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# The Akchagylian Flora and Vegetation of the Udmurtian Kama River Region

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**Abstract**—A paleobotanical study of Akchagylian deposits exposed by a borehole in the Udmurtian Kama River Region was performed. The characteristics of the vegetation cover of the Early, Middle, and Late Akchagylian are provided. The composition of the fossil flora as revealed by palynological and carpological analyses are described. The significance of paleobotanical studies for the subdivision and correlation of Pliocene deposits is shown.

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*Key words*: Upper Pliocene, Akchagylian Regional Stage, vegetative phases, palynological flora, macroremains, correlation.

## INTRODUCTION

The Akchagylian Regional Stage immediately precedes the Quaternary in the general stratigraphic chart. The lower boundary of the Akchagylian coincides with the Gilbert–Gauss paleomagnetic reversal (3.4 Ma), while the upper boundary is slightly above the Olduvai episode (1.87–1.67 Ma), which corresponds to the base of the Santernian and Upper Villafranchian (*Boundary between…*, 1987).

In the Caspian Region, this regional stage includes deposits of the Akchagylian transgression, whereas in the Black Sea Region, deposits of the Kuyal'nik Basin. In the Volga–Kama Region and southern Fore-Urals, Akchagylian sediments partially or completely fill ancient overdeepened valleys, the Kinel Formation (Goretskii, 1964, 1966). Opinions differ as to the age of the Kinel deposits; some researchers dated them as the Akchagylian (Kirsanov, 1971; Kuznetsova, 1971; Pisareva et al., 1981), whereas others assign to the Akchagylian only the upper horizons of the formation and consider the lower horizons to be no younger than the Cimmerian (Yakhimovich, 1971; Bludorova et al., 1987; Zhidovinov et al., 1987; Danukalova, 1990; Linkina, 2003). Such controversy is often caused by lack of paleobotanical material or, occasionally, is related to different approaches to the interpretation of this material, in particular, different views on the role of relicts in the composition of fossil floras and redeposition (Kuznetsova, 1964, 1971; Ananova, 1971).

Over several decades, P.A. Nikitin, V.I. Baranov, I.M. Pokrovskaya, V.P. Grichuk, Z.P. Gubonina, E.N. Ananova, P.I. Dorofeev, A.A. Chiguryaeva, K.V. Nikolaeva, T.A. Kuznetsova, N.D. Kovalenko, V.K. Nemkova, and others carried out paleobotanical studies of the Kinel deposits of the eastern Russian Plain. However, sections that are characterized by both palynoflora and plant macroremains are rare. Therefore, complex studies of the Udmurtian Kama Region are important not only for the characterization of the Akchagylian Flora, vegetation, and climate, but also for the correlation between continental and marine deposits.

Akchagylian paleogeographic reconstructions are closely related to the substantiation of the lower boundary of the Quaternary. Thus, Zagwijn (1985) believes that this boundary should be placed below its current position in the International Geochronological Chart: in the bottom of the Pretegelen, where a sudden depletion of flora occurs and a cryophilic fauna appears. However, such fluctuations of global cooling are also known within other intervals of the Cenozoic. Therefore, for the determination of the boundary it is important to compare the paleogeographic environment of the Late Pliocene and the subsequent period.

## MATERIALS AND METHODS

This paper describes the paleobotanical study of the Akchagylian deposits that outcrop in southeastern Udmurtia in the Kama River paleovalley (Fig. 1).

Borehole no. 15, which is a reference hole of this region, was drilled in 1979 1.1 km north of the village of Chil'cha, on the slope of the Kyrykmas River valley (left tributary of the Izh River), at 130 m above sea level. Here, Akchagylian deposits of 132.2 m thick fill a deep ancient valley (its bottom is –43 m above sea level), cut into the Permian red beds lacking organic remains. The core samples were described by V.V. Pisareva and P.I. Meshkov. A palynological study of 140 samples of borehole no. 15 was accomplished by

Pisareva. Samples from other boreholes were studied by Pisareva and I.F. Dudnakova. The plant macroremains were determined by P.I. Dorefeev, mollusks by V.M. Motuz, and ostracodes by E.V. Postnikova and N.N. Naidina.

Lithological-facial and paleontological studies of the Kyrykmas River revealed five stages in the development of the paleovalley.

Stage 1 (162–165.7 m of depth) is related to river runoff and alluvium accumulation: sand with clay interlayers and weakly rounded pebbles of flint, sandstone, and Ural jasper.

Stage 2 (106.5–162 m) corresponds to the period when a lake with an unstable hydrology existed: montmorillonite clays and montmorillonite-chlorite clays with banded lamination, pyrite concretions, and clayey siderite inclusions prevail.

During stage 3 (58.0–106.5 m), recommencement of runoff took place and lacustrine-alluvial deposits accumulated (aleurites and sands with clay sublayers and occasional pebbles of black flint).

During stage 4 (42.0–58.0 m), a weakly drained lake developed, in which montmorillonite and montmorillonite-chlorite clays deposited.

At stage 5 (33.5–42.0 m), alluvial conditions were restored.

Since determinations of mollusks and ostracodes (as well as preliminary palynological results) have previously been published (Pisareva et al., 1981), they are not considered in the present paper. These results show that, during most stages of the existence of this water body, it was inhabited by a freshwater fauna, with the species typical for Akchagylian deposits of paleovalleys of the Volga and Kama basins and for Bashkir Fore-Urals. However, the rich and diverse ostracode association from stage 4 contains typical halobionts of the subgenus *Galolimnocythere*. This is supposedly related to an ingression of the Akchagyl Sea.

The results of the paleobotanical study of borehole 15 (near the village of Chil'cha), which are described below, give an insight into the Akchagylian landscapes.

## RESULTS AND DISCUSSION

The palynological data obtained and determinations of plant macroremains (depths 57.0–164.0 m) indicate that, during the Akchagylian Time, the territory under consideration was situated within the forest zone. Here, as in other regions, vegetation cover was repeatedly reorganized because of climatic fluctuations. The palynological diagram (Fig. 2) shows the main components of the spectra and outlines five palynological assemblages, which characterize changes in vegetation phases.

Phase 1 (127.0–165.7 m) corresponds to the development of spruce forests, with *Picea* sect. *Omorica*, various pines (*Pinus* sect. *Eupitys*, *P.* sect. *Cembra*, and *P.* sect. *Strobus*), fir, larch, hemlock, birch (including *Betula* sect. *Costatae* and *Betula* sect. *Fruticosae*); other broad leaved taxa such as oak, elm, and linden were rare. Hydrophilous vegetation with abundant sedges and *Lycopodium inundatum* L. grew in floodplain meadows. Among aquatic plants, various pondweeds grew, including the Pliocene species *Potamogeton boristhenicus* Dorof. The pattern of the vegetation and the composition of fossil flora suggest that this phase had a relatively cool and humid climate.

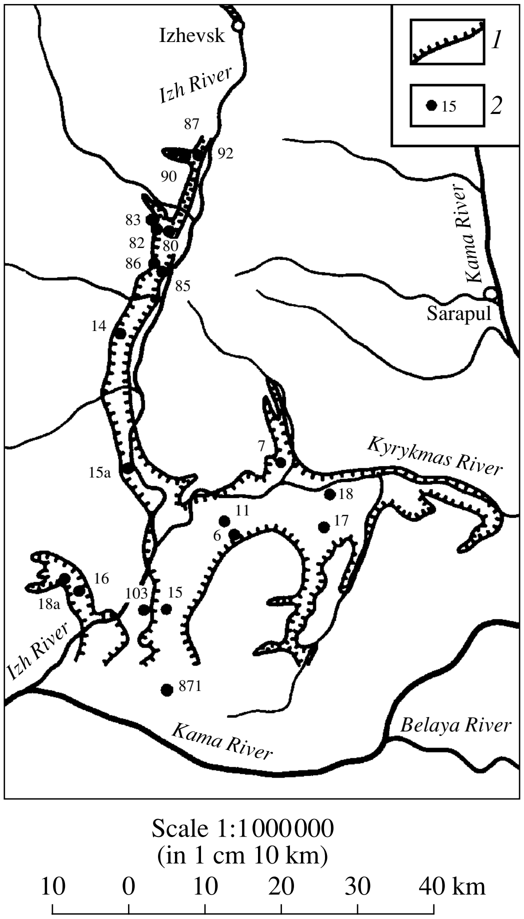

**Fig. 1.** Geographical map of the Udmurtian Kama Region: (*1*) boundary of the Upper Pliocene paleovalley and (*2*) borehole and its number.

Phase 2 (107.0–127.0 m) corresponds to pine forests. Pines, along with spruce and other coniferous species, were components of composite communities with small-leaved and diverse broad-leaved species, including oak, elm, linden, maple, ash, hazelnut, elder, *Euonymus*, and *Daphne* in the understorey. Among the herbs and undershrubs, plants of open landscapes, such as *Artemisia* and members of the Chenopodiaceae, dominated. The climate was probably relatively warm.

Phase 3 (58.0–107.0 m) corresponds to polydominant conifer–broad-leaved forests of the climatic optimum. During this phase, spruce forests prevailed in combination with *Abies*, several species of *Pinus,*

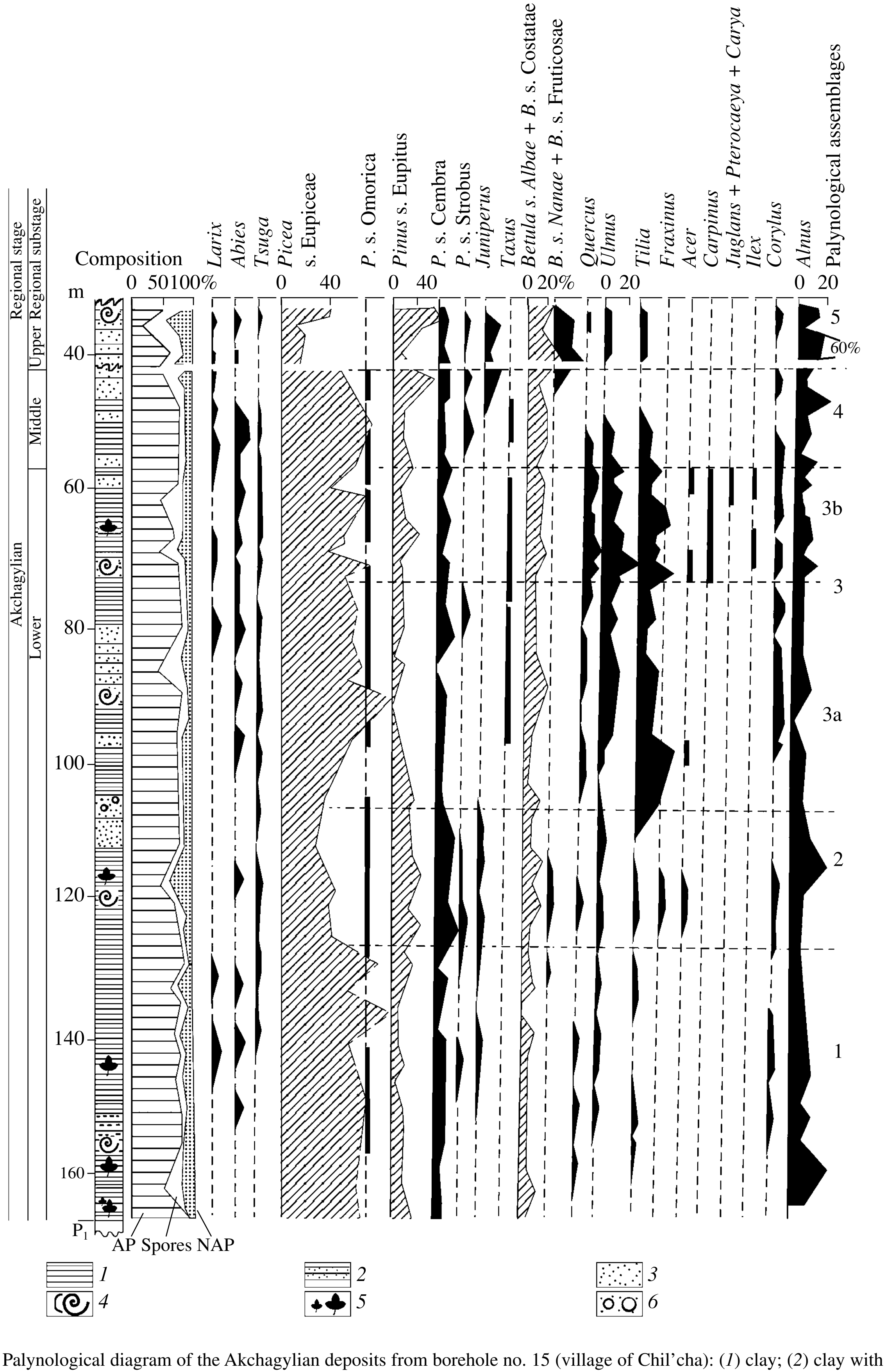

**Fig. 2.** Palynological diagram of the Akchagylian deposits from borehole no. 15 (village of Chil'cha): (*1*) clay; (*2*) clay with sand interbeds; (*3*) sand; (*4*) mollusk shells; (*5*) plant remains; and (*6*) gravel and pebbles.

**Table 1.** Higher plants from the Akchagylian deposits of the Udmurtian Kama River Region

| No. | Index of geographical unit (see Table 2) | Taxon | Carpological remains (*c*), pollen grains (*p*), spores (*s*) |
|---|---|---|---|
| 1 | 2 | 3 | 4 |
| 1 | 7 | *Abies* cf. *firma* S. et Z. | *p* |
| 2 | 4b | *A*. aff. *sibirica* Ledeb. | *p* |
| 3 | 9b | *Acer* cf. *platanoides* L. | *p* |
| 4 | 7 | *Adiantum* sp. | *p* |
| 5 | 7 | *Alnus* aff. *hirsuta* Spach. Turcz. | *p* |
| 6 | 9a | *A*. aff. *glutinosa* Gaertn. | *p* |
| 7 | 5 | *A*. aff. *incana* L. | *p* |
| 8 | 3b | *Athirium* aff. *alpestre* (Hoppe) Ryl. | *s* |
| 9 | 3b | *A*. *filix-femina* L. Roth. | *s* |
| 10 | 4c | *Atriplex patula* L. | *p* |
| 11 | 7 | *Betula* sp. sect. Costatae | *p*, *c* |
| 12 | 7 | *B*. aff. *exilis* Sucacz. | *p* |
| 13 | 4b | *B*. sp. sect. Fruticosae | *p* |
| 14 | 4b | *Betula* sp. sect. Nanae | *p* |
| 15 | 4b | *Betula* aff. *pendula* Roth | *p*, *c* |
| 16 | 4b | *B*. aff. *pubescens* Ehrh. | *p* |
| 17 | 3b | *Botrychium lunaria* L. Sw. | *p* |
| 18 | 4c | *Butomus* cf. *umbellatus* L. | *c* |
| 19 | 6(7) | *Carya* sp. (small grains) | *p* |
| 20 | 8(7) | *Celtis* sp. | *p* |
| 21 | 2 | *Cistopteris fragilis* (L.) Bernh. | *s* |
| 22 | 2 | *Chenopodium album* L. | *p* |
| 23 | 4c | *Ch*. *glaucum* L. | *p* |
| 24 | 4b | *Ch*. *rubrum* L. | *p*, *c* |
| 25 | 3a | *Cornus* sp. | *p* |
| 26 | 9b | *Corylus avellana* L. | *p* |
| 27 | 9a | *Daphne mecereum* L. | *c* |
| 28 | 3c | *Dryopteris filix-mas* L. | *s* |
| 29 | 3a | *Empetrum nigrum* L. | *p* |
| 30 | 4c | *Ephedra* aff. *distachia* L. | *p* |
| 31 | 7 | *Eucommia* sp. | *p* |
| 32 | 4c | *Eurotia ceratoides* (L.) C.A. Mey | *p* |
| 33 | 8 | *Fagus* cf. *orientalis* Lipsky | *p* |
| 34 | 4b | *Frangula alnus* Mill. | *p* |
| 35 | 7 | *Juglans* cf. *cinerea* L. | *p* |
| 36 | 7 | *Keteleeria* sp. | *p* |
| 37 | 4c | *Kochia* aff. *laniflora* (S.G. Gmel) Borb. | *p* |
| 38 | 4c | *K*. aff. *prostrata* (L.) Schrad. | *p* |
| 39 | 4b | *Larix* sp. | *p*, *c* |
| 40 | 3a | *Linnea borealis* L. | *p* |
| 41 | 3c | *Lycopodium annotinum* L. | *s* |
| 42 | 3a | *L*. *clavatum* L. | *s* |
| 43 | 3b | *L*. *complanatum* L. | *s* |

**Table 1.** (Contd.)

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| 44 | 5 | *L. inundatum* L. | s |
| 45 | 2 | *Huperzia selago* L. | *s* |
| 46 | 7 | *Menispermum* sp. | *p* |
| 47 | 4a | *Mentha arvensis* L. | *c* |
| 48 | 4c | *Ophioglossum vulgatum* L. | *s* |
| 49 | 7 | *Osmunda* aff. *cinnamomea* L. | *s* |
| 50 | 7 | *O*. aff. *claytoniana* L. | *s* |
| 51 | 4a | *Picea* sect. Eupicea | *p* |
| 52 | 8(7) | *P*. sect. Omorica | *p*, *c* |
| 53 | 7 | *P*. cf. *schrenkiana* F. et M. | *p* |
| 54 | 4a | *Pinus* sect. Cembra | *p* |
| 55 | 4a | *P*. aff. *sylvestris* L. | *p* |
| 56 | 8(6) | *P*. sect. Strobus | *p* |
| 57 | 4a | *Polycnemum* aff. *arvense* L. | *p* |
| 58 | 9a | *P*. aff. *majus* A. Br. | *p* |
| 59 | 3a | *Polygonum* aff. *bistorta* L. | *p* |
| 60 | 2 | *P*. sp. (ex gr. *P. lapathifolium* L.) | *c* |
| 61 | 9b | *Polypodium* cf. *serratum* (Willd.) Futo | *s* |
| 62 | 3c | *P*. aff. *virginianum* L. | *s* |
| 63 | 1 | *P. vulgare* L. | *s* |
| 64 | 9a | *Prunus fruticosa* Pall. | *c* |
| 65 | 7(8) | *Pterocarya* sp. | *p* |
| 66 | 4b | *Ranunculus acer* L. | *c* |
| 67 | 3c | *Scirpus triqueter* L. | *c* |
| 68 | 6 | *S. torreyi* Oney. | *c* |
| 69 | 1 | *Selaginella helvetica* (L.) Link | *s* |
| 70 | 3b | *S. selaginoides* L. | *s* |
| 71 | 3c | *Stachys palustris* L. | *c* |
| 72 | 9b | *Taxus* aff. *baccata* L. | *p* |
| 73 | 9b | *Thalictrum* aff. *angustifolium* L. | *p* |
| 74 | 9a | *Tilia* aff. *cordata* Mill. | *p* |
| 75 | 7 | *T*. cf. *mandshurica* Rupr. | *p* |
| 76 | 9b | *T*. aff. *platyphyllos* Scop. | *p* |
| 77 | 9b | *T*. aff. *tomentosa* Moench | *p* |
| 78 | 6 | *Tsuga* aff. *canadensis* (L.) Carr. | *p* |
| 79 | 9b | *Ulmus* aff. *carpinifolia* Rupp. ex gr. Suckow (=*foliaceae* Gilib.) | *p* |
| 80 | 9b | *U*. aff.  Pall. | *p* |
| 81 | 7 | *U*. aff. *macrocarpa* Hance (=*propinqua* Koidz.) | *p* |
| 82 | 3a | *Urtica dioica* L. | *c* |
| 83 | 3c | *Vaccinium vitis-idaea* L. | *c* |
| 84 | 7(8) | *Vitis* sp. | *p* |
| 85 | 7 | *Weigela* sp. | *p* |
| 86 | 3b | *Woodsia alpina* (Bolt.) S.F. Gray | *s* |
| 87 | 8(7) | *Zelkova* sp. | *p* |

**Table 1.** (Contd.)

| 1 | 2 | 3 | 4 |
|---|---|---|---|
| | | Hydrophytes and helophytes | |
| 88 | 1 | *Aldrovanda* sp. | *c* |
| 89 | 9b | *Cyperus glomeratus* L. | *c* |
| 90 | 3a | *Cirsium heterophyllum* (L.) Mill. | *c* |
| 91 | 3c | *Euphorbia palustris* (L.) R. Br. | *c* |
| 92 | 3b | *Menyanthes trifoliata* L. | *c* |
| 93 | 1 | *Najas marina* L. | *c* |
| 94 | 3b | *Potamogeton* cf. *obtusifolius* M. et K. | *c* |
| 95 | 4a | *Sagittaria sagittifolia* L. | *c* |
| 96 | 1 | *Salvinia* sp. | *p*, *c* |
| 97 | 3c | *Scirpus maritimus* L. | *c* |
| 98 | 4c | *S. melanospermus* C. A. M. | *c* |
| 99 | 3a | *Utricularia minor* L. | *c* |
| | | Extinct species | |
| 100 | | *Aracispermum jonstrupii* (Hantz) Nikit. | *c* |
| 101 | | *Azolla* sect. *Euazolla* (*A.* cf. *interglacialica* Nikit.) | *c* |
| 102 | | *Caldesia cilindrica* Dorof. | *c* |
| 103 | | *Decodon globosus* (E.M. Reid) Nikit. | *c* |
| 104 | | *Dulichium vespiforme* C. et E.M. Reid | *c* |
| 105 | | *Eleocharis pseudoovata* Dorof. | *c* |
| 106 | | *Epipremnum crassum* C. et E. Reid | *c* |
| 107 | | *Hypericum* ex gr. *coriaceum* Nicit. | *c* |
| 108 | | *H. tertiaerum* Nikit. | *c* |
| 109 | | *Menyanthes pliocenica* Hut-Szaf. | *c* |
| 110 | | *Najas irtyshensis* Dorof. | *c* |
| 111 | | *N. lanceolata* C. et E. M. Reid | *c* |
| 112 | | *N. pliocenica* Dorof. | *c* |
| 113 | | *Pilea pliocenica* Dorof. | *c* |
| 114 | | *Polygonum pliocenicum* Dorof. | *c* |
| 115 | | *Potamogeton* cf. *borysthenicus* Dorof. | *c* |
| 116 | | *P. crispoides* Dorof. | *c* |
| 117 | | *Ranunculus pseudoflammula* Dorof. | *c* |
| 118 | | *Salvinia tuberculata* Nikit. | *c* |
| 119 | | *Scirpus pliocenicus* Szaf. | *c* |
| 120 | | *Selaginella pliocenica* Dorof. | *c* |
| 121 | | *Sparganium noduliferum* C. et E. Reid | *c* |
| 122 | | *Sporites indeterminatae* An. | *c* |
| 123 | | *Swida kineliana* Dorof. | *c* |
| 124 | | *Typha pliocenica* Dorof. | *c* |

*Tsuga, Keteleeria*, and *Taxus*. The most abundant broad-leaved members of the first half of the optimum were linden and elm and, more rarely, oak (palynological assemblage 3a). During the second half of this phase, the role of broad-leaved species first decreased significantly. This was apparently related to a cooling episode. Subsequently, thermophilic elements, including *Zelkova*, *Celtis, Carpinus, Juglans, Pterocarya, Ilex, Morus, Carya*, and *Eucommia*, became widespread. Members of the Myricaceae, wild vine, and the deciduous shrub *Weigela*, which grows in modern forests of the Far East, appeared in the understorey. Ferns

**Table 2.** The composition and relations of geographical elements of the Akchagylian Flora of the Udmurtian Kama River Region

| Geographical unit | Geographical subunit | Number of taxa | Relative abundance of groups of units |
|---|---|---|---|
| 1. Diffuse | | 5 | 9% |
| 2. Hemicosmopolitan | | 4 | |
| 3. Holarctic | (a) panholarctic | 8 | 50% |
| | (b) boreal circumpolar | 8 | |
| | (c) temperate American–Eurasian | 8 | |
| 4. Eurasian | (a) proper Eurasian | 6 | |
| | (b) European–Siberian | 9 | |
| | (c) southern Eurasian | 9 | |
| 5. American-European | | 2 | |
| 6. North American | | 3 | 25% |
| 7. East Asian | | 17 | |
| 8. Balkan-Colchis | | 5 | |
| 9. European | (a) European-West Siberian | 5 | 15% |
| | (b) European-Mediterranean-Caucasian | 10 | |
| Number of extinct species | | 25 | 20% |
| Total | | 124 | |

of the genera *Cystopteris, Adiantum, Osmunda, Dryopteris*, and *Polypodium* were diverse. Among them, *Adiantum* is an indicator of relict Tertiary forests of the Far East, Caucasus, and Central Asia. The palynological data are well complemented with carpological results. *Dulichium vespiforme* C. et E.M. Reid, *Salvinia tuberculata* Nikit., and *Hypericum* ex gr. *noriaceum* Nikit. are inherited from the Miocene flora. Typical Pliocene species are represented by *Potamogeton crispoides* Dorof., *P. boristhenicum* Dorof., *Polygonum pliocenicum* Dorof., *Pilea pliocenica* Dorof., and others. The marsh flora includes *Cyperus glomeratus* L., *Scirpus triqueter* L., and other species that presently grow far to the south of the region studied, in the Black Sea Region, Crimean Peninsula, Caucasus, and western Europe. The subsequent evolution of the vegetation cover was influenced by the cooling.

Phase 4 (42.0–58.0 m) corresponds to the spruce forests of low diversity. Large areas were occupied by green moss / spruce forests, and *Sphagnum* / spruce forests as well as spruce forests with fir, larch, and birch. Limited areas were covered by heathery pine forests. Broad-leaved species, hemlock, and yew were extremely rare. Among conifers, juniper appeared; among deciduous species, *Aatula* aff. *exilis* Sucaz. and *Alnus* aff. *hirsuta* (Spach.) Turcz. appeared. Presently, *Aatula exilis* and *Alnus hirsuta* grow in the swamps of Siberia and the Far East.

Phase 5 corresponds to the degradation of dark coniferous forests and their substitution by pine and birch-dominated communities. *Betula* was represented by both arborescent (sect. *Albae* and *Costatae*) and shrubby (sect. *Fruticosae* and *Nanae*) members. Alder forests grew in wetlands, swamps, and river valleys. Ruderal plants (*Artemisia* and members of the Chenopodiaceae) settled on sandy banks. The climate became unfavorable for broad-leaved species and hemlock, suggested by small and, occasionally, underdeveloped pollen grains.

The data obtained suggest repeated rearrangements of the vegetation cover during the Akchagylian Time. Influenced by cooling periods, the floral composition became poorer and similar to its modern state. During the climatic optimum, a total of 41 tree and shrub genera grew within the area studied. Presently, most of them (including *Eucommia, Keteleeria, Weigela*, and others) occur in North America and eastern Asia or exclusively in eastern Asia. The complete list of the Akchagylian Flora, including species of plakors (flat elevated interfluves), hydrophytes, and helophytes, includes 124 taxa. The taxa are grouped in Table 1 by geographical units and subunits according to the classification of Grichuk (1989). The assignment of each taxon to a particular geographical unit and subunit is marked by an index according to Table 2, which shows a relatively high contribution of exotic taxa to the composition of the flora. The total proportion of North

American, East Asian, Balkan–Colchis taxa is 25%, while the number of extinct species is 20% of the total number of taxa (Table 2). Macroremains of these taxa are most numerous in the deposits of the climatic optimum, which are characterized by palynological assemblage 3.

## CONCLUSIONS

(1) The paleobotanical study has provided a detailed description of the Akchagylian Flora and vegetation of the Udmurtian Kama River Region.

(2) The Akchagylian Flora differs from the Cimmerian Flora in the absence of the Taxodiaceae and many American–East Asian and East Asian elements (Grichuk, 1959, 1989; Zubakov and Borzenkova, 1983; *Climatic and Landscape Changes…*, 1999). The Akchagylian climatic optimum is less prominent than that of the Early Pliocene.

(3) The maximal depletions in forest formations, which were related to cooling episodes, occurred at the very beginning of the Akchagylian and, especially, in the Middle and Late Akchagylian. This second global cooling was more significant. It is traced not only in the Kama River Basin and Bashkir Fore-Urals, but also in many regions of the world (Zubakov, 1990; Akhmetiev, 1991; *Climatic and Landscape Changes…*, 1999). It apparently corresponds to the Pretegelen cooling of Western Europe (Zagwijn, 1985). However, it is incomparable with cooling periods of the Quaternary, which caused the origin and spread of ice sheets, the development of hyperzonal landscapes and a vast cryolithozone, and other paleogeographic events, which separate the Quaternary and Neogene (Velichko, 1973; *Climatic and Landscape Changes…*, 1999).

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