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Fossil plant assemblages from the Pliocene of southern Primory'e Rregion (Russian Far East): implications for reconstruction of plant communities and their environments

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ABSTRACT. This paper focuses on the fossil wood assemblage from the Pavlovskii brown coal field located in the southern Primory'e Region of the Russian Far East and puts these findings in context of a review of previous work on the other fossil material (i.e. palynomorphs and seed remains) and thus presents the most complete interpretation of plant communities and environments of southern Primory'e in the Pliocene. The wood remains were probably transported to the site of deposition by the fluvial activity of one of the tributaries of the palaeo-Razdol'naya River, and that tributary, perhaps, was at the left side of the palaeo-Razdol'naya River and arose in the spurs of the southern Sikhote-Alin Range. The xylotaphocoenosis suggests a mixture of plant remains from both valley and slope habitats. The fossil wood assemblage has enabled the most detailed reconstruction of the woody plant communities and their environments. The Pliocene valley vegetation comprised forest dominated by conifers and elms, whilst the slopes were covered by either mixed coniferous-hardwood or coniferous forest. Profile diagrams of the forest covered the area of Pavlovskaya Group of Depressions in Pliocene are given for the first time.

KEYWORDS: fossil wood, plant communities, palaeoenvironments, Pliocene, southern Primory'e, Russian Far East

INTRODUCTION

The Pliocene is one of the most important stages in the historical development of modern vegetation of the Russian Far East (RFE) because the origin of many extant species and the formation of plant communities similar to those of today took place in Pliocene time. Therefore, the study of fossil plant remains from the Pliocene is of a great importance in understanding the historical development of the modern vegetation. Reconstructions of past plant communities require the combined analysis of all fossil plant records regardless of organ type. However, fossil wood is not often used, probably, because fossil wood remains are usually less abundant than leaf impressions or palynomorphs. Nevertheless, fossil wood can provide additional information on taxonomic composition of taphocoenoses. Wood fragments being relatively resistant to decay and physical destruction have the potential to be transported especially by water for great distances, in contrast to leaf and fruit or seed remains. Besides, pollen grains of some pinaceous plants characterized by the lacking of bladders (for instance, *Larix*) have more limited wind dispersal capability (Dylis 1948, Savina & Burenina 1981). In addition, *Larix* pollen grains having a very thin exine are characterized by a bad ability to preservation in sediments (Neishtadt 1957). Fossil wood assemblages also can provide information on possible altitudinal vegetation zonation, in contrast to palynological records which are capable of reconstructing latitudinal zonation. Poole and van Bergen (2006) suppose that wood assemblages are more likely to represent the local, rather than regional vegetation and provide information about structural dominants of the vegetation, but the applicability depends on the kind of depositional environment in which the wood are preserved– whether they are transported some distance from the source vegetation, or buried directly in or near the source area.

Plant impressions such as leaves and winged seeds are usually rare and poorly preserved in coarse-grained sedimentary deposits such as the Pliocene alluvium typical of southern Primory'e Region of the RFE, and wood fragments may be the only macrofossils preserved. In such cases, fossil wood remains become invaluable for reconstructing plant communities and their environments.

In southern Primory'e, the only locality with numerous, well preserved and taxonomically diverse wood remains of Pliocene age is the Pavlovskii brown coal field. Collections of fossil wood from this locality were undertaken by the authors for the first time in 2000. Wood samples from the Pavlovskaya Depression were first subject to investigation (Blokhina & Bondarenko 2004a, b, 2005, Blokhina et al. 2003, 2005), followed by samples from other sites within the field. This paper focuses on the fossil wood assemblage and puts these findings in context of a review of investigation undertaken to date on the other fossil material (i.e. palynological and carpological studies) from the Pavlovskii brown coal field and thus presents the most complete interpretation of plant communities and environments of southern Primory'e in the Pliocene.

LOCALITY, GEOLOGY AND STRATIGRAPHY

The Pavlovskii brown coal field is located in 35 km north-east of Ussuriisk city within the area of Pavlovskaya Group of Depressions (Fig. 1) in the southern Primory'e Region of the RFE. The Pavlovskaya Group of Depressions, which covers a total area of ~150 km^2, belongs to the structural-formational zone of Khankaiskii massif and comprises the Pavlovskaya Depression and several troughs (including the southern, eastern and northern troughs, and the Luzanovskaya trough). The open-cast coal mine of Pavlovskii-I covers the southern, eastern and northern troughs. The Pavlovskii-II open-cast coal mine is situated within the area of Pavlovskaya Depression. Coal from the Luzanovskaya trough is extracted by a separate open-cast coal mine.

The Pavlovskaya Group of Depressions is filled with the Cenozoic sediments lying unconformably on Palaeozoic deposits and overlain by Quaternary deposits. The Cenozoic deposits are exposed in the open-cast mines and can be divided into three formations: Pavlovskaya, Ust'-Suifunskaya, and Suifunskaya (Krasnyi ed. 1994, Cherepovsky ed. 1997, Klimova & Feoktistov 1997).

The basal Pavlovskaya Formation is composed of sandstones, siltstones, argillites, brown coals, tuffs and tuffites, and contains lenses of conglomerates and gravels in the upper part of section. An exploited coal bed lies within this Formation. The age of the Pavlovskaya Formation is uppermost Oligocene to uppermost middle Miocene. The other formations, composed of mostly gravels, are so far unexploited. The Upper Miocene Ust'-Suifunskaya Formation is deposited unconformably (with erosion) on the Pavlovskaya Formation and composed of obliquely laminated sandstones, gravels and small-pebble conglomerates with siltstone or rare argillite bands. The overlying Suifunskaya Formation, according to the adopted resolution given in Krasnyi ed. (1994), is of the Pliocene age. The same age of the Suifunskaya Formation is given in Cherepovsky ed. (1997). Klimova and Feoktistov (1997) give also the Pliocene age of this formation, even though Pavlutkin (Pavlutkin et al. 1988, Pavlutkin 1998, Pavlutkin & Petrenko 2010) defines its age as Eopleistocene. We share the official notion on the Pliocene age of the Suifunskaya Formation. The formation is represented by a series of fluvial sediment rhythms. At the boundaries of the rhythms there are siltstone lenses containing pollen and spores and plant detritus, i.e. remains of conifer needles, fruits and seeds; but impressions of angiosperm leaves are lacking. In the upper part of the formation there are small-pebble conglomerates containing fossil wood collected by the authors (Figs 2a, b).

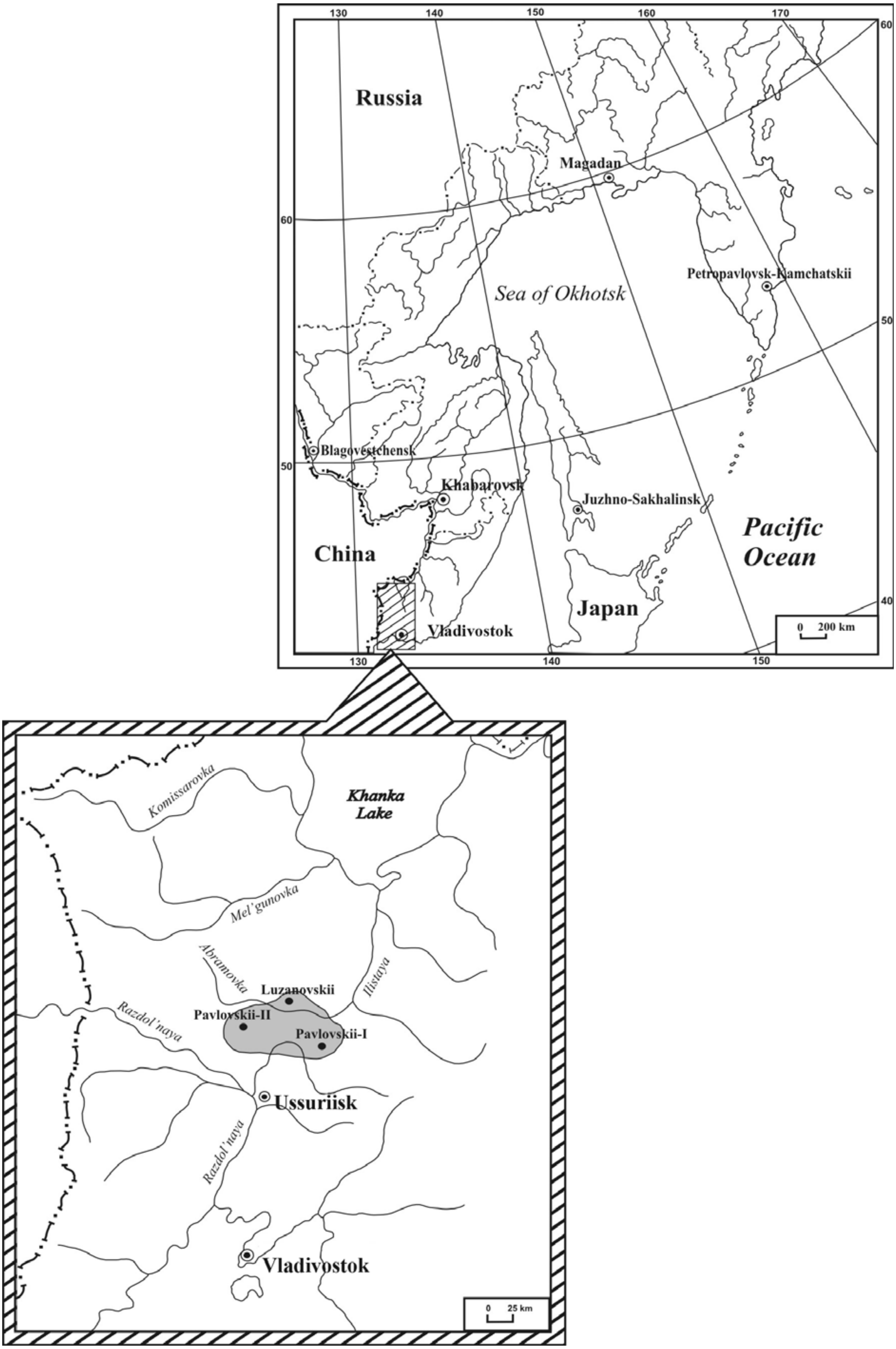

Fig. 1. Map showing location of the Pavlovskii brown coal field

Fig. 2. Collecting sites of the Pliocene fossil wood: **a** – Pavlovskii open-cast coal mine, section of Cenozoic sediments. An arrow indicates the section of the Suifunskaya Formation containing fossil wood remains, **b** – Luzanovskii open-cast coal mine, fossil wood log in horizontal bedding, palaeobotanist O.V. Bondarenko, **c** – piece of the lignitic fossil wood approximately 75 cm in length and 12×30 cm in diameter

MATERIAL

Lignitic wood fragments are abundant, light- to dark-brown in colour, and range in size usually from 6–9 cm but occasionally up to 23 cm in length and from 3–5 cm up to 15–18 cm in diameter (Fig. 2c). A few logs of between 3–6 m in length and 40–50 cm in diameter were also found. Growth rings are distinct, ranging from (0.05)0.2–0.5 mm to 2–3(4–5) mm in width, and generally distinguishable by eye. Wood fragments, stumps and logs were found horizontally aligned to the bedding plane with direction of bed inclination 270° from east to west.

Wood was collected from three sites. Collection No. 20 originated from the southern trough within the Pavlovskii-I mine, Collection No. 20° from the Pavlovskii-II mine, and Collection No. 20b from the Luzanovskii open-cast coal mine. A total of 259 fossil wood specimens have been studied; of these wood specimens, 221 specimens had a well preserved wood anatomical structure and were identified. Anatomical descriptions of the wood are given in the papers of Blokhina and Bondarenko (2004a, 2005, 2008), Blokhina et al. (2003, 2005), and Bondarenko (2006, 2007).

In addition to the wood, we used the information on the other plant remains, i.e. palynomorphs, conifer needles, fruits and seeds, found in the sediments of Suifunskaya Formation and given in the work of Pavlutkin et al. (1988) and in Krasnyi ed. (1994). These plant remains originate from the Pavlovskii-II mine.

METHODS

In order to identify the fossil wood material the wood pieces were sectioned in three planes (transverse, radial, and tangential) following the standard technique of Gammerman et al. (1946) for preparing thin sections of slightly lignitic, weakly modified wood using a hand held razor straight. A total of ~ 8000 thin slides from 259 fossil wood specimens were studied using light microscopes «Mikmed» (LOMO) and «AxioScop-40» (Carl Zeiss).

Reconstruction of plant communities and their environments, especially dating back to the late Cenozoic, is based on the principle of uniformity. The modern flora of southern RFE, as well as the flora of China, Korea, Japan, and western USA, includes members of which possible ancestral taxa were present in the late Neogene floras (Takhtajan 1978). Therefore nearest living relatives (NLR), to the taxa occurring in the Neogene flora of the RFE, along with their geographical distributions and environments can provide information pertaining to palaeoenvironment, altitudinal zonation and biodiversity of the ancestral vegetation that gave rise to vegetation extending today from the Far East to the western United States.

In order to reconstruct the woody plant communities covering the area of Pavlovskaya Group of Depressions (southern Primory'e) in the Pliocene time, possible high-altitude zonation of those communities and profile diagrams of the forest we used all records of fossil plant remains found to date and identified as species, and we used the information regarding the environments in which their NLR were found. We suggested that in case the species determined had two or three NLR, they might be grown in two or three habitat types respectively. Besides, in order to reconstruct visual representations of profile diagrams we used the information on general habitus or biomorpha of the NLR.

PALAEOBOTANIC RECORDS

Fossil plant records from the Pliocene deposits of the Pavlovskii brown coal field are represented by different organ types, namely, wood remains, seeds, pollen and spores and small numbers of conifer needles (Tabs 1, 2).

FOSSIL WOOD

The wood belong to 35 taxa that were identified by xylotomy (Tabs 1, 2). Of the 221 fossil wood specimens identified, 77.1% were coniferous (74.4% Pinaceae Lindl. and 2.7% Cupressaceae Gray) and the remaining 22.9% were angiospermous. Pinaceae is represented mostly by the fossil wood specimens belonging to the species of genera *Laricioxylon* Greguss (20.5%), *Piceoxylon* Gothan (19.1%), *Picea* A. Dietr. (15.4%), and *Larix* Mill. (14.4%), and the remaining 5.0% were *Abies* Mill. (2.8%), *Pseudotsugoxylon* Blokh. & Bondar. (1.8%), and *Keteleeria* Carr. (0.4%). According to Bondarenko (2005, 2006) angiosperms are represented mostly by the fossil wood specimens belonging to the species of Ulmaceae Mirb. (12.7%), Rosaceae Adans. (4.9%), and Aceraceae Juss. only 1.4% (Bondarenko 2005, 2006).

PALYNOMORPHS

The information about pollen and spores from the aleurolite lens is taken from Pavlutkin et al. (1988). Palynomorphs belong to 19 taxa of woody plants (Tabs 1, 2) and are represented mostly by the temperate broad-leaved species of *Quercus* L. (58.7%), *Ulmus* L. (14.4%), *Fagus* L. (4.9%), *Corylus* L. (4.2%), *Carpinus* L. (4.0%), *Tilia* L. (3.0%), and *Juglans* L. (0.6%). A considerable part of palynospectrum comprises small-leaved angiosperms *Betula L.* (8.7%) and *Alnus* Mill. (7.6%). Additionally, single pollen grains of *Magnolia* L., *Celtis* L., *Castanea* Mill., *Pterocarya* Kunth, and *Carya* Nutt. were found. The pollen of Pinaceae is relatively abundant, especially *Picea* (31.0%) and *Pinus* L. (16.6%), although pollen of *Tsuga* Carr. (1.0%) occurred sparsely. Pollen grains of Cupressaceae-Taxodiaceae (2.2%) were also found. Herbs are represented by Cyperaceae Juss. (29.3%), Ranunculaceae Juss. (13.2%), Gramineae Juss. (11.3%), *Artemisia* L. (5.7%) and Compositae Giseke (3.8%). In addition, pollen grains of aquatic plants *Nelumbo* Adans., *Myriophyllum* L., and *Sparganium* L., were also found, and Polypodiaceae Bercht. & J. Presl dominated in spores (Pavlutkin et al. 1988).

Table 1. Palaeobotanical records from the Pliocene of the Pavlovskii brown coal field

Fossils	Taxon	References
Wood	Trees and shrubs	
	Piceoxylon pavlovskiense Blokh. & Bondar., *Laricioxylon pavlovskiense* Blokh. & Bondar.	Blokhina et al. 2003
	Pseudotsugoxylon pavlovskiense Blokh. & Bondar.	Blokhina & Bondarenko 2004a
	Keteleeria zhilinii Blokh. & O.V. Bondar.	Blokhina & Bondarenko 2005
	Quercus primorica O.V. Bondar., Blokh. & Snezhk.	Blokhina et al. 2005
	Abies aff. *sachalinensis* Fr. Schmidt, *Picea jezoensis* (Siebold & Zucc.) Carr., *P. koraiensis* Nakai, *P.* cf. *bicolor* (Maxim.) Mayr, *Piceoxylon* aff. *pavlovskiense* Blokh. & Bondar., *Piceoxylon* sp. 1, *Piceoxylon* sp. 2, *Larix gmelinii* (Rupr.) Rupr., *L. olgensis* A. Henry, *Laricioxylon* aff. *chelebaevae* Blokh., *L.* aff. *korfiense* Blokh., *L.* aff. *sichotealinense* Blokh., *Microbiota decussata* Kom., *Biota orientalis* (L.) Endl., *Ulmus japonica* (Rehd.) Sarg., *U. laciniata* (Trautv.) Mayr, *Betula* aff. *davurica* Pall., *Populoxylon* sp., *Micromeles alnifolia* (Siebold & Zucc.) Koehne, *Malus mandshurica* (Maxim.) Kom., *Pyrus ussuriensis* Maxim., *Padus* aff. *maackii* (Rupr.) Kom., *Cerasus sargentii* (Rehd.) Pojark., *Acer* aff. *tegmentosum* Maxim., *Eleutherococcus* aff. *sessiliflorus* (Rupr. & Maxim.) S.Y.Hu, *Fraxinus* sp., *Sambucus* sp.	Bondarenko 2006
	Laricioxylon blokhinae O.V. Bondar.	Bondarenko 2007
	Abies chavchavadzeae Blokh. & O.V. Bondar., *Piceoxylon ussuriense* Blokh. & O.V. Bondar.	Blokhina & Bondarenko 2008
Seeds	Trees and shrubs	
	Picea jezoensis Siebold & Zucc., *Larix* cf. *gmelinii* (Rupr.) Kuzeneva, *Alnus* sp., *Betula* sect. *Costatae* Regel, *Salix* sp., *Padus asiatica* Kom., *P. maackii* (Rupr.) Kom., *Spiraea betulifolia* Pall., *Crataegus* sp., *Rosa* sp., *Swida* cf. *sanquinea* (L.) Obis, *Aralia* sp., *Sambucus* sp.	Pavlutkin et al. 1988
	Picea sp., *Pinus* sp., *Padus* cf. *jacutica* Dorof., *Cornus tertiaria* Dorof.	Krasnyi ed. 1994
	Woody liana	
	Ampelopsis cf. *aegirophylla* (Bunge) Planch.	Krasnyi ed. 1994
	Herbs	
	Bunias cochlearoides Murr., *Lycopus* cf. *lucidus* Turcz. ex Benth., *Cyperus* cf. *longus* L., *Scirpus* cf. *smithii* A. Gray	Pavlutkin et al. 1988
	Ranunculus sp., *Bunias* cf. *orientalis* L., *Aralia* cf. *crassa* Dorof.	Krasnyi ed. 1994
	Aquatic plants	
	Ferns: *Pilularia pliocenica* Dorof., *Azolla pseudopinnata* Nikit.	Pavlutkin et al. 1988
	Herbs: *Trapella ambiqua* Dorof., *Alisma gramineum* Lej., *Potamogeton* cf. *filiformis* Pers., *P.* cf. *vaginatus* Turcz., *P.* ex. gr. *perfoliatus* L.	Pavlutkin et al. 1988
	Herbs: *Brasenia* sp., *Potamogeton nitilus* Wolsq.	Krasnyi ed. 1994
Palynomorphs	Trees and shrubs	
	Picea sp., *Tsuga* sp., *Pinus* sp., Cupressaceae-Taxodiaceae, *Magnolia* sp., *Celtis* sp., *Ulmus* sp., *Fagus* sp., *Quercus* sp., *Castanea* sp., *Betula mandshurica* (Regel) Nakai, *Betula* sect. *Albae* L., *Carpinus* cf. *betulus* L., *Carpinus* sp., *Alnus* sp., *Corylus* sp., *Juglans* sp., *Pterocarya* sp., *Carya* sp., *Tilia* sp.	Pavlutkin et al. 1988
	Ferns	
	Polypodiaceae Bercht. & J. Presl, *Hymenophyllum* sp.	Pavlutkin et al. 1988
	Herbs	
	Ranunculaceae Juss., *Artemisia* sp., Asteraceae Dum, Cyperaceae Juss., Poaceae (R.Br.) Barnh.	Pavlutkin et al. 1988
	Aquatic plants	
	Herbs: *Nelumbo* sp., *Myriophyllum* sp., *Sparganium* sp.	Pavlutkin et al. 1988
Leaves	Trees	
	Picea jezoensis (Siebold & Zucc.) Carr., *Larix* cf. *gmelinii* (Rupr.) Kuzeneva	Pavlutkin et al. 1988

Table 2. Fossil remains of woody plants found in the Pliocene deposits of the Pavlovskii brown coal field. Legend: (+) – presence

No.	Family	Genus	Species	Fossils			
				Wood	Seeds	Palynomorphs	Leaves
1.	Pinaceae Lindl.	*Abies* Mill.	*A. chavchavadzeae* Blokh. & O.V. Bondar.	+	–	–	–
2.			*A.* aff. *sachalinensis* Schmidt	+	–	–	–
3.		*Keteleeria* Carr.	*K. zhilinii* Blokh. & O.V. Bondar.	+	–	–	–
4.		*Pseudotsugoxylon* Blokh. & Bondar.	*P. pavlovskiense* Blokh. & Bondar.	+	–	–	–
5.		*Tsuga* Carr.	*Tsuga* sp.	–	–	+	–
6.		*Picea* A. Dietr.	*P. jezoensis* (Siebold & Zucc.) Carr.	+	+	–	+
7.			*P. koraiensis* Nakai	+	–	–	–
8.			*P.* cf. *bicolor* (Maxim.) Mayr	+	–	–	–
9.			*Picea* sp.	–	+	+	–
10.		*Piceoxylon* Gothan	*P. pavlovskiense* Blokh. & Bondar.	+	–	–	–
11.			*P.* aff. *pavlovskiense* Blokh. & Bondar.	+	–	–	–
12.			*P. ussuriense* Blokh. & O.V. Bondar.	+	–	–	–
13.			*Piceoxylon* sp. 1	+	–	–	–
14.			*Piceoxylon* sp. 2	+	–	–	–
15.		*Larix* Mill.	*L. gmelinii* (Rupr.) Rupr.	+	–	–	–
16.			*L.* cf. *gmelinii* (Rupr.) Rupr.	–	+	–	+
17.			*L. olgensis* A. Henry	+	–	–	–
18.		*Laricioxylon* Greguss	*L. blokhinae* O.V. Bondar.	+	–	–	–
19.			*L. pavlovskiense* Blokh. & Bondar.	+	–	–	–
20.			*L.* aff. *chelebaevae* Blokh.	+	–	–	–
21.			*L.* aff. *korfiense* Blokh.	+	–	–	–
22.			*L.* aff. *sichotealinense* Blokh.	+	–	–	–
23.		*Pinus* L.	*Pinus* sp.	–	+	+	–
24.	Cupressaceae Gray	*Microbiota* Kom.	*M. decussata* Kom.	+	–	–	–
25.		*Biota* (D. Don) Endl.	*B. orientalis* (L.) Endl.	+	–	–	–
26.	Cupressaceae-Taxodiaceae			–	–	+	–
27.	Magnoliaceae Juss.	*Magnolia* L.	*Magnolia* sp.	–	–	+	–
28.	Ulmaceae Mirb.	*Celtis* L.	*Celtis* sp.	–	–	+	–
29.		*Ulmus* L.	*U. japonica* (Rehd.) Sarg.	+	–	–	–
30.			*U. laciniata* (Trautv.) Mayr	+	–	–	–
31.			*Ulmus* sp.	–	–	+	–
32.	Fagaceae Dumort.	*Fagus* L.	*Fagus* sp.	–	–	+	–
33.		*Quercus* L.	*Q. primorica* O.V. Bondar., Blokh. & Snezhk.	+	–	–	–
34.			*Quercus* sp.	–	–	+	–
35.		*Castanea* Mill.	*Castanea* sp.	–	–	+	–
36.	Betulaceae Gray	*Alnus* Mill.	*Alnus* sp.	–	+	+	–
37.		*Betula* L.	*B.* aff. *davurica* Pall.	+	–	–	–
38.			*B. mandshurica* (Regel) Nakai	–	–	+	–
39.			*Betula* sect. *Albae* L.	–	–	+	–
40.			*Betula* sect. *Costatae* Regel.	–	+	–	–
41.		*Carpinus* L.	*C.* cf. *betulus* L.	–	–	+	–
42.			*Carpinus* sp.	–	–	+	–
43.		*Corylus* L.	*Corylus* sp.	–	–	+	–
44.	Juglandaceae A. Rich. ex Kunth	*Juglans* L.	*Juglans* sp.	–	–	+	–
45.		*Pterocarya* Kunth	*Pterocarya* sp.	–	–	+	–
46.		*Carya* Nutt.	*Carya* sp.	–	–	+	–
47.	Salicaceae Mirb.	*Populoxylon* Mädel-Angeliewa	*Populoxylon* sp.	+	–	–	–
48.		*Salix* L.	*Salix* sp.	–	+	–	–
49.	Tiliaceae Juss.	*Tilia* L.	*Tilia* sp.	–	–	+	–

Table 2. Continued

No.	Family	Genus	Species	Fossils			
				Wood	Seeds	Palynomorphs	Leaves
50.	Rosaceae Adans.	*Micromeles* Decne.	*M. alnifolia* (Siebold & Zucc.) Koehne	+	–	–	–
51.		*Malus* Mill.	*M. mandshurica* (Maxim.) Kom.	+	–	–	–
52.		*Pyrus* L.	*P. ussuriensis* Maxim.	+	–	–	–
53.		*Padus* Mill.	P. *asiatica* Kom.	–	+	–	–
54.			*P. maackii* (Rupr.) Kom.	–	+	–	–
55.			*P.* aff. *maackii* (Rupr.) Kom.	+	–	–	–
56.			*P.* cf. *jacutica* Dorof.	–	+	–	–
57.		*Cerasus* Mill.	*C. sargentii* (Rehd.) Pojark.	+	–	–	–
58.		*Crataegus* L.	*Crataegus* sp.	–	+	–	–
59.		*Spiraea* L.	*S. betulifolia* Pall.	–	+	–	–
60.		*Rosa* L.	*Rosa* sp.	–	+	–	–
61.	Aceraceae Juss.	*Acer* L.	*A.* aff. *tegmentosum* Maxim.	+	–	–	–
62.	Cornaceae Dumort.	*Cornus* L.	*C. tertiaria* Dorof.	–	+	–	–
63.		*Swida* Opiz	*S.* cf. *sanquinea* (L.) Opiz	–	+	–	–
64.	Araliaceae Juss.	*Aralia* L.	*Aralia* sp.	–	+	–	–
66.		*Eleutherococcus* Maxim.	*E.* aff. *sessiliflorus* (Rupr. & Maxim.) S.Y. Hu	+	–	–	–
67.	Vitaceae Juss.	*Ampelopsis* Rich.	*Ampelopsis* cf. *aegirophylla* (Bunge) Planch.	–	+	–	–
68.	Oleaceae Hoffmanns. & Link	*Fraxinus* L.	*Fraxinus* sp.	+	–	–	–
69.	Caprifoliaceae Adans.	*Sambucus* L.	*Sambucus* sp.	+	+	–	–

Nowadays several taxa given in Pavlutkin et al. (1988) have been transferred taxonomically, namely, *Betula mandshurica* (Regel) Nakai – into synonym of *B. platyphylla* Sukacz. (Nedoluzhko & Skvortsov 1996); Compositae Giseke is an older name of the family Asteraceae Dum. (Barkalov et al. 1992), and Gramineae Juss. – of the Poaceae (R.Br.) Barnh. (Probatova 1985).

SEED REMAINS

Information about seed assemblages from the siltstone lenses is taken from Pavlutkin et al. (1988) and Krasnyi ed. (1994). Seed remains of woody plants belong to 18 taxa (Tabs 1, 2). According to Pavlutkin et al. (1988), an abundance of Pinaceae (namely, *Picea* and *Larix*) characterizes the seed assemblage. Besides, seed remains of some herbaceous and aquatic plants were also identified.

Nowadays *Padus asiatica* Kom. given in Pavlutkin et al. (1988) is transformed into synonym of *P. avium* Mill. (Yakubov et al. 1996). *Cornus tertiaria* Dorof., given in Krasnyi ed. (1994), was compared with the living species *C. brachypoda* C.A. Mey. by Dorofeev (1962); the latter is transferred into synonym of *C. macrophylla* Wall. (Wu Raven & Hong eds 2005). *Ampelopsis* cf. *aegirophylla* (Bunge) Planch., given in Krasnyi ed. (1994), has been placed in synonymy under *A. vitifolia* subsp. *vitifoli*a Planch. (Nazimuddin & Quasier eds. 1982).

PALAEORECONSTRUCTIONS

PALAEORELIEF

In the Late Pliocene, the topography of the area occupied by Pavlovskaya Group of Depressions was mountainous with broad plains cutting though them (Denisov 1965, Lebedeva 1956, 1957). This agrees with lithological and facies data derived from the Suifunskaya Formation and characteristics associated with the buried plant remains given in the paper of Pavlutkin et al. (1988). These data suggest that, in the Pliocene, the topography of the Pavlovskaya Group of Depressions probably consisted a broad valley through which a palaeo-river ran (Pavlutkin et al. 1988).

We found that, within the area of Pavlovskaya Group of Depressions, woody stumps and logs were horizontally aligned to the bedding plane with direction of bed inclination 270° from east to west. The alignment of fossil wood suggests their transportation to the site of deposition by a watercourse running in an east-west direction. Therefore this watercourse was arising somewhere in the spurs of the southern Sikhote-Alin Range. This river may have formed one of the tributaries of the palaeo-Razdol'naya River, and that tributary, perhaps, was at the left side of the palaeo-Razdol'naya River. We suggest that the same tributary, possibly, was the palaeo-Ilistaya River (Fig. 3), described by Khudyakov et al. (1972) which is indicated as flowing in the Pliocene through the Pavlovskaya Group of Depressions in a westerly direction. However, in the post Pliocene time, the palaeo-Ilistaya River changed its course.

WOODY PLANT COMMUNITIES AND PALAEOENVIRONMENTS

In the Pliocene, the vegetation of the area of Pavlovskaya Group of Depressions was represented by woody plants (42 genera of trees and shrubs, and one genus of liana), ferns, herbs and aquatic plants (Tab. 1). Many of determined fossil species are represented in the modern flora of southern RFE or have analogues in the floras of Japan, North-Eastern China, Korean Peninsula or western North America (Tab. 3). Information regarding the environments in which NLR of determined fossil species are given in Table 4.

The taphocoenosis based on wood represents an assemblage of woody plants characteristic of valley and slope habitats (Fig. 4). Probably, the valley vegetation comprised forest dominated by conifers and elms while the slopes were covered by mixed coniferous-hardwood

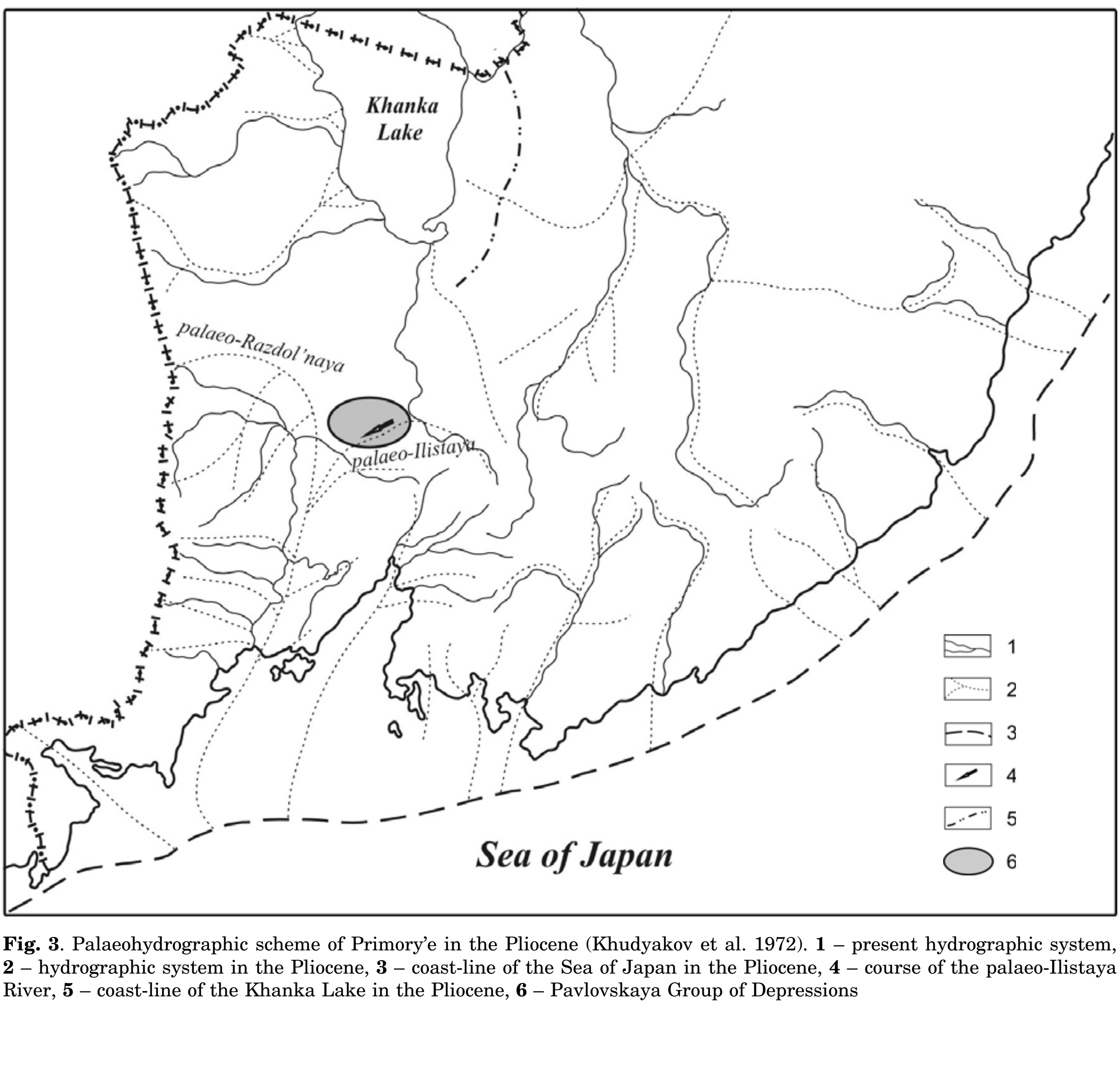

Fig. 3. Palaeohydrographic scheme of Primory'e in the Pliocene (Khudyakov et al. 1972). **1** – present hydrographic system, **2** – hydrographic system in the Pliocene, **3** – coast-line of the Sea of Japan in the Pliocene, **4** – course of the palaeo-Ilistaya River, **5** – coast-line of the Khanka Lake in the Pliocene, **6** – Pavlovskaya Group of Depressions

Table 3. Woody plants represented in the Pliocene within the area occupied by the Pavlovskaya Group of Depressions, and their nearest living relatives

No.	Fossil woody plant species	Nearest living relatives		
		Species	Distribution range	Environments
1.	*Abies* aff. *sachalinensis* (Schmidt) Mast	*Abies sachalinensis* (Schmidt) Mast.	Sakhalin, the southern Kuril Islands, northern Hokkaido	Mountain mixed dark-coniferous forest or pure *Abies*-forest; (400)800–1100 m a. s. l.
2.	*Abies chavchavadzeae* Blokh. & O.V. Bondar.	*Abies magnifica* Murray	California, Nevada, Oregon (USA)	Mixed coniferous forest; 1400–2700 m a.s.l.
		Abies grandis Lindl.	the Atlantic coast of Canada and the USA, western North America	Valley forest, or pure *Abies*-forest; up to 2100 m a.s.l.; humid maritime or rare continental climate
3.	*Keteleeria zhilinii* Blokh. & O.V. Bondar.	*Keteleeria davidiana* (Bertr.) Beissner	central, southern and SE China, northern Vietnam, Taiwan	Mountain forest; (200)700–1000(1400) m a.s.l.; humid warm temperate to subtropical climate
		Keteleeria fortunei (Murr.) Carr.	central, southern and SE China, northern Vietnam	(see *Keteleeria davidiana*)
		Keteleeria evelyniana Masters	central, southern and SE China, northern Vietnam, northern Laos	Mountain forest; up to 2700(3000) m a.s.l.; humid warm temperate to subtropical or nearly tropical climate
4.	*Pseudotsugoxylon pavlovskiense* Blokh. & Bondar.	*Pseudotsuga menziesii* (Mirb.) Franco	the Pacific coast of Canada and the USA	Coniferous and coniferous-hardwood forest; up to 1800 m a.s.l.
		Pseudotsuga macrocarpa Mayr	southern California (USA), northern California Peninsula (Mexico)	Mountain mixed coniferous forest
5.	*Picea jezoensis* (Siebold & Zucc.) Carr.	*Picea jezoensis* (Siebold & Zucc.) Carr.	central Kamchatka Peninsula, coast of the Sea of Okhotsk, southern RFE, NE China, Korea Peninsula, Japan	Dominant in dark-coniferous forest; as admixture in low terrace forest; 860–1200 m a.s.l.
6.	*Picea koraiensis* Nakai	*Picea koraiensis* Nakai	southern Primory'e, Korea Peninsula	Marshy valley forest, sometimes peat bogs
7.	*Picea* cf. *bicolor* (Maxim.) Mayr	*Picea bicolor* (Maxim.) Mayr	central Japan	Mountain forest
8.	*Piceoxylon pavlovskiense* Blokh. & Bondar.	*Picea koraiensis* Nakai	(see No. 6)	(see No. 6)
		Picea jezoensis (Siebold & Zucc.) Carr.	(see No. 5)	(see No. 5)
		Picea sitchensis (Bong.) Carr.	western British Columbia (Canada); southern Alaska, Oregon, NW California (USA)	Mountain mixed forest or pure *Picea*-forest along the flooded rivers, up to 900–1000 m a.s.l.
9.	*Piceoxylon* aff. *pavlovskiense* Blokh. & Bondar.	(see No. 8)	(see No. 8)	(see No. 8)
10.	*Piceoxylon ussuriense* Blokh. & O.V. Bondar.	*Picea rubens* Sarg.	the Atlantic coast of Canada and the USA	Mountain forest; up to 2000 m a.s.l.
		Picea koraiensis Nakai	(see No. 6)	(see No. 6)

11.	*Larix gmelinii* (Rupr.) Kuzeneva	*Larix gmelinii* (Rupr.) Kuzeneva	Siberia, northern Inner Mongolia, NE China	Pure monodominant *Larix*-forest or with admixture of hardwood; valley forest up to subalpine and northern timber line
12.	*Larix* cf. *gmelinii* (Rupr.) Kuzeneva	(see No. 11)	(see No. 11)	(see No. 11)
13.	*Larix olgensis* A. Henry	*Larix olgensis* A. Henry	Primory'e (the coast from Valentine to Vladimir Bays)	Coniferous-hardwood forest; from valleys up to 100–500 m a.s.l.
14.	*Laricioxylon blokhinae* O.V. Bondar.	*Larix olgensis* A. Henry	(see No. 13)	(see No. 13)
		Larix leptolepis (Siebold & Zucc.) Gord.	central Honshu	Mountain pure *Larix*- or mixed forest; (500)1600–2300(4000) m a.s.l.
15.	*Laricioxylon pavlovskiense* Blokh. & Bondar.	*Larix occidentalis* Nutt.	British Columbia (Canada); Washington, Montana, Idaho (USA)	Pure *Larix*- or mixed coniferous forest; 600–1200 m a.s.l.
		Larix gmelinii (Rupr.) Kuzeneva	(see No. 11)	(see No. 11)
		Larix olgensis A. Henry	(see No. 13)	(see No. 13)
16.	*Laricioxylon* aff. *chelebaevae* Blokh.	*Larix lyallii* Parl.	the Cascade Range and Rocky Mountains (USA)	Mountain pure *Larix*- or mixed coniferous forest; 1200–2400(3000) m a.s.l. in subalpine belt near upper timber line
17.	*Laricioxylon* aff. *korfiense* Blokh.	*Larix occidentalis* Nutt.	(see No. 15)	(see No. 15)
		Larix leptolepis (Siebold & Zucc.) Gord.	(see No. 14)	(see No. 14)
18.	*Laricioxylon* aff. *sichotealinense* Blokh.	*Larix gmelinii* (Rupr.) Kuzeneva	(see No. 11)	(see No. 11)
		Larix sibirica Ledeb.	Siberia	Pure *Larix*- or mixed forest; moss bogs in tundra, forest tundra ecotone zone and mountain slopes
19.	*Microbiota decussata* Kom.	*Microbiota decussata* Kom.	the Sikhote-Alin	Stone debris; from sea coast up to subalpine
20.	*Biota orientalis* (L.) Endl.	*Biota orientalis* (L.) Endl.	NW China	Up to 800 m a.s.l.
21.	*Ulmus japonica* (Rehd.) Sarg.	*Ulmus japonica* (Rehd.) Sarg.	eastern Siberia, RFE, Mongolia, China, Japan	Coniferous-hardwood or hardwood forest in valleys of big rivers or by woodsides
22.	*Ulmus laciniata* (Trautv.) Mayr	*Ulmus laciniata* (Trautv.) Mayr	southern RFE	Mountain broad-leaved forest; up to 600–700 m a.s.l.
23.	*Quercus primorica* Bondar., Blokh. & Snezhk.	*Quercus mongolica* Fisch. ex Ledeb.	SE Transbaikalia, southern RFE, northern China, Korea Peninsula, northern Japan	Pure oak- or hardwood forest; dry loam soils of mountain slopes and valleys
		Quercus crispula Blume	SW coast of the Sea of Japan, southern Sakhalin, the Kuril Islands, Japan	Coniferous-broadleaved forest; up to 220–400 m a.s.l. in cool temperature zone, and up to 1700 m a.s.l. in warm temperature and subtropical zone
		Quercus dentata Thunb.	the Sea of Japan coast of southern Primory'e, China, Korea Peninsula, Japan	Mixed forest; dry mountain slopes

Table 3. Continued

No.	Fossil woody plant species	Nearest living relatives		
		Species	Distribution range	Environments
24.	*Betula* aff. *davurica* Pall.	*Betula davurica* Pall.	eastern Transbaikalia, southern RFE, eastern Mongolia, northern China, Korea Peninsula, northern Japan	Mixed hardwood forest, sometimes pure *Betula*- forest; nutrient rich soils
25.	*Betula mandshurica* (Regel) Nakai	*Betula platyphylla* Sukacz. (syn. *B. mandshurica* (Regel) Nakai)	eastern Siberia, Transbaikalia, southern RFE, Mongolia, China, Korea Peninsula, Japan	Pure or mixed coniferous-hardwood forest and sparse growth of trees; swamplands up to near upper timber line in mountains; temperate and subarctic zones
26.	*Carpinus* cf. *betulus* L.	*Carpinus betulus* L.	western, central and southern Europe, the Black Sea region, northern Asia Minor	Hardwood or mixed forest and oak groves; at the 600 m a.s.l.; warm climate and moderate soil fertility
27.	*Populoxylon* sp.	*Populus koreana* Rehd.	Primory'e, NE China, Korea Peninsula	Polydominant valley forest or poplar-forest; sometimes up to 1200 m a.s.l.
		Populus tremula L.	the European Russia, Siberia, RFE, the Caucasus, the eastern Middle Asia, Europe, Mediterranean, Asia Minor, Mongolia, China, Japan	Pure or mixed aspen-forest; various coenosis and habitats in woodlands
28.	*Micromeles alnifolia* (Siebold & Zucc.) Koehne	*Micromeles alnifolia* (Siebold & Zucc.) Koehne	Primory'e, southern Sakhalin, the southern Kuril Islands, China, Korea Peninsula, Japan	Coniferous-broadleaved or coniferous- Ermann stone birch forest
29.	*Malus mandshurica* (Maxim.) Kom.	*Malus mandshurica* (Maxim.) Kom.	RFE, NE China, Korea	Hardwood or mixed forest; mostly valleys; up to 900 (1000) m a.s.l.
30.	*Pyrus ussuriensis* Maxim.	*Pyrus ussuriensis* Maxim.	southern RFE, China, Korea Peninsula	Hardwood or mixed valley forest; terraces
31.	*Padus asiatica* Kom.	*Padus avium* Mill. (syn. *P. asiatica* Kom.)	the European Russia, Siberia, RFE, the Caucasus, the eastern Middle Asia, Europe, Asia Minor, Mongolia, China, Japan	Valley forest or wood and shrub thickets in silt soils; rarely various slope coenosis and habitats with bad or well drained soils
32.	*Padus maackii* (Rupr.) Kom.	*Padus maackii* (Rupr.) Kom.	southern RFE, NE China	Dark-coniferous or coniferous-broadleaved mountain forest; mostly in river banks and terraces; up to 800 m a.s.l.
33.	*Padus* aff. *maackii* (Rupr.) Kom.	(see No. 32)	(see No. 32)	(see No. 32)
34.	*Padus* cf. *jacutica* Dorof.	*Padus maackii* (Rupr.) Kom.	(see No. 32)	(see No. 32)
		Padus maximoviczii (Rupr.) Sokol.	southern RFE, China, Korea Peninsula, Japan	Coniferous-broadleaved and Ermann stone birch forest; up to 700–800 m a.s.l.
35.	*Cerasus sargentii* (Rehd.) Pojark.	*Cerasus sargentii* (Rehd.) Pojark.	southern Primory'e, Sakhalin, the southern Kuril Islands, NE China, Korea Peninsula	Coniferous-broadleaved or broadleaved forest, solitary trees or in groups; low belts of hills
36.	*Spiraea betulifolia* Pall.	*Spiraea betulifolia* Pall.	eastern Siberia, southern RFE, China, Japan	Mountain forest or valley forest; rocky slopes and screes
37.	*Acer* aff. *tegmentosum* Maxim.	*Acer tegmentosum* Maxim.	southern RFE, NE China, Korea Peninsula	Various mixed forest

38.	*Cornus tertiaria* Dorof.	*Cornus macrophylla* Wall. (syn. *Cornus brachypoda* C.A. Mey.)	Afganistan, Pakistan, India, Bhutan, Kashmir, Myanmar, Nepal, China, Taiwan, Korea Peninsula, Japan	Dense forest, mixed woods, margins of woods, slopes or streamsides; up to 1200–1800(3600) m a.s.l.
39.	*Swida* cf. *sanquinea* (L.) Opiz	*Swida sanquinea* (L.) Opiz	the southern and middle European Russia, Europe to northern Balkan Peninsula	Broadleaved forest
40.	*Eleutherococcus* aff. *sessiliflorus* (Rupr. & Maxim.) S.Y. Hu	*Eleutherococcus sessiliflorus* (Rupr. & Maxim.) S.Y. Hu	southern RFE, northern China, Korea Peninsula	Broadleaved or coniferous-broadleaved forest; valleys, ravines, woodsides
41.	*Ampelopsis* cf. *aegirophylla* (Bunge) Planch.	*Ampelopsis vitifolia* subsp. *vitifolia* Planch. (syn. *Ampelopsis* cf. *aegirophylla* (Bunge) Planch.)	Iran, Pakistan, Central Asia (Pamir Alaj)	Dry mountain slopes, stone debris, 850–1300(1500–2500) m a.s.l.
42.	*Fraxinus* sp.	*Fraxinus mandshurica* Rupr.	Southern RFE, NE China, Korea Peninsula, Japan	Coniferous-broadleaved or hardwood forest; valleys or gentle slopes; up to 700–800 m a.s.l.
		Fraxinus rhynchophylla Hance	southern Primory'e, southern Sakhalin, northern and NE China, Korea Peninsula, Japan	Coniferous-broadleaved or hardwood forest
43.	*Sambucus* sp.	*Sambucus coreana* (Nakai) Kom. & Aliss.	southern Primory'e, NE China, Korea Peninsula	Underwood in mixed broadleaved forest; gravel slopes and woodsides
		Sambucus racemosa L.	the European Russia, Siberia, RFE, the Caucasus, Atlantic and Middle Europe, Middle Asia, NE China, Korea Peninsula	Coniferous or mixed forest; mountain and ravines slopes and river banks

and coniferous forest (Blokhina & Bondarenko 2004b). Based on taxonomical analysis of the fossil plant remains and the preferred environments of their NLR we have suggested that the valley bottom probably supported meadows on the wide, flat areas within the valley bottoms with shrub thickets (Fig. 4) of willow and alder.

Low terraces were covered with elm forest comprising *Ulmus japonica*, and/or spruce forest of *Picea koraiensis* with *P. jezoensis* co-occurring in swampy sites (Fig. 4). In low lying regions subject to swampy conditions or disturbed habitats, larch forest comprising *Larix gmelinii*, *L. olgensis*, *Laricioxylon blokhinae*, *L. pavlovskiense*, and *L.* aff. *sichotealinense* grew.

On the high terraces, mixed elm forest of *Ulmus japonica* were established with one or more of the following taxa forming the understory: *Juglans*, *Tilia*, *Fraxinus*, poplar (*Populoxylon*), *Padus*, *Pyrus ussuriensis*, *Malus mandshurica*, and spruces (*Picea koraiensis*, *P. jezoensis*, *Piceoxylon pavlovskiense*, and *P. ussuriense*). *Spiraea*, *Corylus*, and *Eleutherococcus* aff. *sessiliflorus* with *Sambucus* are present in ravines. Oak and spruce forest grew also in the high terrace (Fig. 5).

Low hills neighbouring the valley supported a mixed coniferous-hardwood forest (Fig. 6) of spruce (*Piceoxylon pavlovskiense*), larches (*Larix gmelinii*, *L. olgensis*, *Laricioxylon blokhinae*, *L. pavlovskiense* and *L.* aff. *sichotealinense*), and broadleaved trees (i.e. *Tilia*, *Quercus primorica*, *Ulmus laciniata*, *Betula* aff. *davurica*, *Corylus*, *Fraxinus*, poplar (*Populoxylon*), *Acer* aff. *tegmentosum*, *Padus* aff. *maackii*, *Malus mandshurica*, *Micromeles alnifolia*, *Crataegus*, *Rosa*, *Cerasus sargentii*, *Sambucus*, *Aralia*, and *Eleutherococcus* aff. *sessiliflorus* with a mix of *Keteleeria zhilinii*, *Biota orientalis*, *Magnolia*, *Castanea*, *Fagus*, *Celtis* among others). Dry slopes were covered by oak forest (Fig. 7A) of *Quercus primorica* sometimes mixed with *Betula* aff. *davurica*, *Tilia*, *Fraxinus*, poplar (*Populoxylon*), as well as *Acer* aff. *tegmentosum*, *Aralia*, *Eleutherococcus* aff. *sessiliflorus* for example. Dark-coniferous forest (Fig. 7B) of *Picea jezoensis* with a mix of *Abies* aff. *sachalinensis*, *A. chavchavadzeae*, *Pseudotsugoxylon pavlovskiense*, spruces (*Piceoxylon pavlovskiense* and *P. ussuriense*) sometimes also grew in this belt. Perhaps, pure larch and spruce forest were widespread on the wetter, more northern slopes.

Table 4. References containing the information on distribution ranges and environments of the nearest living relatives of the determined fossil species

No.	Species	References
1.	*Abies sachalinensis* (Schmidt) Mast.	Matsenko 1963, Koropachinskii 1989
2.	*Abies magnifica* Murray	Matsenko 1963, Farjion 1989, FNA Editorial Committee 1993
3.	*Abies grandis* Lindl.	
4.	*Keteleeria davidiana* (Bertr.) Beissner	Farjion (1989), Wu Zhengyi & Raven (eds), 1999
5.	*Keteleeria fortunei* (Murray) Carr.	
6.	*Keteleeria evelyniana* Masters	
7.	*Pseudotsuga menziesii* (Mirb.) Franco	Farjion 1989, FNA Editorial Committee 1993
8.	*Pseudotsuga macrocarpa* Mayr	
9.	*Picea jezoensis* (Siebold & Zucc.) Carr.	Man'ko 1987, Koropachinskii 1989
10.	*Picea koraiensis* Nakai	
11.	*Picea bicolor* (Maxim.) Mayr	Farjion 1989, Iwatsuki et al. (eds), 1995
12.	*Picea sitchensis* (Bong.) Carr.	Farjion 1989, FNA Editorial Committee 1993
13.	*Picea rubens* Sarg.	
14.	*Larix gmelinii* (Rupr.) Rupr.	Bobrov 1972, Gukov 1976, Koropachinskii 1989
15.	*Larix olgensis* A. Henry	
16.	*Larix leptolepis* (Siebold & Zucc.) Gord.	Bobrov 1972, Iwatsuki, et al. (eds), 1995
17.	*Larix occidentalis* Nutt.	Farjion (1989), FNA Editorial Committee 1993
18.	*Larix lyallii* Parl.	
19.	*Larix sibirica* Ledeb.	Bobrov 1972, Sokolov et al. 1977
20.	*Microbiota decussate* Kom.	Shishkin 1935, Sokolov et al. 1977
21.	*Biota orientalis* (L.) Endl.	Wu Zhengyi & Raven (eds), 1999
22.	*Ulmus japonica* (Rehd.) Sarg.	Sokolov et al. 1977, Grudzinskaya 1991
23.	*Ulmus laciniata* (Trautv.) Mayr	
24.	*Quercus mongolica* Fisch. ex Ledeb.	Menitskii (1984), Wu Zshengyi & Raven (eds) 1999, Dobrynin 2000
25.	*Quercus dentata* Thunb.	
26.	*Quercus crispula* Blume	Menitskii 1984, Dobrynin 2000
27.	*Betula davurica* Pall.	Nedoluzhko & Skvortsov 1996
28.	*Betula platyphylla* Sukacz. (syn. *B. mandshurica* (Regel) Nakai)	
29.	*Carpinus betulus* L.	Sokolov et al. 1977
30.	*Populus koreana* Rehd.	
31.	*Populus tremula* L.	
32.	*Micromeles alnifolia* (Siebold & Zucc.) Koehne	Yakubov et al. 1996
33.	*Malus mandshurica* (Maxim.) Kom.	Yakubov et al. 1996
34.	*Pyrus ussuriensis* Maxim.	
35.	*Padus avium* Mill.	
36.	*Padus maackii* (Rupr.) Kom.	
37.	*Padus maximoviczii* (Rupr.) Sokol.	
38.	*Cerasus sargentii* (Rehd.) Pojark.	Yakubov et al. 1996
39.	*Spiraea betulifolia* Pall.	Yakubov et al. 1996
40.	*Acer tegmentosum* Maxim.	Nedoluzhko 1987a
41.	*Cornus macrophylla* Wall. (syn. *Cornus brachypoda* C.A. Mey.)	Wu Zhengyi et al. (eds), 2005
42.	*Swida sanquinea* (L.) Opiz	Derevya i kustarniki 1974
43.	*Eleutherococcus sessiliflorus* (Rupr. & Maxim.) S.Y. Hu	Klyuikov and Tikhomirov 1987
44.	*Ampelopsis vitifolia* subsp. *vitifoli*a Planch. (syn. *Ampelopsis* cf. *aegirophylla* (Bunge) Planch.)	Shishkin B.K. & Bobrov E.G. (eds), 1949, Nazimuddin & Quasier (eds), 1982
45.	*Fraxinus mandshurica* Rupr.	Nedoluzhko 1991
46.	*Fraxinus rhynchophylla* Hance	
47.	*Sambucus coreana* (Nakai) Kom. & Aliss.	Nedoluzhko 1987b
48.	*Sambucus racemosa* L.	

Upslope mixed coniferous forest (Fig. 8) were represented mainly by *Picea* cf. *bicolor* and *Piceoxylon ussuriense*, *Abies* aff. *sachalinensis*, *A. chavchavadzeae*, *Pinus*, *Keteleeria zhilinii*, *Pseudotsugoxylon pavlovskiense*, and *Tsuga*. We suggest that these forest occurred at distance from the valley and covered spurs of the southern Sikhote-Alin Range. In the

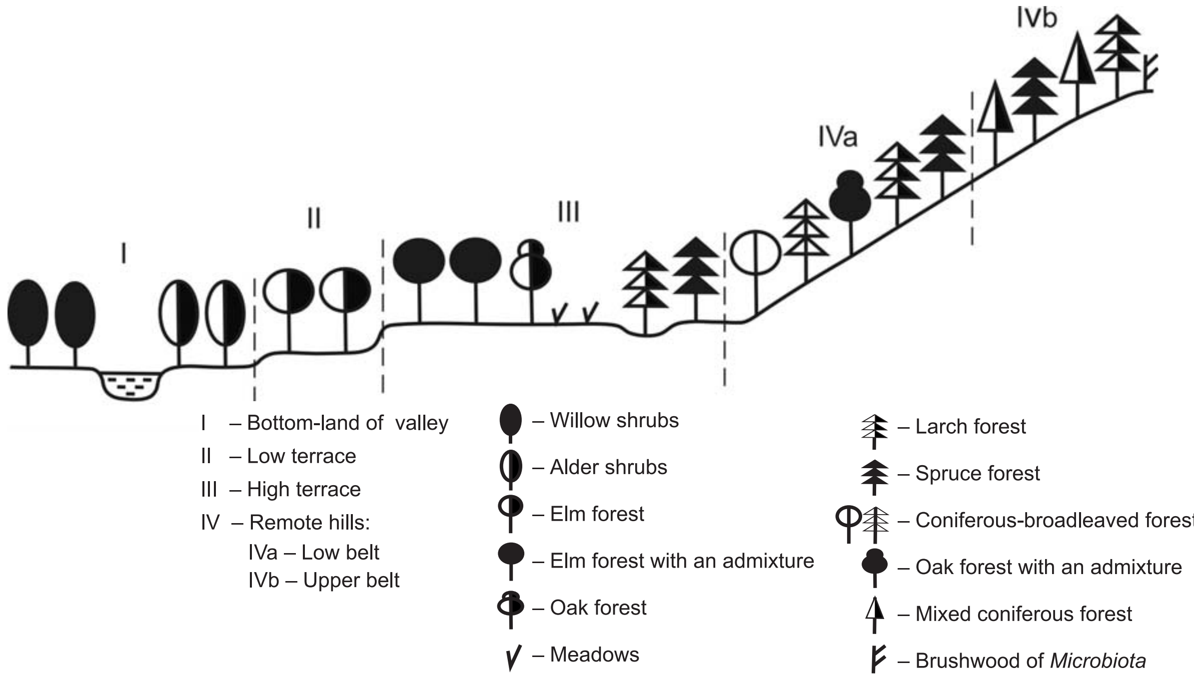

Fig. 4. Scheme of the possible high-altitude zonation of woody plant communities within the Pavlovskaya Group of Depressions

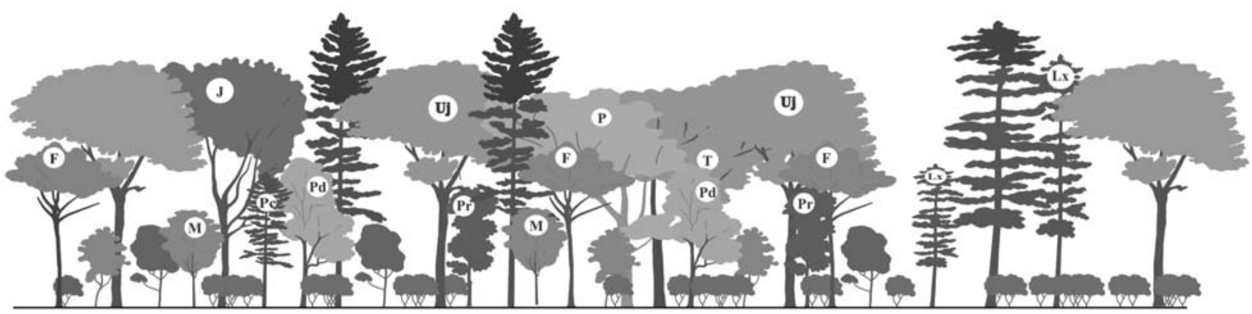

Fig. 5. Profile diagram of elm forest with an admixture of hardwood and coniferous trees in the high terrace: **Uj** – *Ulmus japonica*, **J** – *Juglans*, **T** – *Tilia*, **F** – *Fraxinus*, **P** – *Populoxylon*, **Pd** – *Padus* aff. *maackii*, **Pr** – *Pyrus ussuriensis*, **M** – *Malus mandshurica*, **Pc** – spruce (*Picea koraiensis*, *P. jezoensis*, *Piceoxylon pavlovskiense*, *P. ussuriense*), **Lx** – *Larix* (*Larix gmelinii*, *L. olgensis*, *Laricioxylon blokhinae*, *L. pavlovskiense*, *L.* aff. *sichotealinense*) and others. In undergrowth: *Spiraea*, *Corylus*, *Sambucus*, *Eleutherococcus* aff. *sessiliflorus*

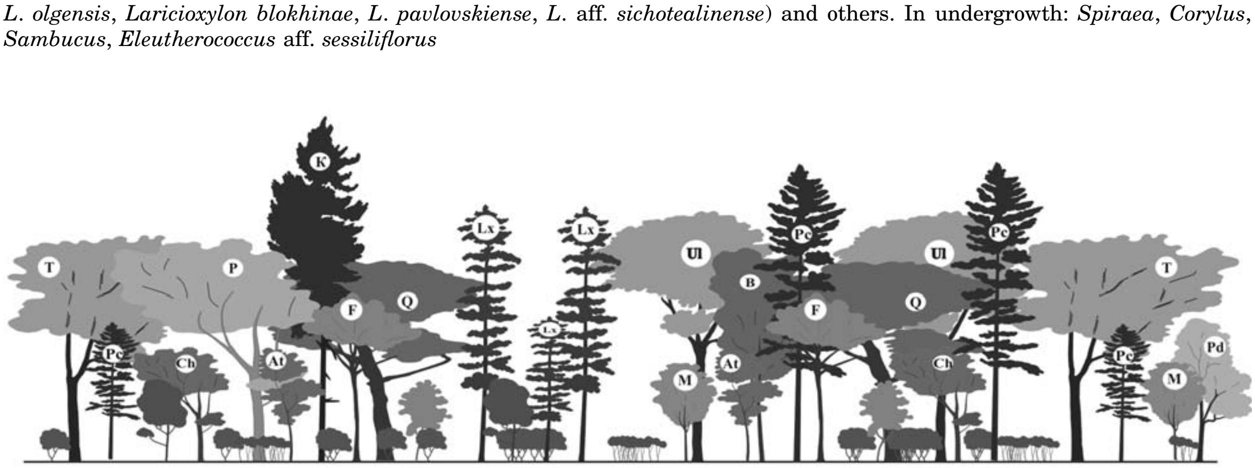

Fig. 6. Profile diagram of coniferous-broadleaved forest in the low belt of hills: **Pc** – spruce (*Piceoxylon pavlovskiense*), **Lx** – *Larix* (*Larix gmelinii*, *L. olgensis*, *Laricioxylon blokhinae*, *L. pavlovskiense*, *L.* aff. *sichorealinense*), **K** – *Keteleeria zhilinii*, **T** – *Tilia*, **Q** – *Quercus primorica*, **Ul** – *Ulmus laciniata*, **B** – *Betula* aff. *davurica*, **F** – *Fraxinus*, **P** – *Populoxylon*, **At** – *Acer* aff. *tegmentosum*, **Pd** – *Padus* aff. *maackii*, **M** – *Malus mandshurica*, **Mc** – *Micromeles alnifolia*, **Cs** – *Cerasus sargentii* and others. In undergrowth: *Corylus*, *Sambucus*, *Crataegus*, *Rosa*, *Aralia*, *Eleutherococcus* aff. *sessiliflorus* and others

Fig. 7. Profile diagram of forest in the low belt of hills: **A** – oak forest with an admixture of hardwood trees: **Q** – *Quercus primorica*, **B** – *Betula* aff. *davurica*, **T** – *Tilia*, **P** – *Populoxylon*, **F** – *Fraxinus*, **At** – *Acer* aff. *tegmentosum*, and others. In undergrowth: *Aralia*, *Eleutherococcus* aff. *sessiliflorus* and others; B – coniferous forest: **Pc** – spruce (*Picea jezoensis*, *Piceoxylon pavlovskiense*, *P. ussuriense*), **Ab** – *Abies* aff. *sachalinensis*, *A. chavchavadzeae*, **Pt** – *Pseudotsugoxylon pavlovskiense*

Fig. 8. Profile diagram of mixed coniferous forest in the upper belt of hills: **Pc** – spruce (*Picea* cf. *bicolor*, *Piceoxylon ussuriense*), **Lx** – *Larix* (*Larix gmelinii*, *Laricioxylon blokhinae*, *L.* aff. *chelebaevae*, *L.* aff. *korfiense*, *L.* aff. *sichotealinense*), **Ab** – *Abies* aff. *sachalinensis*, *A. chavchavadzeae*, **Pn** – *Pinus*, **K** – *Keteleeria zhilinii*, **Ts** – *Tsuga*, **Pt** – *Pseudotsugoxylon pavlovskiense*, **Mb** – *Microbiota decussata*

wetlands and open places or in the disturbed habitats, larches *Larix gmelinii*, *Laricioxylon blokhinae*, *L.* aff. *chelebaevae*, *L.* aff. *korfiense*, and *L.* aff. *sichotealinense* were, perhaps, dominated. Possibly, the coniferous forest; pure larch and spruce forest were also spread there. The rocky tops of the hills or mountains were probably covered by brushwood of *Microbiota decussata* (Fig. 4).

CONCLUSIONS

The Pavlovskii brown coal field located within the area of Pavlovskaya Group of Depressions is, to date, the only source of numerous, well preserved and taxonomically diverse wood remains of Pliocene age from the southern Primory'e Region of the RFE. In total, 221 wood specimens have been identified. The fossil wood material was compared with data on palynological and seed assemblages taken from the literature.

In the Pliocene, the area of Pavlovskaya Group of Depressions is considered to have been a broad river valley, probably forming one of the tributaries of the palaeo-Razdol'naya River. The valley vegetation was represented by forest with a considerable presence of conifers and elms, while the slopes were covered by mixed coniferous-hardwood and coniferous forest.

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