PRESENT ACHIEVEMENTS IN A PALYNOLOGICAL STUDY OF THE QUATERNARY PERIOD IN THE USSR

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ABSTRACT

Enormous palynological data are accumulated over the continental and marine deposits from the various regions of the USSR.

Palynological data are usually applied together with the geological ones. At a time diatoms and large plant remains are analysed. The absolute age determination by C 14 are in common use.

The general pattern of distribution and dynamic of vegetation and natural zones in the Pleistocene and Holocene are traced in large scale regions and in all the country.

Palynological data serve usually as a main criteria for the differentiation and subdivision of interglacials and interstadials with reference to their relative chronological estimates.

Palynological method is used also for the identification of the Pliocene-Pleistocene and Pleistocene-Holocene boundaries, for the sub-division of deposits into horizons and zones on the base of vegetational changes, for the determination of past climates, for the typization of interglacial, interstadial and holocene diagrams with reference to their geographical position, time correlation, of marine transgressions etc.

There are found some sections representing palynologically continuous vegetational development from the last interglacial to the present. The data from arid zone are very interesting to study pluvial and interpluvial periods.

Palynological data show the extremely complicated development of the Pleistocene and Holocene vegetation, the significant mobility and transformation of natural zones.

Only due to the use of palynological method it became possible to study climatic conditions, vegetational development and stratigraphical position of the Pleistocene and Holocene deposits.

IN the USSR an extensive complex study of the Quaternary period is proceeding from many aspects: stratigraphic, paleogeographic, archeological, palaeobotanical, etc. This is caused not only by an interest in the environments in which man was living in the past, but also by actual practical problems of today. The study of Quaternary deposits is of vital importance in a search for minerals, in the construction of big hydro-electric power plants, roads, cities, oil and gas pipelines, etc.

The tremendous territory of the Soviet Union with its varied natural conditions, specific features of different zones and provinces, the presence of vast plains and mountainous areas, its sea expanses, makes the study of the Quaternary period a very complicated matter. On the other hand, it makes it extremely interesting as it permits to establish regional differences and makes important generalizations.

A special place in the study of the Quaternary period is assigned in the USSR to palaeobotany and particularly to the palynological method, the application of which is constantly becoming wider (NEUSTADT, 1952, 1960). One of the reasons is that, in many cases, thick masses of Quaternary deposits have no paleontological remains with the exception of spores and pollen. Enrichment methods elaborated in the Soviet Union permit to apply this method successfully to the subdivision of such " barren " rock masses and to study sequences from boreholes. This does not mean, however, that the palynological method is used in an isolated way. Together with palynological researches, the scientists of the Soviet Union try to use also a complex of other methods, including diatom and carpological analyses, studies of bogs, etc. During recent years absolute age determinations by carbon C^{14} radioisotope are used more and more widely for the study of the top part of Pleistocene and the Holocene. It is, of course, evident that palynological studies of Quaternary deposits are intimately connected with researches on the geological structure and geomorphology of the territory. We consider it absolutely impossible to dissociate palynological data from the actual geological structure of the section, its analysis, including the facies analysis.

Palynologists, who study the Quaternary period, work in all territorial geological administrations (surveys) in many scientific-research organizations of our country (geological, geographical, botanical, archeological, etc.), in universities and institutes of a corresponding profile.

Naturally, a correct interpretation of collected palynological data demanded methodological instructions, particularly on spore and pollen morphology (with a determination detalization, in a number of cases, up to a plant species), on the study of spore and pollen transportation by air currents and rivers, on the formation conditions of spore and pollen spectra and other problems. Of course, many questions are still unsolved, but certain successes in this respect permit to use the results of palynological analyses with greater confidence. Very important in interpreting pollen diagrams is the detalization of the problem of spectra types: forest, tundra, steppe and transition types between them, a study of pollen spectra in surface samples from different regions, in different physico-geographical conditions and from different facies. At the present time an abundant palynological material is accumulated on the history of flora and vegetation in the USSR during the Quaternary period. It should be mentioned, however, that no complete summarization of this material is yet prepared, which is understandable considering the extremely vast territory that it embraces and the considerable interval of geological time it covers. Yet there are summaries of this material for separate regions.

Of vital importance is the palynological method in boundary determinations for the entire Quaternary period and for its subdivisions. A significant role belongs here to regional differences, which should always be borne in mind in solving any problems by the palynological method.

There are various criteria for the determination of the Pliocene-Pleistocene boundary, which is drawn, consequently, at different levels by different authors. In 1961 at the VIth INQUA Congress in Warsaw the report of INQUA Subcommission on the Pliocene-Pleistocene boundary (GRICHUK *et al.*, 1964) listed a number of features that can be used for this purpose, including climatic features. It is known that the latter are clearly reflected in the character of vegetation. Grichuk (1961) made an analysis of Pliocene and Pleistocene floras (leaf, carpological and palynological), the results of which established that there is a distinct break in the composition of fossil floras at a certain time limit. Thermophile elements, which predominated in the older parts of the geological sections at a certain point give place to modern flora components of the Northern Hemisphere (panholarctic plants). During this process there is a sharp decrease in the total number of genera in the floras. Such an analysis has been done for the European part of the USSR, Georgia, Poland, Northern Holland and Northern Italy. This breaking point can be very significant for the determination of the Pliocene-Pleistocene boundary, which, according to the recommendations of the above mentioned Subcommission, " needs a further study by all available geological, biological and physical methods ".

A great investment into the application of the palynological method to a study of Pleistocene deposits in the USSR was made by V. N. Sukachev, V. S. Dokturovsky (†), G. A. Blagoveschensky (†), I. M. Pokrovskaia, N. Ya. Katz and especially V. P. Grichuk, as well as a number of other palynologists.

It is impossible to demonstrate and characterize the numerous pollen diagrams for thick Pleistocene deposits in the European part of the USSR, in Western and Eastern Siberia, in the Far East and Middle Asia area, though they are extremely interesting.

For this reason we are going to deal only the biggest summarizing papers, which used the palynological method in the compilation of paleogeographical maps as a result of a synthesis of an extensive analytical material. But before that we would like to give a correlation scheme of Pleistocene stratigraphy in the USSR and certain foreign countries (TABLE 1).

A number of maps illustrating the character of vegetation in the European part of the USSR (Russian plain) has been compiled by Girchuk (1964). We will give only two maps — for the climatic optimum of Mikulino (Eemian) interglacial and for the period of a subsequent glaciation — Valdai (Würmian) — for the time of its maximum phase.

During the Mikulino interglacial (FIG. 1A) there has been a boreal sea transgression in the north, sea waters were flooding a considerable part of the present land having a connection with the Baltic Sea. A well expressed zonality is noticeable on the territory of the Russian plain. The forest zone came directly to the northern basin. There has been no tundra and forest-tundra zones. The northernmost part of the forest zone consisted of birch forests with an admixture of spruce. Further south was

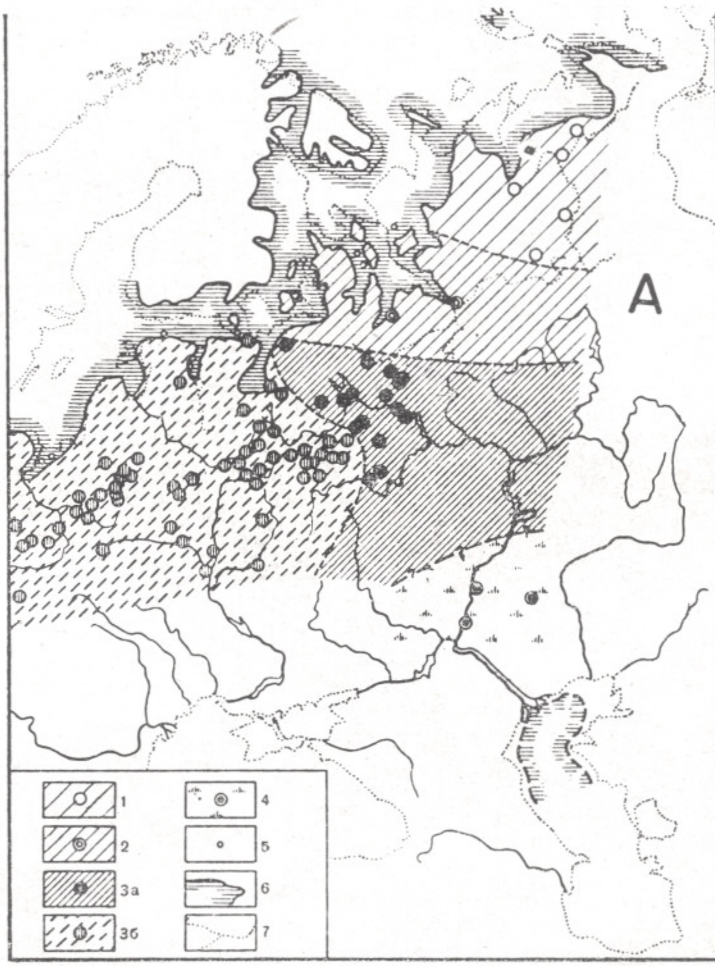
TABLE 1

	European Part of the USSR	Siberia and the Far East	Poland	North-German Lowland	Alpine chronology
Upper Pleistocene	Valdai glaciation	Zyriansk glaciation	Baltic glaciation	Vistula glaciation	Würmian
	Mikulino interglacial	Kazantzevo interglacial	Eemian interglacial	Saale-Vistula interglacial	Riss-Würmian
Middle Pleistocene	Moscow glaciation	Tazov glaciation	Warthe stage	Warthe stage	Riss II
	Odintzovo interglacial	Messovo interglacial	Esker interstadial	Esker interstadial (interglacial ?)	
	Dnieper glaciation	Samarovo glaciation	Warsaw glaciation	Saale glaciation	Riss I
	Likhvin interglacial	Tobol interglacial	Mazovian interglacial	Elster-Saale interglacial	Mindel-Riss
Lower Pleistocene	Oka glaciation	Demianovo glaciation	Cracow glaciation	Elster glaciation	Mindel
	Lower Pleistocene interglacial (or warmer spell)		Tegelen interglacial		
	Lower Pleistocene glaciation (or colder spell)		Cieszyn glaciation		

a strip of coniferous-broadleaf forests, where spruce and birch forests had an admixture of broadleaf species. Even further south was a well developed zone of broadleaf forests with distinctive province features. In its eastern continental part the forests consisted of oaks with a certain participation of hornbeam and linden; the western part (coastal) was characterized by forests consisting of horbeam and linden. There has been little oak in these forests. Further south there was a predominance of steppes with isolated patches of broadleaf forests. The boundaries of zones and provinces are shown on Fig. 1A.

Quite obviously the character of vegetation distribution considerably changed by the end of the interglacial. A great number of diagrams of Mikulino (Eemian, Riss-Würmian) interglacial indicates a considerable vegetation mobility during that time interval.

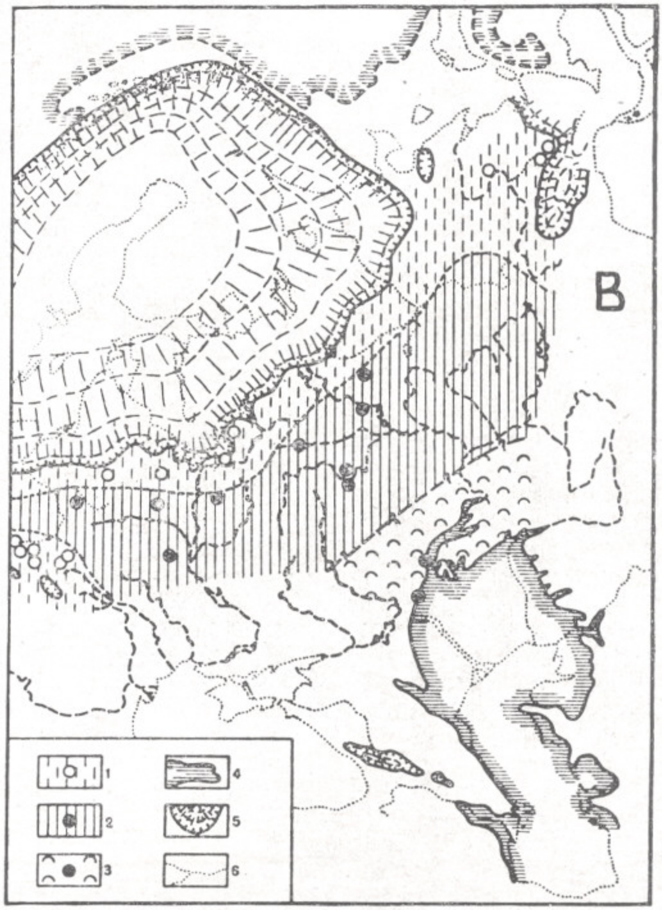
The distribution character of the vegetation cover during other interglacials differed from that of Mikulino interglacial, both by the position of the boundaries of vegetation zones and subzones and, to a certain extent, by the participation in their composition of some other species, for instance, fir (*Abies*) in Likhvin (Elster-Saale, Mindel-Riss) inter-



TEXT-FIG. 1A — Vegetation of the Russian plain during Mikulino interglacial (climatic optimum, zone M_{5+6}); 1 — birch forests with the participation of spruce; 2 — birch and spruce forests with a small participation of broadleaf species; 3a — broadleaf forests consisting of oak with a small participation of hornbeam and linden; 3b — broadleaf forests consisting of hornbeam and linden with a small participation of oak; 4 — area of predominantly steppe formations with forests of broadleaf species; 5 — stations of palaeobotanical study of marine sediments; 6 — sea basins; 7 — recent sea coasts and drainage system.

glacial. Palynological data establish a full possibility (in typical cases) of separation interglacials of different age by the spectra composition of a full diagram or of its large portions.

During the period of Valdai glaciation we observe (FIG. 1B) a striking change of natural conditions. In addition to the presence of a thick ice sheet, there is a great northward retreat of the sea boundary (not only as compared with the optimum of Mikulino interglacial, but also in respect to its present boundary). There is also a drastic change in the general character of vegetation. The forest zone, which during Mikulino interglacial occupied the greater part of the country, disappeared on the territory of the Russian plain. Vegetation zones were located not latitudinally, but radially in respect to the glacial sheet. Directly adjacent was a strip of forestless expanses or sparse birch forests with representatives of tundra and steppe elements. The second radial strip consisted of a birch forest-steppe with a considerable participation of xerophytic herbaceous groups. The



TEXT-FIG. 1B — Vegetation of the Russian plain during Valdai glaciation (maximum phase). 1 — forestless vegetation or sparse birch forests with participation of tundra and steppe elements; 2 — birch forest-steppe with considerable participation of xerophyte herbaceous groups; 3 — xerophile vegetation of a steppe outlook (with forests of boreal species); 4 — sea basins; 5 — ice sheets; recent sea coasts and drainage system (according to V. P. Grichuk, 1964).

third belt immediately adjoining the sea basin (Caspian) was a vegetation of steppe character with isolated portions of boreal-type forests.

An approximately analogous character of changes can be traced in each cycle (glaciation-interglacial), i.e. we observe here a sharply differing nature of zonal landscape structure. This has already been recorded by Guerassimov & Markov (1939). However, the character of vegetation distribution in periglacial areas of the Russian plain had its specific features for each glaciation and each interglacial. Eight maps of an analogous kind to the above described have been compiled for the entire Pleistocene. For the time being, they do not embrace the whole territory of the European part of the USSR, but they represent sufficiently well the extremely complicated pattern of vegetation development during the Pleistocene.

The last — Valdai — glaciation, just as the others, is characterized by a number of interstadial deposits of varying age (Berezaevka, Somino, Msta interstadials, etc.), formed as result of a successive ice retreat northwards from their maximum advance. Some of these interstadials have their own palynological characteristic, but all of them have features in common — the absence in the deposits of pollen belonging to broadleaf thermophile species, which distinctly differs them from interglacial deposits.

It is interesting that during glaciations and especially by the end of these periods there has been a great development of the family Chenopodiaceae in the periglacial zone during the phase of pine-birch sparse forests. Their specific variety has been much greater than at the present time on the territory of the European part of the USSR. For instance, 23 species of varying ecolcgy have been established for the time of Valdai (Würmian) glaciation. They include: typical halophytes associated with soils of different salinity and humidity (*Salicornia herbacea* L., *Atriplex verrucifera* M. B., *Salsola soda* L., species *Suaeda*, *Petrosimonia*, etc.), xerophytes growing on sands, solonchaks, stony grounds (*Kochia prostrata* (L.) Schrad., *Eurotia ceratoides* (L.) C. A. Mey., *Kochia scoparia* (L.) Schrad., *Kochia laniflora* Borb. etc.) ruderal species (*Chenopodium album* L., *Atriplex patula* L., etc.).

Peculiarities of physico-geographical conditions on a territory freed from an ice sheet — a hilly-morainic relief, imperfectly developed soils, residual permafrost — created also a variety of ecological environments, which encouraged a dispersion of plants of a varying ecological profile.

Finds of *Eurotia ceratoides*, *Kochia prostrata*, etc. pollen in glacial deposits beyond the limits of their present areal, indicate a wide migration of steppe elements in a northward direction during glacial periods, as well as a presence of saline soils in the periglacial zone (MONOSZON, 1961).

Grichuk (1961) has processed a great amount of material on Western Siberia. Pollen diagrams for a considerable number of sections have shown a very complicated development of Pleistocene vegetation on this territory as well. A number of phases in the development of vegetation is distinguished during the Pleistocene some of them corresponding to the vegetation cover similar to the present in this area or to a cover developed south and south-west of this territory, while other phases correspond the vegetation cover of more northern or north-eastern regions. An analysis of these phases leads us to a conclusion that the first ones have been developed under climatic conditions similar to the present and should be referred to interglacial periods, while the others — existed under conditions typical for glaciations.

An inspection of a summarized pollen diagram compiled by the above-mentioned author for the southern part of Ob basin shows that all interglacial periods were characterized by the development of a forest zone, whereas the glacial periods — by an absence of the forest zone and the presence only of a forest-tundra and a forest-steppe. Further south, in certain regions, there has also been a steppe zone. The mentioned replacements took place repeatedly throughout the Pleistocene, when there has been an interchange of glacial and interglacial periods.

A summarization of factual palynological material on the Quaternary period in Eastern Siberia and the Far East of the USSR resulted in striking data analogous, as a whole, to the information obtained for the European part of the USSR. These data have been generalized by Giterman, *et al.* (1963) into a number of maps of the vegetation cover in these regions. Admittedly, for the time being these maps are schematic, they are a first approximation, the boundaries between separate types of vegetation are tentative, but the character of the vegetation cover stands out sufficiently distinctly.

Such maps have been compiled for the following period: the maximum glaciation of Siberia — Samarovo glaciation (two phases), Zyriansk glaciation (two phases) and Kazantzevo interglacial.

We are giving only two maps — for Kazantzevo interglacial, for which there is the greatest amount of palynological data and which, apparently, has been the warmest interglacial known during the Pleistocene in these areas and a map for Zyriansk glaciation. These maps are chosen because they are synchronous to the maps we discussed for the European part of the USSR. Another common feature is that in both cases glaciation immediately follows the interglacial described and we have a chance here to follow directly one climatic period after another.

Throughout both glacial and interglacial periods there have been, in their turn, also changes in the character of vegetation and these phases can be distinctly traced. We have chosen those maps, which express the most striking special features of each period

— the time of a climatic optimum for Kazantzevo interglacial and the time of a maximum advance of the ice during Zyriansk glaciation.

The main special feature of Kazantzevo interglacial (FIG. 2A) was a wide development of forest associations in Siberia and in the Far East, the northern boundary of the forest passing along higher altitudes than at the present time. A number of provinces is distinguished in the forest cover. A dark coniferous taiga consisting of spruce, Siberian pine [*Pinus sibirica* (Rupr.) Mayr.] and fir (*Abies*), was predominant in the West-Siberian lowland and in Middle Siberia. Another province was distinguished in Lena basin with a predominance of a clear coniferous taiga consisting of larches and pines with a substantial participation of birch. In the southern part of Soviet Far East and on Sakhalin a third province was distinguished with a predominance of coniferous forests with a participation of broadleaf species of Manchurian type (*Quercus mongolica* Fisch. et Turcz, etc.). Depending upon the relief and slope exposition the taiga acquired certain features of its structure. There have been strips of steppes, etc. Tundra occupied a narrow fringe along the northernmost margin of the continent.

During Zyriansk glaciation, when the territory of the land extended much farther north than during Kazantzevo interglacial and as compared with its present position, the territory under question had an essentially different pattern. The forests disappeared completely with the exception of the southern part of the Far East, where sparse birch forests were dominating and of the south-western part of this area, where there have been mixed forests with strips of steppes (FIG. 2B). The role of tree vegetation was reduced to minimum and

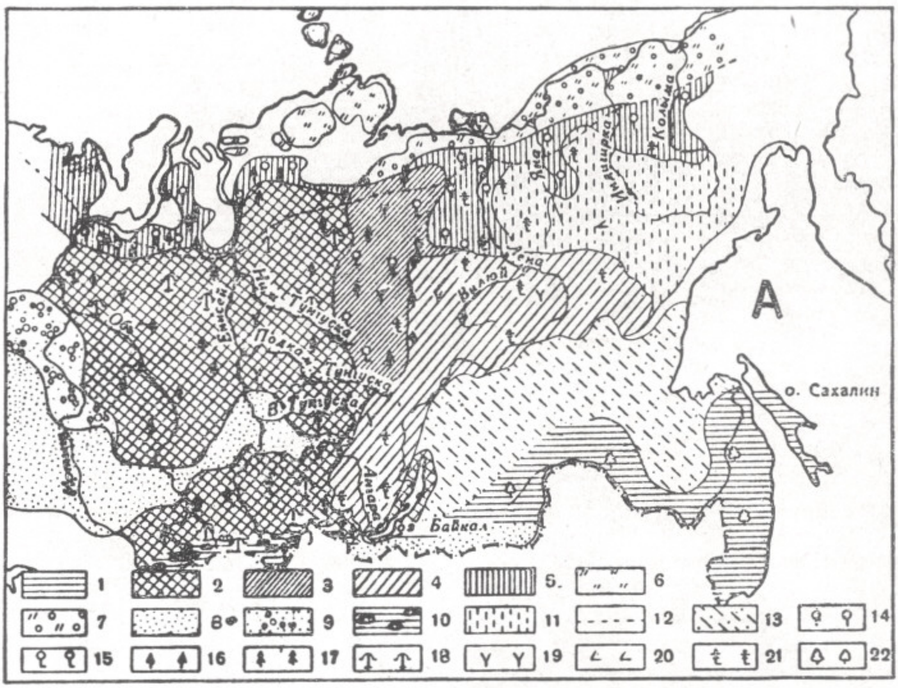
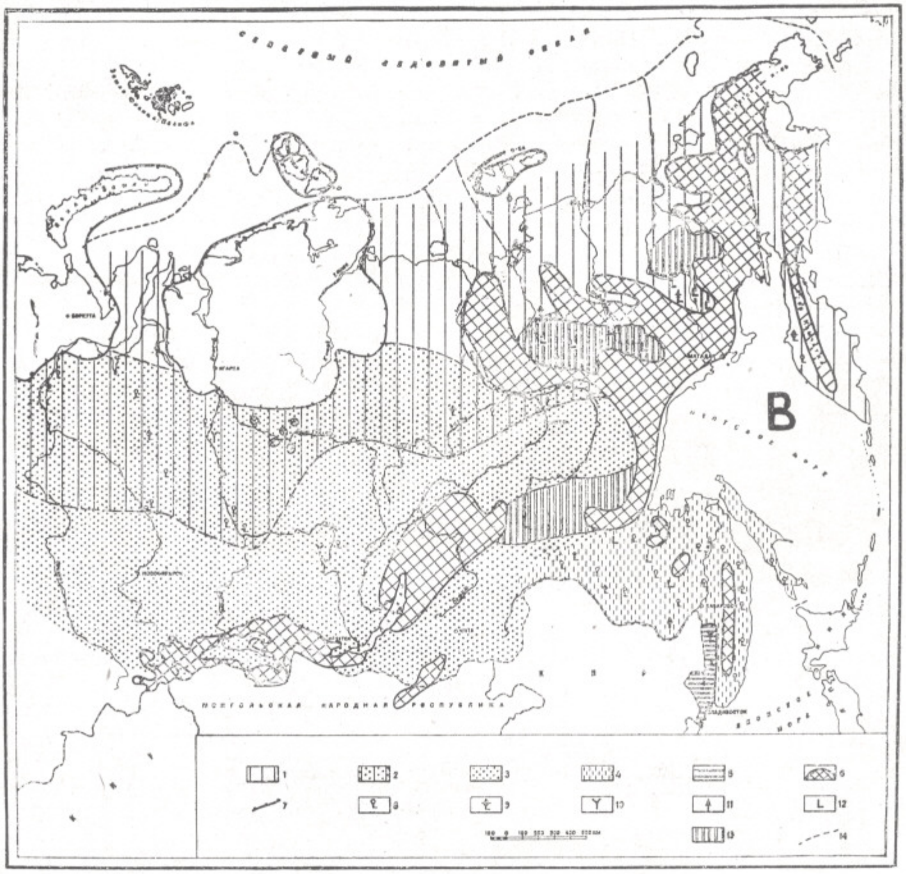


FIG. 2A — Schematic vegetation map of Kazantzevo interglacial in Siberia (2nd phase). 1 — coniferous forest with admixture of broadleaf species; 2 — dark coniferous taiga; 3 — clear coniferous taiga with spruce; 4 — clear coniferous taiga; 5 — sparse forests of northern type; 6 — tundra; 7 — forest-tundra; 8 — steppe; 9 — forest-steppe; 10 — dark coniferous taiga with strips of mountain steppes; 11 — mountain sparse forests with *Pinus pumila* and larch; 12— recent northern boundary of the forest zone; 13 — assumed development of clear coniferous open stand forests in combination with mountainous tundras; 14 — birch shrubs; 15 — birch trees; 16 — spruce; 17 — fir; 18 — *Pinus sibirica*; 19 — *Pinus silvestris*; 20 — *Pinus pumila*; 21 — larch; 22 — broadleaf species.



TEXT-FIG. 2B — Schematic vegetation map for Zyriansk glaciation (2nd phase). 1 — tundra with participation of xerophytes; 2 — tundra-steppes; 3 — periglacial steppes; 4 — sparse forests; 5 — mixed forestswith strips of steppes; 6 — area of alpine-valley glaciers and mountainous tundras; 7 — limit of maximum ice advance; 8 — birch trees; 9 — *Larix*; 10 — *Pinus silvestris*; 11 — *Picea*; 12 — *Pinus pumila*; 13 — mountainous tundras; 14 — land boundary. (According to R. E. Gitterman *et al.* 1964).

only under the most favourable conditions birch, larch and rarely pine were growing. Spruce is completely absent (with the exception of the south-western part of the Far East). The territory was divided into 4 zones. In the north tundra occupied a wide stretch. The central regions were occupied by tundra-steppes with a predominance of xerophytic groups and a considerable participation of tundra elements. The southern stretch was represented by periglacial steppes, which, like the two preceding zones, covered very extensive expanses. In Eastern Siberia wormwood associations with a participation of Chenopodiaceae, *Ephedra*, Plumbaginaceae were predominant in these steppes.

The fourth zone is represented by the south of the Far East, where the mitigative effect of the ocean permitted a development of sparse forests (*see* above).

It is interesting that for the Last glaciation of Eurasia Frenzel (1964) gives generally a similar picture, though it varies considerably in details. In particular, for Lena basin he indicates a taiga with boreal conifer species.

Quite obviously the above described changes did not take place suddenly or during a very brief time interval, but have been prepared gradually, adequately with climatic changes, reaching their extreme expressions at the climatic optimum of the interglacial and during the phase of a maximum advance of the ice. It is possible to assume that the degradation character of the forests and their reestablishment had its distinctions, especially in the structure and ecology of transition phytocoenoses.

Thus, for instance, in Eastern Siberia at the beginning and during the first half of Zyriansk glaciation, with a substantial forest degradation, the tree-less landscapes were characterized by a wide development of tundra and northern-taiga elements, including *Betula* from the nanae section, representatives of different grass families, the presence of *Lycopodium alpinum* L., *L. pungens* La Pyl., *Selaginella selaginoides* (L.) Spring. and others. There was less participation of more xerophytic plants like worm-woods, representatives of the fam. Chenopodiaceae.

On the contrary, after the maximum glaciation and during the period of ice degradation tundra-type forest-less landscapes are replaced by forestless landscapes of a cold steppe type. Xerophytes play a much greater role, wormwood-herbaceous with the participation of Chenopodiaceae and gramini-wormwood associations are formed, *Ephedra* is present. There is also a much lesser participation of hydrophilous plants (GOLUBEVA & RAVSKII, 1964).

Interesting data have also been obtained for other areas, like, for instance, for Western Turkmenia and the Pamirs. In Western Turkmenia in the region of recent deserts, Quaternary deposits contain beds with an alternating predominance of either xerophytic plants, for instance, in Lower Bakinian deposits (Lower Pleistocene), which contain up to 34-83 per cent Chenopodiaceae, from 6 to 21 per cent *Artemisia*, up to 12 per cent *Ephedra*, a certain amount of *Calligonum* and oth., Polygonaceae and oth. with an insignificant amount of tree pollen, or forest-type spectra, like, for instance, in Upper Bakinian deposits, where the amount of pollen belonging to tree species amounts to 50-70 per cent: *Pinus* from 13 to 48 per cent, *Corylus* from 10 to 57 per cent, *Betula* up to 12 per cent, Moraceae (possibly redeposited) up to 22 per cent, *Alnus* from 9 to 10 per cent, *Castanea, Quercus, Ulmus, Rhus, Tilia,* single *Nyssa* etc. During that time forest vegetation was associated with mountain regions and ac onsiderable amount of xerophytes in these spectra reflects an arid climate of the plain.

These data permit to speak about an alternation of pluvial and arid periods in Western Turkmenia during the Quaternary (MALGINA, 1964).

In South-Western Pamirs at a height of 4200 m. a great amount of pollen with a distinct predominance of tree species has been discovered in a 40 m. thick mass of dark-grey lacustrine clays. In the lower part of the deposits there is a predominance of spruce pollen (up to 64 per cent), in the middle part *Cedrus* pollen (up to 80 per cent) and *Quercus* (up to 39 per cent). *Pinus* pollen comes up to 30 per cent. In the top part the amount of *Cedrus* and *Quercus* pollen sharply diminishes at the expense of an increase of *Picea* and *Abies*, etc. pollen. Both geologically and by palynological data these deposits belong to the pliocene-old quaternary flora. The presence of *Cedrus* and *Quercus* pollen permits to speak about intimate relations between Pamir flora and the flora of Hindu-Kush-Himalaya area. Mixed groups of *Pinus, Cedrus* and *Quercus* are growing at the present time in Eastern Hindu-Kush at a height of 2400-2600 m. The possibility of these trees growing at a height of 4200 m. is absolutely excluded and one can assume that during the time of deposition these deposits occurred at a height of 1600-2000 m. or even less than that. Truly Quaternary deposits on Eastern Pamirs are characterized by an absolute predominance of xerophytes, which indicates a desert-steppe character of the vegetation and a continental dry climate. Interglacial deposits have also been found with a great amount of tree pollen (*Cedrus, Pinus, Picea, Alnus*). This way as result of palynological analyses the paleogeography of the Pamirs had obtained many new and interesting data (PAKHOMOV, 1961, 1964).

The Pleistocene-Holocene boundary is a point of dispute, however, to a lesser extent than the Pliocene-Pleistocene boundary. One group of researchers, that includes the author, thinks that Holocene should start with the bottom of Alleröd, in other words, from a period about 12,000 years ago. This means that Holocene should include both the Late glacial and post-glacial periods. Another group includes into the Holocene only the post-glacial time, i.e. approximately 10,000 years ago, including the Upper Dryas and Alleröd into the Pleistocene. There are also other points of view. Palynologically Holocene deposits differ rather well from Pleistocene deposits: both of interglacial and glacial periods. In practice Holocene forms do not differ from present, however, there have been quantitative mutual redistributions of tree species in the composition of the vegetation cover, which resulted in a replacement of one phase in the history of vegetation by another. We do not mention here the Anthropogen factor. Transitions are established of the palynological composition from the Last glaciation to the Holocene with rather distinct geographical differences. For instance, in the central part of the European territory of the USSR Holocene (in our meaning of the term) begins in pollen diagrams with a maximum development of spruce; in the southern part of the Far East — with a predominance of birch and alder and an absence of conifers, etc.

Researches on the Holocene form a special division and are regarded as very important. This is due to the fact that during the very last stages in the history of the earth, after the glacial period, final phases in the development of vegetation cover, the formation of the composition and distribution of the fauna, drainage system, the incipience of human society (Mesolith and Neolith) were taking place in the Holocene and brought them down to their present state.

An abundant factual palynological material has been accumulated for the Holocene (N. Ya. Katz, M. I. Neustadt, N. I. Piavchenko, S. N. Tiuremnov and many other), which permitted to establish quite distinctly the shifts of areal boundaries of separate tree species, the formation of various forest formations and the changes in natural zones and areas in space and time.

It became possible to observe all these processes in their dynamics because, thanks to palynological analysis data, it was possible to subdivide the Holocene period lasting the last 12,000 years into a number of separate intervals and zones. Owing to correlation difficulties over vast expanses by zones, the number of which varies from 9 to 13 with different authors in the USSR and abroad, we have divided the Holocene into four time intervals comparable with divisions based on other criteria. This subdivision is given on Table 2 (NEUSTADT, 1957).

TABLE 2 — SCHEME OF HOLOCENE SUBDIVISION

Period	Chronology		Index	Stratigraphy		Climatic periods according to Blytt-Sernander	Development stages of the Baltic
	time	absolute chronology		division	horizons		
Holocene	Late Holocene (Neo-Holocene)	0-2500 years	Hl_4	Holocene	recent	Subatlantic	Baltic
	Middle Holocene (Meso-Holocene)	2500-7700 years	Hl_3		Yukhovitzky	Subboreal Atlantic	Limnaea time Litorina time
	Early Holocene (Eo-Holocene)	7700-9800 years	Hl_2		Shuvalovsky	Boreal Beginning of climate improvement	Ancylus time 2nd Yoldia sea
	Old Holocene (Paleo-Holocene)	9800-12000 years	Hl_1		Msharovsky	Subarctic Arctic (second half)	2nd Baltic glacial lake. 1st Yoldia sea, 1st Baltic glacial lake.

At the present time, owing to the application of the radio-carbon method, certain absolute dates in this table are being verified; for instance, the boundary between the old and early Holocene is established at about 10,000 years etc.

It has been established that big migrations of tree species were taking place, their directions being different: from south to the north (for inst. *Quercus mongolica* Fisch.), from the east to the west (*Abies sibirica* Ldb.), from the west to the east (*Pinus silvestris* L.). Sometimes migrations proceeded in a wide front from different directions (e.g. *Carpinus betulus* L. from the south and from the west).

Parallel to a change throughout the Holocene in climatic conditions and a wide migration, there has been the formation of various forest formations on the territory freed from the ice sheet.

Considering the ruin by the ice sheet of the former forest structure and bearing in mind that nothing in nature returns in the process of its development to an exact past, it is justified to assume that their types formed during the Holocene to a certain extent differed from the forests of the last interglacial, though the formations remained the same. Owing to extensive migrations and a greater role of a number of tree species in the composition of forests, separate botanical-geographic areas became repeatedly transformed into other areas.

And, finally, it is possible on the territory of the USSR to observe during this time period a transformation of natural zones and subzones, as well as a considerable shift in their boundaries.

As indicated by researches, these processes took place sufficiently rapidly, in tempos that would not be expected for such a brief time period as the Holocene.

The amazingly fast rate at which a closed vegetation cover and, particularly the tree stand, was reestablished on a territory abandoned by a glacier (considering the natural ability of dispersion) is still a riddle. One of its solutions can be, probably, found in an assumption that the distribution of tree species and herbaceous vegetation on a territory freed from an ice sheet should be regarded not only as a vegetation movements from the edge of the ice sheet, but also its spreading from isolated oases, shelters within the territory of the last glaciation and specially from those places, where it existed since that fundamental break in physico-geographical conditions that began at the earliest stages in the retreat of the glacier, when the climate started to differ noticeably from the climate of the greatest " fluorish " of the last glaciation. This was also assisted by the latitude of the territory. In such oases there could be favourable conditions for the growth of such species as pine, birch, spruce, willow, which were forming the first Holocene forests.

One should not also dismiss the possibility of a rapid seed dispersal, especially during the retreat of the glacier, by water, animals and man.

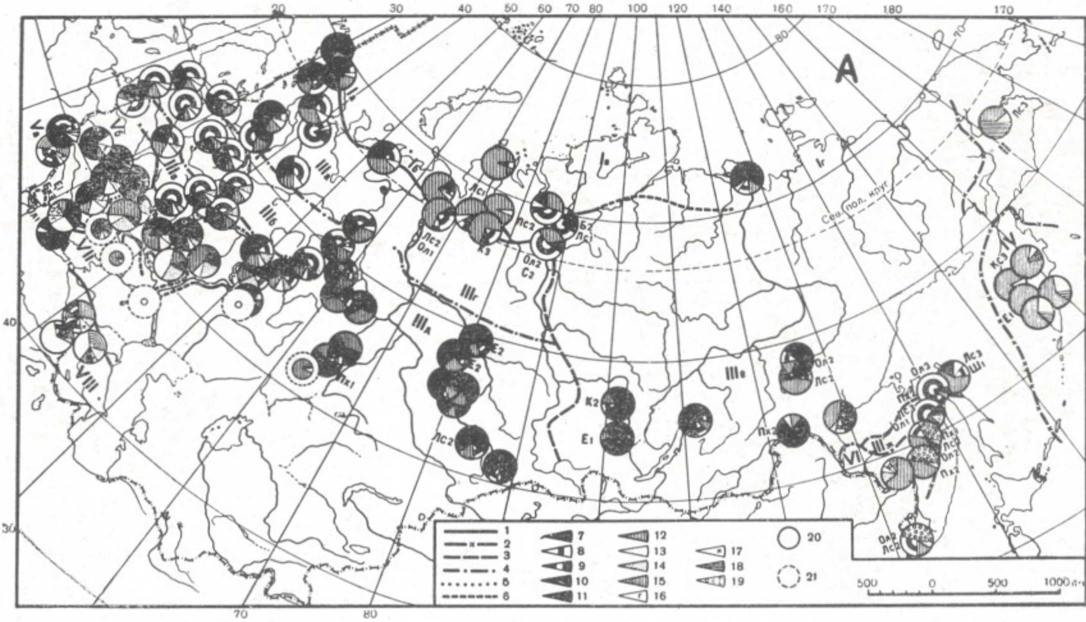
The varying original composition of the vegetation cover that existed on the territory of the USSR at the beginning of the Holocene, was then subjected to a further transformation, differentiation and complication in the process of its gradual development and migrations depending upon the geological history of the area, climatic, orographic and soil conditions, as well as upon the biological and ecological peculiarities of individual plants (especially the dominants).

Let us also briefly review two maps illustrating the character of vegetation and natural zones reconstructed by palynological data for the Middle and Late Holocene.

During Middle Holocene synchronous with the climatic optimum (FIG. 3A) there has been the greatest shift of natural zones to the north for about 3-4°. In some portions of the continent tundra and forest-tundra zones have disappeared completely and the forests directly approached the coast. We had here a predominance of a dark coniferous spruce taiga. During the time interval after Old Holocene the southern boundary of this taiga retreated northwards to a distance in some points up to 1000 km.

Further south in the European part of the USSR there has been a stretch, where along with spruce, pine and birch the forests consisted also of a certain amount of thermophile broadleaf species (oak, linden, elm).

Further south there has been a vast area of broadleaf forests consisting of oaks, linden, elm and other species. As compared with its present boundaries, the zone of broadleaf forests advanced northwards to a distance up to 300 km, while the total width of this stretch along a meridian came



TEXT-FIG. 3A. PALEOGEOGRAPHIC MAP OF THE LATE HOLOCENE
(According to M. I. Neustadt)

I. Zone of the Tundra: Ia, Kola province; Iσ, Eastern European; IB, Western Siberian; Ir, Eastern Siberian
II. Bering Shrub (forest-tundra) Area
III. Forest Zone: IIIa, Eastern European province of the European-Siberian subarea of dark coniferous forests of the Eurasian conifer-forest (tayga) area; strip without broadleaf species; IIIσ, Same; strip with participation of broadleaf species; IIIB, Same; strip with considerable participation of broadleaf species; IIIr, Western Siberian province of the same subarea; strip with predominance of spruce; III Λ, Same; with predominance of Siberian pine; IIIe, Eastern Siberian subarea of clear conifer forests of the same area; III ж, Southern Okhotsk subarea of dark conifer forest.
IV. Kamchatkan Herbaceous and Leaf-forest Area
V. European Broadleaf-forest Area: Va, Carpathian subprovince; Vσ, Polessian subprovince; BV, Middle Russian subprovince
VI. Far Eastern Conifer and Broadleaf-forest Area
VII. Steppe Zone
VIII. Mediterranean Forest Area

Boundaries:

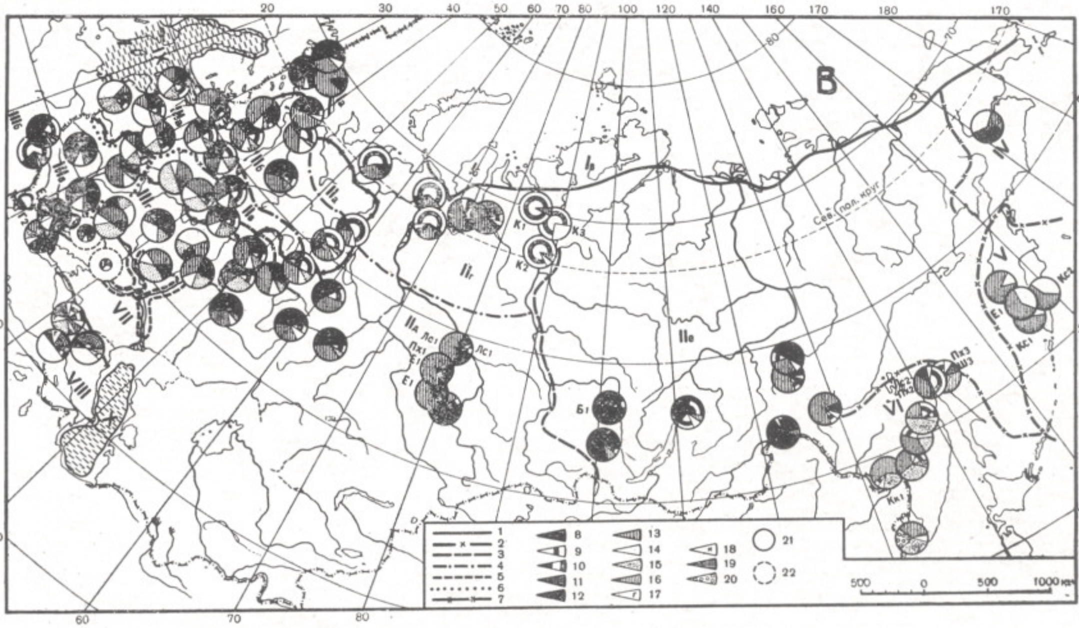
1. Natural zones
2. Botanical areas
3. Subareas
4. Strips of vegetation
5. Presumed natural zones
6. Subprovinces

Symbols on the pollen cyclograms:
7. pine; 8. spruce; 9. fir; 10. larch; 11. Siberian pine; 12. birch; 13. alder; 14. oak & linden & elm; 15. beech; 16. hornbeam; 17. willow; 18. *Pinus pumila*; 19. *Pinus koreyensis*; 20. spectra of the forest type; 21. spectra of the steppe (and forest-steppe) type

to 900 km, instead of the present maximum of 550 km. The Pacific analogue of this zone was the far eastern area of broadleaf forests, which reached the coasts of the Sea of Okhotsk. The main forest-forming species here was *Quercus mongolica*, which in the west reached the Transbaikal region.

In the European part a forest-steppe and steppe strip were located south of this zone. The Caucasus was an independent phytogeographic area with a predominance of beech forests at medium levels. The forest boundary has been by 300-600 m. higher than at present.

During Late Holocene (FIG. 3B), which was characterized by a colder and more humid climate after Middle Holocene the tundra and forest-tundra zone encircles the



TEXT-FIG. 3B. PALAEOGEOGRAPHIC MAP OF THE MIDDLE HOLOCENE
(According to M. I. Neustadt)

I. Zone of the Tundra: Ia, Kola province; 1σ, Western Siberian; I в, Eastern Siberian.
II. Forest Zone: IIa, Eastern European province of the European-Siberian subarea of dark coniferous forests of the Eurasian conifer-forest (tayga) area; strip without broadleaf species; IIσ, Same; strip with participation of broadleaf species; IIв, Same; strip with considerable participation of broadleaf species; IIΓ, Western Siberian province of the same subarea; strip with predominance of spruce; IIД, Same; strip with considerable participation of Siberian pine [*Pinus sibirica*]; IIe, Eastern Siberian subarea of clear conifer forests of the same area.
III. European Broad leaf Area: IIIa, Baltic subprovince; IIIσ, Carpathian subprovince; IIIв, Polessian subprovince; IIIД, Middle Russian subprovince.
IV. Bering Shrub Forest-tundra Area.
V. Kamchatkan Herbaceous and Leaf-forest Area.
VI. Far Eastern Broadleaf-forest Area.
VII. Steppe zone.
VIII. Mediterranean Forest Area.
IX. Littorine Sea.
X. Caspian Sea (according to Leont'yev and Fedorov).

Boundaries:

1. Natural zones
2. Geobotanical areas
3. Subareas
4. Strips of vegetation
5. Presumed natural zones
6. Subprovinces
7. Regions of distribution of peat bogs with horizon

Symbols on pollen cyclograms:

8. pine; 9. spruce; 10. fir; 11. larch; 12. Siberian pine [*Pinus sibirica*]; 13. birch; 14. alder; 15. oak + linden + elm; 16. beech; 17. hornbeam; 18. willow; 19. *kedrovyy slanik* [*Pinus pumila*, a pine of creeping, matted habit]; 20. Korean pine [*Pinus koreyensis*]; 21. spectra of the forest type; 22. spectra of the steppe (and foreststeppe) type.

entire northern coast. The forest zone retreated everywhere from its northern boundary. Simultaneously there is a rapid advance southwards of a dark coniferous taiga with spruce becoming a predominant tree. The northern boundary of the zone of broadleaf forests shifts substantially southwards. The Far Eastern broadleaf area becomes transformed in the north into a subarea of dark coniferous forests and in the south into a coniferous-broadleaf area, etc. The main role belongs here to *Pinus korajensis*, which replaced *Quercus mongolica* over a considerable area. In the southern part of Western Siberia the participation of *Pinus sibirica* has greatly increased in the forest composition. In the Carpathians there is now a wide development of *Fagus silvatica* and *Abies alba*, as well as of *Carpinus betulus*, etc. At the present time these maps have been somewhat detalized and made fuller. These two maps distinctly demonstrate a sharp change in the character of forests and the shifting of natural zone boundaries (NEUSTADT, 1957, 1964).

The above given examples illustrate a striking difference in the vegetation cover of vast territories during the glacial and interglacial periods and a great dynamics of vegetation changes during separate interglacials.

Especially distinctly can be traced changes that took place in the vegetation cover during the Holocene, when geographical zones and subzones were extremely mobile. While during Old Holocene the vegetation cover has been very simple and experienced the mutual influence of various natural factors that also changed during this time, as well as the effect of migration streams, it was getting more and more complex achieving its most complicated structure during Late Holocene. Actually such a character of changes is typical of each interglacial.

From our point of view the determination of these cardinal repeated changes in the vegetation during the Pleistocene and Holocene is one of the greatest successes of the palynological method and paleobotany as a whole during the last twenty-thirty years.

Valuable data have been obtained by a combined application of the palynological method and absolute age determinations by C^{14}. Thus, for instance, lacustrine-bog deposits exposed by Ula river in Lithuania that indicated an interstadial character by palynological data have been assigned an age of 16260 $\pm$ 640 years. This interstadial (named Ula interstadial) preceded the ice advance of the Pomeranian stage.

Age determinations of the last two interstadials permit to trace in a chronological order the degradation of the last glaciation.

A combined application of these methods was especially important for the establishment of the time of processes and phenomena, which took place in the Holocene. In particular, the oldest deposits of a recent bog Polovetz-Kupanskoe (Melekhovo) consisting of deposits of its primary lacustrine stage (sapropels) proved to have an age of 11975 $\pm$ 370 years. This point gives a date for the beginning of the Holocene (12,000 years) and is characterized by a maximum of spruce pollen. After that the development of this tree species diminishes (in some cases from 60 per cent of pollen content to nearly zero). A drop in the spruce curve and a corresponding mount of birch and pine curves indicates by pollen data a transition from Old Holocene to Early Holocene, which by radio-carbon dating is about 10,000 years ago or, by West-European data, corresponds to the boundary between the Late glacial and Postglacial periods. In the light of a combined application of palynological and radiocarbon data as well as the study of bogs a new approach is arising to the problem of the so-called boundary horizon (the age of its upper and lower boundary) in peat bogs, etc.

The results of palynological studies of Pleistocene and Holocene deposits are not only extremely important from a theoretical point of view for the reconstruction of the picture of the Earth's nature (vegetation cover, natural zones, etc.), but are also of outstanding practical value for stratigraphy and geological mapping. In the USSR these results are widely used for the subdivision of Pleistocene deposits of varying age. Data of the palynological analysis greatly helped the determination of Pleistocene stratigraphy; for instance, the existence of Moscow glaciation (*see* scheme) was finally established only by an extensive use of the palynological method. On the basis of a concept established by us that each recent botanical-geographic area and province is characterized by its own course of development of vegetation landscapes, which finds its reflection in a regional type of pollen diagrams, the history of vegetation can serve as a basis for the complication of Holocene regional stratigraphic schemes. On the territory of the USSR 26 schemes of the development of the vegetation cover, are distinguished, which sufficiently distinctly differ from each other and are used as Holocene regional stratigraphic schemes.

This way a relative dating of Holocene deposits becomes possible; with the use of the radiocarbon method this dating can be absolute. These data serve also as a basis for the introduction of tree species.

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