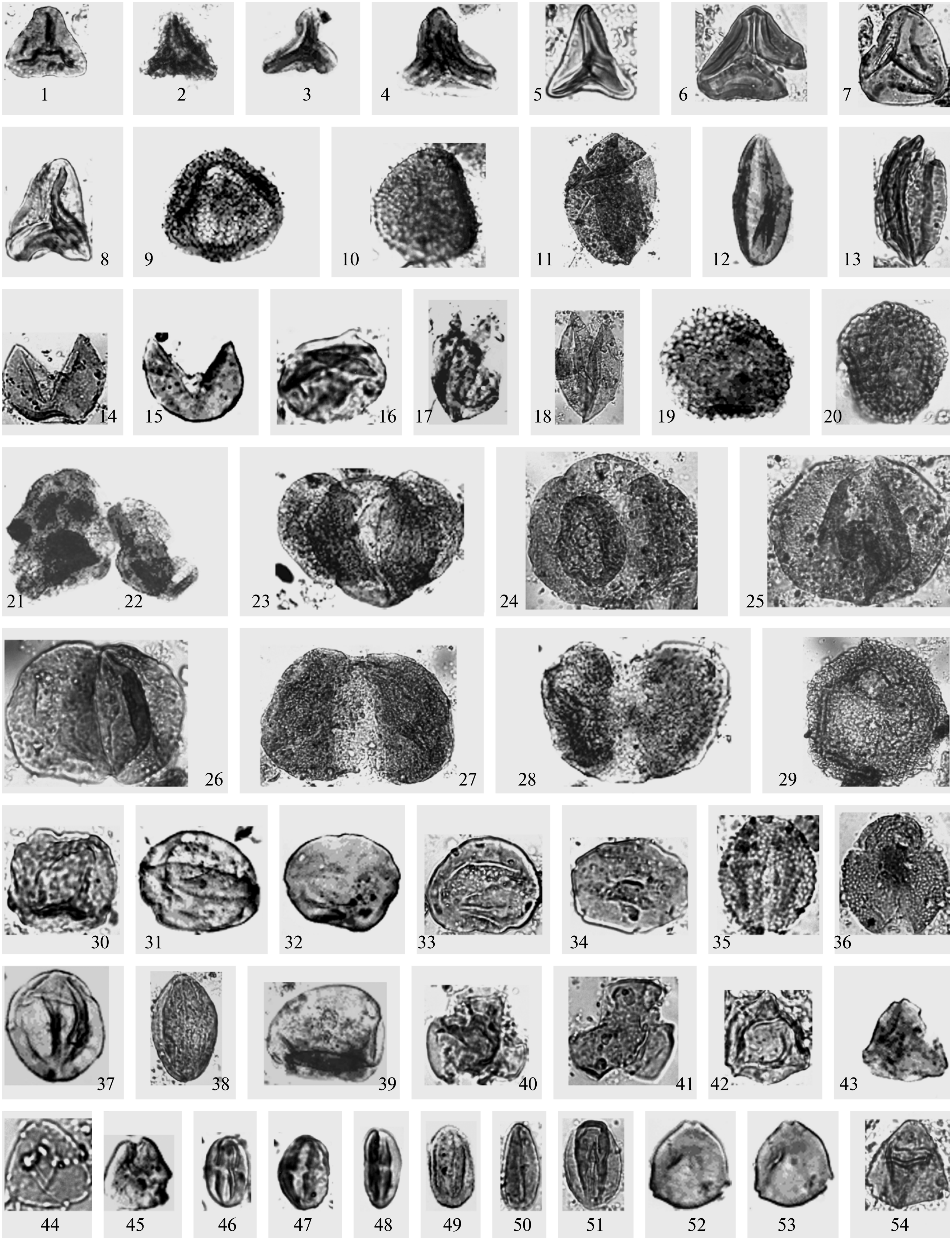
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Fig. 5. Spores and pollen of the Voznovo palynoflora; all the images of gymnosperms are given with magnification of 400, and the others with magnification of 600.

(*1*) *Concavisporites* sp.; (*2*) *Ornamentifera* sp., (*3–6*) *Gleichenia* sp.; (*7*) *Leiotriletes* sp.; (*8*) *Gleicheniidites* sp., (*9–11*) *Osmunda* sp.; (*12, 13*) *Ephedra* sp., (*14*) Taxodiaceae sp.; (*15*) *Taxodium* sp.; (*16*) *Sequoia* sp.; (*17, 18*) *Glyptostrobus* sp.; (*19, 20*) *Sciadopitys* sp.; (*21*) *Pinus* s/gen. *Haploxylon*; (*22–24*) *Pinus* s/gen. *Diploxylon*; (*25*) *Pinus mirabilis* (Rudolph) Anan.; (*26*) *Podocarpus* sp.; (*27, 28*) *Cedrus* sp.; (*29*) *Tsuga canadensis* (L.) Carr.; (*30*) *Zelkova* sp.; (*31–33*) *Carya* sp.; (*34*) *Juglans* sp.; (*35*) *Hamamelis* sp.; (*36*) Hamamelidaceae sp.; (*37*) *Fagus* sp.; (*38*) *Acer* sp.; (*39*) Campanulaceae sp.; (*40, 41*) *Platanus* sp.; (*42*) *Triatripollenites confusus* Zakl.; (*43*) *Triporopollenites* sp.; (*44*) *Platycarya* sp.; (*45*) cf. *Actinidia* sp.; (*46, 47*) *Castanea* sp.; (*48*) *Castanopsis* sp.; (*49*) *Quercus conferta* Boitz.; (*50*) *Quercus graciliformis* Boitz.; (*51*) *Quercus* sp.; (*52, 53*) *Comptonia* sp.; (*54*) *Myrica* sp.

gocene *"Engelhardia"* and older Eocene floras of the region under consideration.

The aforesaid provides evidence for correlating the Voznovo and Granatnenskaya formations with the Early Oligocene stage in the geological history of the Sikhote-Alin mountainous system. Here, we should touch on the problem of the age of this system. There are different standpoints concerning this aspect. In the opinion of [11, 18], Sikhote Alin is a young mountainous system that appeared after the formation of basalt plateaus, since its buried prebasalt relief shows no intense differentiation. A similar opinion is shared by E.P. Denisov, who believes that the present-day Sikhote-Alin represented in the Paleogene a peneplain with separate low mountainous ranges [12]. Such a slightly exotic assumption has found no factual substantiation; therefore, most geologists and geomorphologists [3, 28, 31] think that Sikhote-Alin permanently existed as a mountainous system through the entire Cenozoic.

Our data are consistent with this inference. The wealth and taxonomic diversity of the coniferous, as well as the ccurrence of several flowering taxa usually confined to mountainous slopes (*Tetracentron, Fagus, Betula, Carpinus, Ostrya, Corylus, Acer, Sorbus*, and *Ericaceae*) imply the mountainous type of the Voznovo forest. At the same time, some plant taxa such as *Glyptostrobus, Liquidambar*, and *Aesculus* are more typical of lowland forest communities, while the occurrence of coal seams in the Voznovo Formation indicates the development of swampy landscapes. It is more likely that the Voznovo flora characterizes different biotopes: it reflects vegetation groupings of mountainous slopes and lowland areas surrounded by fluvial lakes. The latter likely resulted from blocking of river systems by flows of basaltic lavas. Observations in areas of young (Quaternary) volcanism [19] show that such lakes are ephemeric on geological scales, since lava dams are rapidly eroded and the lakes become drained with subsequent swamping and formation (under favorable conditions) of peats, which serve as material for future coal seams.

The mountainous affinity of the Amgu flora is also evident from the diverse coniferous plants belonging to the Pinaceae family and the occurrence of diverse Ericaceae genera, abundant *Acer*, *Betulaceae*, and *Rosaceae* representatives. This flora demonstrates a distinct similarity with the Voznovo one. It is remarkable that both floras are practically lacking Salixaceae (*Salix, Populus*) and Ulmaceae (*Zelkova, Ulmus*) typical of fossil phytocomplexes associated with fluvial facies. It is conceivable that the paleorivers that fed the blocked lakes were of low orders and lacking any developed floodplains and, correspondingly, open areas, which prevented light-demanding Salixaceae and Ulmaceae taxa from dispersion.

The idea of defining the Svetlyi Formation as an autonomous stratigraphic unit seems productive, although this may be reasonable only for the eastern segment of the Zerkal'nenskaya Depression. However, the formation should be correlated with a different stratigraphic interval; it is separated from the Voznovo formation by basalts constituting the marginal part of the lava flow. Most researchers, including the authors of the recent variant of the geological map[3], attribute these basalts to the Suvorovo Complex, which is dated by radioisotopic methods back to 47 ± 1.2 Ma [34] or 45.8 ± 1.1 Ma [35].

According to our preliminary data, the Svetlyi Formation corresponds to the late Paleocene and, probably, initial Eocene and may be correlated (based on the macrofloral and palynological complexes) with the Tuyanovo Formation defined in the western part of the depression. In the stratotype area, the Voznovo Formation is overlain by a member of pebble and loose conglomerates with sand and clay intercalations, which is known as the Krushevo Sequence. Its formation is conditionally dated to the Miocene. Inasmuch as reliable data on the age of these sediments are unavailable, we assume a longer span for its accumulation that also includes the Pliocene.

CONCLUSIONS

(1) Our data do not support the revision of the Oligocene age of the Voznovo Formation for the Miocene age, as is proposed in [27]. The corresponding flora characterizes the Oligocene stage in the geological history of the Sikhote-Alin mountainous system. We accept the age of this formation as corresponding to the early Oligocene (Rupelian on the International Stage Scale).

(2) The Voznovo sediments were deposited in a closed basin, which was produced by damming the

[3] V.M. Losiv, *The Geological Structure and Mineral Resources, Sheets L-53-XXVIII, L-53-XXXIII, L-53-XXXIV, and L-53-XXXV* (Vladivostok, 2002) [in Russian].

Table 2. Taxonomic composition of the Voznovo palynoflora

Point 9206	Bed 4											
Sample	5B		6B		1B		2B		3B		4B	
Total abundance of spores and pollen	600		540		595		497		607		425	
	abundance	%	abundance	%	abundance	%	abundance	%	abundance	%	abundance	%
1	2	3	4	5	6	7	8	9	10	11	12	13
Abundance of spores	92	15.3	75	13.9	43	7.2	20	4.0	25	4.1	9	2.1
Abundance of gymnosperm pollen	217	36.2	225	41.7	297	49.9	283	56.9	350	57.7	337	79.3
Abundance of angiosperm pollen	291	48.5	240	44.4	255	42.9	194	39.0	232	38.2	79	18.6
Sporiferous												
Sphagnum sp.	1	0.2	1	0.2	1	0.2						
Polypodiaceae sp.	40	6.7	30	5.5	5	0.8	4	1.4	4	0.6	7	1.6
Leiotriletes sp.	20	3.3	8	1.5	11	1.8			2	0.3	1	0.2
Osmunda sp.	20	3.3	22	4.1	12	2.0	9	1.8	7	1.1	1	0.2
Lophotriletes sp.	5	0.8	4	0.7	1	0.2			1	0.2		
Ophioglossum sp.			1	0.2								
Botrychium sp.	5	0.8	3	0.5	4	0.7			1	0.2		
Gleichenia sp.					4	0.7	2	0.4	6	1.0		
Gleicheniidites sp.							1	0.2				
Ornamentifera sp.					1	0.2						
Cibotium sp.					1	0.2			1	0.2		
Cyathea sp.			2	0.4			1	0.2	3	0.5		
Lygodium sp.	1	0.2										
Concavisporites sp.			2	0.4								
Lycopodium sp.			2	0.5	3	0.5						
Gymnosperms												
Ginkgo sp.	1	0.2							2	0.3		
Araucaria sp.									3	0.5		
Podocarpus sp.	3	0.5			5	0.8	1	0.2	5	0.8	1	0.2
Pinaceae sp.			1	0.2					2	0.3		
Abies sp.	1	0.2	1	0.2	4	0.7			6	1.0	2	0.5
Tsuga canadensis (L.) Carr.	5	0.8	8	1.5	7	1.2	11	2.2	28	4.6	18	4.2
T. diversifolia (Maxim.) Mast							5	1.0	1	0.2		
Tsuga sp.			1	0.2	4	0.7			5	0.8	1	0.2
Picea sect. *Omorica*	14	2.3	12	2.2	18	3.4	10	2.0	45	7.4	40	9.4
Cedrus sp.			1	0.2	1	0.2	2	0.4	4	0.6		
Larix sp.					2	0.3	1	0.2	4	0.6		
Keteleeria sp.					1	0.2	2	0.4	1	0.2	1	0.2
Pinus s/gen. *Diploxylon*	45	7.5	40	7.4	60	10.1	68	13.7	35	5.8	32	7.5
P. s/gen. *Haploxylon*	55	9.2	60	11.1	90	15.1	65	13.1	85	14.0	115	27.1
Pinus mirabilis (Rudolph) Anan.			2	0.4	5	0.8	8	1.6	6	1.0	2	0.5
Sciadopitys sp.			2	0.4	10	1.7	7	1.4	22	3.6	14	3.3
Taxodiaceae sp.	78	13.0	77	14.3	50	8.4	75	15.1	45	7.4	80	18.8
Taxodium sp.	4	0.7	4	0.7	3	0.5	3	0.6	5	0.8	3	0.7
Glyptostrobus sp.			4	0.7	18	3.0	14	2.8	18	3.0	4	0.9
Sequoia sp.	7	1.2	6	1.1	2	0.3	5	1.0	6	1.0	15	3.5
Cryptomeria sp.			1	0.2					1	0.2	2	0.5
Metasequoia sp.									1	0.2		
Cupressaceae sp.	2	0.3	4	0.7	17	2.9	4	0.8	15	2.5	6	1.4
Ephedra sp.	2	0.3	1	0.2			2	0.4	5	0.8	1	0.2
Angiosperms												
Salix sp.									1	0.2		
Myrica sp.	7	1.2	8	1.5	6	1.0	8	1.6	2	0.3		
Comptonia sp.			1	0.2	5	0.8	3	0.6	4	0.6		
Pterocarya sp.			1	0.2	1	0.2	1	0.2	1	0.2		

Table 2. (Contd.)

1	2	3	4	5	6	7	8	9	10	11	12	13
Juglans sp.	26	4.3	21	3.9	10	1.7	6	1.2	13	2.1	6	1.4
Carya sp.	26	4.3	22	4.1	24	4.0	17	3.4	35	5.7	10	2.4
Engelhardtia sp.									2	0.3		
Carpinus sp.	1	0.2	3	0.5			3	0.6	8	1.3		
Corylus sp.	31	5.2	19	3.5	6	1.0	10	2.0	4	0.6	1	0.2
Betula sp.	60	10.0	40	7.4	48	8.1	28	5.6	22	3.6	7	1.6
Alnus sp.	48	8.0	35	6.5	10	1.7	16	3.2	6	1.0	3	0.7
Quercus sp.	2	0.3	1	0.2								
Quercus graciliformis Boitz.	1	0.2	1	0.2					1	0.2		
Q. conferta Boitz.	5	0.8	2	0.4	1	0.2	3	0.6	1	0.2		
Fagus sp.	2	0.3	2	0.4	5	0.8	10	2.0	11	1.8	5	1.2
F. grandifoliiformis Pan.	1	0.2					1	0.2			1	0.2
Castanea sp.	3	0.5	1	0.2	3	0.5	5	1.0	6	1.0	5	1.2
Castanopsis sp.			2	0.4	3	0.5	4	0.8	3	0.5		
Ulmus sp.	11	1.8	15	2.8	10	1.7	8	1.6	8	1.3	5	1.2
Zelkova sp.	2	0.3	2	0.3	1	0.2	1	0.2	1	0.2	1	0.2
Hamamelidaceae sp.					2	0.3			3	0.5		
Fothergilla sp.					1	0.2			1	0.2		
Corylopsis sp.					4	0.7	1	0.2	6	1.0	1	0.2
Hamamelis sp.					1	0.2			3	0.5	4	0.9
Liquidambar sp.	5	0.8	12	2.2	22	3.7	11	2.2	28	4.6	5	1.2
Platanus sp.			2	0.4	4	0.7	2	0.4	12	1.9	2	0.5
Ilex sp.	4	0.7	2	0.4			1	0.2	2	0.3	2	0.5
Oleaceae sp.			2	0.4								
Acer sp.	2	0.3	1	0.2	1	0.2	4	0.8				
Cardiospermum sp.			1	0.2								
Parthenocissus sp.	2	0.3										
Vitaceae sp.					1	0.2			1	0.2		
Tilia sp.	2	0.3	4	0.7	2	0.3					1	0.2
Nyssaceae sp.					1	0.2						
Eucommia sp.	1	0.2	3	0.5	2	0.3	2	0.4	6	1.0		
Araliaceae sp.									1	0.2		
Sambucus sp.							1	0.2				
Diervilla sp.	4	0.7	2	0.4					1	0.2		
Lonicera sp.					1	0.2			1	0.2		
Viburnum sp.					1	0.2			1	0.2		
Triporopollenites sp.							1	0.2				
Triatriopollenites confusus Zakl.									1	0.2		
Triatriopollenites *plicoides* Zakl.									1	0.2		
Plicatopollis plicatus R. Pot.									1	0.2		
tricolpate pollen	5	0.6	5	0.9	8	1.3	5	1.0			3	0.7
triporate pollen	2	0.3	4	0.7	11	1.8	7	1.4	5	0.8	1	0.2
tricolpate to triporate pollen	1	0.2	2	0.4	6	1.0			2	0.3	1	0.2
Sparganium sp.			2	0.4								
Alismataceae sp.									1	0.2		
Campanulaceae sp.					1	0.2	1	0.2				
Rosaceae sp.	20	3.3	10	1.9	30	5.0	18	3.6	14	2.3	14	3.3
Leguminosae sp.	1	0.2	1	0.2	3	0.5	1	0.2	1	0.2		
Pleurospermum sp.	1	0.2							1	0.2		
Ericales sp.	15	2.5	10	1.9	20	3.4	12	2.4	10	1.6	1	0.2
cf. *Actinidia* sp.							1	0.2				
Liliaceae sp.			1	0.2					1	0.2		

river channel by basaltic lava flows. After shoaling caused by the disintegration of the basaltic dam, the lake was swamped with the formation of peats, which were subsequently transformed into brown coals. Such a sedimentation type was particularly characteristic of the east Sikhote-Alin Mountains through the Tertiary.

(3) The Voznovo macro- and microfloras include single elements of Eocene floral complexes, revealing distinct links with the *"Engelhardia"* floras of the region (the Kraskino, Rettikhovka, Klyuch Tikhii, and others).

(4) The taxonomic compositions of the Voznovo macro- and microfloras indicate its mountainous ecotype. Its equivalents among the fossil species are dwellers of mountainous slopes.

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REFERENCES

1. A. G. Ablaev, *Paleogene Biostratigraphy of the Southern Amur Region Coast* (Dal'nauka, Vladivostok, 2000) [in Russian].
2. A. G. Ablaev, *Paleogene of the Pritumanskii Coal-Bearing Basin (the Southern Far East* (Dal'nauka, Vladivostok, 2001) [in Russian].
3. M. A. Akhmet'ev, *Phytostratigraphy of the Paleogene–Miocene Continental Deposits of Off-Tropical Asia* (Nauka, Moscow, 1993) [in Russian].
4. M. A. Akhmet'ev and N. A. Shevyreva, "Fossil Gymnosperms of Amgu (Eastern Sikhote Alin)," in *Paleoflora and Stratigraphy of the Phanerozoic* (GIN AN SSSR, Moscow, 1989), pp. 104–117 [in Russian].
5. M. A. Akhmetiev and S. R. Manchester, "A New Species of *Palaeocarpinus* (Betulaceae) from the Paleogene of the Eastern Sikhote-Alin," Paleontol. Zh., No. 4, 107–112 (2000) [Paleontol. J. **34**, 469–473 (2000)].
6. N. I. Blokhina and R. S. Klimova, *"Keteleeria* from the Tertiary Deposits of the Middle Sikhote Alin (Primorye)," Paleontol. Zh., No. 1, 99–106 (2000) [Paleontol. J. **34**, 105–113 (2000)].
7. L. Yu. Budantsev and E. R. Mokhov, "Morphological Variability of Leaves and Taxonomy of Genus Troshodendroides in the Early Eocene Flora of Western Kamchatka," in *Problems of Paleobotanics* (Nauka, Leningrad, 1986), pp. 19–27 [in Russian].
8. L. Yu. Budantsev, "Early Paleogene Flora of Western Kamchatka," (Nauka, St. Petersburg, 2006), Tr. Biol. Inst. Ross. Akad. Nauk, vol. 22.
9. E. V. Bykovskaya and N. S. Podgornaya, "Stratigraphy and Petrology of the Upper Cretaceous and Tertiary Volcanogenic Complexes of the Ol'ga-Tetyukha Area," Inform. Sb. VSEGEI, No. 17, 29–40 (1959).
10. G. M. Vlasov, "Stratigraphic Scheme of Tertiary Deposits of the Southern Russian Far East," in *Proceedings of Conference on Development of Unified Stratigraphic Scheme of the Far East* (Khabarovsk, 1956) [in Russian].
11. G. S. Ganeshin, *Geomorphology of Primorye* (Gosgeotekhizdat, Leningrad, 1957) [in Russian].
12. E. P. Denisov, *Recent Tectonics and Late Cenozoic Volcanism of the Southern Primorye and Adjacent Areas* (Vladivostok, 1965) [in Russian].
13. R. S. Klimova, "On Age of the Stratorypes of the Nadezhdino and Ust-Davydov Formations," Inform. Sb. PGU, No. 7, No. 7, pp. 38–40 (1971).
14. R. S. Klimova, A. F. Kramchanin, and T. I. Demidova, "New Data on the Stratigraphy of the Rettikhovsky Coal Sequence," in *Cenozoic Stratigraphy of the Far East* (DVNTS Akad. Nauk SSSR, Vladivostok, 1977), pp. 66–75 [in Russian].
15. R. S. Klimova, "Miocene Flora and Phytostratigraphic Horizons of the Primorskii Krai," in *Paleobotanics and Phytostratigraphy of the USSR East* (DVNTS Akad. Nauk SSSR, Vladivostok, 1983), pp. 65–76 [in Russian].
16. A. N. Krishtofovich, "Tertiary Plants Collected by A. G. Kuznetsov in the Amgu River, Primorye," Mater. Geol. Polezn. Iskop. Dal'n. Vost., No. 15, 1–15 (1921).
17. A. S. Kundyshev, "On the Age of the Uglov, Nadezhdino, and Ust-Davydov Formations of Southern Primorye in the Stratotype Section," in *Stratigraphy of the Precambrian and Phanerozoic of Transbaikalia and Southern Far East. Proceedings of 4th Far East Regional Stratigraphic Conference, Khabarovsk, Russia, 1990* (Khabarovsk, 1990), pp. 279–280 [in Russian].
18. N. A. Lebedeva, "Geomorphology of the Neogene–Quaternary Deposits and Neotectonics of the Western Part of the Southern Primorye, Khanka Area," in *Proceedings of Commission on Studying Quaternary Period* (Nauka, Moscow, 1957), No. 13, pp. 221–227 [in Russian].
19. I. V. Melekestsev, *Volcanism and Relief Formation* (Nauka, Moscow, 1980) [in Russian].
20. V. A. Mikhailov, Yu. M. Feoktistov, and R. S. Klimova, "New Data on the Cenozoic Phytostratigraphy of the Eastern Part of the Zerkal'nenskaya Depression," in *Cenozoic of the Far East* (DVO AN SSSR, Vladivostok, 1989), pp. 38–49 [in Russian].
21. B. I. Pavlyutkin, S. I. Nevolina, T. I. Petrenko, and T. K. Kutub-Zade, "On Age of Nazimovskaya and Khasan Formations in the Paleogene Succession of Southwestern Primor'e," Stratigr. Geol. Korrelyatsiya **14** (3), 116–129 (2006) [Stratigr. Geol. Correlation **14**, 444–457 (2006)].
22. B. I. Pavlyutkin, "Representatives of Suborder Erisanae from the Oligocene Voznovo Flora of the Primorsky Krai," Bot. Zh. **92** (2), 293–307 (2007).
23. B. I. Pavlyutkin, *Eocene Ust-Davydov Flora of the Southern Primorye* (Dal'nauka, Vladivostok, 2007) [in Russian].
24. B. I. Pavlyutkin, Extended Abstract of Doctoral Dissertation in Geology and Mineralogy (Vladivostok, 2008).
25. *Resolutions of Interdisciplinary Conference on Development of Unified Stratigraphic Schemes for Far East* (Gosgeoltekhizdat, Moscow, 1958), p. 51 [in Russian].
26. *Resolutions of Interdisciplinary Stratigraphic Conference on the Precambrian and Phanerozoic of the USSR Far*

East (Vladivostok, 1978 g.) (GKP SVPGO, Magadan, 1982), p. 182 [in Russian].

27. *Resolution of 4th Interdisciplinary Stratigraphic Conference on the Precambrian and Phanerorozoic of the Southern Far East and Eastern Transbaikalia, Khabarovsk, Russia*, (KhGGGP, Khabarovsk, 1994) [in Russian].
28. V. I. Rybalko, V. N. Ovechkin, and R. S. Klimova, "Cenozoic Basaltoids of the Amgu Group (Northeastern Primorye)," Ofioliti, No. 12, 59–71 (1980).
29. V. Z. Skorokhod, *Main Features of the Geological Structure of the Southern Russian Far East* (Primorsk. Geogr. O-vo, Vladivostok, 1941) [in Russian].
30. *Stratigraphic Code. 3rd Edition* (VSEGEI, St. Petersburg, 2006), p. 95 [in Russian].
31. G. I. Khudyakov, "Regularities of the Formation of Continental Morphostructures (Southern Part of the Soviet Far East)," in *Regional Morphotectonics, Geomorphology, and Quaternary Geology of Far East* (DVNTS Akad. Nauk SSSR, Vladivostok, 1977), pp. 3–16 [in Russian].
32. B. M. Shtempel', "Uglovskii Area. Report on Geological Study on Autumn, 1924," Mater. Geol. Polezn. Iskop. Dal'n. Vost., No. 45, 1–88 (1926).
33. K. Huzioka, "Tertiary Floras of Korea," J. Minn. Coll. Akita Univ. Ser. A **5** (1), 1–83 (1972).
34. S. Okamura, Y. A. Martynov, K. Furuyama, and K. Nagao, "K–Ar Ages of the Basaltic Rocks from Russian Far East: Constraints on the Tectono-Magmatism Associated with the Japan Sea Opening," The Island Arc, No. 7, 271–282 (1998).
35. Y. Otofuji, T. Matsuda, T. Itaya, et al., "Late Cretaceous to Early Paleogene Paleomagnetic Results from the Sikhote Alin, Far Eastern Russia: Implications for Deformation of East Asia," Earth Planet. Sci. Lett. **130**, 95–108 (1995).
36. T. Tanai and T. A. Onoe, "Mio-Pliocene Flora from the Ningyo–Toge Area on the Border Between Tottori and Okayama Prefecture, Japan," Rep. Geol. Surv. Japan, No. 187, 1–62 (1961).
37. T. Tanai, "The Oligocene Floras from the Kushiro Coal Field, Hokkaido, Japan," J. Fac. Sci. Hokkaido Univ. Ser **14** (4), 383–514 (1970).
38. T. Tanai, "The Revision of the So-Called Cercidiphyllum Leaves from the Paleogene of the North Japan," J. Fac. Sci. Hokkaido Univ. Ser **19** (4), 451–484 (1981).
39. T. Tanai and K. Uemura, "Lobed Oak Leaves from the Tertiary of East Asia with Reference to the Oak Phytogeography of the Northern Hemisphere," Trans. Proc. Palaeont. Soc. Japan, N.S., No. 4, 343–365.
40. J. A. Wolfe, "Paleogene Floras from the Gulf of Alaska Region," Geol. Surv. Prof. Pap., No. 997, 1–108 (1977).

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