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On Age of Nazimovskaya and Khasan Formations in the Paleogene Succession of Southwestern Primor'e

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Abstract—Materials of previous studies and new original geological and paleobotanic data are used to substantiate synchronism (late Eocene) of the Khasan and Nazimovskaya formations, the key stratigraphic units of the Paleogene in Primor'e. Coal-bearing sediments of the units rest upon early–middle Eocene volcanics (Kraskino rhyolite tuffs, Zaisanovka basaltic andesites) being overlain by the lower Fatash Subformation of the lower Oligocene with flora of the Kraskino type. The Ust'-Davydovskaya Formation of the Rechnoi Peninsula (outskirts of Vladivostok) is the most probable analogue of the Khasan (=Nazimovskaya) Formation.

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Key words: Stratigraphy, Eocene, Oligocene, fossil flora assemblages, Primor'e region.

INTRODUCTION

Most of the problems related to Paleogene stratigraphy of the Primor'e region are connected, directly or indirectly, with different interpretations of geological data on the southwestern part of the Khasan (=Kraskino) depression. The case in point is two regional stratigraphic units: the Nazimovskaya and Khasan formations. Problems of their age and stratigraphic position are considered in this work. In our opinion, they are vital in view of the Fifth regional stratigraphic meeting that is forthcoming.

Inferences formulated in the paper are based on materials of previous research and new original data obtained for the known and additional geological sections (Fig. 1). In addition to published results characterizing core samples from boreholes 40 and 161 drilled in the Pos'et Peninsula and near the Gladkaya River mouth, the stratotype areas of the Nazimovskaya Formation (Pavlyutkin and Petrenko, 1997), we studied palynological assemblages from the other sites. These are sequence of the Kraskino flora type locality (Site 9182), different sections of the Khasan Formation, including that adjacent to the above locality, and coaliferous sediments of the so-called "coal precipice" in the depression western part (Site 8).

New materials on the Kraskino flora from beds exposed in the quarry near the Shakhterskii Settlement (type locality) and in the Kraskino–Khunchun road ditch (collection of Pavlyutkin, sites 9182, 9196) are considered as well. Besides, we revised collections of fossil macroflora from the Nazimovskaya Formation stratotype section (sites 12, 23), from core samples recovered by boreholes, which penetrated the Khasan Formation (Nevolina's collection of the mid-1960s), and from wastes of a coal pit (Site 1257, collection of A.K. Sedykh). Sedykh (1989) who initially studied the last collection published preliminary results only as a lists of identified plant taxa. Pavlyutkin and Kutub-Zade analyzed geological data and fossil floras, Petrenko carried out palynological study, Nevolina and Pavlyutkin reexamined all the collections mentioned above.

REVIEW OF THE PROBLEM

Vlasov (1956) was first to discriminate the Nazimovskaya and Khasan formations. Studying the coal-bearings potential of the Cenozoic Khasan depression and being acquainted with problems of Tertiary stratigraphy of the Rechnoi Peninsula, which were discussed by Shtempel' (1926) and other researchers, he noted an analogy in succession of main lithostratigraphic units in these two areas.

The Uglovoe (coal-bearing), Siltstone, and Lignite formations (sequences) of the Rechnoi Peninsula were correlated to the Khasan coal-bearing formation, clayey–tuffaceous, and siltstone–sandstone sequences of the Khasan depression. Lignite interbeds identified in the upper part of the last sequence. The lithological similarity between sections was so distinct that this likely provided grounds for the inference on synchronism of corresponding stratigraphic units in the areas under consideration.

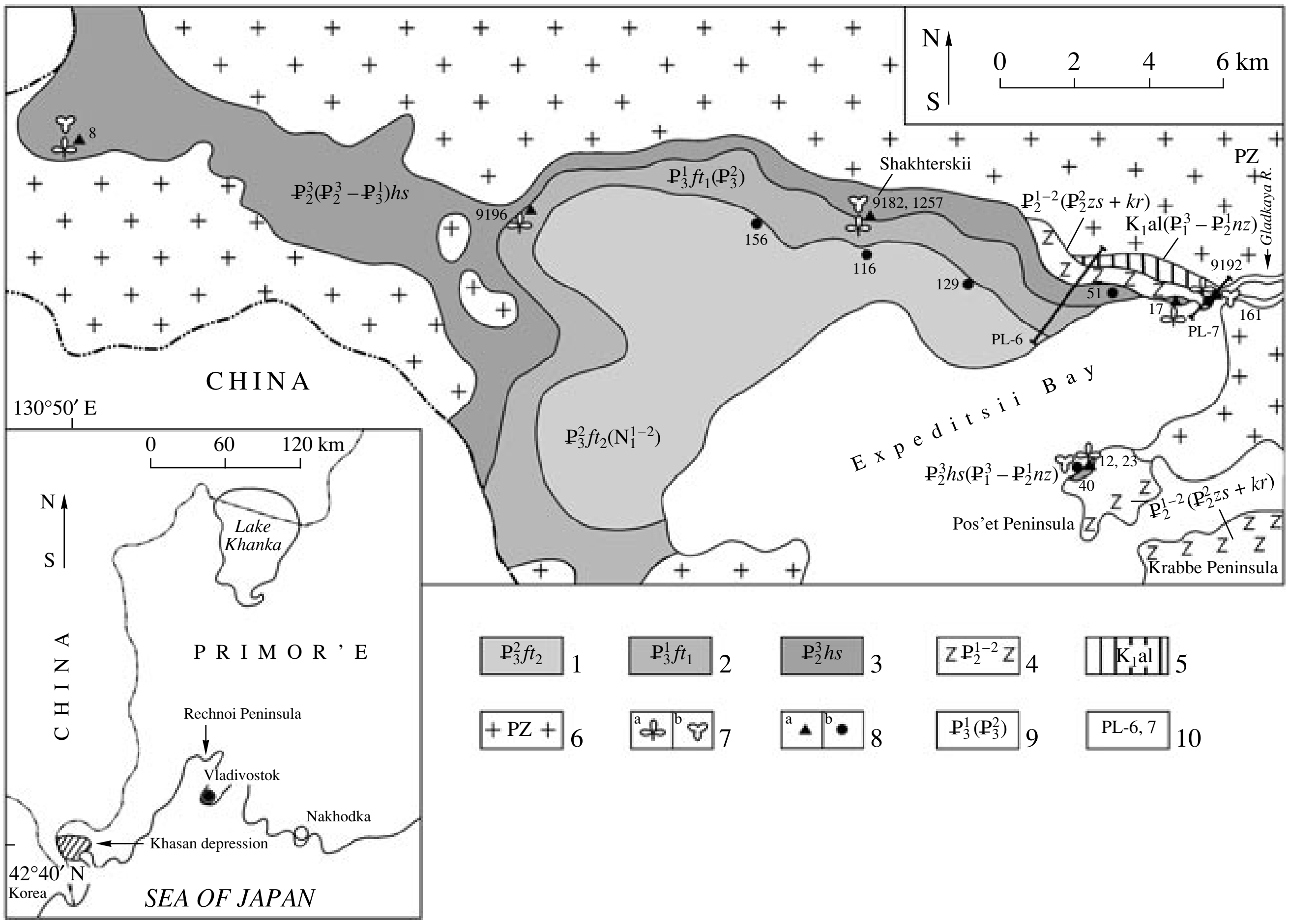

Fig. 1. Schematic geological structure of the Khasan depression (compiled by Kutub-Zade using data of additional geological survey, scale 1: 200000): (1) upper and (2) lower Fatash subformations; (3) Khasan (=Nazimovskaya) Formation; (4) undivided Zaisanovka and Kraskino volcanics; (5) Lower Cretaceous sediments; (6) pre-Cretaceous rocks (granites, hornfels); (7) localities of fossil flora (a) and sampling sites (b) for palynological analysis; (8) observation points (a) and boreholes (b) with their numbers; (9) geological indices of subdivisions (in brackets, after Vlasov, 1949); (10) prospecting lines and their numbers.

Based on the results of mining works in the Gladkaya River mouth area and west of the later in outskirts of the abandoned Zaisanovka Settlement (prospect lines 6, 7, Figs. 1, 2), where relations between main lithostratigraphic units were established, Vlasov (unpublished report of 1944) arrived at two conclusions. First, he inferred that sedimentary and volcanic Tertiary rocks alternate through the section in the eastern part of the depression. Second, one more coal-bearing formation overlain by basalts was distinguished in addition to the Khasan Formation. The coaliferous deposits and overlying basalts were attributed to the Nazimovskaya and Zaisanovka formations, respectively.

The section of the Gladkaya River mouth area was lacking paleobotanic substantiation, although relationships between the siltstone–sandstone sequence with low coal content (Nazimovskaya Formation, after Vlasov) and basalts of the Zaisanovka Formation were established precisely here (Fig. 2b). Similar geological relationships were observed also west of the Gladkaya River mouth (Fig. 2a). In the Pos'et Peninsula, the siltstone–sandstone (coal-bearing) sequence of local distribution appeared to be bearing fossil flora, but its relationships with the Zaisanovka basalts remained unclear. Rocks of the sequence are exposed at the lower hypsometric level as compared to that of basalts, and this coal-bearing sequence of the Pos'et Peninsula, which was accepted by Vlasov for the standard (stratotype) of the Nazimovskaya Formation, was placed below basalts in the succession. The formation was first considered as coeval with the Khasan Formation, which was thought to replace it in the southeastern part of the depression (Vlasov, unpublished report of 1944). In subsequent interpretation after geological study of the Rechnoi Peninsula, Vlasov (1949, unpublished material) was of opinion that the Nazimovskaya Formation is older than the Khasan Formation and correlative with the Uglovoe Formation of the Rechnoi Peninsula, although this was in conflict with paleobotanic data.

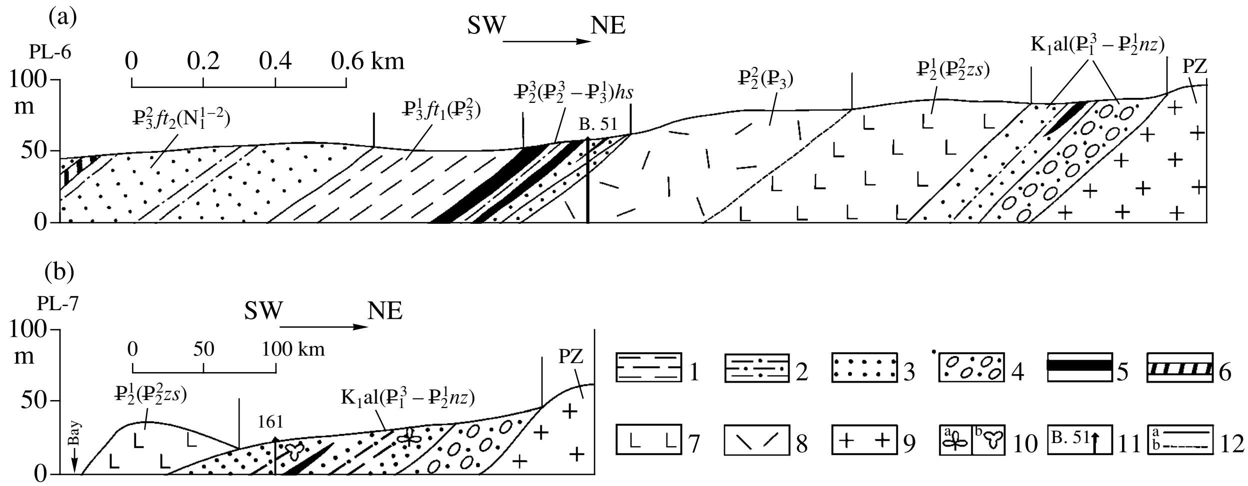

Fig. 2. Geological cross sections based on mining works (Vlasov, 1944; indices as in Fig. 1): (1) argillite; (2) siltstone; (3) sandstone; (4) pebble, gravel; (5) brown coal; (6) carbonaceous shale; (7) basalt, basaltic andesite; (8) rhyolite lava and tuff; (9) granite, hornfels; (10) localities of fossils flora (a) and intervals (b) sampled for palynological analysis; (11) boreholes and their numbers; (12) stratigraphic (a) and facies (b) boundaries.

In opinion of M.O. Borsuk, the Nazimovskaya assemblage of plant fossils (collection of Vlasov from the Pos'et Peninsula section) is of the Eocene age, and this inference remained unchanged later on (Borsuk, 1967). In the final version of the Paleogene stratigraphic scheme suggested for the Khasan depression, Vlasov dated the Nazimovskaya Formation base by the late Paleocene, however, and correlated its upper limit with the lower–middle Eocene boundary. The Zaisanovka basalts corresponded in that scheme to the middle Eocene; the Khasan coal-bearing formation to the upper Eocene–lower Oligocene. This viewpoint was authorized in the official stratigraphic document (*Resolutions of the Interdepartmental…*, 1958).

Later on, ages of stratigraphic units in the Rechnoi Peninsula section were revised (Vlasov, 1949; unpublished materials). The Uglovoe Formation was dated as the late Eocene–early Oligocene in age, while the siltstone sequence termed the Nadezhdinskaya Formation and the lignite sequence termed the *Ust'-Davydovskaya Formation* were attributed respectively to the late Oligocene and the early–middle Miocene. This was inconsistent, by the way, with the Paleogene age determined by Shtempel (1926) for floral assemblages from all the formations of the Rechnoi Peninsula. The correctness of this determination was confirmed during subsequent research of micro- and macroflora remains in the section of the peninsula (Klimova, 1983; Kundyshev, 1990; Pavlyutkin and Petrenko, 1993; Akhmet'ev, 1993). The situation, when "lower–middle Miocene" sediments of the Ust'-Davydovskaya Formation stratotype contain the Eocene–early Oligocene plant remains, is paradoxical of course. Despite this, the Paleogene stratigraphic scheme of the southern Primor'e remained unchanged since the terminal 1940s until recent time (*Resolutions of the Fourth…*, 1994).

BRIEF GEOLOGICAL REVIEW

Before discussing the obtained data, let us consider briefly the geological structure of examined objects. Scheme of stratigraphic units distribution in the Khasan depression is shown in Fig. 1. Outcrops of the Khasan Formation are confined to peripheral parts of the depression, which are connected with the adjacent Khunchun depression of China. The Nazimovskaya Formation is of a patchy distribution. Its rocks are traceable in a narrow chain of exposures along the northwestern coast of the Pos'et Peninsula for a distance less than 200 m.

Lithology of the formations is illustrated in columns of Fig. 3. The Khasan Formation resting upon granites, Paleozoic hornfels, Lower Cretaceous sedimentary rocks, and so-called Kraskino volcanics is divided in two subformations. The lower conglomeratic subformation (6–190 m) is confined only to depressions in the pre-Cenozoic basement, being composed of conglomerates, gravelstones, and sandstones with siltstone and coaly argillite interbeds. It is conceivable that some Lower Cretaceous strata are also included in this subformation. The upper coal-bearing subformation (30–170 m) consisting of sandstones, siltstones, argillites and brown coal seams is distributed throughout the depression. Its is of highly variable lithology in vertical and lateral directions. According to Vlasov, the integral thickness of the Khasan Formation is 300 m.

The Nazimovskaya Formation (Pos'et Peninsula) overlies the Zaisanovka basalts and rudaceous rhyolite tuffs that dominate among Kraskino volcanics. Its base is locally represented by a thin conglomerate–breccia bed with fragments of rocks derived from surrounding mountainous structures. The formation is dominated by fine- to, less commonly, medium-grained sandstones, siltstones, and brown coals seams (one of the latter is

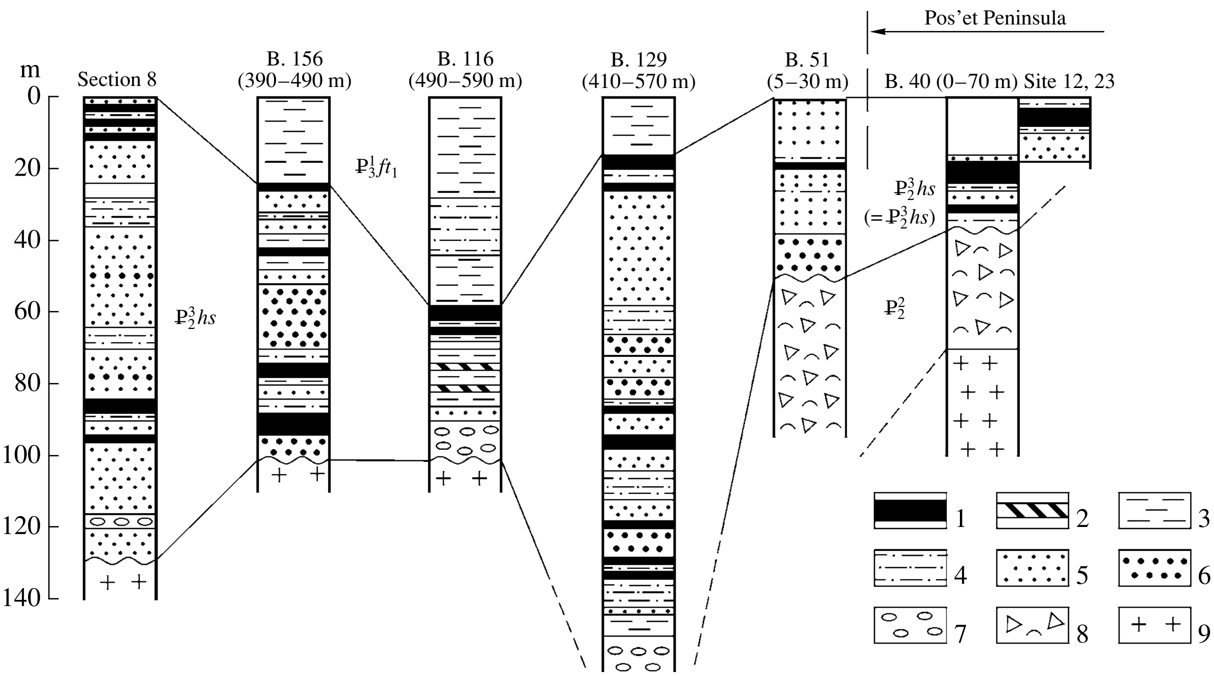

Fig. 3. Lithology of Paleogene sections recovered by boreholes in the Khasan depression (in brackets are depth intervals, m): (1) brown coal; (2) carbonaceous shale; (3) argillite; (4) siltstone; (5) fine- to medium-grained sandstones; (6) gravely sandstone; (7) conglomerate; (8) rhyolite tuff; (9) granite, hornfels.

under mining). The formation thickness does not exceed 30–40 m. The Khasan and Nazimovskaya formations are similar in lithology. No signs of stratigraphic hiatus are observable at transition from the Khasan Formation to the overlying clay–tuffite sequence (after Vlasov) or Fatash Formation (after Yu.B. Ustinovskii and his colleagues; *Geological Structure…*, 1966). The boundary between these units is placed at the top of the upper coal seams or at the replacement level of relatively coarse-grained rocks of the Khasan Formation by thin-platy tuffaceous siltstones of the lower Fatash Subformation.

RESULTS AND DISCUSSION

Geological Data

Sections in the Gladkaya River mouth area. The Lower Cretaceous plant assemblage with *Nilssonia densinervis* (Font.) Berry (determination by S.A. Shorokhova) discovered in the siltstone–sandstone sequence of the Gladkaya River mouth area (Nazimovskaya Formation in interpretation by Vlasov) in the early 1960s required revision of stratigraphy in this area. The inference of Shorokhova was subsequently confirmed by palynological study of samples from the outcrop (Site 9192) and core section of the control Borehole 161 (Markevich, 1981). It was established that in the Gladkaya River mouth area and west of the latter (Fig. 2a, b), the Zaisanovka basalts rest upon the **Lower Cretaceous (!)** slightly coaliferous deposits and, thus, there are no geological arguments in favor of alternating volcanic and normal sedimentary **Paleogene** formations in the section of the northeastern Khasan depression. None of numerous boreholes drilled in this area during prospecting works for brown coal evidenced such an alteration. Volcanics of presumably early–middle Eocene age (Zaisanovka basalts and Kraskino rhyolite tuffs) resting upon Lower Cretaceous deposits are overlain here by the coal-bearing Khasan Formation. Its relationships with the Kraskino volcanics established by Vlasov during mining works of 1944 were confirmed by control drilling (Borehole 51).

Section in the Pos'et Peninsula. Within the Pos'et Peninsula, relationships between the Zaisanovka basalts and Nazimovskaya Formation have never been established unambiguously. Adherents of the Nazimovskaya Formation position under basalts emphasize its lower hypsometric position relative to basaltic outcrops and dip of bedding under the "slope," i.e., as if under the basaltic body. Nevertheless, there are also other dip directions of a wide spectrum. A plausible explanation is a wide development of landslides in the area, which is in progress nowadays. Another phenomenon is unusual: in the Shufan and Shkotovskii volcanic plateaus (southern Primor'e region), where basaltic flows overly Tertiary sediments, landslide bodies are composed of different-size allochthonous basaltic blocks almost lacking underlying sedimentary rocks. In outcrop area of the Nazimovskaya Formation, the situation is opposite: the landslide complex is entirely composed of large blocks of sedimentary rocks and only the

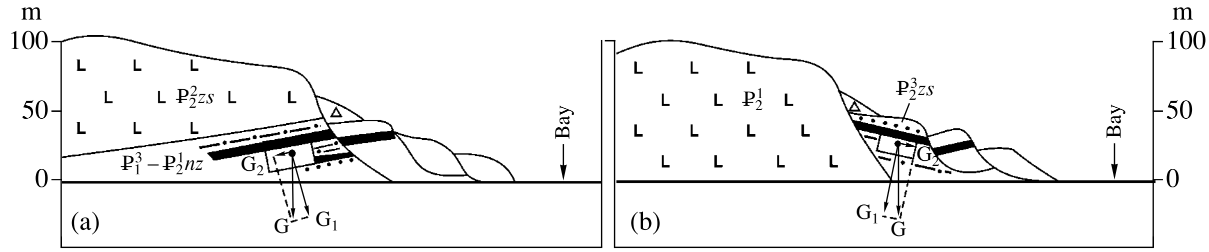

Fig. 4. Relationships between the Nazimovskaya and Zaisanovka formations and model of landslide development in the Pos'et Peninsula (a) accepted previously and (b) proposed (symbols as in Fig. 3).

rear suture of the landslide cirque is fringed by basaltic blocks.

If beds of the Nazimovskaya Formation dip "under the slope," as is assumed, then, according to the classical scheme of gravitational landslides, they cannot be composed of sedimentary rocks presumably underlying basalts, as it would be inconsistent with laws of rock mechanics (Fig. 4a). This is admissible in the other situation, when sedimentary beds are "leaned" against the basaltic massif (Fig. 4b). Only in this case, the gravity component G_2 stimulates the lateral displacement of rock blocks to the slope foot. Consequently, there are no geological evidence in favor of the official scheme with Nazimovskaya Formation placed below Zaisan basalts. In the Pos'et Peninsula cliffs, only a small portion of the coal-bearing sequence (Nazimovskaya Formation) is exposed, and its main part is covered by waters of the Expeditsii Bay. The wave abrasion of coastal cliffs is the likely factor of sedimentary landslides development.

Borehole 40 drilled in the Pos'et Peninsula proved that the coal-bearing Nazimovskaya Formation rests on rhyolite tuffs attributed by Vlasov in 1949 to the Novopos'etskaya Formation of the Upper Cretaceous (?)–Paleocene, although there was no evidence implying such an old age of relevant rocks. As for lithology and composition of the tuffs, they are analogous in these aspects to the Kraskino volcanics. Synchronism of the Novopos'etskaya and Kraskino volcanics is confirmed by geochronological data. The K–Ar dates obtained indicate their middle Eocene age (Sedykh, 1989). Such old age of volcanics from the Novopos'etskaya Formation is consistent with the scheme suggested by Vlasov who accepted the late Paleocene–early Eocene age of the Nazimovskaya Formation.

Volcanic complex. The Nazimovskaya and Khasan formations in their type area (Khasan Depression) contact immediately the Kraskino rhyolites and Zaisanovka basalts. Moreover, in all the known cases, Site 17 included (Fig. 1), they occur stratigraphically higher and alternate **nowhere (!)** with volcanic rocks in a common section. At the same time, according to official documents based on the Vlasov's scheme, the Kraskino rhyolites replace a clay–tuffite "facies" (=lower Fatash Subformation) in the eastern part of the Khasan depression, while the Zaisanovka basalts represent an autonomous formation.

This scheme is however poorly consistent with the available factual material. As is known, the volcanic rocks under consideration are of a limited distribution (Pos'et and Krabbe peninsulas, Gladkaya River mouth area). For example, the distribution area of the Zaisanovka basalts does not exceed 20 km^2, while the Shufan and Shkotovskii basalts (the Shufan Formation of southern Primor'e) form a plateau over 1000 km^2 in size. The Zaisanovka volcanic field cannot be a stratiform object according to its relief patterns. The Kraskino rhyolites are even of a more limited distribution: they fill in depressions (probably, subsided tectonic blocks) in the basaltic massif. Relationships between basaltic and rhyolitic constituents of the volcanic complex are intricate, and observed contacts can hardly be taken for stratigraphic boundaries. Silicic rocks originated during the later volcanic phase after eruption of basalts though without a noticeable break. Rocks of both types represent the so-called contrasting volcanic series widespread in the Tertiary complex of the eastern flank of the Sikhote Alin Ridge. Their formation is most likely related to a large volcanic edifice that existed during a long period east of the Khasan depression and was subsequently destroyed and partly subsided under the sea. In the schematic map (Fig. 1), silicic and basic constituents are shown as undivided subvolcanic rocks.

Thus, geological data confirm the initial viewpoint of Vlasov who suggested that the Khasan Formation of the depression greater part is laterally replaced by the Nazimovskaya Formation in the Pos'et Peninsula. When revising his own initial inference on the age of the Nazimovskaya Formation, Vlasov judged from erroneous interpretation of the section in the Gladkaya River mouth area. With the same grounds, he assumed alternation of volcanic and sedimentary rocks in the Tertiary succession of the Khasan depression eastern part.

Data of Paleobotany

In connection with the problem under consideration, it is important to obtain additional data on relationships between the Khasan and Nazimovskaya formations.

Table 1. Palynological spectra of samples from Paleogene sediments of the southern Primor'e (the abridged list with herbaceous taxa denoted as "others")

Groupings of pollen and spores	Section numbers												
	b. 40			b. 129			c. 8			ud formation, o.p. 9142			o.p. 9182
	Sample number												
	1	2	3	1	2	3	1	2	3	1	2	3	1
Total abundance of palynomorphs	644	632	647	455	655	496	573	475	373	364	706	447	558
gymnosperms	213	259	58	126	177	48	223	164	182	121	224	233	192
angiosperms	391	316	532	256	450	362	277	265	163	224	431	174	347
sporiferous	40	57	57	47	28	86	73	46	28	19	51	40	19
Sporiferous													
Polypodiaceae	31	45	45	44	18	80	60	38	18	11	38	21	12
Osmunda	1	1	–	1	1	–	–	–	–	–	4	8	1
Botrychium	1	3	3	–	1	1	2	2	4	–	1	2	1
Cyathea	–	–	–	–	3	–	–	–	–	–	–	–	2
Lophotriletes	–	1	–	–	3	–	–	–	–	5	1	3	1
Leiotriletes	3	4	6	–	1	3	4	5	1	1	5	3	2
Gleichenia	–	–	1	–	–	1	4	–	4	–	–	–	–
Others	4	3	2	2	1	1	3	1	1	2	2	3	–
Gymnosperms													
Ginkgo	–	1	–	–	1	1	–	–	–	–	–	–	–
Podocarpus	1	–	–	–	2	–	4	–	3	–	1	2	2
Dacrydium	–	–	–	–	–	–	–	–	1	–	–	–	1
Pinaceae	–	–	–	–	–	–	7	–	39	–	–	–	–
Abies	3	12	–	–	4	1	3	2	3	1	4	–	2
Pseudotsuga	–	–	–	–	–	–	–	–	3	–	–	–	–
Tsuga spp.	7	7	1	–	4	–	3	6	6	–	10	6	2
Picea	48	42	6	1	1	4	37	56	31	61	63	63	25
Cedrus	4	20	4	–	6	1	12	7	23	3	3	9	15
Keteleeria	–	–	–	–	–	–	1	–	–	1	–	–	–
Pinus spp.	73	75	24	5	95	15	92	49	66	?	101	124	41
Sciadopitys	–	–	–	–	1	–	2	–	1	–	1	–	–
Taxodiaceae	70	92	22	110	45	–	55	40	4	12	36	26	90
Taxodium	1	4	–	3	2	–	3	1	–	–	–	–	7
Glyptostrobus	–	1	–	2	4	2	1	1	–	–	3	1	4
Sequoia	2	–	–	4	2	1	2	–	1	–	1	–	1
Cryptomeria	2	–	–	1	–	–	–	–	–	–	1	–	–
Cupressaceae	–	–	–	–	2	2	–	–	–	–	–	–	–
Ephedra	2	5	1	–	–	–	1	1	1	–	–	–	–
Angiosperms													
Myrica	3	3	4	1	10	5	9	13	3	5	10	2	3
Comptonia	8	4	6	3	12	3	12	14	3	1	7	3	5
Pterocarya	4	2	4	–	4	3	1	5	5	–	2	–	–
Juglans	18	7	20	3	15	12	4	8	2	4	8	5	20
Carya	20	20	40	44	22	46	16	7	4	5	21	7	25
Engelhardia	2	1	4	2	1	2	1	–	–	1	–	–	4
Platycarya	–	–	–	–	2	2	–	–	1	–	–	–	2
Carpinus	4	4	5	11	33	7	1	5	–	1	10	5	2
Corylus	17	14	25	2	4	1	5	7	3	6	17	–	5

Table 1. (Contd.)

Groupings of pollen and spores	Section numbers												
	b. 40			b. 129			c. 8			ud formation, o.p. 9142			o.p. 9182
	Sample number												
	1	2	3	1	2	3	1	2	3	1	2	3	1
Betula	70	34	61	10	8	15	10	18	5	19	19	8	22
Alnus	14	55	40	26	47	20	17	10	9	28	49	9	15
Quercus sp.	–	–	–	8	8	5	–	–	1	–	–	–	–
Q. graciliformis	6	1	5	3	1	4	1	7	–	–	–	1	–
Q. conferta	2	6	6	3	1	8	–	7	–	1	3	7	4
Q. forestdalensis	–	–	–	2	–	–	–	–	–	–	–	–	4
Quercites sparsus	–	–	–	–	1	–	–	1	–	–	1	–	–
Fagus spp.	22	11	33	12	26	22	17	18	1	15	50	26	58
F. grandifoliiformis	5	2	2	1	2	6	3	4	–	1	10	1	6
Castanea	1	2	3	–	30	15	1	–	–	–	8	–	4
Castanopsis	–	1	–	–	2	–	–	–	–	–	–	–	1
Ulmus	115	66	145	30	42	44	60	65	57	72	87	37	86
Zelkova	1	2	1	–	2	4	–	–	–	2	2	1	10
Celtis	–	2	1	2	6	–	–	–	–	–	3	–	1
Corylopsis	1	1	–	–	5	–	5	1	–	1	5	–	1
Hamamelis	–	–	–	–	–	–	1	2	–	–	–	–	1
Fothergilla	1	–	2	–	5	2	1	–	1	–	–	1	–
F. gracilis	–	–	–	–	–	–	–	1	–	–	–	–	–
F. vera	–	–	–	–	–	–	–	8	–	–	–	–	–
Liquidambar	6	3	10	8	44	5	12	7	10	26	16	7	11
Platanus	–	–	–	1	2	–	–	–	–	–	2	–	–
Rhus	–	–	–	2	–	3	1	–	1	–	3	1	1
Ilex	2	1	8	1	1	–	2	–	–	3	3	4	2
Acer	–	–	2	1	1	2	2	2	–	–	–		1
Parthenocissus	–	1	3	–	–	2	1	1	–	–	–		–
Tilia	1	3	8	8	–	46	6	2	3	3	3	1	–
Nyssa	–	–	1	–	–	1	3	1	1	–	–	1	–
Alangium	–	–	1	–	–	–	–	–	–	–	–		–
Araliaceae	–	1	–	–	12	2	3	2	–	–	2	1	–
Caprifoliaceae	2	2	–	1	1	1	–	5	2	1	5	1	–
Trochodendron	–	–	–	–	–	–	–	–	1	–	–	–	–
Eucommia	–	–	–	–	8	–	–	–	–	–	1	–	1
Sterculia	–	–	–	–	–	–	1	–	–	–		–	–
Triporopollenites sp.				1	–	–				1	–	–	–
Tricolpopollenites sp.	–	–	–	–	1	–	–	–	–	–	1	1	–
Elytranthe striatus	1	–	–	–	–	–	–	–	–	–	–	–	–
Rhoipites sp.	–	–	–	–	–	–	–	–	–	–	–	1	–
Pseudoplicapollis sp.	–	1	1	–	2	–	1	–	–	–	–	–	–
Pokrovskaja	–	–	–	–	–	–	–	–	–	–	1	–	1
Nelumbo	–	–	–	–	–	–	–	–	1	–	–	–	–
Rosaceae	25	24	30	12	37	26	32	18	2	10	14	6	38
Others	40	42	61	58	52	48	48	26	47	18	68	37	13

Note: (b.) borehole; (c.) clearing; (o.p.) observation point; (ud) Ust'-Davydovskaya Formation, stratotype, (Rechnoi Peninsula); (–) palynomorphs not detected.

These two units enclose productive coal seams and are similar in lithology. Their correlation is of principal importance, because there is also the problem of dating the clay–tuffite sequence (lower Fatash Subformation) that replaces higher in the section the Khasan Formation and encloses fossil flora of the Kraskino type confined, as is known from publications, to the *Engelhardia* Beds (Endo, 1938). There are two viewpoints on age of the latter. According to one of them, the flora and host sequence correspond to the so-called main climatic optimum of the Miocene (Ablaev and Vasil'ev, 1998). We believe however that the Kraskino flora is the early Oligocene in age. Both standpoints admit the gradual (without stratigraphic gap) transition from the Khasan Formation to the clay-tuffite sequence in understanding of Vlasov. Nevertheless, interpretations of this fact are different. Ablaev and Vasil'ev (1998) consider both the Kraskino and Khasan floras as the Miocene in age (in contrast to the Nazimovskaya flora attributed to the Eocene), whereas in our opinion the Khasan flora is characteristic of the upper Eocene sediments. Our inference is based on original paleobotanic data.

Palynological data. Let us consider first palynological materials (Table 1). In our earlier article (Pavlyutkin and Petrenko, 1997), we reported data on spores and pollen from the stratotype of the Nazimovskaya Formation (Borehole 40). The relevant palynological complex is most similar to the complex from the stratotype section of the Ust'-Davydovskaya Formation (Pavlyutkin and Petrenko, 1993). Spore-pollen spectra from the Khasan Formation (data on boreholes of the northern Khasan depression and outcrops in its western part) show no principal differences from the palynological spectra of the Nazimovskaya Formation and retain their Paleogene affinity.

In palynological spectra, angiosperms dominate over gymnosperms: 43.7–61.7% versus 34.5–48,8%. The content of spores is much lower (3.8–12.7%). The group of sporiferous plants is dominated by the family Polypodiaceae (up to 10.5%). Of interest is presence in that group of *Gleichenia* spores, which are unknown so far in the Miocene floras of Primor'e. Pollen of Taxodiaceae (8.4–21.5%) and *Picea* sect *Omorica* (up to 11.4%) prevails in the group of gymnosperms. Noteworthy is presence of *Cedrus* pollen (up to 6.2%) accompanied by single pollen grains of *Dacrydium, Podocarpus*, and *Keteleeria.* The angiosperm group lacking distinct dominants reveals a relatively high content of *Comptonia, Fagus, Carya, Alnus*, and *Ulmus* pollen. Pollen of *Engelhardia, Quercus graciliformis* Bolitz., *Q. conferta* Bolitz., *Quercites sparsus* (Mart.) Samoil., *Ulmoideipites, Corylopsis, Hamamelis, Fothergilla vera* Lubom., *F. gracilis* Lubom., *Sterculia, Trochodendron, Reevesia, Casuarina, Pseudoplicapollis*, and *Plicapollis* occurs in quantities from single grains to 1–2%. In Primor'e, such spectra are known from Eocene sediments of the Rechnoi Peninsula (Pavlyutkin and Petrenko, 1993).

Fossil floras

N a z i m o v s k a y a f l o r a. First data on fossil flora from coal-bearing sediments of the Pos'et Peninsula have been reported by Borsuk who examined a small collection sampled by Vlasov in 1994 provided. Taxa determined in this collection are *Osmunda sachalinensis* Krysht., *Sequoia langsdorfii* (Brongn.) Heer, *Taxodium dubium* (Sternb.) Heer, *Metasequoia disticha* (Heer) Miki, *Glyptostrobus europaeus* (Brongn.) Heer, *Alnus* sp., *Betula prisca* Ettingsh., *Juglans nigella* Heer, and *Euonymus celastrophylla* Baik. These data have never been published. Nevolina who studied the Nazimovskaya flora in the 1960s emphasized similarity between the latter and the Raichikha flora of the Amur region, which is the Paleocene in age (Baikovskaya, 1950). After the comprehensive study of the Raichikha flora, Fedotov (1983) attributed it however to the middle–late Eocene. Later on, Baikovskaya (1986) admitted the Eocene age of this flora. Thus, the age revision of the Nazimovskaya flora is unavoidable.

Ablaev (Ablaev and Shmidt, 1978) was first to insist on this revision. In his opinion, the flora in question is coeval with or younger than the Paleogene Uglovoe flora from the southern Primor'e. Sharing his viewpoint on necessity to revise age of the Nazimovskaya flora, we should note the following, however. Authors of the mentioned work point to absence of thermophilic genera *Ficus, Cinnamomum*, and some others among macroscopic plant remains in their collection from the Nazimovskaya Formation, although these genera were suspected earlier as components of the Nazimovskaya flora (Shtempel, 1963). However, Shtempel has mentioned the last flora as a probable analogue only of the examined flora from the Conglomerate Formation of Sakhalin, where he found leaf impressions of the above genera.

Leaf impressions from the Nazimovskaya flora are poorly preserved, and their taxonomic identification is difficult. High-order peculiarities of venation are invisible even under the binocular microscope with different-angle lighting. This probably explains why information on the Nazimovskaya flora was always limited by lists of taxa never accompanied by illustrations of plant remains. We reproduce drawn leaf impressions of most important species present in the flora under consideration (Fig. 5) in addition to the list of taxa (Table 2).

Our revision of collection sampled by Nevolina in the 1960s confirmed an insignificant role of Early Cenophytic taxa in the Nazimovskaya flora. For example, the genus *Trochodenroides* is represented by single impressions, while *Platanus* remains are missing at all. A low share of these taxa is also confirmed by additional sampling of fossils flora from the Nazimovskaya Formation (Ablaev and Shmidt, 1978; Baskakova and Lepekhina, 1990). At the same time, a remarkable feature of the plant assemblage is presence of *Equisetum arcticum* Heer, *Osmunda sachalinensis* Krysht.,

Table 2. Taxonomic composition of the Nazimovskaya and Khasan floras

Taxon	Flora	
	Nazimovskaya, o.p. 12, 23	Khasan, o.p. 116, 129
Equisetum arcticum Heer	+	–
Osmunda sachalinensis Krysht.	+	–
Acrostychum ochoticum Budants.	+	–
Ginkgo ex gr. *adiantoides* (Unger) Heer	+	+
Torreya sp.	–	+
Sequoia affinis Lesq.	–	+
Metasequoia occidentalis (Newb.) Chaney	+	+
Taxodium dubium (Sternb.) Heer	+	–
Glyptostrobus europaeus (Brongn.) Heer	+	+
Magnolia cf. *kryshtofovichii* Borsuk	+	–
Laurophyllum sp.	+	–
Trochodendroides ex gr. *arctica* (Heer) Berry	+	+
Cercidiphyllum palaeojaponicum Endo	–	+
Parrotia sp.	–	+
Platanus zhuravlevii subsp. *zhuravlevii* Medjul.	–	+
Zelkova kushiroensis Oishi et Huz.	+	–
Zelkova sp.	+	+
Alnus shestakovae Ablaev	–	+
A. cf. *ezoensis* Tanai	+	+
Alnus sp. (pistillate catkin)	+	–
Fagopsis nipponica Tanai	–	+
Myrica vindobonensis (Ettingsh.) Heer	+	–
Populus arnaudii (Sap.) Iljinsk.	+	–
Populus celastrophylla (Baik.) Sycheva	+	–
Populus sp.	+	–
Salix sp. (?)	+	–
Cornus sp.	+	–
Byttneria iizimae Tanai	+	–
Ziziphus harutoriensis Tanai	+	–
Grewiopsis sp.	+	–
Viburnum sp.	+	+
Sambucus sp.	+	–
Phyllites kvačekii Bůžek	+	–
Arundo goeppertii (Munst.) Heer	+	–
Carex sp.	+	–
Carpites sp.	+	–

Note: (o.p.) observation point; (b.) borehole.

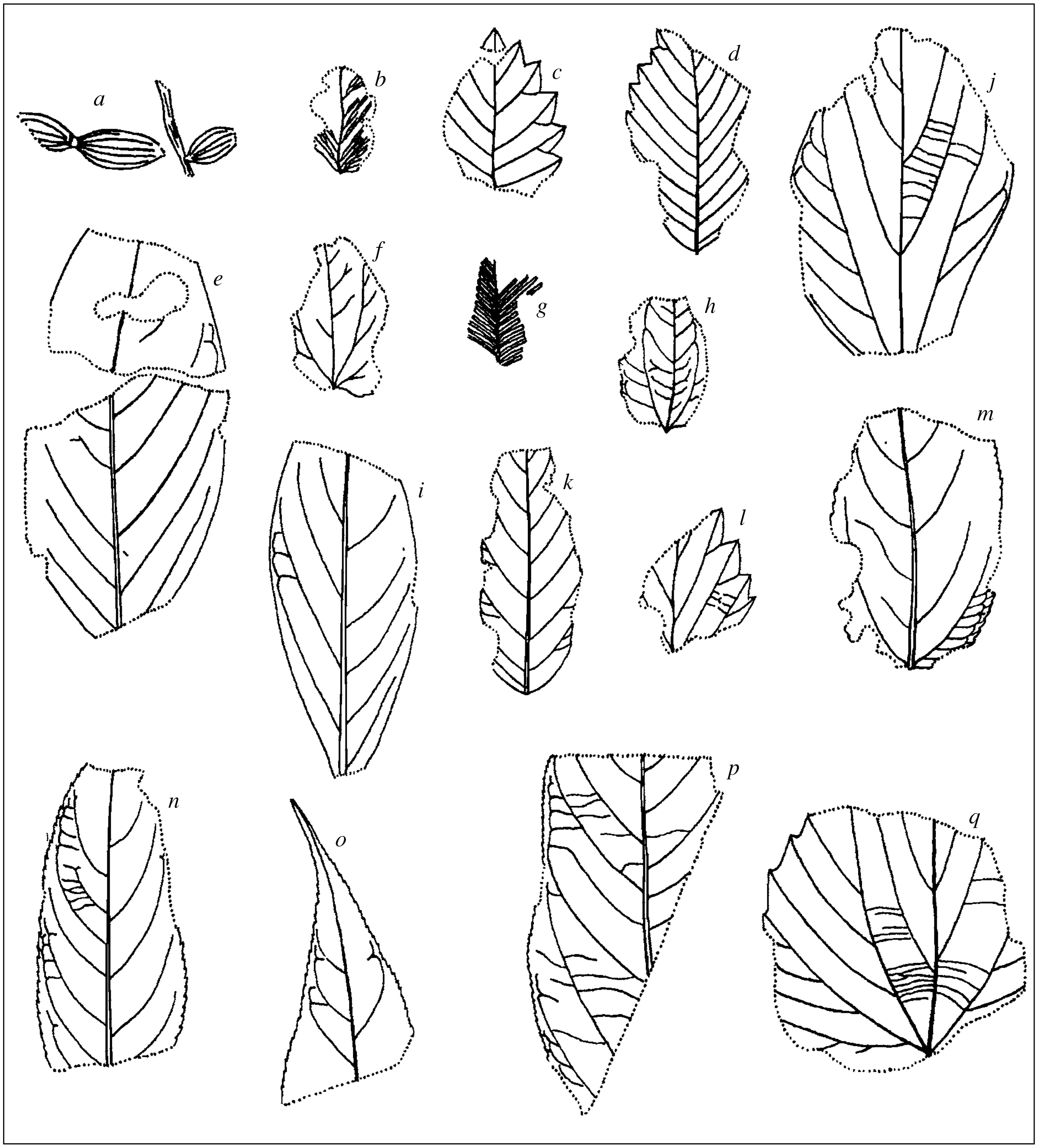

Fig. 5. Leaf impressions of the Nazimovskaya flora, the Pos'et Peninsula (all drawings in natural size: (*a*) *Equisetum arcticum* Heer; (*b*) *Osmunda sachalinensis* Krysht.; (*c*) *Zelkova* sp.; (*d*) *Zelkova kushiroensis* Oishi et Huz.; (*e*) *Magnolia* cf. *kryshtofovichi* Borsuk; (*f*) *Trochodendroides* ex gr. *arctica* (Heer) Berry; (*g*) *Metasequoia occidentalis* (Newb.) Chaney; (*h*) *Ziziphus harutoriensis* Tanai; (*i*) *Laurophyllum* sp.; (*j*) *Byttnerium iizimae* Tanai; (*k*) *Alnus* cf. *ezoensis* Tanai; (*l*) *Phyllites kvačekii Bůžek*; (*m*) *Populus* sp.; (*n*, *o*) *Sambucus* sp.; (*p*) *Populus celastrophylla* (Baik.) Sycheva; (*q*) *Grewiopsis* sp.

Ginkgo ex gr. *adiantoides* (Unger) Heer, *Magnolia* cf. *kryshtofovichi* Borsuk, *Laurophyllum* sp., *Alnus* cf. *ezoensis* Tanai, *Myrica vindobonensis* (Ettingsh.) Heer, *Ziziphus harutoriensis* Tanai, and *Grewiopsis* sp. These plants are missing from doubtless Miocene floras of Primor'e, being although characteristic of Paleogene floras known in this region, Kamchatka, Sakhalin, and Hokkaido. Shoots of deciduous *Metasequoia occidentalis* (Newb.) Chaney are most abundant in the Nazimovskaya floral assemblage. In some layers, they are particularly abundant and form along with *Equisetum arcticum* the oligodominant taphocoenoses. Foliaceous shoots of *Taxodium* and *Glyptostrobus* are less common. Leave impressions of *Alnus* cf. *ezoensis* Tanai dominate in collection 23, where *Osmunda* remains are also frequent.

Abundant impressions of the genus *Zelkova* are represented by two morphotypes: by elongated oval leaves with many (≈10) lateral veins and by small leaves with nearly round blade, rare (4–6) lateral veins, and large distant denticles. Impressions of the first type resemble *Z. kushiroensis* Oishi et Huz., while those of the second type are closer to *Z. zelkovifolia* (Unger) Buzek et Kotlaba, although leaves of the last type are smaller. We do not exclude as well that leaves of the second type belong to another genus *Hemiptelea* Planch of Ulmaceae.

Species of the genus *Populus* are relatively diverse. In addition to narrow-leaved *Populus* cf. *arnaudii* (Sap.) Iljinsk. and *P. celastrophylla* (Baik.) Sycheva, many leaf impressions belong to *Populus* sp. They are broad oval in shape, having a pair of low-elevated basal veins and small round denticles with glandular hairs. Collection 12 includes numerous leaf impressions of *Sambucus* sp., which have no analogues among known fossil species of this genus. They are accompanied by impressions of *Spiraea, Betula*, and narrow willow-type leaves (*Salix* ?). Also remarkable are numerous impressions that resemble microscopic strobilus accumulations of some Pinacea species and are determined as *Carpites* sp. in the list of taxa. Linear impressions similar to gramineous leaves and considered here as the composite species *Arundo goeppertii (Münst.)* Heer are also noteworthy. Previously, Nevolina attributed these specimens to *Nythophyllites zaisanica* Iljinsk.

In general, the Nazimovskaya flora is lacking remarkable features maybe because of the collection incompleteness. It is hardly comparable with known Paleogene floras and may represent local paleophytocoenoses being dominated by plants of lowland ecotopes. Owing to insignificant abundance of *Platanus* and *Trochodendroides* remains, this flora differs from floras predating the Eocene climatic optimum and from older Paleocene assemblages of plant remains. Being moderately thermophilic, the Nazimovskaya flora cannot be attributed to floras of that optimum as well. For instance, it is much less thermophilic than the thoroughly studied Bolotninskaya flora (Ablaev, 2000) characterizing the Eocene climatic optimum in southern Primor'e. Thus, it belongs most likely to younger "post-optimum" Eocene floras of the Ust'-Davydovskaya type.

K h a s a n f l o r a. We can judge about appearance and composition of the Khasan flora from a limited amount of leaf impressions obtained from the drill core sections (Table 2). Among its taxa, most interesting are species characteristic of Paleogene floras in the Far East. These are *Trochodendroides* ex gr. *arctica* (Heer) Berry, *Platanus zhuravlevii* subsp. *zhuravlevii* Medjul., *Alnus shestakovae* Ablaev (?=*A. savitskii* Cheleb.), *A. ezoensis* Tanai, and *Fagopsis nipponica* Tanai (Fig. 6).

T h e K r a s k i n o f l o r a. Approximately 700 impressions of leaves and fruits collected by Pavlyutkin characterize this flora very well. A comprehensive analysis of the Kraskino flora is beyond the scope of this work, because main peculiarities of its composition have been considered previously (Pavlyutkin, 2002). The point of interest is presence of some plant remains characteristic of the Far East Eocene floras (Fig. 6). This is extremely important with due account for absence of stratigraphic gap between the Khasan Formation and clay–tuffite sequence hosting the Kraskino flora. An abridged list of representative taxa and their stratigraphic ranges are considered below.

Species *Platanus aculeata* Klimova has been described first by Klimova (1988) from the lower–middle Miocene sediments in her interpretation. It is registered in the Eocene Bolotninskaya flora of the southern Primor'e region (Ablaev, 2000). In our opinion, the **late Paleocene–Eocene** morphotypes, which are classed with *P. snatolana* Cheleb. (Budantsev, 1997; Budantsev and Ozerov, 2001) and *Alchornea harutoriensis* Tanai (Tanai, 1990), should be considered as synonyms of that species. *Cocculus* cf. *ezoensis* Tanai is established in Oligocene (Eocene at present) sediments of Hokkaido. Morphologically close species *C. mariae* Cheleb. and *C. schischkinii* Iljinsk. (Il'inskaya, 1972) are the **Eocene–early Oligocene** in age. *Dryophyllum curticellence* (Watel.) Sap. et Marion (Il'inskaya, 1957; Palamarev and Mai, 1998), *Acer arcticum* Heer, and *"Tilia" eojaponica* auct. non Endo (Tashchi et al., 1996)) are thought to be the **Paleocene–early Eocene, Paleocene–Eocene,** and **Eocene** forms, respectively. According to the leaf base architecture, the last form does not belong to the genus *Tilia*: basal veins depart from the axis in alternate manner with offsets along the main vein, being exposed near the leafstalk. None of these features has been observed in modern *Tilia* species. *"Cordia"* sp., mentioned in some works as *Cordia japonica* Tanai (Ablaev, 2000, 2001), is of the Eocene age. It seems doubtful that impressions from Primor'e belong to the genus *Cordia*, because its recent species known in Asia and North America have leaves with venation the camptodrome type. *Quercus kodairae* Huz. is the **late Eocene–initial Oligocene** taxon (Fot'yanova, 1997). A specimen from the Kharaulakh Formation, which has been described as *Quercus grinenkoi* (Budantsev and Ozerov, 2001), should probably be considered as a synonym of *Quercus kodairae.*

The presented list of species characteristic of the late Paleocene–early Eocene floras in Primor'e and other regions is far from being complete, although even the listed forms confidently disprove the Miocene age of the Kraskino flora, as we believe. From our viewpoint, presence of taxa typical of Eocene floral assemblages in different areas of the Far East is doubtless, although their subordinate abundance (≈10% of all the species identified) may indicate that the Kraskino flora corresponds in age to the early Oligocene, most likely to the first half of this substage. Consequently, the

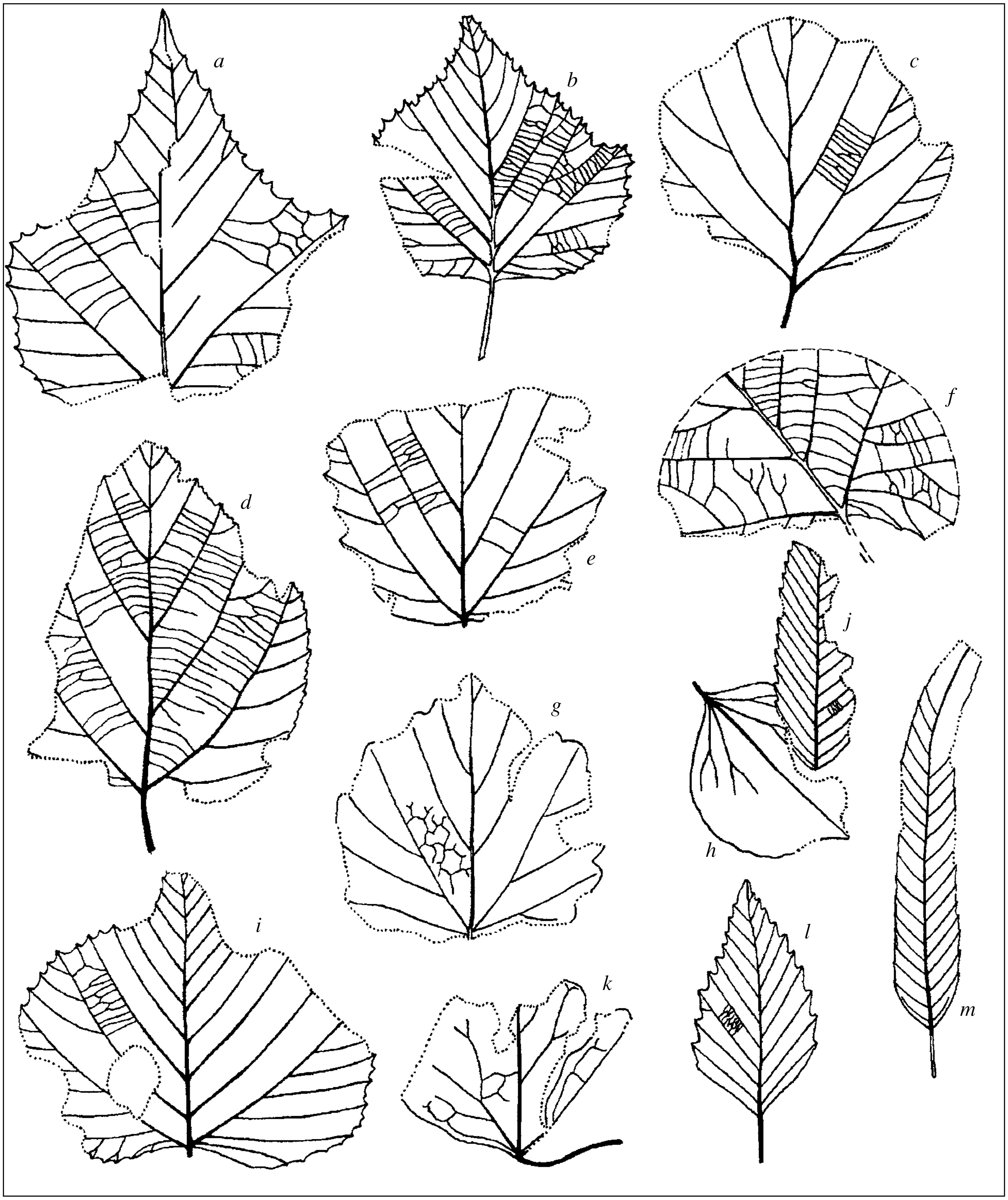

Fig. 6. Leaf impressions of the Kraskino and Khasan (marked by asterisks) floras from outskirts of Shakhterskii Settlement (0.7 of natural size): (*a*, *b*) *Platanus aculeata* Klimova; (*c*, *d*) *"Tilia" eojaponica* non Endo; (*e*) *"Cordia" japonica* non Tanai; (*f*) **Platanus zhuravlevi* subsp. *zhuravlevi* Medjul.; (*g*) *Acer arcticum* Heer; (*h*) **Trochodendron* ex gr. *arctica* (Heer) Berry; (*i*) *Alchornea harutoriensis* Tanai; (*j*) **Fagopsis nipponica* Tanai; (*k*) *Cocculus ezoensis* Tanai; (*l*) *Quercus kodairae* Huz.; (*m*) *Dryophyllum curticellense* (Watel.) Sap. et Marion.

Khasan Formation underlying the host beds of the Kraskino flora cannot be the Miocene in age as well.

CONCLUSIONS

(1) The Vlasov's revision of the coal-bearing sequence age in the Pos'et Peninsula (pre-late Paleocene) is a result of erroneous interpretation of sections exposed in the Gladkaya River mouth area. One stratigraphic level has been suggested for sediments of that area, which contain a few coal seams and Lower Cretaceous flora, as it appeared subsequently, and for the Eocene coal-bearing deposits of the Pos'et Peninsula. The former are overlain by the Zaisanovka basalts, while the latter are "leaned' against these basalts.

(2) The coal-bearing Nazimovskaya Formation locally exposed in the Pos'et Peninsula and the Khasan Formation in the remaining part of the Khasan depression are coeval stratigraphic units. Their sediments overlie either the pre-Tertiary rocks (in the western part of the depression) or the Kraskino rhyolite tuffs (in the eastern part). According to palynological data and remains of macroflora, both units correspond in age to the Eocene. We propose to retain the priority name Khasan Formation (Vlasov, 1948) for these units.

(3) No evidence for the lateral replacement of the coal-bearing Khasan Formation by the Kraskino and Zaisanovka volcanics is established in the eastern part of the Khasan (=Kraskino) depression.

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