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Postglacial Development of Kazakhstan Pine Forests
Développement postglaciaire des pinèdes au Kazakhstan
Postglaziale Entwicklung von Kiefernwäldern Kasachstans

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Résumé de l'article

Les données palynologiques de quatre stations au Kazakhstan ont permis de reconstituer l'histoire de la végétation depuis 13 000 BP. Au Tardiglaciaire, des pessières claires à Picea obovata ont commencé à occuper les vallées des fleuves et les collines de Kazakhs. Vers 9500 BP la limite méridionale moderne de Picea obovata fut atteinte. Entre 9500-8000 BP les steppes et forêts claires de bouleaux (Betula alba) étaient répandues au sud de la Sibérie occidentale. Des steppes sèches et des semi-déserts constituaient alors la végétation du nord du Kazakhstan. Entre 7000 et 5500 BP, le pin sylvestre (Pinus sylvestris) s'est répandu au Kazakhstan jusqu'à sa limite méridionale actuelle. Depuis 5500 BP, Ie pin a constitué des forêts monospécifiques dans la région de Semipalatinsk-lrtysh et dans la partie septentrionale des collines de Kazakhs. Vers 5000 BP. Ie tilleul (Tilia cordata) fut présent dans la partie septentrionale des collines de Kazakhs. Les aires du chêne (Quercus robur), de l'orme (Ulmus glabra) et de l'aulne (AInus glutinosa) se sont étendues. Entre 4500 et 3600 BP, le climat est devenu plus sec et plus continental. L'aire de peuplement des forêts a diminué. La répartition des arbres aux larges feuilles et de l'aulne ont diminué. Un climat moins continental s'est instauré entre 3300 et 2800/2700 BP. Vers 1500 BP, la limite méridionale actuelle du pin s'est établie.

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POSTGLACIAL DEVELOPMENT OF KAZAKHSTAN PINE FORESTS

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ABSTRACT Fossil pollen records from two peatlands and two lakes in Kazakhstan provide radiocarbon-dated evidence of vegetation change since 13 000 BP. During the Lateglacial open spruce (*Picea obovata*) forests started spreading along river valleys and over the Kazakhstan Foothills. By 9500 BP, the southern limit of spruce approached its present-day position. Between 9500 and 8000 BP steppe and open birch forests formed the vegetation in the south of the West Siberian Lowland. Dry steppe and semidesert were the main types of vegetation in north Kazakhstan. From 7000 to 5500 BP Scots pine (*Pinus sylvestris* L.) expanded in Kazakhstan and reached its present day southern limit. Since 5500 BP pine has formed monospecific forests in the Irtysh-Semipalatinsk area and in the northern part of the Kazakhstan Foothills. By 5000 BP lime (*Tilia cordata*) penetrated into the northern part of the Kazakhstan Foothills. The ranges of oak (*Quercus robur*), elm (*Ulmus glabra*) and black alder (*Alnus glutinosa*) also expanded. The period 4500-3600 BP was characterised by a drier and more continental climate. During that time, the forested area decreased. The ranges of broadleaved trees and alder were reduced. A phase of less continental climate occurred 3300-2800/2700 BP. By 1500 BP the present southern limit of Scots pine was established.

RÉSUMÉ *Développement postglaciaire des pinèdes au Kazakhstan.* Les données palynologiques de quatre stations au Kazakhstan ont permis de reconstituer l'histoire de la végétation depuis 13 000 BP. Au Tardiglaciaire, des pessières claires à *Picea obovata* ont commencé à occuper les vallées des fleuves et les collines de Kazakhs. Vers 9500 BP la limite méridionale moderne de *Picea obovata* fut atteinte. Entre 9500-8000 BP les steppes et forêts claires de bouleaux (*Betula alba)* étaient répandues au sud de la Sibérie occidentale. Des steppes sèches et des semi-déserts constituaient alors la végétation du nord du Kazakhstan. Entre 7000 et 5500 BP, le pin sylvestre (*Pinus sylvestris)* s'est répandu au Kazakhstan jusqu'à sa limite méridionale actuelle. Depuis 5500 BP, le pin a constitué des forêts monospécifiques dans la région de Semipalatinsk-Irtysh et dans la partie septentrionale des collines de Kazakhs. Vers 5000 BP, le tilleul (*Tilia cordata)* fut présent dans la partie septentrionale des collines de Kazakhs. Les aires du chêne (*Quercus robur*), de l'orme (*Ulmus glabra)* et de l'aulne (*Alnus glutinosa)* se sont étendues. Entre 4500 et 3600 BP, le climat est devenu plus sec et plus continental. L'aire de peuplement des forêts a diminué. La répartition des arbres aux larges feuilles et de l'aulne ont diminué. Un climat moins continental s'est instauré entre 3300 et 2800/2700 BP. Vers 1500 BP, la limite méridionale actuelle du pin s'est établie.

ZUSAMMENFASSUNG *Postglaziale Entwicklung von Kiefernwäldern Kasachstans.* Fossile Pollen-Belege von zwei Torfmooren und zwei Seen in Kasachstan liefern mittels Kohlenstoffdatierung den Nachweis einer Vegetationveränderung seit 13 000 v.u.Z. Im Spätglazial begannen offene Fichtenwälder (*Picea obovata*) sich entlang der Flusstäler und über die Gebirgsausläufer Kasachstans auszubreiten. Um 9500 v.u.Z. bildeten Steppen und offene Birkenwälder die Vegetation im Süden des westsibirischen Tieflands. Trockene Steppen und Halbwüsten waren die hauptsächlichen Vegetationstypen in Nord-Kasachstan. Von 7000 bis 5500 v.u.Z. breitete sich die Föhre (*Pinus silvestris L.*) in Kasachstan aus und erreichte ihre heutige südliche Grenze. Seit 5500 v.u.Z. hat die Kiefer monospezifische Wälder im Irtysh-Semipalatinsk-Gebiet und im nördlichen Teil der Gebirgsausläufer Kasachstans gebildet. Um 5000 v.u.Z. drang die Linde (*Tilia cordata*) in den nördlichen Teil der Gebirgsausläufer Kasachstans ein. Die Ausdehnung von Eiche (*Quercus robur*), Ulme (*Ulmus glabra*) und Schwarzerle (*Alnus glutinosa*) nahm auch zu. Die Zeit von 4500 - 3600 v.u.Z. zeichnete sich durch ein trockeneres und mehr kontinentales Klima aus. Während dieser Zeit nahm die bewaldete Zone ab. Das Vorkommen von grossblättrigen Bäumen und Erlen nahm ab. Eine Phase weniger kontinentalen Klimas trat zwischen 3300 - 2800/2700 v.u.Z. ein. Um 1500 v.u.Z. war die gegenwärtige südliche Grenze der Föhre etabliert.

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INTRODUCTION

Until recently no reliable evidence was available for the Holocene climatic and vegetation history of the vast area of Kazakhstan. Studies carried out thus far are sketchy (Aubekerov *et al.*, 1989), and are not supported by radiocarbon measurements. In part, this is due to the general climatic character of the country. Peatlands and fresh water lakes that may provide pollen records occur only rarely and in specific places with locally favourable landform conditions, such as river valleys and at higher elevations in the Kazakhstan Foothills.

During July-August 1990, an expedition of the Laboratory of Evolutionary Geography (Institute of Geography, Russian [USSR] Academy of Sciences), under the leadership of Dr. C.V. Kremenetski, and with the participation of P.E. Tarasov (Post-Graduate student, Moscow State University) carried out investigations of two peat swamps and two fresh water lakes in Kazakhstan (Kremenetski and Tarasov, 1992, 1994; Kremenetski *et al.* 1994, 1997). The palynological data and radiocarbon measurements obtained are the first that enable a reconstruction of the vegetation and climate of that area since the Lateglacial, and the correlation of this evidence with other regions of inner Eurasia.

CASE STUDY

THE STUDY AREA

Kazakhstan is situated south of Russia in the inner part of Asia (Fig. 1). The area of investigation is located along the southern margin of the West Siberian Lowland and in the Kazakhstan Foothills. Elevations in the lowland region range from 100 to 250 m. The highest point of the Kazakhstan Foothills reaches 1400 m. The main bedrock types of the Kazakhstan Foothills are granites. Lowland watersheds are covered by a layer of Quaternary sediments, typically loess-like loams. The area is located within the continental steppe part of the western Siberian temperate climate belt, with cold winters, hot summers and a low amount of precipitation (rainfall in summer and snowfall in winter). Areas with greater amounts of rainfall are restricted to elevated areas of the Kazakhstan Foothills (Table I).

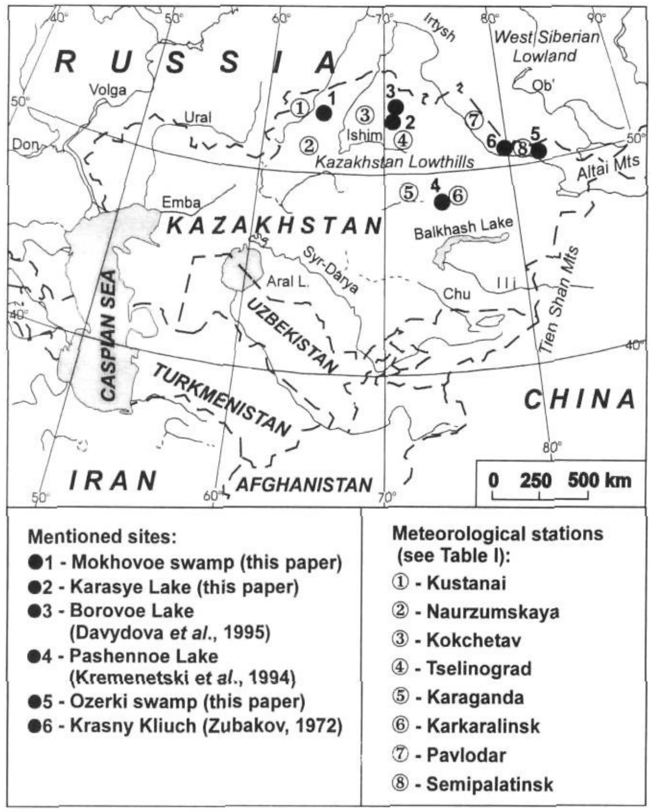

FIGURE 1. Location of the studied and mentioned sites.
Localisation des sections étudiées et signalées.

The vegetation cover of the Kazakhstan varies from birch-poplar forest-steppe in the most northern parts to dry deserts in the southern part (Fig. 2). The present-day vegetation includes southern margin of scots pine *Pinus sylvestris* L. (Fig. 3). Insular scots pine forests grow in the steppe belt of the Kazakhstan and in neighbour regions of Russia within the river valleys, and on granite outcrops in the Kazakhstan Foothills (Gribanov, 1960; Gorchakovski, 1987). The southern limit of *Pinus sylvestris* L. in Kazakhstan is determined by high summer temperature and low precipitation.

TABLE I

Present (1930-1960) climatic characteristics of several meteorological stations in the Kazakhstan

Sites	Lat. N	Long. E	Altitude (m)	Mean temperature °C January	Mean temperature °C July	Mean annual precipitation (mm)
1. Kustanai	53°13'	63°37'	171	−17.8	+20.4	280
2. Naurzumskaya	51°30'	64°31'	130	−18.2	+20.4	250
3. Kokchetav	53°17'	69°21'	229	−16.2	+19.9	285
4. Tselinograd	51°08'	71°25'	347	−17.6	+20.4	302
5. Karaganda	49°48'	73°08'	555	−15.9	+20.6	315
6. Karkaralinsk	49°25'	75°32'	831	−14.7	+18.7	300
7. Pavlodar	52°17'	76°57'	146	−17.8	+21.4	250
8. Semipalatinsk	50°21'	80°15'	206	−16.2	+22.1	275

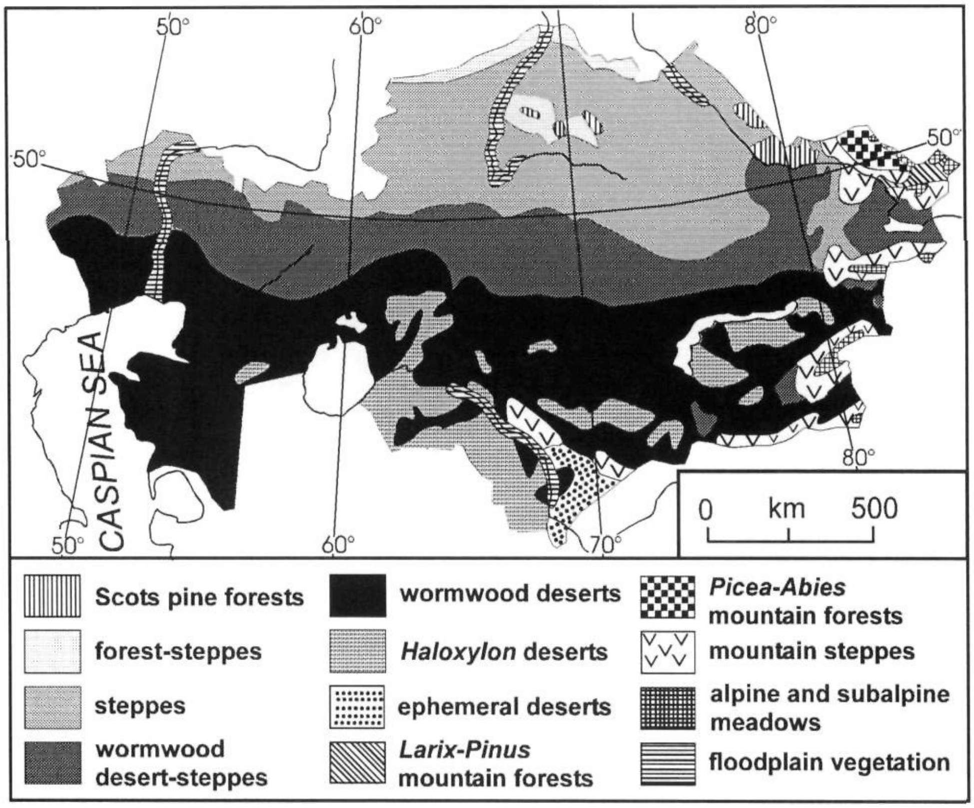

FIGURE 2. Modern vegetation belts of the Kazakhstan (after Physico-geographic World Atlas, 1964).

La végétation actuelle du Kazakhstan (d'après le Physico-geographic World Atlas, 1964).

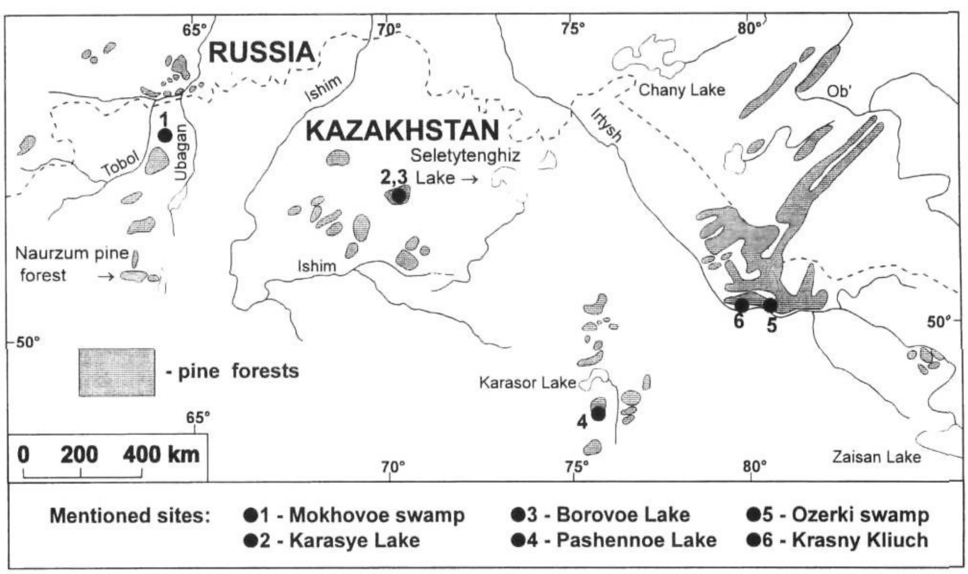

FIGURE 3. Distribution of Scots pine (*Pinus sylvestris* L.) forests in the steppe belt of Kazakhstan and neighbouring regions of Russia (after Gribanov, 1960 with modifications).

*La répartition des forêts de pin sylvestre (*Pinus sylvestris *L.) dans les steppes du Kazakhstan et dans les régions voisines de la Russie (modifié d'après Gribanov, 1960).*

METHODS

Two lakes and two peatlands were cored with a Russian sediment sampler. Conventional radiocarbon measurements of whole core segments have been carried out in the Radiocarbon Laboratory of the Institute of Geography, Russian Academy of Sciences (Dr. Cherkinsky) and in the Radiocarbon Laboratory of Moscow State University, Geographical Department (Dr. O.B. Parunin, index MGU). The measurement of samples from Mokhovoe (TO-3027) and Ozerki (TO-3026) has been obtained on the AMS installation at the Isotrace Laboratory, the University of Toronto, Canada (Table II). There are no local sources of radiocarbon sample contamination by "dead carbon" so the normal procedure to remove carbonate with hydrochloric acid was used under treatment of radiocarbon samples.

Standard methods (Faegri *et al.*, 1989) were used for the preparation of samples for pollen analysis and for pollen counting. One gram of sediment was processed. Carbonates

TABLE II

Radiocarbon dates

Depth (cm)	Lab No.	Material dated	Age BP
Ozerki swamp:			
15-25	IGRAS-1442*	Humic acids	3915±80
40-50	MGU-1318	Humic acids	1470±60
90-100	MGU-1319	Humic acids	3920±160
115-125	IGRAS-1443	Humic acids	5774±131
215-225	IGRAS-1445	Humic acids	6154±151
265-275	IGRAS-1446	Humic acids	7229±138
315-325	IGRAS-1447	Humic acids	7290±142
365-375	IGRAS-1448	Humic acids	8513±161
390-400	MGU-1320	Humic acids	9280±380
430-450	TO-3026	Humic acids	11,710±90
Karasie Lake**:			
190-200	IGRAS-1197	Humic acids	779±122
240-250	IGRAS-1196	Humic acids	1368±125
290-300	IGRAS-1195	Humic acids	2553±122
340-350	IGRAS-1194*	Humic acids	2260±170
365-375	IGRAS-1276	Humic acids	3250±260
390-400	IGRAS-1193*	Humic acids	3150±210
440-450	IGRAS-1192	Humic acids	3590±250
465-475	IGRAS-1275	Humic acids	4610±220
490-500	IGRAS-1191	Humic acids	5280±120
Mokhovoe swamp:			
40-50	MGU-1312***	Peat	1,02% ^{14}C
90-100	MGU-1311	Peat	1680±80
140-150	MGU-1315	Peat	1750±310
190-200	MGU-1314	Peat	1780±140
240-250	MGU-1313	Peat	2760±130
280-300	TO-3027	Humic acids	5100±60

MGU – Moscow State University Radiocarbon Laboratory, conventional dates
IGRAS – Institute of Geography, Moscow, Radiocarbon Laboratory, conventional dates
TO – Toronto Isotrace Radiocarbon Laboratory, AMS dates
All dates are $\delta^{13}C$ corrected.
* Omitted from Figure 9.
** Depth from the surface of the lake. Water depth : 160 cm.
*** The measured activity is higher than in the etalon ^{14}C sample (the carbon cycle is open)

were removed with hydrochloric acid. Heavy liquid fractionation was used to remove mineral matter. Glycerine was used as a mounting medium. A minimum count of 300 pollen grains was done to provide valid percentage calculations (Maher, 1972). Reference collections of the Institute of Geography and of the Geographical Department of Moscow University were used for pollen identifications. The default pollen sum (all AP+NAP+Spores) in the computer program Tilia was used to calculate pollen sums and pollen percentages (Grimm, 1992). Zonation of the pollen diagrams was established using the CONISS procedure of the TILIA program (Grimm, 1987). Raw count data are available through the NAPD database in Boulder, Colorado.

The modern flora of Kazakhstan includes Scots pine (*Pinus sylvestris* L.), so the *Pinus* subgenus Diploxylon identified in the pollen spectra is assumed to be from *Pinus sylvestris* pollen. Pollen grains of *Pinus* subgenus Haploxylon identified in the Ozerki core are assumed to be from *Pinus sibirica*, which is currently found in west and south Siberia. There are no other pines in that part of Siberia today.

In the lower part of the Ozerki core pollen grains of the shrub birches *Betula fruticosa* and *Betula nana* were identified. Pollen grains of shrub birch species are much smaller than pollen grains of the tree species (*Betula* sect. *Alba*). *Betula nana* pollen grain was identified using reference collection and morphological criteria (Terasmäe, 1951; Birks, 1968). *Alnus* pollen identified in the bottom part of the Ozerki core is interpreted as belonging to shrub alder *Alnus* (*Alnaster*) *rotundifolia*, which currently grows in high mountains in the Altai area. In all other cases *Alnus* pollen probably belongs to *Alnus glutinosa* Gaertn., the only alder species in Kazakhstan. The ranges of other alder species are remote from the study area and their pollen is unlikely to occur in the sampled core. Plant nomenclature follows Czerepanov (1995).

Peat stratigraphy was described by V.A. Georgieva (Russian Geological Survey). For macrofossil identifications peat samples were seived through a 0.25 mm sieve. All material greater than 0.25 mm was examined. Mainly roots, stem and leaf fragments were identified. Seeds were relatively rare. Molluscs were sieved from lake sediment samples using a 0.5 mm seive. Molluscs were identified by Dr. P.V. Matekin, Moscow State University.

OZERKI SWAMP (50° 25' N; 80° 28' E)

Site location

Ozerki swamp is located in the Irtish River valley (5 on Fig. 1) and is the most easterly of the sites studied. At this locale the floodplain of the Irtysh River, 1.5 m high and up to 100 m wide, gradually transforms into the first terrace, its width varying from 3 to 5 km and the altitude being 3-4 m above the level of the floodplain. Former small, narrow ox-bow lakes, often transformed into peat-swamps, are visible in the rear part of this terrace, at the base of the second terrace. The second terrace, formed predominantly by sandy and silty deposits, is usually 4-6 m higher than the first one. A narrow strip of peat-swamps is located at the terrace margin, close to the base of the third sandy terrace. These swamps have been studied by the botanist A.A. Smirensky (1946,1951). The surface of the uppermost terrace is 3-6 m higher than level of the second one (Fig. 4).

The floodplain and the two lower terraces are covered with meadows and birch-poplar forests on wetter habitats. Scots pine forest grows on the surface of the third terrace. Watersheds on the left side of the Irtish valley are dominated by steppes, now mostly transformed into pastures and arable land. The Ozerki peat-swamp at the back of the second terrace is the largest and deepest one in the entire Semipalatinsk-Irtysh area (see Fig. 4).

Coring was carried out in the area of the greatest thickness of peat. The following stratigraphy was established: 0-240 cm – eutrophic reed peat (see Table III); 240-410 cm – diatom gyttja, darkish in colour, sandy below 3.0 m, with

FIGURE 4. Location map of the Ozerki peatland.

Carte de localisation de la tourbière d'Ozerki.

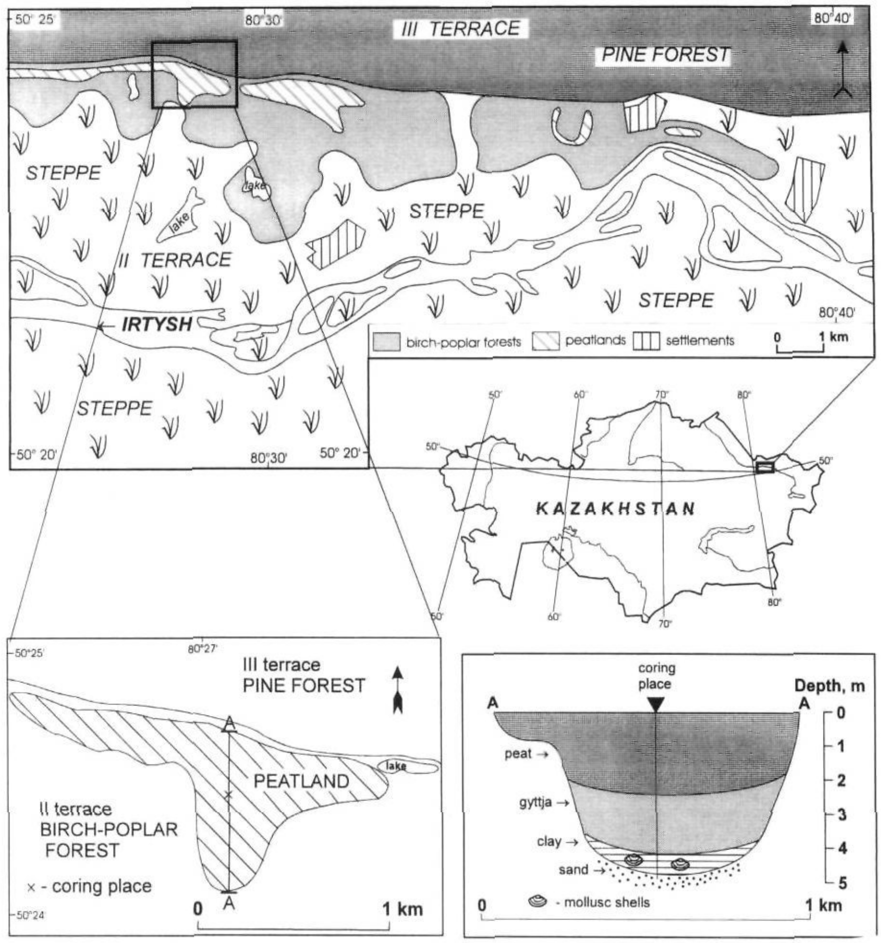

TABLE III

The botanical composition of peat in Ozerki peatland

Depth (cm)	Description	Depth (cm)	Description
25	*Phragmites australis* (Cav.) Trin. ex Steud. - 95% *Carex rostrata* Stokes - 5% *Betula* sp. - +	150	*Phragmites australis* (Cav.) Trin. ex Steud. - 95% *Scirpus lacustris* L. - 5% *Betula* sp. - +
50	*Phragmites australis*(Cav.) Trin. ex Steud. - 85% *Carex rostrata* Stokes - 5% *C. caespitosa* L. - 5% *Scirpus lacustris* L. - 5%	175	*Phragmites australis*(Cav.) Trin. ex Steud. - 90% *Scirpus lacustris* L. - 5% *Menyanthes trifoliata* L. - 5% *Carex elata* All. - +
75	*Phragmites australis* (Cav.) Trin. ex Steud. - 95% *Carex rostrata* Stokes - + *C. caespitosa* L. - + *Scirpus lacustris* L. - 5% *Betula* sp. - +	200	*Phragmites australis* (Cav.) Trin. ex Steud. - 95% *Scirpus lacustris* L. - 5% *Betula* sp. - +
100	*Phragmites australis* (Cav.) Trin. ex Steud. Steud. - 95% *Carex rostrata* Stokes - + *C. appropinquata* Schum. - 5% *Betula sp.* - +	225	*Phragmites australis* (Cav.) Trin. ex Steud. - 90% *Scirpus lacustris* L. - 5% *Betula* sp. - 5%
125	*Phragmites australis* (Cav.) Trin. ex Steud. - 95% *Scirpus lacustris* L. - + *Menyanthes trifoliata* L. - 5% *Betula sp.* - +	250	*Phragmites australis* (Cav.) Trin. ex Steud. - + *Menyanthes trifoliata* L. - + *Betula sp.* - + (gyttja)

inclusions of plant remains; 410-470 cm – sandy clay, darkish in colour, with inclusions of plant remains and shells of molluscs *Pisidium* (*Eupisidium*) *amnicum* Müller, *Planorbis planorbis* L., *Radix lagotis* Schrank. Below 445 cm colour is yellowish; 470-475 cm (minimum thickness) – yellow fine-grained sand.

Ozerki-Lake was formed in a depression of an ancient oxbow. Age-depth relationships, using available ^{14}C dates, shows that sedimentation rates were considerably greater in the diatom gyttja and the base of the reed peat (Fig. 5 and *Table II*).

Results of pollen analysis

The analysis of surface samples in eastern Kazakhstan has shown (Chupina, 1969; Chalykhian, 1976) that pollen produced by mountain forests in the Altai and Tien Shan Mountains is not encountered in the Kazakhstan plains, mainly due to the prevailing westerly winds. Hence in interpreting the pollen records of the Ozerki and Pashennoe sites, one may reasonably suggest that we are dealing with regionally produced pollen. We assume therefore that observed changes in the pollen content reflect local modifications in the vegetation, which then may reflect changes in climate. The uppermost sample of the diagram is the surface sample.

The pollen stratigraphy of the swamp was divided into six pollen assemblage zones (Fig. 6). Polypodiaceae spores dominate the upper part of the diagram. To eliminate the effect of Polypodiaceae domination and to facilitate the reconstruction of the regional vegetation, an additional pollen diagram, which includes only terrestrial arboreal and non-arboreal pollen, was made (Fig. 7).

The pollen spectra from the bottom of the lower unit of the old lake sandy clay forms pollen zone 1 (the percetages are based on Fig. 6). Non arboreal comprises 60-80% of the total assemblage, with the arboreal pollen making up about 10%, the rest consisting of fern (Polypodiaceae) spores.

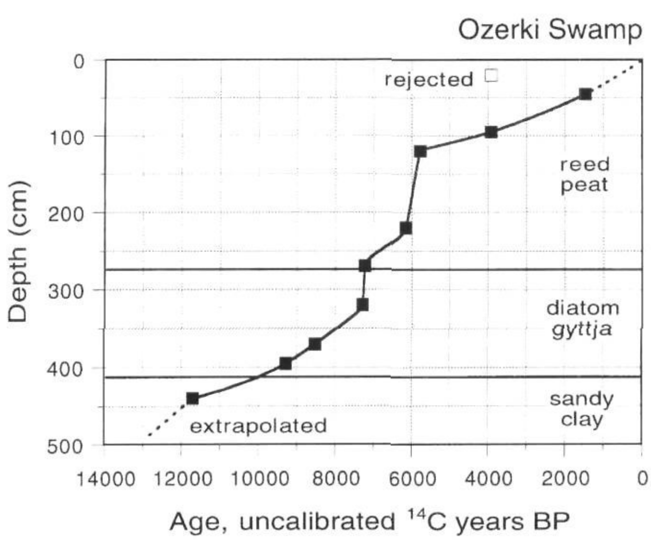

FIGURE 5. Sedimentation rate in the Ozerki swamp.
La vitesse de sédimentation à la tourbière d'Ozerki.

Amongst the arboreal pollen, birch predominates (5-7% of the total pollen sum). There is also *Picea* pollen. Single pollen grains of *Pinus sylvestris*, *P. sibirica*, *Salix*, shrub alder (*Alnus fruticosa*) and shrub birch occur in that zone. Pollen of sea buckthorn (*Hippophäe rhamnoides*) (up to 7% of total pollen) also occurs. Chenopodiaceae is dominant among the herbs (up to 48%), with *Artemisia* being second in importance (up to 26%). Poaceae are present in considerable quantities (up to 7%), together with Compositae and Brassicaceae. Few pollen grains of aquatic plants (*Sparganium* and *Myriophyllum*) have been identified.

Pollen zone 2 has been distinguished in the upper part of lake sandy clay unit and covers the time span of 12,000-9500 BP. An increased importance of pollen of the aquatic *Myriophyllum* is apparent. Pollen of *Picea* (up to 3.6%) and sea buckthorn (3-4%) is identified. Single pollen grains of honeysuckle (*Lonicera*) is present. Amongst the herbs, there is a decrease in the amount of Chenopodiaceae (up to 20-25%), accompanied by an increase in pollen from *Artemisia* (up to 40%) and Poaceae (up to 20%). The predominance of *Artemisia* over Chenopodiaceae attained at this level is equally preserved in the upper parts of the whole sequence. Among the aquatic plants, *Myriophyllum* is the most common; other plants (*e.g. Typha*) were represented by only a few grains.

Judging from radiocarbon measurements, the most substantial change in the regional vegetation and depositional environment occurred at about 9500 BP, at the time of the initial formation of diatom gyttja in the lake. Pollen zone 3 (9500-8000 BP), identified in slowly accumulating lake deposits, shows no dramatic changes in the abundances of the main groups of pollen and spores. The most obvious distinction is the decrease in the content of *Picea* and *Hippophae rhamnoides* pollen. The percentage of the aquatic pollen decreased in the upper part of the zone; these no longer play a significant role in the pollen spectra. The disappearance of the pollen of *Picea*, *Hippophae rhamnoides* and shrub birch mark the upper limit of this zone. Buckthorn (*Rhamnus* sp.) pollen occurs in small amounts. The percentage of Poaceae increases up to 30% of the total pollen sum. As in the previous zones, Polypodiaceae remain dominant among the spores.

Pollen zone 4 has an estimated age of 8000-6500 BP. At about 7500-7000 BP there is a sharp increase in the frequencies of tree *Betula* pollen to 60% (Fig. 6), and pollen of *Salix* is present, but pollen of other trees is sporadic. There are no major changes in the herb pollen content although the abundance of *Artemisia* pollen decreases, while Poaceae pollen increases. A sharp increase in Polypodiaceae spores occurs in the upper part of zone 4 and affects the percentage values of all taxa. When we consider separately terrestrial pollen (Fig. 7), it is evident that there are no major changes in the terrestrial pollen in the upper part of the zone 4. Pollen of aquatic plants is rare. In the upper part of the zone *Typha* pollen curve rises.

Pollen zone 5 has an estimated age of 6500-5500 BP. The content of arboreal and herb pollen is minimal, and Polypodiaceae spores dominate. *Pinus* and Cyperaceae pollen reappear in upper part of the zone 5. Pollen of *Hippophae*

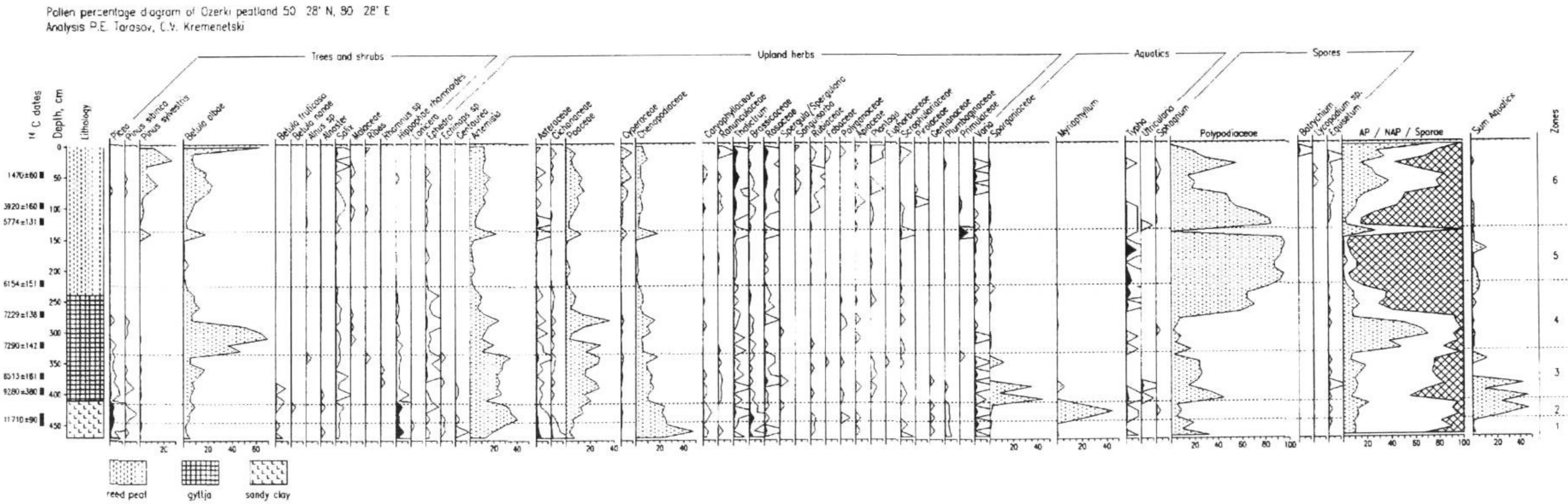

FIGURE 6. Pollen percentage diagram of the Ozerki peat swamp. (Analysis C.V. Kremenetski and P.E. Tarasov). Open curves represent 10x exaggeration.

Diagramme des pourcentages polliniques de la tourbière d'Ozerki. (Analyse de C.V. Kremenetski et P.E. Tarasov.) Les courbes ouvertes présentent une exagération de 10x.

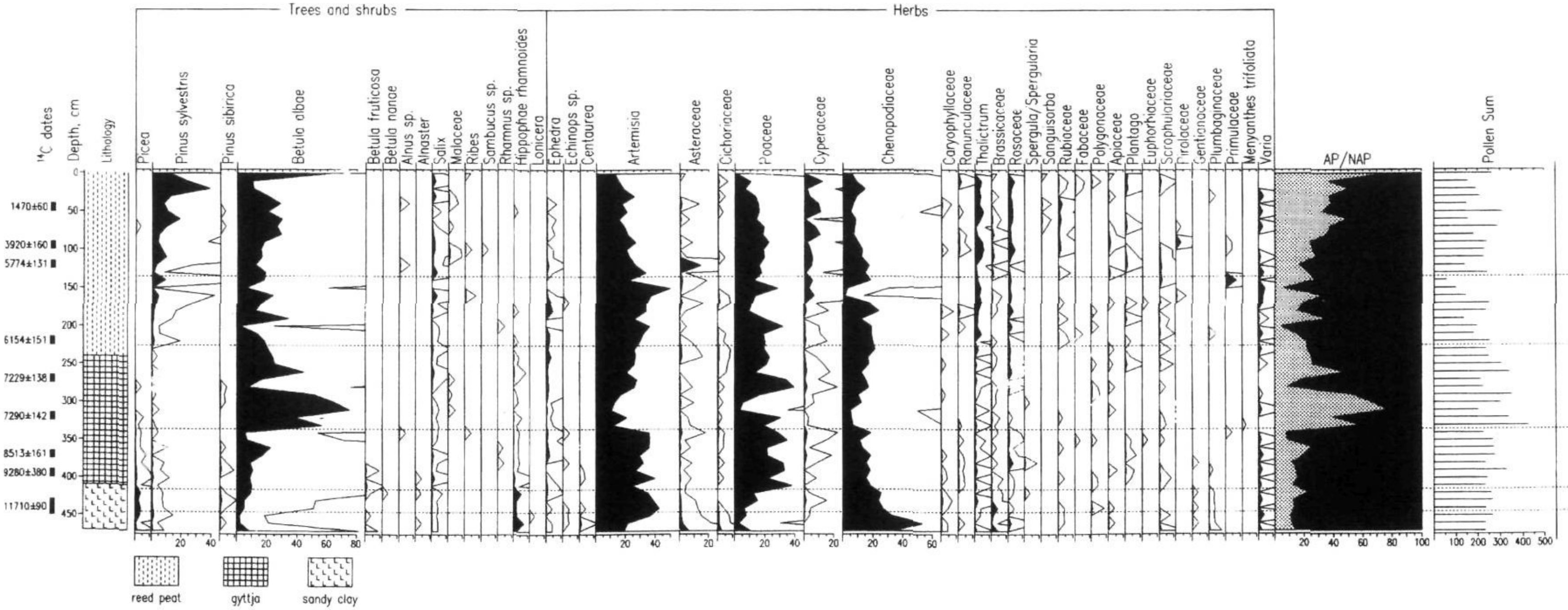

FIGURE 7. Selected terrestrial pollen percentage diagram (AP + NAP) of the Ozerki peat swamp. Open curves represent 10x exaggeration.

Diagramme des pourcentages polliniques de taxons terricoles choisis (AP + NAP) de la tourbière d'Ozerki. Les courbes ouvertes présentent une exagération de 10x.

is sporadic. High *Typha* pollen values dominate the aquatic record. That reflects increasing terrestrialization of the swamp. When we consider the terrestrial pollen (Fig. 7) we can see that without the effect of a sharp rise in the Polypodiaceae percentage no major changes in the terrestrial pollen occurred. We can mention a slight increase in the *Pinus* pollen percentage.

In the pollen zone 6, covering the last 5500 years, both the arboreal and non-arboreal pollen increase and spores decrease. *Pinus* and tree *Betula* pollen became a significant component of the assemblage. The shape of pollen curves of terrestrial plants (Fig. 7) is similar to that in Figure 6. That suggests the decreased significance of the Polypodiaceae factor.

Vegetation reconstruction

Extrapolating results of the radiocarbon measurement of a sample from the upper part of the lake sandy clay unit (Figs. 6 and 7; Table II), one may conclude that the accumulation of these deposits started *ca* 13,000 BP. Sedimentation rate was very low (Fig. 5). At that time, which corresponds to pollen zone 1, dry grass-wormwood steppe and semi-desert were the prevailing types of vegetation in the Irtish-Semipalatinsk area. Chenopodiaceae-dominated communities were predominant on saline and disturbed soils. Arboreal vegetation consisted of scattered birch forests effectively restricted to the Irtish valley, with spruce occasionally growing on south-facing valley slopes. Shrub birch, shrub alder and willow grew along the waterways, with sea buckthorn occupying disturbed slopes.

A milder climate marked the end of the Late Glacial and beginning of the Holocene transition (12,000-9500 BP). Grass-wormwood dry steppe communities remained dominant in the Irtish valley and its watershed, while the decline in the abundance of Chenopodiaceae resulted from the reduction aridity and reduced area of saline soils. Open spruce forests with birch spread along the Irtish balley. Sea buckthorn remained in considerable quantities on slopes. Shrub birch and shrub alder also occurred. The climate at that time was considerably colder than present. Both summer and winter temperatures were lower than modern values. This suggestion, based on the pollen records, is further substantiated by the character of the lacustrine sediments, poor in organic matter. These deposits contain molluscs (*Pisidium* [*Eupisidium*] *amnicum* Müller, *Planorbis planorbis* L., *Radix lagotis* Schrank) belonging to Panholarctic species, indicative of stagnant water and/or slow currents, such as *Radix lagotis*, a derivative of *Radix auricularia*, characteristic of an unfavourable environment for the mollusc growth (Zhadin, 1952) (see Fig. 4).

Coniferous trees disappeared from the Irtish-Semipalatinsk area following 9500 BP. Against a background of predominantly dry steppe, open birch forests with willow survived in the wetter habitats. *Typha* grew along lake. The observed changes in the vegetation probably resulted from a regional warming of climate, accompanied by slightly reduced rainfall. Diatom gyttja sedimentation started in the Ozerki Lake (Fig. 4). Sedimentation rate slightly increased (Fig. 5), suggesting an increase in the productivity of the Ozerki Lake.

Between 8000-6000 BP birch forests grew on a sandy terrace and in the Irtish floodplain. Dry steppes covered the watersheds. Between 7500-7000 BP the sedimentation rate in the Ozerki Lake sharply increased, suggesting increased lake productivity. The lake was transformed around 6500 BP into an eutrophic reed peat swamp. Sedges and ferns also contributed to the vegetation cover.

West from Semipalatinsk City in the Irtysh River valley at Krasny Kliuch (50°31'N; 80°05' E) is a 30 cm peat layer buried under sands of 3-d Irtysh River terrace (6 on Fig. 1). In that peat layer wood of *Pinus* and *Betula* was dated to 6290±100 (LG-40) (Zubakov, 1972). These data suggest that pine reached the Irtish-Semipalatinsk area by 6300-6200 BP, initially participating in the composition of forests on the surface of the third, sandy river terrace, and later, at about 5500 BP forming predominantly pure pine forests on the same terrace. Since that time, the vegetation in this area gradually acquired its present-day aspect.

Radiocarbon dates suggest a hiatus between 5500-4000 BP. Peat layers might have been lost after fire, which could be caused by temporary drying up of upper part of the swamp. Small charcoals are recorded in the pollen slides at that level.

KARASYE LAKE (53° 02' N; 70° 13' E)

Site location

Karasye fresh water lake lies in the Kokchetav or Borovoe Mountains, an intrusive granite massif, reaching an altitude of 947 m above sea level, in the northern part of the Kazakhstan hills (2 on Fig. 1). These mountains, due to favourable edaphic conditions and a wetter climate, are covered by pine (*Pinus sylvestris* L.) forests with an admixture of birch. The surrounding area is covered by steppes and forests of birch and poplar (Fig. 8). The climate of the Borovoe massif is less continental than in the neighbouring steppes (see Table IV). Several fresh-water lakes occur in the area of pine forests (see Fig. 8) due to favourable conditions of greater precipitation. Some of these lakes have been investigated, but with inadequate radiocarbon dating (Davydova *et al.*, 1995). Tarasov (1991) studied the pollen sequence of Kotyrkol swamp (Fig. 8).

Karasye Lake, selected for our case study, is situated in the middle part of Borovoe massif, which reaches 700 m a.s.l., within an intermountain depression at an altitude of 435 m. The size of the oval-shaped lake is 20 ha. In the moistest seasons the lake drains over the granite threshold into the neighbouring small intermountain depression of Maloe Karasye Lake. Such was the situation in the wet summer 1990. The mean depth of the water in the lake is 1.3-1.6 m. Pine forests are spread on the surrounding hills, with birch, willow and aspen growing close to the lake. Karasye Lake was visited and cored by P.E. Tarasov in 1989, but no samples for radiocarbon dating were collected then.

New coring was conducted from a boat in the same part of the lake as in 1989. Under 160 cm of water, a 350 cm core of brown-greyish diatom gyttja was recovered. The bedrock is granite. Figure 9 shows the pattern of change in sedimentation rate of the lake, established by radiocarbon dating

TABLE IV

Present (1930-1960) climatic characteristics of meteorological stations in Kokchetav and in Borovoe region

Sites	Lat.	Long.	Altitude	Mean temperature ° C		Mean annual
	N	E	(m)	January	July	precipitation (mm)
1. Borovoe - kurort	53°05'	70°18'	318	−14.7	+19.8	380
2. Schuchinsk	52°57'	70°13'	384	−16.6	+19.0	306
3. Borovoe - forest tekhnikum	52°58'	70°17'	356	−16.3	+19.2	390
4. Kokchetav	53°17'	69°21'	229	−16.2	+19.9	285

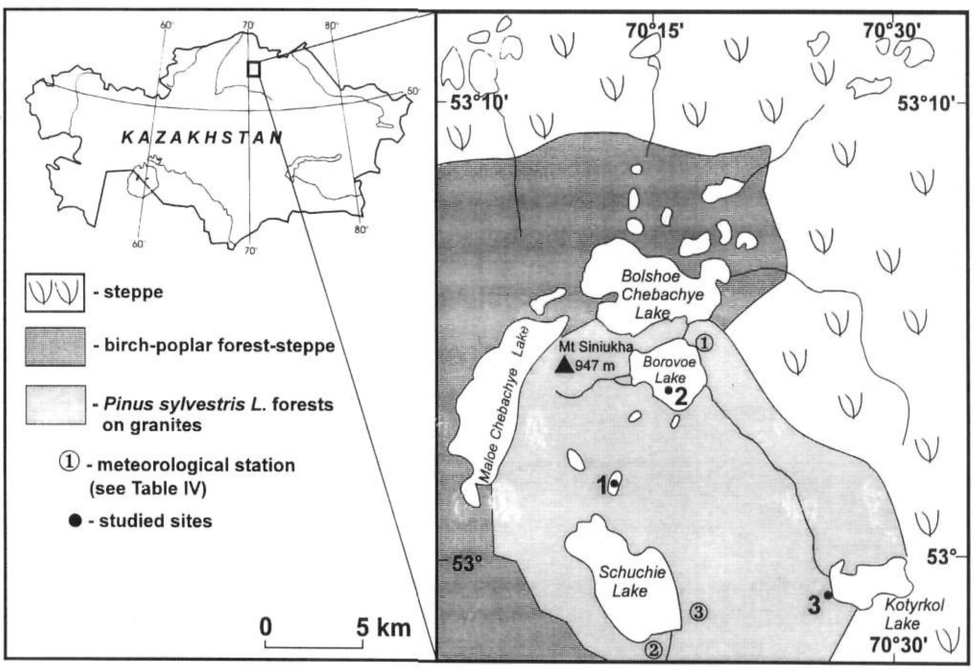

FIGURE 8. Location map of the Borovoe massif area. Location of the studied sites: 1- Karasye Lake 53° 02' N; 70° 13' E; 2- Borovoe Lake 53° 04' N; 70° 17' E (Berdovskaya, 1990; Davydova *et al.*, 1995); 3 - Kotyrkol swamp 52° 58' N; 70° 23' E (Tarasov, 1991).

Carte de localisation du massif de Borovoe. Localisation des sites étudiées: 1- lac Karasye 53° 02' N; 70° 13' E; 2- lac Borovoe 53° 04' N; 70° 17' E (Berdovskaya, 1990; Davydova et al.*, 1995); 3- tourbière de Kotyrkol 52° 58' N; 70° 23' E (Tarasov, 1991).*

(Table II). Dates IGRAS-1193 and IGRAS-1194 are considered too young and were not taken into consideration for interpreting results of investigation. The curve of sedimentation rate in Karasye Lake (Fig. 9) suggests that higher rate of sedimentation occurred *ca.* 3500-2500 BP. Sedimentation rate also slightly increased within 1300-800 BP. Sedimentation rate was slow within 4500-3500 BP, 2500-1300 BP and after 800 BP.

Results of pollen analysis

The pollen stratigraphy of the lake was divided into three pollen assemblage zones (Fig. 10). The pollen stratigraphy of the lake is homogenous. Arboreal pollen dominates the pollen spectra (60-70%). Birch and pine pollen dominate among arboreal pollen. The ratio of these two taxa enables us to distinguish three pollen assemblage zones. In lower pollen zone 1 birch pollen dominates. In the middle pollen zone 2 pine pollen dominates and alder pollen is present (up to 2-3%). In the upper pollen zone 3 a small increase in birch pollen content is registered. A small amount of pollen of broad leaved trees occurs throughout.

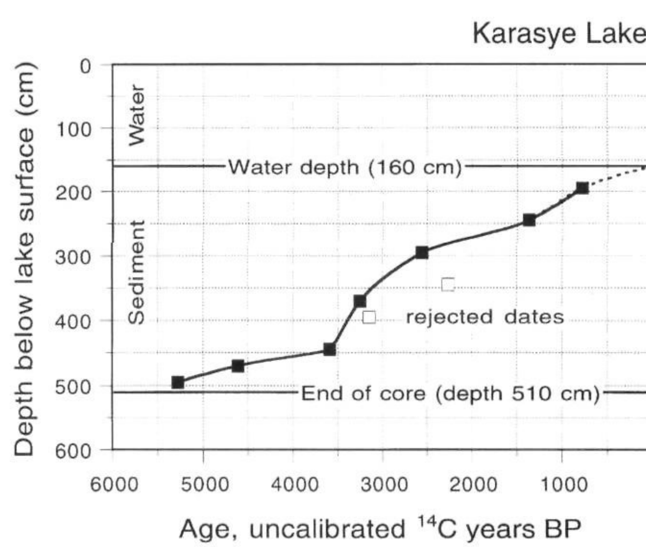

FIGURE 9. Sedimentation rate in Karasye Lake.

Taux d'accumulation sédimentaire au lac Karasye.

Among herbs, pollen of *Artemisia* dominates. Pollen of Chenopodiaceae, Poaceae, Ranunculaceae and Rosaceae is present in significant amounts.

Vegetation reconstruction

Our data and results of other investigators enable a reconstruction of the history of the Borovoe massif vegetation during the entire Holocene. A pollen diagram from Borovoe Lake (53° 04' N; 70° 17' E) (Berdovskaya, 1990; Davydova *et al.*, 1995) suggests that in the early Holocene birch forests and steppes grew in Borovoe massif. A near-basal sample from the core of the Karasye Lake recovered in 1970's provided a radiocarbon age of *ca*. 7000 BP and *Pinus* pollen was present in considerable amounts (Davydova *et al.*, 1995). It allows us to conclude that pine *Pinus sylvestris* L. penetrated in the Borovoe massif area soon after 7000 BP. Basing upon the present pine ecology in the area we can suggest that monospecific pine forests were formed in that area *ca* 5300/5200 BP. Since that time the general structure of regional vegetation has remained similar to present vegetation.

Ca 5000 BP lime (*Tilia cordata* Mill.) penetrated the Borovoe massif and persisted there up to 800 BP. Since then only pine and birch forests with poplar, willow have grown in Borovoe massif. Poplar is a very common component of birch forests in Kazakhstan and south west Siberia. *Populus* pollen is not preserved in sediments, but probably grew in the area through the Holocene. The massif is now surrounded by grass steppes (see Fig. 8).

MOKHOVOE SWAMP (53° 46' N; 64° 15' E)

Site location

The eutrophic Mokhovoe swamp is located in west Kazakhstan in the watershed of the Tobol and Ubagan Rivers (1 on Fig. 1). It is an area of forest-steppe with grass steppes, now mainly transformed into arable land, and patches of birch-poplar forests, known in south west Siberia and northern Kazakhstan as 'kolki'. Pine (*Pinus sylvestris* L.) grows on the sandy terraces of the Tobol and Ubagan Rivers (Fig. 3).

Mokhovoe swamp is situated in a hollow. It is oval-shaped with an area of 67 ha. The Mokhovoe peat-swamp is the deepest mire known in the entire northern Kazakhstan area. Coring was carried out in the area of the greatest thickness of peat. The following stratigraphy has been established: 0-210 cm – eutrophic reed peat (see Table V); 210-260 cm – eutrophic reed-sedge peat (see Table V); 260-325 cm – grey loam, sandy in lower part; > 325 cm – fine grained yellow sand.

Based upon results of radiocarbon dating (Table II) we can assume that sedimentation in the lake started *ca* 6000 BP. The sedimentation rate in Mokhovoe Lake was very low. There is a hiatus which covers time between likely 4500/4000 and 3000/2900 BP. At that time the lake probably dried up. Only by *ca* 2900-2800 BP the lake developed into a peat swamp probably resulting from increased climate moisture. At 2800-2500 BP peat sedimentation also started in Barabinskaya steppe in south-east part of West Siberian Lowland (Klimanov *et al.*, 1987).

Results of pollen analysis

The pollen stratigraphy of the swamp was divided into four pollen assemblage zones (Fig. 11). The pollen spectra from the bottom of the lower unit of lake grey loam and sandy loam form pollen zone 1, dated at between 6000 and 4500 BP. Herbs form 40-60% of the total assemblage, with arboreal pollen making up about 40-60%, the rest consisting of spores, mainly fern Polypodiaceae. Amongst the arboreal pollen, birch predominates (up about 60% of the total pollen sum). There are also *Pinus sylvestris* pollen and small amounts of *Picea*, *Salix* and alder (*Alnus* sp.) pollen. *Artemisia* pollen is dominant among the herb types (up to 45% of total sum) throughout the diagram, with Poaceae being next most significant (up to 25% of total sum). Chenopodiaceae are present in considerable quantities (up to 18%), together with Rosaceae and Cyperaceae. Few pollen grains of aquatic plants (*Sparganium* and *Typha*) have been identified. Spores consist mainly of Polypodiaceae with small amounts of *Sphagnum*.

Pollen zone 2 has been distinguished in the layer of eutrophic reed-sedge peat. It corresponds to 2900-1900 BP. Among arboreal pollen types, *Betula*, *Pinus* and *Salix* are most frequent. Pollen of *Ulmus*, *Tilia*, *Quercus*, *Corylus* is recorded. Among herbs, the abundance of Cyperaceae pollen is higher then in pollen zone 1. There are two peaks of *Sphagnum* spores at depths of 260 and 230 cm (2700 and 2000 BP respectively).

Pollen zone 3 corresponds to the layer of eutrophic reed peat, dated at 1900-400 BP. In this zone, there is an increase of *Pinus* pollen curve, with a corresponding *Betula* pollen curve decrease. Pollen of *Salix* and of broadleaved trees is present. There are no major changes in the herb pollen, but *Artemisia* and Poaceae pollen content increases. There is a peak of *Sphagnum* spores in depth of 190 cm and some peaks of Polypodiaceae spores. In upper part of zone 3 the abundance of spores in spectra decreased sharply. Pollen of aquatic plants is represented by *Sparganium*, *Typha*, *Myriophyllum* and *Utricularia*.

Upper pollen zone 4 corresponds to the last 400 years. The pollen assemblage here is similar to the surface sample. Pollen of broadleaved trees is almost absent. There is some increase in birch and Poaceae pollen content, and a marked increase in *Artemisia* pollen. In the uppermost sample the frequency of Poaceae pollen is higher than that of *Artemisia*.

Vegetation reconstruction

This pollen records allows reconstruction of the vegetation history for last 6000 years since the beginning of sedimentation in the Mokhovoe section. Between 6000 and 4500 BP forest-steppe with grass steppes and birch forest patches was widespread in Tobol-Ubagan watershed. Although poplar is not preserved in pollen records it was probably present in regional vegetation together with birch, as in the present day vegetation. Pine and birch forests grew on sandy terraces of the Tobol and Ubagan Rivers. There is a hiatus which covers time between 4500 and 3000/2900 BP. Only by *ca* 2900-2800 BP the basin developed into a peat swamp probably resulting from increased climate moisture. Peaks of

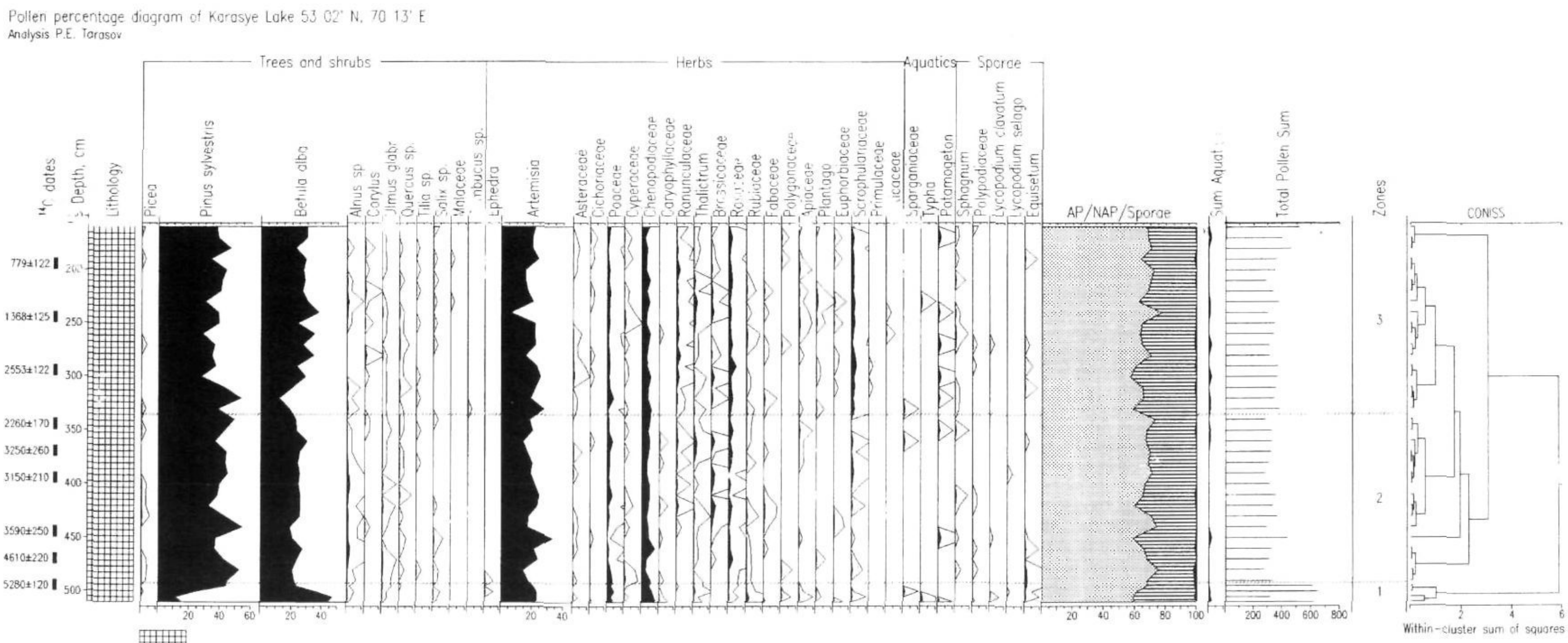

FIGURE 10. Pollen percentage diagram of Karasye Lake (analysis P.E. Tarasov). Open curves represent 10x exaggeration.

Diagramme des pourcentages polliniques du lac Karasye (analyse de P.E. Tarasov). Les courbes ouvertes présentent une exagération de 10x.

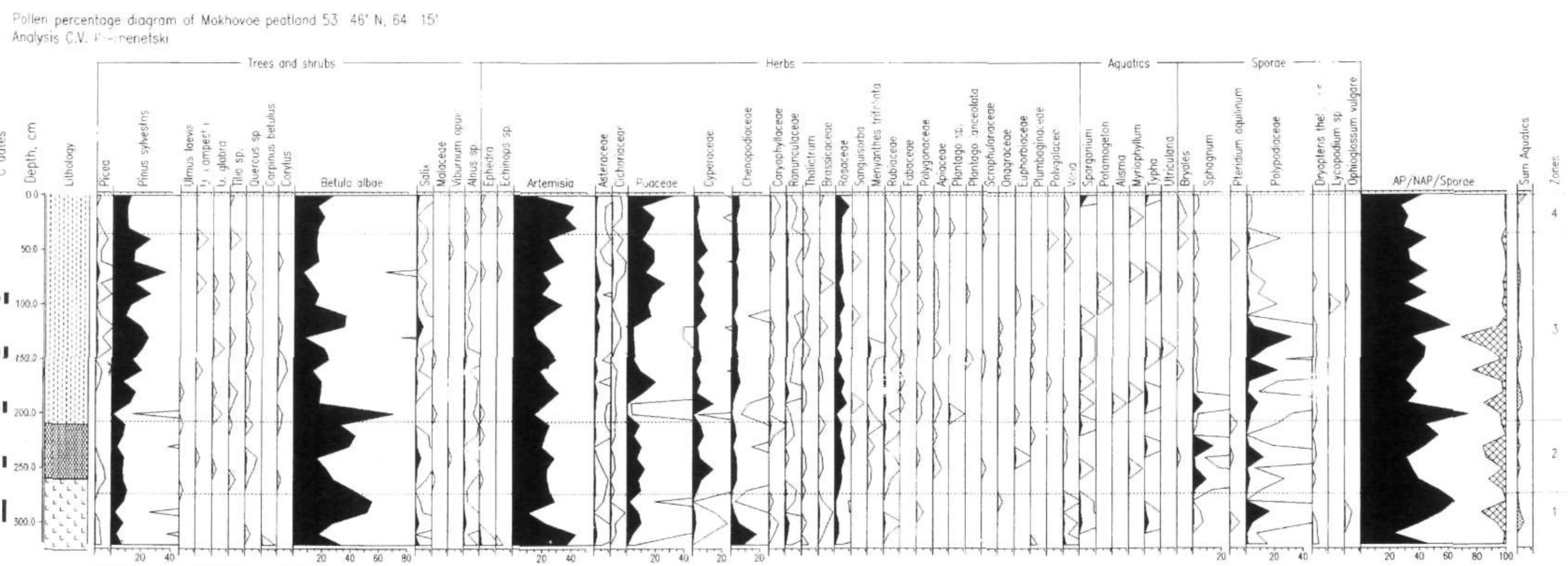

FIGURE 11. Pollen percentage diagram of Mokhovoe peat swamp (analysis C.V. Kremenetski). Open curves represent 10x exaggeration.

Diagramme des pourcentages polliniques de la tourbière de Mokhovoe (analyse de C.V. Kremenetski). Les courbes ouvertes présentent une exagération de 10x.

TABLE V

The botanical composition of peat in Mokhovoe peatland

Depth (cm)	Description	Depth (cm)	Description
25	*Phragmites australis* (Cav.) Trin. ex Steud. - 55% *Carex lasiocarpa* Ehrh. - 15% *C. diandra* Schrank. - 15% *C. appropinquata* Schum. - 5% *Drepanocladus* sp. - 5% *Betula* sp. - 5%	150	*Phragmites australis* (Cav.) Trin. ex Steud 80% *Carex lasiocarpa* Ehrh. - 5% *C. rostrata* Stokes - 5% *Drepanocladus aduncus* Warnst. - 5% *Scirpus lacustris* L. - 5%
50	*Phragmites australis* (Cav.) Trin. ex Steud. - 80% *Carex diandra* Schrank. - 5% *C. appropinquata* Schum. - 5% *Drepanocladus aduncus* Warnst. - 5% *Calamagrostis canescens* (Web.) Roth. - 5%	175	*Phragmites australis* (Cav.) Trin. ex Steud. 65% *Drepanocladus aduncus* Warnst. - 10% *Menyanthes trifoliata* L. - 10% *Carex rostrata* Stokes - 5% *Sphagnum warnstorfii* Russ. - 5% *S. teres* (Schimp.) Angstr. - 5%
75	*Phragmites australis* (Cav.) Trin. ex Steud. - 85% *Carex rostrata* Stokes - 5% *Scirpus lacustris* L. - 5% *Calamagrostis canescens* (Web.) Roth. - 5%	200	*Phragmites australis* (Cav.) Trin. ex Steud. 45% *Carex lasiocarpa* Ehrh. - 15% *C. rostrata* Stokes - 15% *C. caespitosa* L. - 5% *Sphagnum squarrosum* Pers. - 15% *Equisetum palustre* L. - 5%
100	*Phragmites australis* (Cav.) Trin. ex Steud. - 80% *Carex lasiocarpa* Ehrh. - 10% *Carex rostrata* Stokes - 5% *C. caespitosa* L. - + *Scirpus lacustris* L. - 5% *Menyanthes trifoliata* L. - +	225	*Carex lasiocarpa* Ehrh. - 30% *C. rostrata* Stokes - 10% *C. elata* All. - 5% *Phragmites australis* (Cav.) Trin. ex Steud. 30% *Equisetum palustre* L. - 5% *Scirpus lacustris* L. - 5% *Menyanthes trifoliata* L. - 5% *Betula* sp. - 5% *Comarum palustre* L. - 5%
125	*Phragmites australis* (Cav.) Trin. ex Steud. - 85% *Carex lasiocarpa* Ehrh. - 5% *Drepanocladus aduncus* Warnst. - 5% *Scirpus lacustris* L. - 5%	250	*Phragmites australis* (Cav.) Trin. ex Steud. 30% *Carex lasiocarpa* Ehrh. - 15% *C. rostrata* Stokes - 5% *C. caespitosa* L. - 5% *C. elata* All. - 5% *Equisetum palustre* L. - 5% *Drepanocladus aduncus* Warnst. - 5%

Sphagnum spores suggest an active expansion of *Sphagnum* over swamp (Piavchenko 1963).

The general vegetation structure by 2900-2500 BP was similar to that of 6000-4500 BP. Oak, elm and linden appeared as admixture in local birch and pine forests and as understory. Between 1900-1500 BP, the climate became wetter. A new phase of *Sphagnum* moss expansion occurred. Pine forests were established on sandy terraces of Tobol and Ubagan Rivers. An admixture of broadleaved trees was present in forests. Black alder grew in wet places. After 400 BP broadleaved trees disappeared from that area. The range of black alder has reduced. General composition of vegetation cover became as it is now.

Our data allow us to conclude that modern monospecific pine forests in north-west Kazakhstan were established by about 2000 BP. It is possible now to re-evaluate results of pollen investigation of thin peat in Naurzum pine forest (51° 30' N; 64° 30' E), the most southern pine forest in that part of Kazakhstan (Krupenikov, 1941) (see Fig. 3). In lower part of that undated section, pine pollen is sporadic. The Naurzum pine forest is likely to be as young as more northern pine forests. The results of pollen investigations of Pashennoe Lake (Kremenetski *et al.*, 1994, 1997) together with other data suggest that only by about 2000 BP had pine reached its maximum abundance at the southern margin of its range in Kazakhstan.

DISCUSSION

Based on data presented here, we suggest the predominant occurrence of dry bunchgrass-wormwood and wormwood steppe in the south of the West Siberian Lowland and the Kazakhstan hills at the final stages of the Late Glacial. Refugia of forest vegetation remained throughout the course of the Sartan Glaciation in the Irtysh Valley (Krivonogov, 1988) as well as in the south Altai Mountains, and on granite outcrops of the Kazakhstan hills. This is verified by the present day distribution of boreal relics in forests of the Kazakhstan hills granite massifs (Kremenetski, 1995). Patches of sea buckthorn covered open slopes of the Irtysh Valley.

Global warming at the end of the Late Glacial/beginning of the Holocene transition caused considerable changes in the vegetation of the west Siberian Lowland and the Kazakhstan Lowhills (Kazakhskiy Melkosopochnik), resulting in the spread of forest trees from their Ice-Age refugia. Open spruce (*Picea obovata* Ledeb.) forests started spreading along river valleys and over the Kazakhstan hills. Dwarf alder (*Alnus fruticosa* Rupr.) and dwarf birch (*Betula fruticosa* Pall., *B. rotundifolia* Spach.) occurred in Irtysh valley. Willow (*Salix* spp.) and honeysuckle (*Lonicera* spp.) occurred in wetter habitats. Sea buckthorn (*Hippophae rhamnoides*), although still covering open slopes, was slightly reduced in abundance. Bunchgrass-wormwood and wormwood (*Artemisia* spp.) assemblages remained dominant in the herb layer.

Available pollen data (Akiyanova *et al.*, 1984) suggests the occurrence of open spruce forests in the northern Kazakhstan Lowhills. Spruce (*Picea obovata* Ledeb.) was widespread in the valleys in the southern West Siberian Lowland (Volkova *et al.*, 1989). The occurrence of spruce at the end of the Late Glacial in the southern West Siberian Lowland and the Kazakhstan Lowhills much to the south of its present-day range, was presumably possible due to a much colder climate (Kremenetski *et al.*, 1997).

With the transition to the Holocene, the climate became warmer and more continental. By 9500 BP, the southern limits of spruce had retreated to its present-day positions. The area of sea buckthorn similarly shrank and also approached its present-day range.

During 9500-8000 BP, both steppe and open birch forests formed the vegetation in the south of the west Siberian Lowland (Volkova *et al.*, 1989; Firsov *et al.*, 1982). Birch and willow forests grew on small areas close to waterways and on granite outcrops. These, along with the overall domination of dry bunchgrass-wormwood steppe and semi-desert, were the main types of vegetation in Kazakhstan. The climate became drier and more continental. That time was favourable for the northward progress of desert flora elements. Botanists suppose that the appearance of the Central Asia desert floristic elements in the Kazakhstan Lowhills is likely due to the period of drier climate (Baymukhambetova, 1989).

Between 7000-5500 BP, pine (*Pinus sylvestris* L.) expanded in Kazakhstan and reached its present day southern limit. Since 5500 BP, pine has formed pure monodominant forests of modern type in Irtysh-Semipalatinsk area and in the northern part of Kazakhstan Lowhills. In other parts of southern margin of West Siberian Lowland and of Kazakhstan Lowhills pine grew together with birch as suggested by the relatively low *Pinus* pollen percentage in the pollen diagrams.

By 5000 BP, *Tilia cordata* had spread into the northern part of the Kazakhstan Lowhills. That was a time of its expansion over West Siberia (Kremenetski, 1995b). The range of oak (*Quercus robur* L.), elm (*Ulmus glabra* Huds.) and black alder (*Alnus glutinosa* Gaertn.) also expanded. Herb cover of steppes was also more mesophytic than it is now. The favourable climate conditions 6000-4500 BP are verified by palaeosol evidence. Soils buried under barrows of *ca.* 5000 years BP age show features of increased climate moisture relative to the period 4500-3500 years BP (Ivanov, 1992).

The period between 4500-3600 BP was characterised by a drier and more continental climate, and the forest area decreased. The ranges of broadleaved trees and black alder were reduced.

A new phase of less continental climate occurred *ca.* 3300-2800/2700 BP. The present day abundance of Scots pine on its southern limit was established about 2000 BP. *Ca.* 1900-1700 BP pine forests expanded in western Kazakhstan in Tobol River basin and *ca.* 1500 in south-east part of Kazakhstan Lowhills in Karkarala massif (Kremenetski *et al.*, 1997). So the southern limit of pine in Kazakhstan was variable within the Holocene. The results obtained in Kazakhstan correlate well with evidence from southern part of East Europe, including Ukraine and southern Russia (Kremenetski, 1991, 1995a, 1997).

There is no evidence of any human impact in pollen diagrams. Although the Kazakhstan area has been peopled since prehistoric times, up to the end of 19th century, the local population was strictly nomadic, and farming was practiced in very limited areas. Virgin steppes were ploughed in late 19th to mid-20th centuries. Forests were preserved as a source of timber and now for ecological purposes. Ozerki and Karasiye are located in protected forest area so the absence of indicators of human impact in diagrams can be explained by the status of these areas.

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