Pergamon

PII: S1040-6182(96)00039-0

Quaternary International, Vols 41/42, pp. 71–96, 1997.

1040-6182/97 $32.00

CLIMATE AND VEGETATION DYNAMICS IN THE TUNDRA AND FOREST ZONE DURING THE LATE GLACIAL AND HOLOCENE

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Analysis of palynological successions has enabled reconstruction of climate variations throughout the Late Glacial and Holocene in the tundra and forest zones of northern Eurasia. Statistical analysis allows estimation of mean annual precipitation, and mean annual and July temperatures, based on palynological assemblages. Thus, the dynamic relationships between climate and vegetation changes can be established. Throughout the Late Glacial and Holocene, climate fluctuations were more dramatic in eastern Europe than in Siberia, primarily as a result of the influence of westerly air masses. In contrast, the "autochthonous" climate of Siberia, dominated by local air masses, was less prone to influence from climate changes elsewhere in the Northern Hemisphere, and shows only an attenuated Younger Dryas signal. Mid-Holocene warming characterizes all of northern Eurasia, although the regions of Siberia most influenced by continental climates show less pronounced cooling during the later Holocene. Sharp changes between summer monsoonal and winter anti-cyclonic regimes characterize the Pacific Maritime region. © 1997 INQUA/Elsevier Science Ltd

INTRODUCTION

The reconstruction of the dynamic elements of past environments is extremely important for understanding both the present state and evolutionary trends in future development. The Late Glacial period and the Holocene which are close to modernity are absolutely vital in this respect.

The Holocene and also partly the Late Glacial palaeoenvironmental development of Northern Eurasia have been intensively studied in Russia since the 1950s (Neustadt, 1957; Khotinsky, 1977). A great number of studies covering the history and vegetation of that area over the period of 12,000–14,000 years has been published during the last few years.

The present article is targeted at the reconstruction of landscape and climatic changes in northern areas of Eastern Europe, and Siberia over the mentioned span of time, based on both our own data and the published records. In doing so we were following the temporal–spatial dynamics of the climate and vegetation in three main latitudinal vegetation zones: (1) the tundra and forest-tundra (north of 68°N); (2) the taiga (60–68°N); (3) mixed and broad-leaved forests (south of 60°N). This differentiated approach enabled us to follow up the emergence of main landscape units in the boreal and Arctic zones of the eastern hemisphere, and to identify regional peculiarities in the vegetational dynamics within each zone, thus forming the base for the inter-zone correlation.

At the same time, one should bear in mind that this approach unavoidably implies a simplification. This was particularly obvious in spatial reconstructions, the studied sequences being distributed unevenly both in space (Fig. 1), and in time (Fig. 2). The northernmost areas are inadequately provided by the available data; the central belt being in a better position, and the southern forest regions being most appropriately characterized by the existing evidence. Consequently, the maximum amount of available data has been used for the reconstruction in the northern area. By contrast, for southern areas, we chose the most reliable sites, with detailed pollen records, supported by radiocarbon measurements, and covering the entire Holocene and the Late Glacial period, thus enabling one to carry out quantitative palaeoclimatic reconstructions.

Estimations of mean July, January and annual temperatures, and the total amount of precipitation, have been obtained for each key site and each pollen assemblage with the use of the informative-statistical method (Klimanov, 1976). The mean statistical error for mean July and annual temperatures being ±0.6°C, that of January ±1°C, and an annual precipitation of 25 mm. Quantitative characteristics are quoted as deviations from the present values.

THE TUNDRA AND FOREST-TUNDRA (NORTH OF 68°N)

The available pollen and radiocarbon evidence for this area being of a limited and fragmentary nature, reconstructions of vegetation and climate here are less detailed than for other regions (Fig. 3). The most informative pollen sequences have been obtained for the second half of the Holocene, covering the end of the Atlantic, the Subboreal and Subatlantic periods, based on the cores from the Khaipudyr estuary, in the northeastern Russian Plain (Fig. 4), and the site of Kazach'e in northern Yakutia (Fig. 5). The sequences referring to the Late Glacial of northern Eurasia are known only from Siberia.

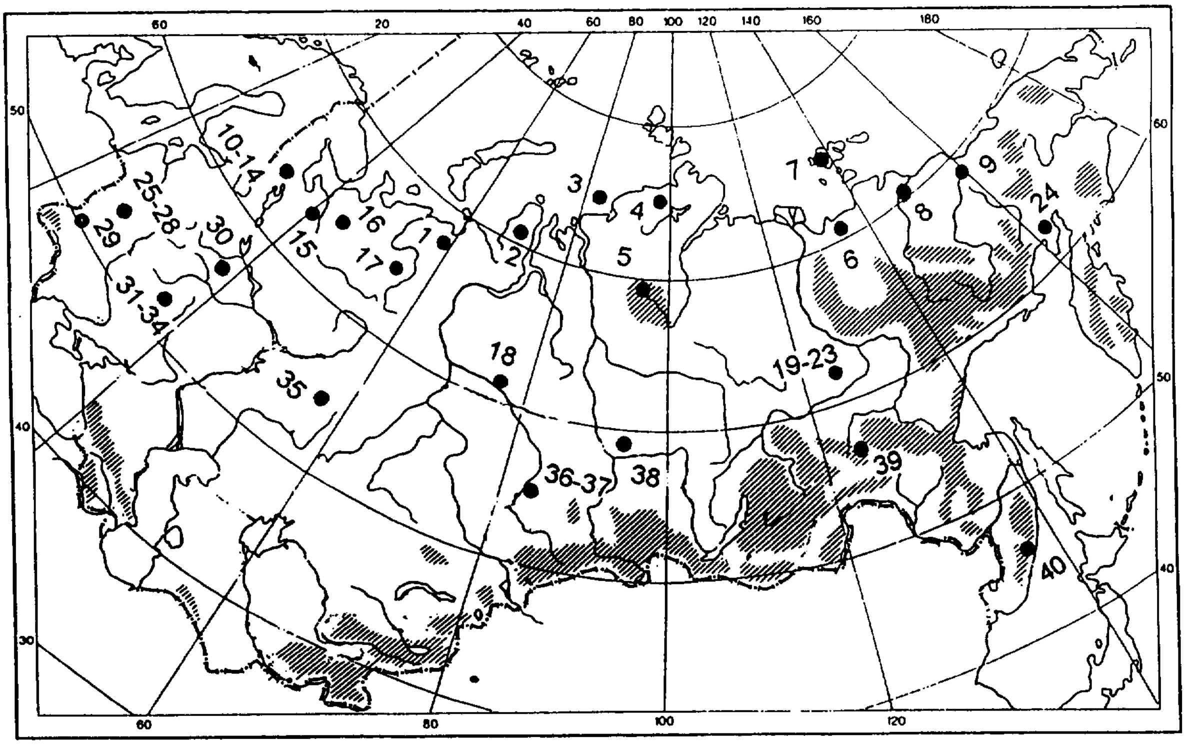

FIG. 1. Location of sites mentioned in the article: 1—Khaipydyrskaya guba; 2—Yamal; 3—Sverdrup Island; 4—Tyimyr; 5—Anabar; 6—Yana; 7—Kotel'ny Island; 8—Indigirka; 9—Kolyma; 10–14—Karelia; 15—Northern Dvina; 16—Seb-boloto; 17—Pechera; 18—Entarnoe; 19-23—Central Yakutia; 24—Penzhina; 25–28—Central Belarus; 29—Maloe Poles'e (Ukraina); 30—Polovetsko-Kupanskoe; 31–34—Tulitsa (center of Russian plain); 35—Bashkiriya; 36–37—Zhukovka (southern part of West Siberia); 38—Enisei mountain range; 39—Southern Yakutia; 40—Primor'e (Far-East).

Judging from the publications (Ukraintseva, 1988, 1990, 1993), the Late Glacial environmental setting in the high latitudes of the western and middle Siberia was basically similar to that of today. Arctic tundra occurred in the north of the Yamal Peninsula, tundra and larch forest-tundra being spread on the Taimyr Peninsula. As quantitative estimates show, the mean July temperatures of the Taimyr Peninsula were similar to the present ones (slightly lower in the Bölling, and higher in the Alleröd). According to Ukraintseva, the maximum cold occurred during the Younger Dryas. Even at that time, however, larch tundra-forest was in existence, large stumps of Younger Dryas being found in presently treeless regions (Ukraintseva, 1990).

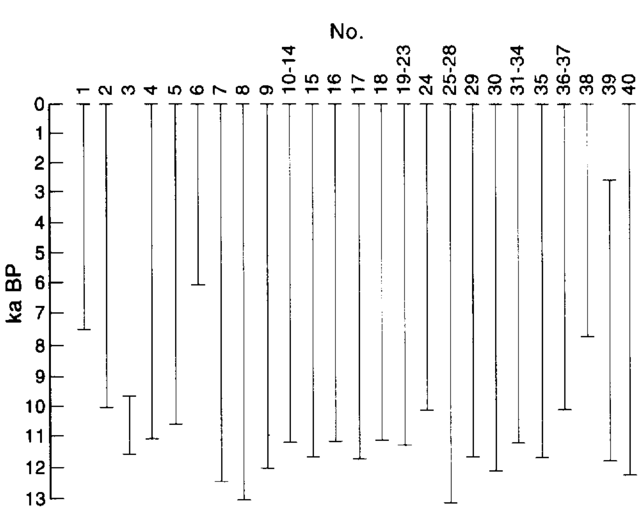

FIG. 2. Chronological range of the sites. The number of sites are the same as in Fig. 1.

At the same time, the data reported from the eastern Taimyr by Nikol'skaya (1980, 1982) suggest the occurrence of tundra vegetation in the mouth of Pravaya Boyarka river, in the area of present-day open larch woodland. According to quantitative estimates based on this evidence (Klimanov and Nikol'skaya, 1983), temperature of that time was similar to that of today, precipitation being less by 25–50 mm. During the maximum Younger Dryas cold, the July temperature was 2–3°C lower than now, that of January was lower by 3–4°C, and precipitation was 100–150 mm less than at present.

Pollen data supported by radiocarbon dates from Sverdrup Island (Andreev and Klimanov, 1994; Andreev *et al.*, this volume), suggest the occurrence of Arctic tundra, alternating with the steppe on the island and the dry shelf of the Kara Sea during the Alleröd. The occurrence of the tundra in the area of present-day Arctic desert implies a higher summer temperature. Dry-resistant associations gaining in importance during the Younger Dryas suggest the climate became drier at that time. Periglacial formations were dominant on the southern slope of the Anabar Plateau (the Annygalian Depression) during the Younger Dryas (Bardeeva and Nikol'skaya, 1988).

Arctic tundra occurring in the present-day northern tundra of coastal lowlands of Yakutia farmed by the Yans, Indigirka and Kolyma rivers during the Late Pleistocene (14,000–15,000 BP), is suggested by the dominance of

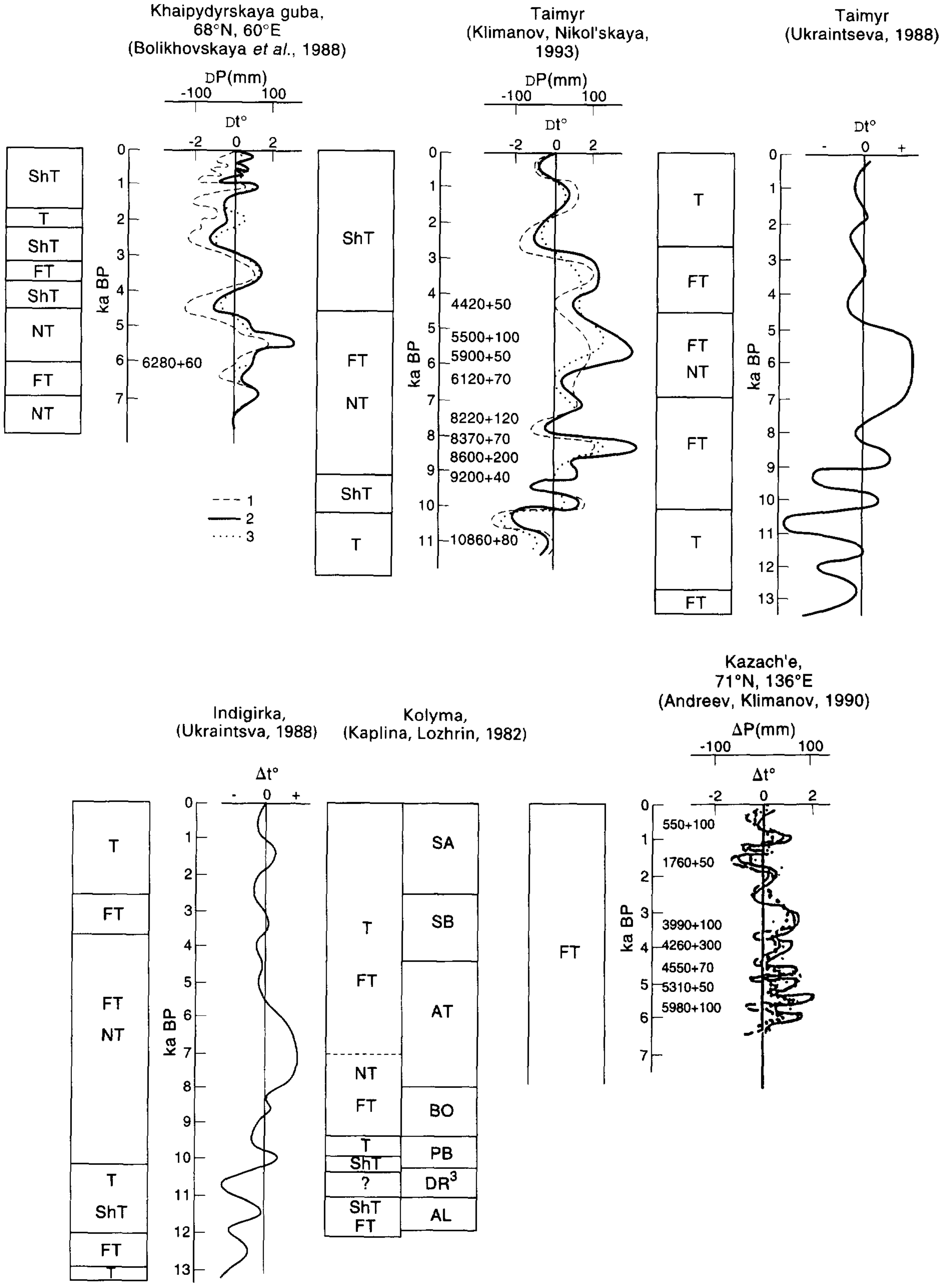

FIG. 3. Vegetation and climate changes in tundra and forest-tundra zones (north from 68°N) during Holocene and Late Glacial time.PC—Periglacial complex (steppe-tundra formation and park forest); T—tundra; ShT—shrub tundra; FT—forest tundra; NT—northern taiga; MT—middle taiga; ST—southern taiga; CF—coniferous forest; BF—broad leaf forest; 1—January temperature; 2—July temperature; 3—annual precipitation.

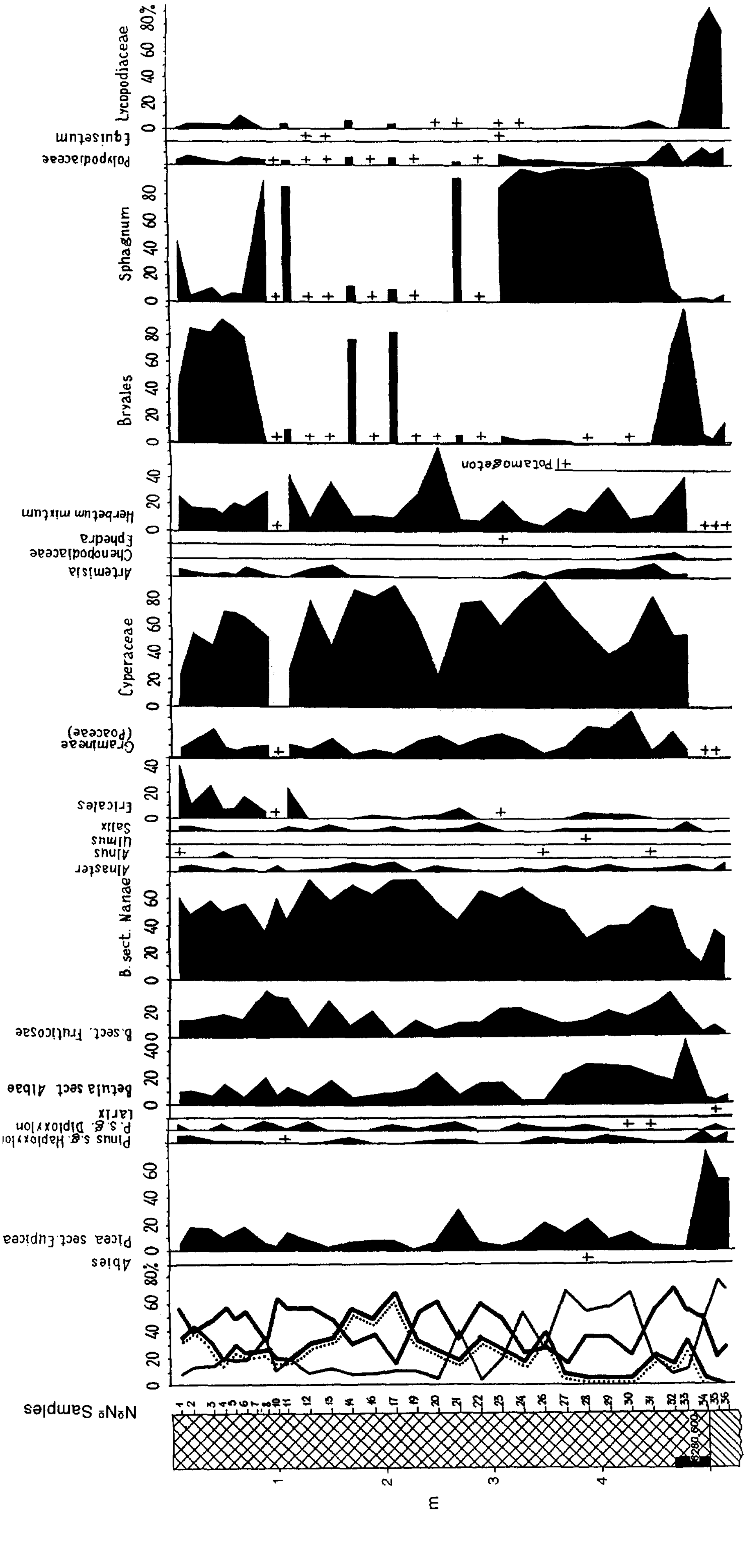

FIG. 4. Pollen diagram of Khaipudyrskaya guba section, 68°N, 60°E. +—pollen frequency less than 1%. [///]—peat; [#]—gyttja; [●]—radiocarbon dated sample.

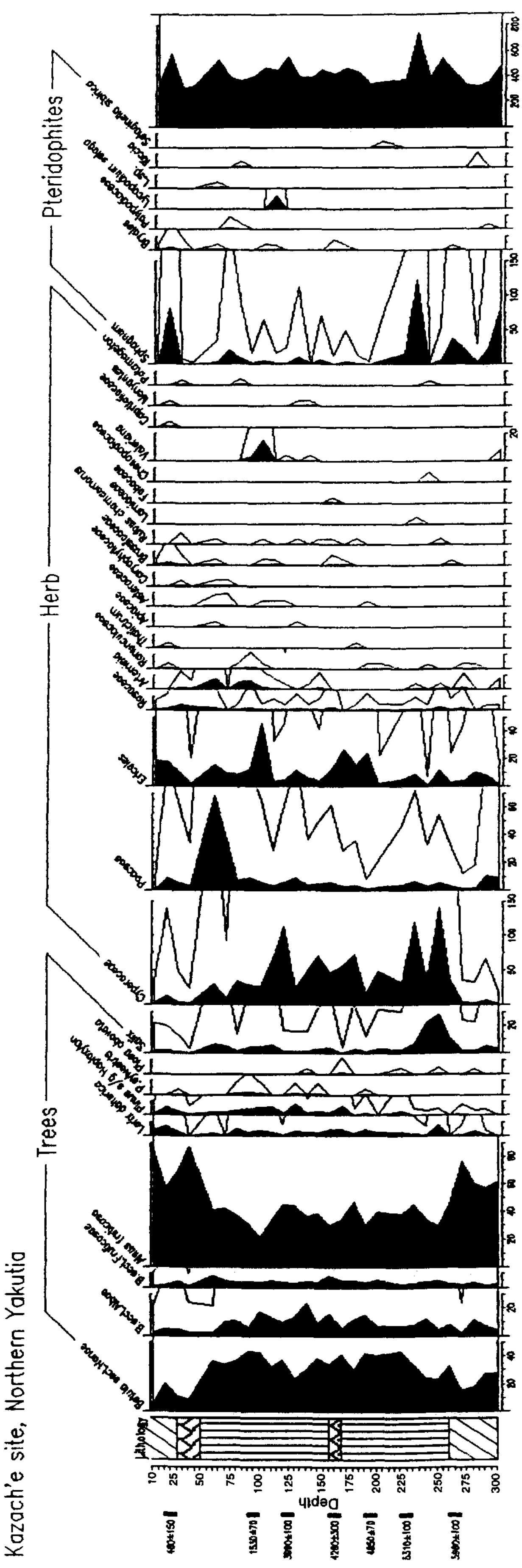

FIG. 5. Pollen diagram of peat section near Kazach'e, Northern Yakutia, 71°N, 136°E. 1—oligotrophic sphagnum peat; 2—mesotrophic sphagnum peat; 3—sedge-sphagnum peat; 4—woody peat.

herbs, and spores of *Bryales* in the pollen spectra (Kaplina and Lozhkin, 1982). The Alleröd spectra show the appearance of the pollen of larch, dwarf and common birch, and shrub alder, suggesting the existence of shrub-tundra and forest-tundra. The occurrence of wood in the present-day tundra area suggests a warmer climate (Kaplina and Lozhkin, 1982). Pollen spectra from the present-day zone of the southern tundra, ^{14}C dated to the Younger Dryas, contain a small amount of dwarf birch, suggesting the vegetation of a northern variety of tundra.

Ukraintseva (1988) argues for the occurrence of forest-tundra and shrub-tundra in the lower Indigirka catchment during the Late Glacial, the climate change being similar to that of the Taimyr, albeit of lesser magnitude. The same author (Ukraintseva *et al.*, 1989), quoting the evidence of a buried peat from the Bol'shoi Lyahkovsky Island and indicating the shrub-tundra with shrub alder and dwarf birch, suggests that the climate was milder than today.

Makeev and Ponomareva (1988) and Makeev *et al.* (1989) quoting the evidence for near-by Kotel'nyi Island, suggest the following sequence of Late Glacial landscape and climate: (1) warm oscillation of 12,200–12,500 BP, with the initial spread of shrub vegetation and the formation of peat; (2) an increased continentality of climate, 10,000–12,200 BP, with an increase of dry-resistant elements in the vegetation cover and the disappearance of arboreal pollen.

Pollen data supported by radiocarbon measurements for the Postglacial period are much more numerous for the entire area of Eurasian high latitude, implying a much more favourable environment for the accumulation of organic matter. In the first half of the Preboreal period, the vegetation in the extreme northeastern area of the Russian Plain featured the dominance of tundra elements and the common occurrence of communities consisting of *Graminae*, *Artemisia* and *Chenopodiaceae*, suggesting the survival of periglacial vegetation (Nikiforova, 1982). The Arctic tundra increasingly gave way to the shrub-tundra further to the east, in the north of the Yamal Peninsula, suggesting a more favourable climate (Ukraintseva, 1988). The vegetation typical of present-day shrub-tundra (with dwarf birch and possibly shrub alder) has been established on Sverdrup Island at the beginning of the Preboreal; the climate being much more favorable than now.

Moss tundra, with dwarf birch and shrub alder, occurred in the Taimyr, with forest-tundra reportedly existing in the south. According to Klimanov and Nikol'skaya (1983) estimates, mean July and January temperatures were 1.5°C higher than now, with precipitation exceeding the present level by 25 mm. Ukraintseva (1988) suggests the spread of larch forest-tundra resulting from the amelioration of climate in the catchment of Ulakhen-Yuryakh river.

On the southern slope of Anabar Plateau, where periglacial associations changed into open larch woodland, the climate was similar to that of today (Bardeeva and Nikol'skaya, 1988).

In the coastal lowland of Yakutia where the pollen spectra contained higher concentrations of *Artemisia*, *Chenopodiaceae*, *Graminea* and the spores of *Bryales*, the vegetation retained periglacial features (Kaplina and Lozhkin, 1982; Lozhkin, 1987). At the same time, Ukraintseva (1988) reports not only the forest-tundra, but also north taiga open woodland in the Indigirka lowlands, thus suggests temperatures slightly above the present level.

Makeev and Ponomareva (1988) and Makeev *et al.* (1989) mention the spread of shrub communities dominated by dwarf birch on Kotelny Island, indicative of a considerable amelioration of climate.

The early Preboreal warm oscillation was the Holocene Climatic optimum for the entire high latitude Arctic area, both the lowland and the islands, the latter forming an elevated part of the mainland. This was due to these areas being situated, at that time, inside the mainland dominated by an extremely continental climate. The subsequent rapid rise of sea-level resulted in the climate being moderated by the influence of the ocean.

A cold stage is recognizable in the Taimyr during the second half of the Preboreal period, ca. 9500 BP. Temperature at that time was 1.0–1.5°C below the present-day, and precipitation was 50 mm less (Klimanov and Nikol'skaya, 1983).

This cold stage led to the disappearance of forest and shrub vegetation in the coastal lowland of Yakutia, even in the present area of larch open woodland (Kaplina and Lozhkin, 1982). Rybakova (1988) reports tundra formations with a significant distribution of dry-resistant communities in the present forest-tundra areas of the middle stretches of the Alazeya river at the end of the Preboreal period, the climate being both colder and drier than now.

The Boreal period featured a significant amelioration of the environmental setting, the maximum rise of temperature being attained at ca. 8500 BP. At that time the limit of forests expanded by 100–120 km north of its present position in the northeastern part of European Russia, the birch woodland taking up the entire forest-tundra and, part of the tundra. Insular birch and spruce forests occurred along the Barents Sea coast, the leading position being taken by *yernik* (dwarf birch formations) and moss tundra (Nikiforova, 1982).

Birch-larch forest-tundra reportedly expanded to the north in the Yamal (Ukraintseva, 1988; Vasil'chuk *et al.*, 1983), and this equally suggests the amelioration of the climate. In the southern regions of Taimyr, birch expanded into the present-day forest-tundra, shrub tundra and larch open woodland, appearing in the present Arctic tundra in the north. Mean July temperature exceeded the present values by 3–4°C, that of January by 2–3°C, and precipitation surpassed the present value by 100–125 mm. Ukraintseva (1988) reconstructs forest-tundra formations spreading over the entire Taimyr in the Boreal period, suggesting that the warm oscillation at 8500 BP was the maximum temperature rise in that area. The latter suggestion is not in agreement with the views of other scholars. The occurrence of a significant warm phase at 8500 BP has been established on the Anabar Plateau, however, where birch and spruce appear in the larch woodland (Bardeeva and Nikol'skaya, 1988).

The emergence of spruce at that time has been reported in the floodplain forests of the middle stretches of Molodo river (the left tributary of the Lena) in the northern Central Yakutia. Mean July temperature exceeded the present one by 1–3°C, and that of January by ca. 3°C (Klimanov and Shofman, 1982).

A significant shift of vegetation zones has been acknowledged in the lower Kolyma and Indigirka (Kaplina and Lozhkin, 1982; Rybakova, 1988) thus suggesting a significant warm oscillation. In Ukraintseva (1988)'s view, the spread of woodland recognized in that area implied a less intense warming than in the Taimyr area. At the same time, the evidence for Kotelny Island further north indicates a restriction of shrub-type vegetation and an increased domination of grass tundra, supposedly resulting from the submergence of the continental shelf and the subsequent increased humidity and the lowering of summer temperature.

The end of the Boreal period in the northeastern European Russia was marked by a short-lived, yet intensive, cold. The southern limit of the tundra zone which was formed at that time along the Barents Sea coast, coincided with its present position in the west, shifting northward in the east. *Yernik*, shrub and moss tundra were dominant in the vegetation cover (Nikiforova, 1982).

The beginning of the Atlantic period in the European North marked a further shift of vegetation zones by at least 100–150 km to the north. The middle substage was relatively cool, with an increase of birch forests and *yernik* formations. The peak in the development of forest woodland was attained 5000–6000 BP, featuring the participation of fir, Siberian pine and common pine in predominantly spruce woodland (Nikiforova, 1982).

Pollen sequences with radiocarbon dates obtained for the site near the Khaipudyr estuary of the Barents Sea (Bolikhovskaya *et al.*, 1988) provide a basis for the detailed reconstruction of the vegetation and the climate in that area (see Fig. 4). The spread of spruce woodland, of northern taiga type, with the participation of larch and Siberian pine has been recognized for the Early Atlantic stage. Woodland reached the sea coast during the Mid Atlantic. Figure 3 shows quantitative estimates of the climate.

During the Atlantic period, birch forest-tundra gave way to north-taiga woodland with a considerable participation of spruce in the south of the Yamal Peninsula. The second half of this period corresponded to the climatic optimum in that area (Vasil'chuk *et al.*, 1983). Similar changes in the composition of the vegetation during the Atlantic period are acknowledgeable in the Taimyr, the climatic characteristics in that area being basically similar to that of the northeastern European Russia (Klimanov and Nikol'skaya, 1983). At the same time, spruce, birch and larch woodland with fir were dominant in the south of the Anabar Plateau, where the climate was warmer than now (Bardeeva and Nikol'skaya, 1988).

The vegetation on the coastal lowland of Yakutia remained basically unchanged at the beginning of the Atlantic period, the climate being much warmer than today (Kaplina and Lozhkin, 1982; Ukraintseva, 1988). The warming was insignificant on the New Siberia Islands, in the north (Makeev and Ponomareva, 1988). A southern shift of vegetation zones, implying a significant cooling, has been recognized for the end of the period.

An asynchronous character of landscape-climatic changes recognized for the coastal lowland of Yakutia in relation to other areas, probably resulted from the ongoing rise of sea-level and the marine transgression during the second half of the Atlantic. This led to the climate in the areas south of the Arctic Ocean becoming less continental. Similar oceanic influence on the climate has been identified on the coast of the Chukchi Sea (Polyakova and Danilov, 1988).

Detailed reconstruction of the vegetation and the climate over the period of 6000 years, obtained for the coastal lowland (Fig. 3), are largely based on the pollen records and ^{14}C dates from a peat-bog in the Lower Yana river at Kazach'e (Fig. 5). These data show that during the second half of the Holocene, the local vegetation consisted of open larch woodland with shrub alder, alternating with the *yernik* of the dwarf birch and dwarf willow, the climate at ca. 6000 BP being slightly warmer than now. For the entire Atlantic period, four warm stages separated by coolings are acknowledgeable. These oscillations are well in agreement with those established at the peat-bog of Khaipudyr bai in northeastern European Russia.

During the course of the early Subboreal cool phase, tundra-type associations in northeastern European Russia became the dominant element of the vegetation at the expense of woodland, the limit of the latter drifting by 100–150 km to the south (Nikiforova, 1982). By the middle of this period, the woodland advanced to the north, again reaching the coastline, thus implying a new significant amelioration of the climate. The end of the period was marked by the reduction of spruce woodland and a new rise of shrub formations.

In the Khaipudyr mouth area, the beginning of the period corresponded to the northern forests changing into shrub formations, designating a significant cooling. The middle Subboreal mild phase encouraged the spread of spruce forests including Siberian fir and Siberian pine to the north. Yernik-type tundra became dominant by the end of this period. On the Yamal Peninsula during the Subboreal period, the forest limit shifted to the south; woodland generally changing into forest-tundra, and typical tundra, at the later stage. Precipitation markedly rose, while temperature decreased (Vasil'chuk *et al.*, 1983; Ukraintseva, 1988).

Birch were eliminated from the woodland in the Taimyr, and the forest-tundra shifted to the south. According to our estimates, the temperature was similar to the present one; Ukraintseva (1988) suggested a small fall.

In the south of Anabar Plateau, the composition of woodland only changed slightly. By the end of the period, larch forests with the participation of spruce and birch gave way to open larch woodland. Climatic characteristics remained above the present values (Bardeeva and Nikol'skaya, 1988).

In the coastal lowland of Yakutia, no significant changes in the vegetation are reported. Ukraintseva (1988) suggests that tundra vegetation replaced the forest-tundra in the northern regions, temperatures being slightly less than at present.

A pronounced cooling at the beginning of the Subatlantic period in the northeastern European Russia, caused the vegetation zones to shift to the south by 100–150 km (Nikiforova, 1982). The same cooling led to the spread of the tundra zone, recognizable in the area of the Khaipudyr embayment in the Barents Sea (Bolikhovskaya *et al.*, 1988). The middle Subatlantic phase was relatively mild in that area, with spruce woodland partly restored and the yernik tundra remaining dominant. The latter particularly gained in importance by the end of this period, reaching its present-day position. Several mild oscillations are identified at the sequence of the Khaipudyr embayment, with a maximum rise of temperature of 1.0–1.5°C at ca. 1000 BP, combined with precipitation exceeding the present values by 50 mm. The grass tundra at that time gave way to the shrub tundra. The northern expansion of woodland, at a lesser intensity, is equally identifiable as in the Atlantic period in the south of Yamal (Vasil'chuk *et al.*, 1983).

A vegetation assemblage similar to the present dominated the Taimyr. The July mean temperatures were 1°C higher than modern values, and those for January were 1.5°C higher, with the precipitation exceeding present values by 25–50 mm (Klimanov and Nikol'skaya, 1983). Shrub tundra dominated the vegetation on the Anabar Plateau, the climate being slightly warmer than now (Bardeeva and Nikol'skaya, 1988).

The pollen data on the coastal lowland of Yakutia suggest that the vegetation was basically similar to the present. A small climatic optimum with a temperature rise of 1°C is recognizable at the end of the period. A cooling comparable to the Little Ice Age may be identified only in the sequence of the Khaipudyr embayment; July temperatures were 1°C, and those of January by 2°C lower than presently, precipitation being similar to that of today. Similar cooling with average temperatures of 1°C lower than now, and precipitation 25–50 mm less than presently, is recognized in the Taimyr (Klimanov and Nikol'skaya, 1983).

Based on the available, albeit limited, evidence, one may suggest dynamic movement of the vegetation cover in the high latitudes (Fig. 6). It is remarkable that the Younger Dryas cooling is identifiable both in the west and east of that area. The Preboreal warming and the late Atlantic interval caused dramatic restructuring in the tundra. The southern limit of the tundra shifted at that time by 100–150 km to the north. Taiga including spruce and fir

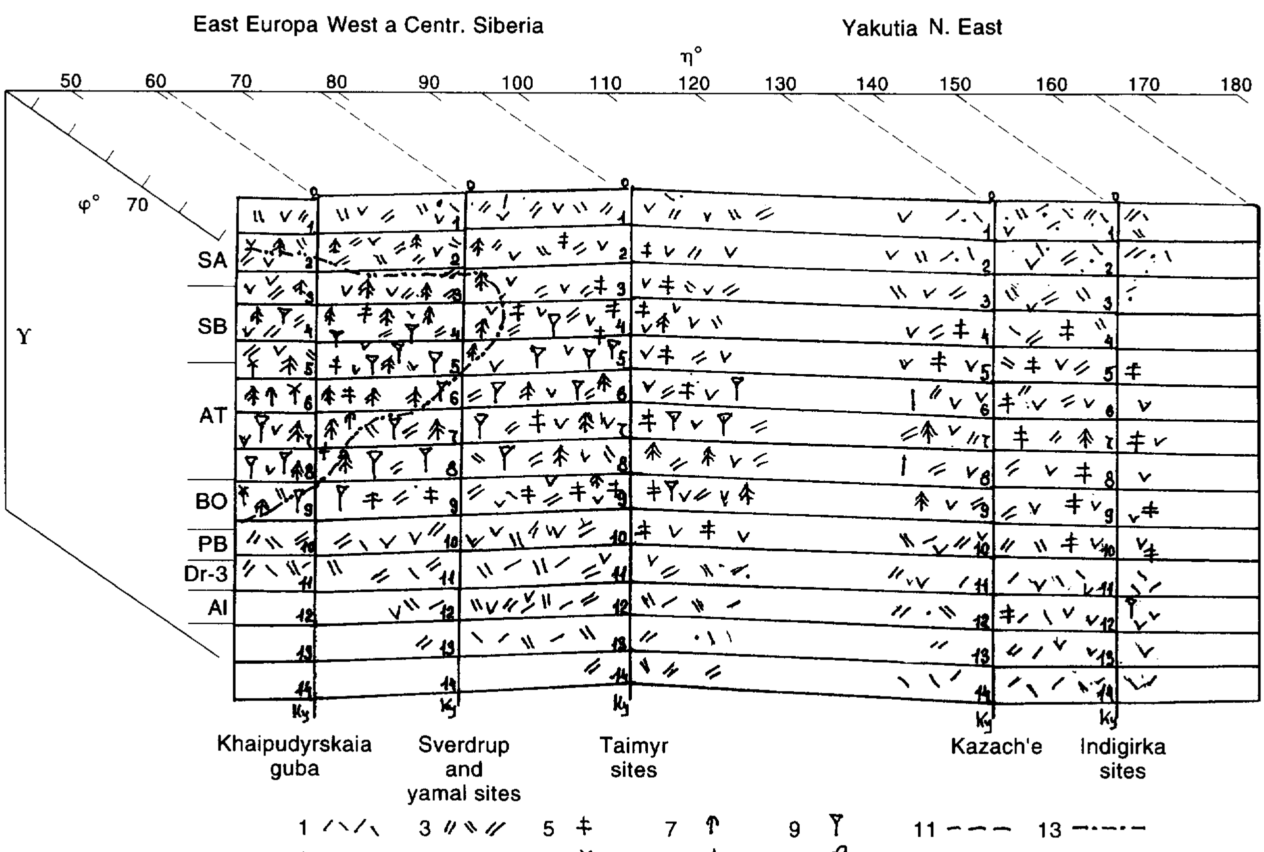

FIG. 6. Vegetation dynamics in tundra and forest-tundra zones (north of 68°N) during Holocene and Late Glacial time: 1—periglacial vegetation complex; 2—arctic desert; 3—tundra; 4—shrub tundra; 5—larch; 6—pine; 7—fir; 8—spruce; 9—birch; 10—broad leaved trees; 11—forests with spruce domination; 12—forests with associated broad leaved trees; 13—forests with broad leaved trees dominant; 14—forests with spruce.

spread in the tundra area of northeastern European Russia. Large expanses of woodland are evident in the European sector until the beginning of the Subatlantic period.

THE FOREST ZONE, 60°–68°N

The number of the sites studied in this zone is considerable, with several sequences covering the entire Holocene and extending over to the Alleröd and Younger Dryas. The reconstruction of vegetation and climate based on this evidence is much clearer than those suggested for the northern areas (Fig. 7, Table 1)

Two sequences are considered as the key sites. The key-site for the western area is that of the Sebboloto peat-bog, on the right bank of the Pinega river (Fig. 8) (Yurkovskaya *et al.*, 1989). The lacustrine sequence of Khomustakh, in the middle reaches of the Vilyui river near the town of Vilyuisk, is considered as the key site for the eastern sector (Fig. 9) (Andreev *et al.*, 1989).

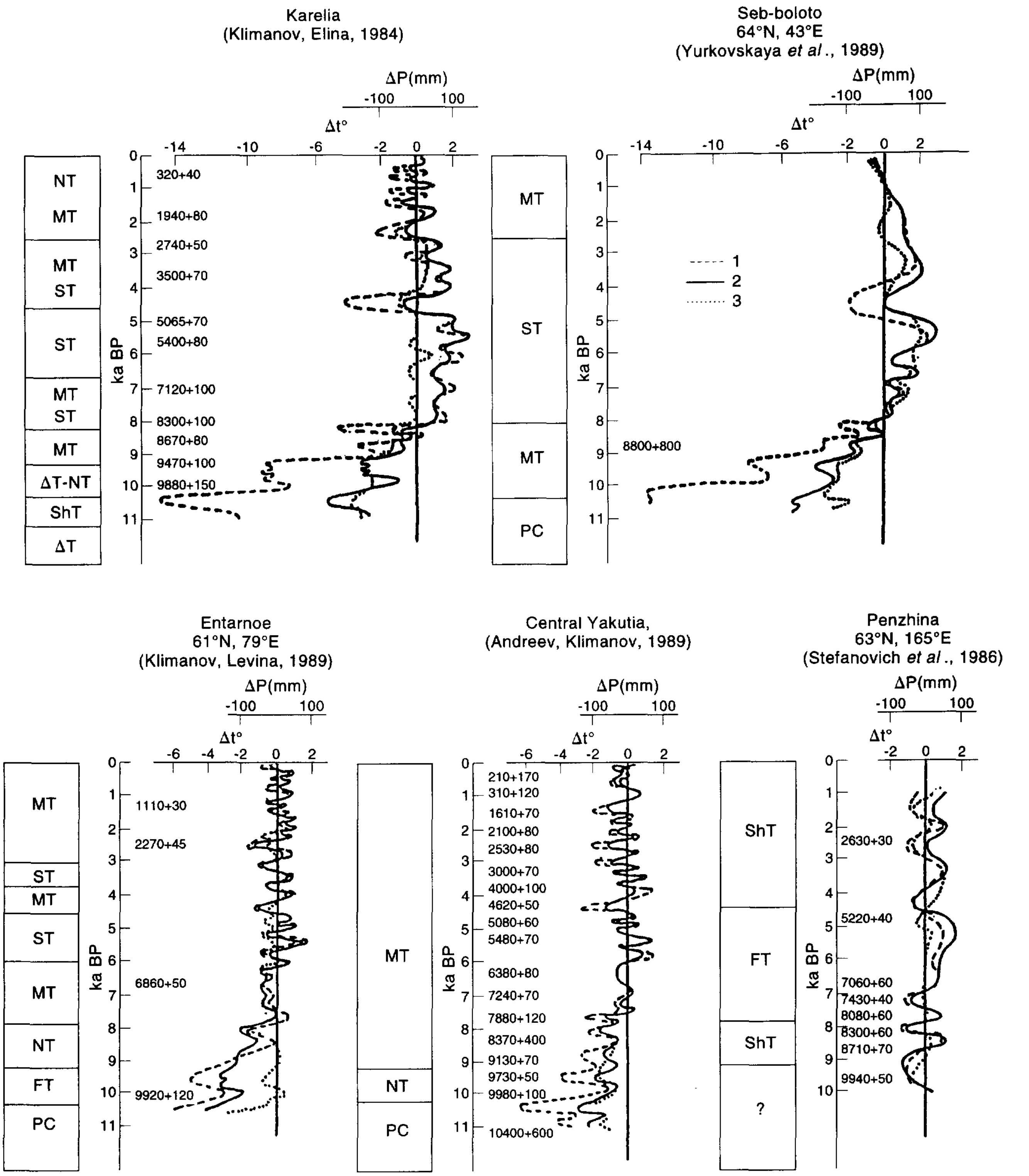

FIG. 7. Vegetation and climate changes in forest zone (60–68°N) during Holocene and Late Glacial time. For the explanation see Fig. 3.

TABLE 1. 5 sites 60–68°N

Periods	Year BP	ΔT_{VII} 34°	43°	79°	125°	165°	ΔT_{I} 34°	43°	79°	125°	165°	ΔPrecipitation (mm) 34°	43°	79°	125°	165°
SA	700	−1	−1	0	−1		−1.5÷	−1	−1	−0.5÷1		−25	−50	0	−50	—
	1000	−1÷1.5	?	−1	1	−1	1	?	−1	−2	0 ?	−25÷50	?	−25	−25÷50	—
	2500	−1	?	−1	−1	−1	−2÷3	?	−1÷2	−1	−1	−50÷75	?	−25÷50	−50	—
SB	3500	−2	−2	−1	−1	1	−2	−1.5÷2	−1	−2	−1	−25	−50	−50	−50	—
	4500	−1÷1.5	0	−1	−1	−0.5÷1	−4÷5	−2÷3	−1	−2÷3	−0.5÷1	−50÷75	0	−25	−50÷75	—
AT	5500	−3	−3	−1.5÷2	−1.5	−1.5÷2	−3	−2÷3	−1.5÷2	−1.5	−1	0	−100	0	−50÷75	—
BO	8300	−1.5	−1	−2	−1÷1.5	−1	−5	−3	−2	−2÷3	−1.5	−75	−25÷50	−50÷75	−25	−50
	8500	0	0	−1	−0÷0.5	1	−1	−1÷2	0	−0.5÷1	1	0	0	0	−50÷75	−25
PB	9500	−3÷4	−3÷4	−3	−2	−1	−8÷9	−8	−5	−4	−1.5	−150	−125÷150	−50	−50÷75	−25÷50
	9900	−1.5	−3	−2	−0.5	0	−7	−6÷7	−3	−1	−1	−100÷150	−100÷150	−25	−25	−25
Dr-3	10,500	−6	−5	−4	−2.5		−14÷16	−14	−6÷7	−6		−150÷200	−175÷200	−150	−150	—
All	11,300	−4			−1.5		−10			−3		−100÷150			−75	—

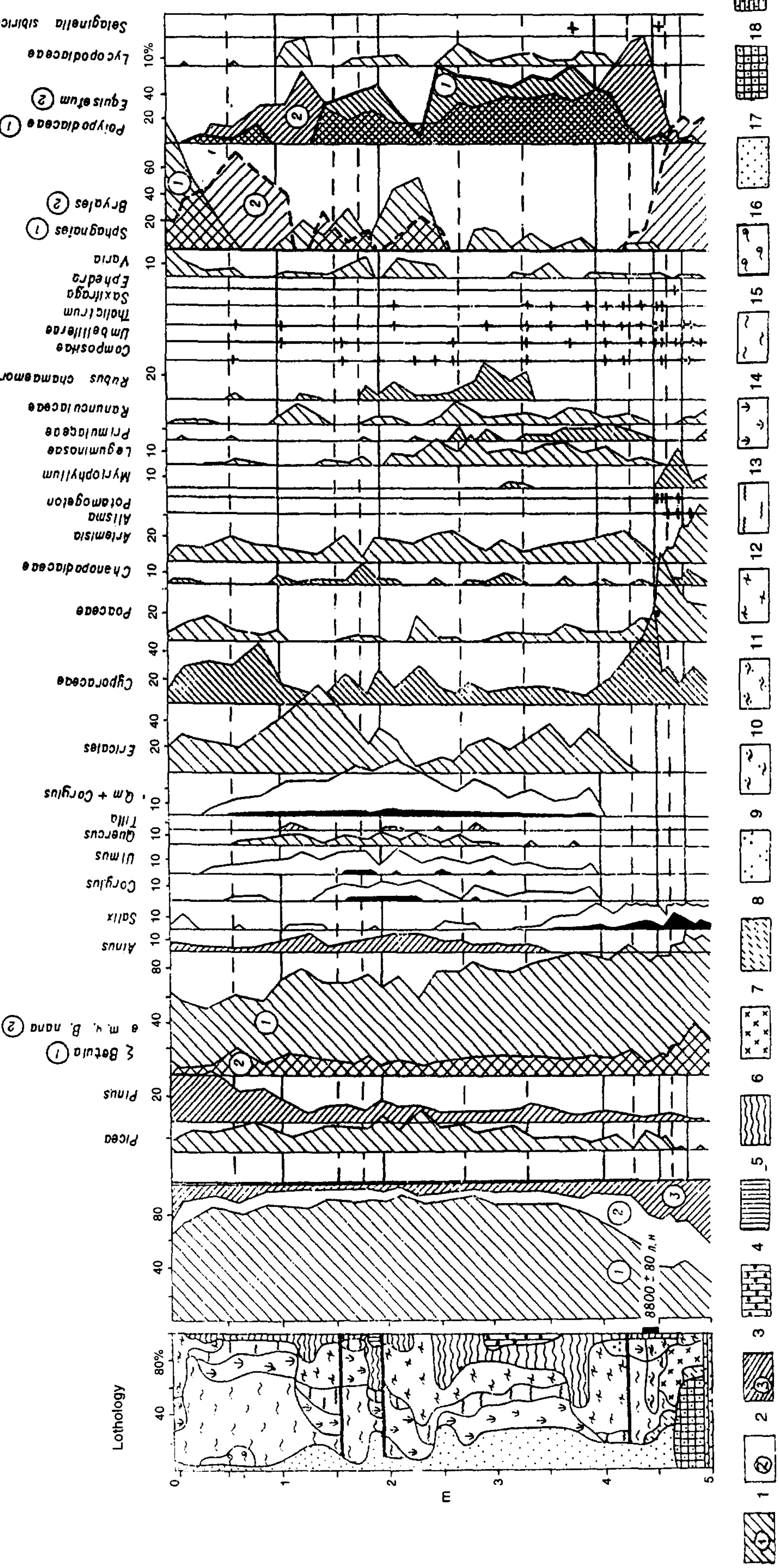

FIG. 8. Pollen diagram of Seb-boloto section (Arkhangelsk region, 64°N, 43°E): 1—tree pollen; 2—herb pollen; 3—spores; 4—pine macrofossils; 5—wood macrofossils; 6—Eriophorum macrofossils; 7—Equisetum macrofossil; 8—Bryales macrofossil; 9—Politrichum; 10—Sphagnum teres; 11—S.warnstorfii; 12—S.fuscum; 13—S.magelanicum; 14—S.angustifolium; 15—S.balticum; 16—S.majus; 17—indeterminate plant remains; 18—gyttja; 19—clayey sands.

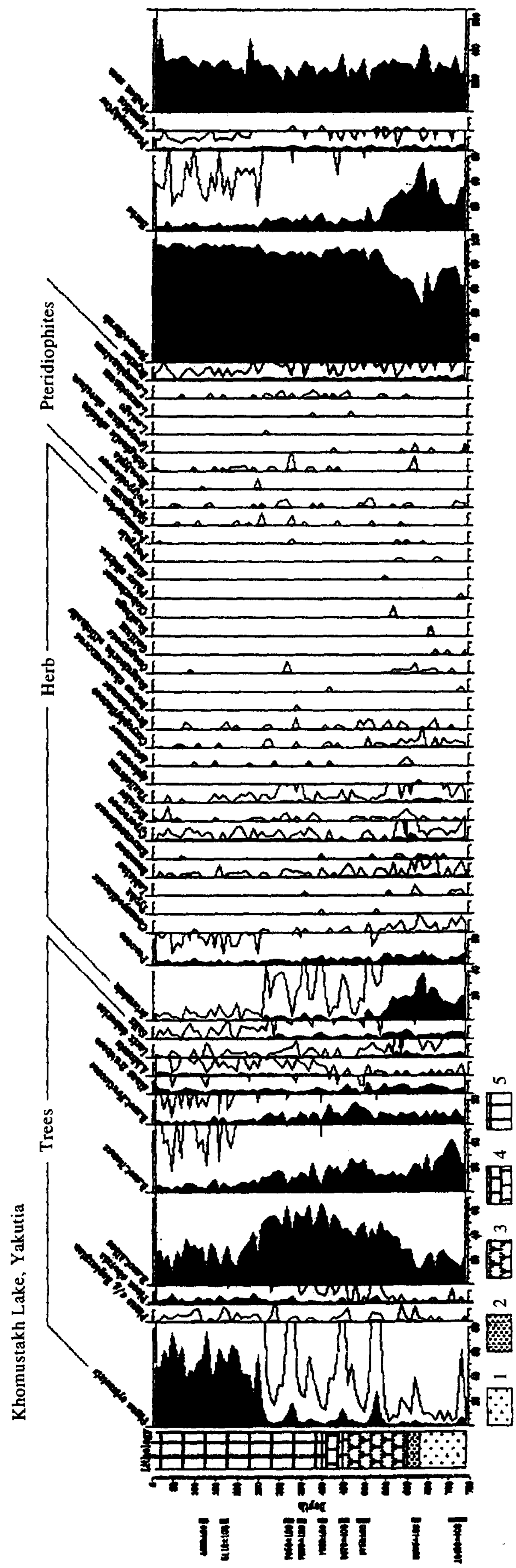

FIG. 9. Pollen diagram of Khomustakh section, Central Yakutia, 63°N, 121°E: 1—clayey sands; 2—clayey gyttja; 3—calcareous algal gyttja; 4—calcareous-ferrous gyttja; 5—ferrous gyttja.

THE LATE GLACIAL

Open birch woodland dominated the vegetation of northern Karelia during the Alleröd, the proportion of spruce increasing in the southern areas (Elina, 1981). The areas taken up by periglacial vegetation were considerable, with tundra elements in the north and steppic ones in the south. Insular birch and spruce forests, alternating with the yernik and wormwood-grass steppe, occurred further east, on the right bank of the Northern Dvina (Elina and Yurkovskaya, 1980), as well as in northeastern European Russia (Nikiforova, 1982).

Wormwood-grass steppe, yernik consisting of dwarf birch, and open birch woodland with spruce and larch, were the dominant types of vegetation in western Siberia (Arkhipov *et al.*, 1980). Wormwood-grass steppe, alternating with yernik and steppic larch and birch woodland were most common in Yakutia during the Alleröd (Andreev *et al.*, 1989).

According to our estimates, based on the evidence for Karelia and central Yakutia, during the maximum Alleröd warming, ca. 11,500 BP mean July temperature was about 4°C below the present level in the west and ±1.5°C in the east. Respective figures for January are 10°C and 3°C. Precipitation was 100–150 mm less than now in Karelia and 75 mm less in Yakutia.

Periglacial tundra and steppe communities were dominant in northern Karelia during the Younger Dryas. The forest-tundra with periglacial elements was more common in the south (Elina, 1981). Periglacial formations gained equally in importance on the right bank of the Northern Dvina (Elina and Yurkovskaya, 1980). Tundra-type landscapes with dwarf birch and willow, alternating with steppe, have been identified at Sebboloto peat-bog. Nikiforova (1982) also reports the degradation of woodland in northeastern European Russia during the Younger Dryas. At the same time wormwood-grass steppe communities expanded in central Yakutia, the areas occupied by the *yernik* and particularly by woodland diminishing (Andreev *et al.*, 1989).

Seen as a whole, during the maximum Younger Dryas cold at ca. 10,500 BP, the mean July temperature was 6°C colder in the west, and 2.5°C in the east. The figures for January were, respectively, 14–16°C and 6°C. The deviation of precipitation was less pronounced in the west than in the east.

The Late/Post Glacial boundary at 10,300 BP is clearly identifiable by the degradation of the periglacial vegetational complex, accompanied by the rapid rise of forest formation throughout northern Eurasia.

The Preboreal period in northern Karelia was marked by the active spread of birch, with spruce woodland dominating in the south (Elina, 1981). The left bank of the Northern Dvina was equally dominated by birch woodland, pine forests with the admixture of spruce and birch being more common further east (the basins of the Vychegda and Pinega). Spruce and birch open woodland replaced periglacial landscapes in western Siberia (Volkova and Levina, 1985). Larch-birch forests of the north-taiga type, retaining steppe elements, remained dominant in central Yakutia during the first half of the Preboreal period.

During the Preboreal climatic optimum, ca. 9900 BP, the mean January temperature remained below the present figures: by 7°C in Karelia, and by 1°C in central Yakutia. The deviations of the July temperature and precipitation were of a more complex character. The July temperature remained below the present by 1.5°C in Karelia; by 3°C in Archangelsk district; by 2°C in western Siberia; and by 1°C in Yakutia, approaching the present values in the area of Penzha mouth. The precipitation total was 100 mm lower than now in Karelia, it exceeded the present level by 25 mm in western Siberia, and further east was 25 mm less than at present.

Certain rises in periglacial elements, indicative of cooling, are acknowledgeable during the second half of the Preboreal period. In contrast to the previous substage during Preboreal time the deviations of July and January temperatures, as well as of precipitation, regularly diminish from west to east, January's deviations being of greater magnitude than those of July.

The Boreal period featured a further enhancement in the position of forest formations. Birch woodland of north-taiga type occupied northern Karelia, spruce appearing further south. Treeless areas disappeared from the Archangelsk district, where birch and spruce forests of middle-taiga type were dominant. Dark coniferous spruce forests were dominant in northeastern European Russia.

Open spruce-birch woodland prevailed in western Siberia. A further development of yernik and wormwood-grass formations proceeded in Yakutia. Larch–birch forests of middle-taiga type gave way to larch forests of middle-taiga type with rare pine. In the extreme east at the Penzhina mouth, scrub tundra, with dominant alder assemblages, have been reported (Borisova, 1988).

During the maximum Boreal warming, ca. 8500 BP, one may witness a distortion of the earlier established regular diminishment in the deviations of temperature and precipitation from the west to the east. The mean July temperature exceeded the present value in the area from Karelia to western Siberia, being below the present level in central Siberia, and exceeding the present ones further east, in the Penzhaina mouth. A more complicated pattern has been established for January temperatures. They were below present in European Russia, the magnitude of deviation diminishing in the direction of western Siberia, then rising again in Yakutia and exceeding the present values in the Penzhina mouth area. Precipitation in the area from Karelia to western Siberia was similar to the present, being 25 mm below the present level in Yakutia, and exceeding it by the same amount in the Penzhina mouth area. The late Boreal cooling at ca. 8200 BP, shows a regular decrease in the deviations of the January temperature from the west to the east, the trend being less clear for the July temperature and precipitation.

The Atlantic period, and particularly its final third, 4500–6000 BP, was the time-span most favourable for the development of forest vegetation in Karelia. Pine and spruce woodland of south-taiga type, with the presence of elm, oak (and lime in the south) form mixed forests. The appearance of broad-leaved species has been acknowledged in the Archangelsk district and in northeastern European Russia.

Birch–spruce, pine–birch and spruce forests were dominant in western Siberia during the first half of the Atlantic period (Glebov and Toleiko, 1974; Volkova, 1988). During the second half of this period, in suburalian forests one notes the enhancement in the importance of fir and Siberian pine, as well as the appearance of elm and oak. Spruce forests, often with an admixture of fir and Siberian pine, gained in importance further east, in the Tomsk district and the Yenisei left bank.

In the Nizhnyaya Tunguska/Podkamennaya Tunguska interfluve (Kutaf'eva, 1975), during the first half of the Atlantic period, spruce–birch forests prevailed in the west, and birch–larch woodland dominated in the east. Spruce, fir and Siberian pine dark coniferous forests developed during the second half of this period.

Larch woodland of the middle-taiga type with rare pine and spruce prevailed in central Yakutia during the first half of the Atlantic. During its second half, after 6000 BP, pine forests became dominant on sandy soils, spruce woodland prevailing in other areas. In the Penzhina mouth, where shrub forests remained dominant, one notes an increased development of shrub pine, common birch and alder.

Seen as a whole, several warm and cold oscillations may be identified in the course of the Atlantic period. Temperature during the cool sub-stages never fell below the present values in European Russia, although this was the case in Siberia. During the climatic optimum, at 5–6 ka ago, temperature exceeded the present value throughout the latitudinal zone, gradually diminishing from the west to the east. Precipitation totals in Karelia and central western Siberia approached present values, exceeding this level in the Archangelsk district (by 100 mm), Yakutia (by 50 mm), and in the Penzhina estuary (by 25 mm). The estimated variations may also be due to the difference in latitude (Yentarnoe site in western Siberia situated further south, and Sebboloto in the Archangelsk area further north).

The Subboreal period. A marked change in the vegetation resulting from a significant cooling, is noted throughout the area at the Atlantic/Subboreal transition. In European Russia and the subralian part of western Siberia, this took the form of reduction and later a disappearance of broad-leaved elements. Spruce combined with pine became dominant in Karelia. An increased proportion of pine in predominantly spruce forests is remarkable in the Archangelsk district. In central western Siberia, one notes the disappearance of fir and the reduction of Siberian pine, combined with an increase in common birch. In the Nizhnyaya Tunguska/Podkamennaya Tunguska interfluve, a reduction in fir, Siberian pine and spruce was accompanied by increased importance of pine and larch (Kutaf'eva, 1975).

A reduction of spruce and an increase in the importance of *yernik* communities has been reported in central Yakutia. Shrub tundra, including shrub-alder and dwarf birch, became dominant in the Penzhina mouth area.

Deviations of temperature and precipitation fail to show a clear pattern, yet a general trend in the reduction in the eastern direction is acknowledgeable. A partial revival of the communities dominant at the end of the Atlantic period, universally identifiable in the middle Subatlantic, obviously resulted from an amelioration of the climate. During the maximum warming, at ca. 3500 BP, the temperature deviations were higher in the west, and those of precipitation were generally uniform. In general terms, during the course of the Subboreal period, as in the Atlantic, temperatures never fell below the present values, the only exception being Siberia. In the Siberian northeast, however, the temperature remained above the present level.

In the Subatlantic period the vegetation throughout the area acquired its present features. Pine and spruce-pine forests became dominant in Karelia, broad-leaved elements totally disappearing in their composition, and only elm and lime occasionally occurring in the southeast. The importance of pine and pine–birch forests grew on the left bank of the Northern Dvina, where the areas of spruce forests diminished. In suburalian western Siberia, the participation of spruce and Siberian pine diminished, accompanied by an increase of common pine and birch, with Siberian pine forests gaining in importance further east (Glebov and Toleiko, 1974).

Pine gained ground in the Nizhnyaya Tunguska/Podkamennaya Tunguska interfluve. Pine–larch forests dominated in its eastern part, and pine–larch forests with spruce and Siberian pine in the west. In the Penzhina mouth area, the vegetation was of its present character.

During the cooling at the Subboreal/Subatlantic boundary, ca. 2500 BP, the deviations of the January temperature were greater in the west, those of July being uniform. Precipitation deviations were greater in the west.

During the course of the Little Climatic Optimum, ca. 1000 BP, the characteristics of the climate were universally above the present values, the deviations being fairly uniform. Several minor oscillations were established for the subsequent Little Ice Age. The maximum cooling occurred in Karelia at the beginning of this stage, while it corresponded to its end in western Siberia. One may ascertain that temperature deviations were greater in the west, no such trend being obvious in relation to precipitation.

Summing up the evidence for the entire latitudinal zone, from Karelia to Penzhina, one may ascertain that several major climatic oscillations, such as the Alleröd and Younger Dryas are acknowledgeable throughout that area, as far as eastern Siberia. In this case the speculations about the role of cold melt-water in the northern Atlantic hardly make sense. Yet another universal feature was the penetration of southern warm-loving species far to the north during the Atlantic period: spruce in Yakutia, broad-leaved elements in western Siberia, and particularly in eastern Europe, where coniferous–broad-leaved forests emerged during the second half of the Atlantic period.

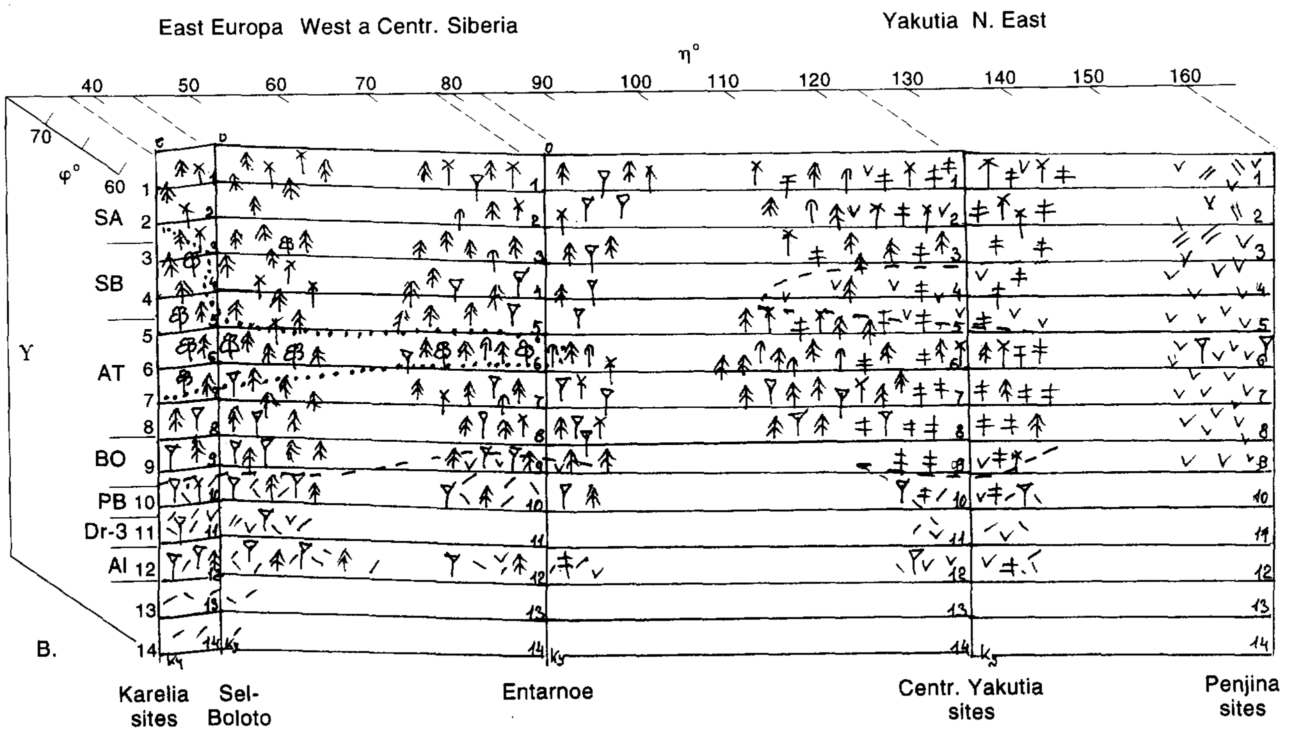

FIG. 10. Vegetation dynamics in forest zone (60–68°N) during Holocene and Late Glacial time. For the explanation, see Fig. 6.

THE FOREST ZONE (60°–54°N)

This zone being characterized by the largest number of well-dated pollen diagrams, much more detailed reconstructions of the vegetation and climate are available for it covering the time-span from the Alleröd to the present time (Figs 10 and 11, Table 2). As the key-site for the western sector, we are using the sequence of Polovetsko-Kupanskoye peat-bog near the town of Pereyaslavl'-Zalesky in central Russia (Fig. 12) (Khotinsky *et al.*, 1991). The sequence of Suollakh in southern Yakutia is the key-site for the eastern or Siberian section (Fig. 13) (Andreev and Klimanov, 1994).

During the Alleröd, birch–pine, pine and spruce forests with a limited participation of broad-leaved elements in the south prevailed in the western sector. Grass–herb communities occurred in open places (Yakushko *et al.*, 1988). Pine woodland with birch, and a limited number of broad-leaved species, spread in the Ukraine. Steppe dominated by wormwood took up large areas (Bezus'ko *et al.*, 1988).

Pine–birch open woodland occurred along river valleys in the central Russian upland, communities with *Chenopodiaceae* covering upper levels (Serebryannaya, 1982; Klimanov and Serebryannaya, 1986). In the Upper Volga catchment, spruce and birch forests were dominant, although large areas were taken up by tundra and steppe communities.

The periglacial vegetation was dominant in western Siberia, with prevailing wormwood steppe and rare birch patches. Larch–birch open woodland of forest-tundra type domineered the southern Yakutia landscape (Andreev and Klimanov, 1989). In the south part of Far East province, *larch open forests, yernik and wormwood steppe were spread throughout the Late Glacial period.*

Palaeoclimatic reconstructions have been carried out for European Russia, southern Yakutia and the Far East (Fig. 12, Table 2). The greater deviations of temperature and precipitation has been acknowledged in the Maritime Primore.

The Younger Dryas corresponded to the universal degradation of forest-type vegetation. Coniferous–birch forests deprived of broad-leaved elements have been reported for the Ukraine and Belorussia. Grass communities dominated by *Artemisia, Chenopodiaceae* and *yernik* formations were widespread.

Patches of pine–birch forests occasionally survived in the thawed areas of river floors in the central Russian Highland *Chenopodiaceae* communities in the distorted landscapes, as well as grass–herb formations, were dominant in the vegetation. Open birch forests occurred in the Upper Volga catchment, steppe and tundra communities taking up large areas. Periglacial formations and birch–pine patches were dominant in Bashkiria (Nemkova, 1978).

Tundra and steppe elements dominated the periglacial complex in western Siberia. Herb communities and yernik were equally important in the vegetation of southern Yakutia.

The smallest deviations of temperature and precipitation are identifiable in Belarus, the largest values corresponding to the upper Volga and the Far East. In the former case, this was due to the proximity of the Scandinavian ice-sheet. In the latter case, the glaciation of the Sikhote-Alin Mountains may have had an effect (Korotky, 1981; Shumova and Klimanov, 1986).

The transition to the Post-Glacial was marked by a

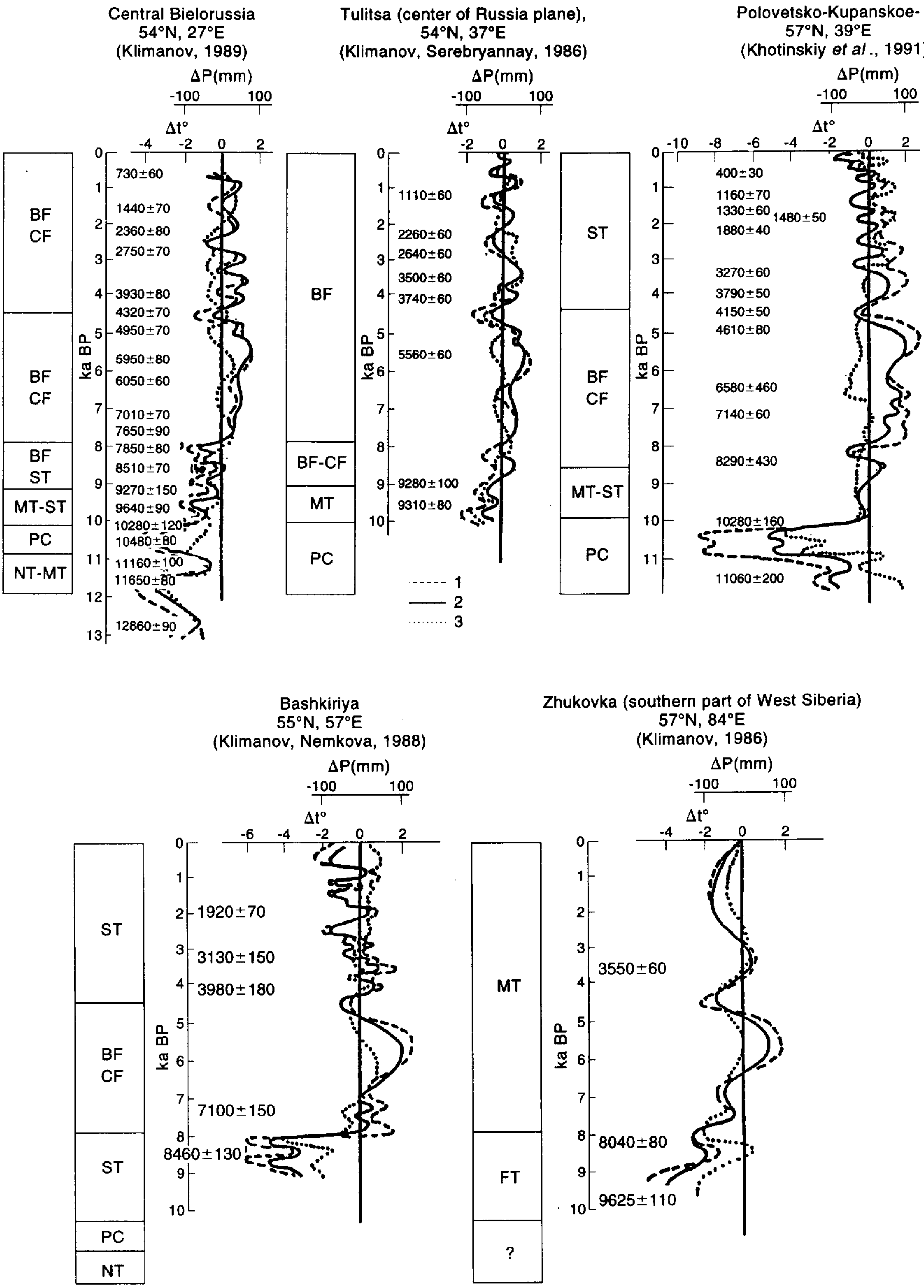

FIG. 11. Vegetation and climate changes in forest zone (south of 60°N) during Holocene and Late Glacial time. For the explanation see Fig. 3.

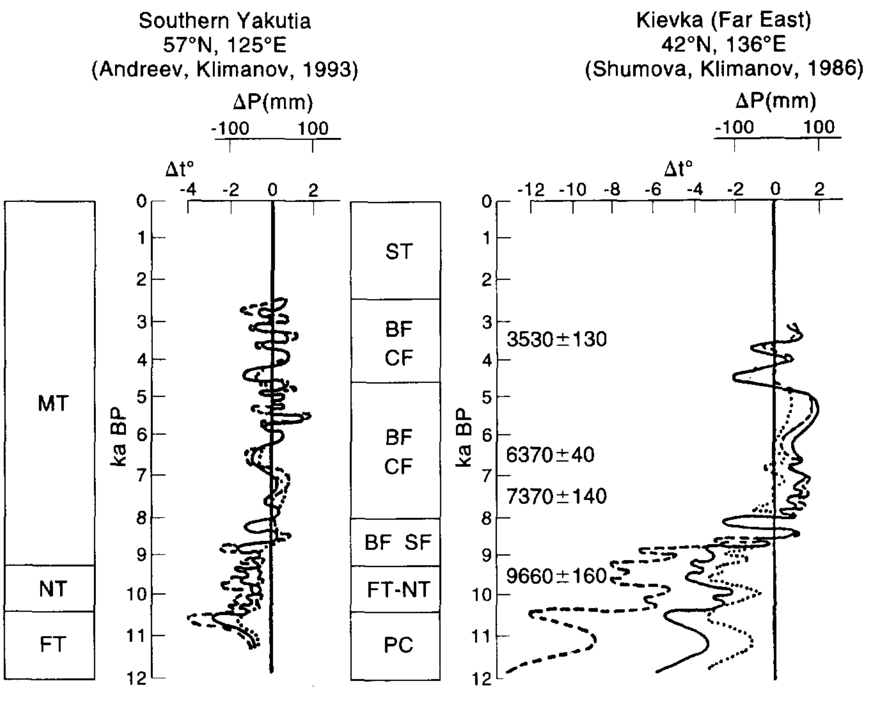

FIG. 11. *Continued.*

rapid degradation of periglacial formations and the development of forest-type vegetation. The Preboreal period in Belarus was dominated by pine and pine–birch woodland of middle and south-taiga type with the appearance of broad-leaved elements towards the end. Birch forests with limited broad-leaved elements were widespread in the Ukraine at the beginning of the period, large areas being taken up by xeromorphic associations.

Areas of birch–pine woodland considerably expanded in the central Russian Uplands, at the expense of xeromorphic associations. Pine and birch forests dominated the Upper Volga, the area of grass and shrub communities being restricted. The periglacial communities were partly restored in importance during the second half of the period. Areas of steppic communities diminished in the area between the Volga and the Urals and in Bashkiria, where the importance of pine–birch forests grew.

Birch–spruce open woodland replaced Late Glacial periglacial landscapes in the south of western Siberia, large areas being taken up by the steppe. Steppe and tundra associations grew in importance during the second half of this period (Arkhipov and Votakh, 1980; Volkova and Levina, 1985; Glebov and Karpenko, 1988). Larch–birch forests of north-taiga type with shrub alder and shrub pine (Pinus pumila) in the understory, occurred in southern Yakutia. Parkland larch forest of forest-tundra type with shrub alder and yernik formation were dominant in the southern Far East.

During the Preboreal warming (the Polovetskoye warm phase according to Khotinsky, 1977), ca. 1000 year BP the temperatures and the precipitation were below modern ones, but in Siberia the deviations were less, than on the Russian Plain and in the Far East.

During the subsequent cooling (the Peryaslavl' cool phase according to Khotinsky), at ca. 9500 BP, the greatest deviations of temperature are estimated for the Far East and southern western Siberia, supposedly resulting from the additional impact of the glaciation of the south Siberian mountains and the Sikhote-Alin.

The Boreal period featured a further development of forest formations. Forests of south-taiga type gave way to mixed forests in Belarus. The importance of pine increased in the Ukraine where the presence of broad-leaved elements is increased. The areas of xeromorphic herb associations diminished.

The forest-steppe is acknowledged in the north of central Russian Upland, birch–pine forests being most common, with limited broad-leaved elements. Pine and birch dominated the forests in the east of the Russian Plain, where elm, oak and lime made their appearance.

Open spruce–birch forests and pine–birch forests with spruce were dominant in western Siberia, large areas being taken up by meadow-steppe formations. Larch–birch forests with shrub alder of middle-taiga type spread during the Boreal period in southern Yakutia, where pine and spruce appeared at ca. 8500 BP. Birch–broad-leaved forests with the dominance of oak and the herb–bunchgrass steppe with wormwood occurred in the Far East.

During the Boreal optimum, at ca. 8500 BP, temperatures in the entire area reached present values, exceeding them in some cases. Mid January temperature were higher than now in the Upper Volga, Yakutia and the Far East, remaining lower than presently in the Cisurals, and

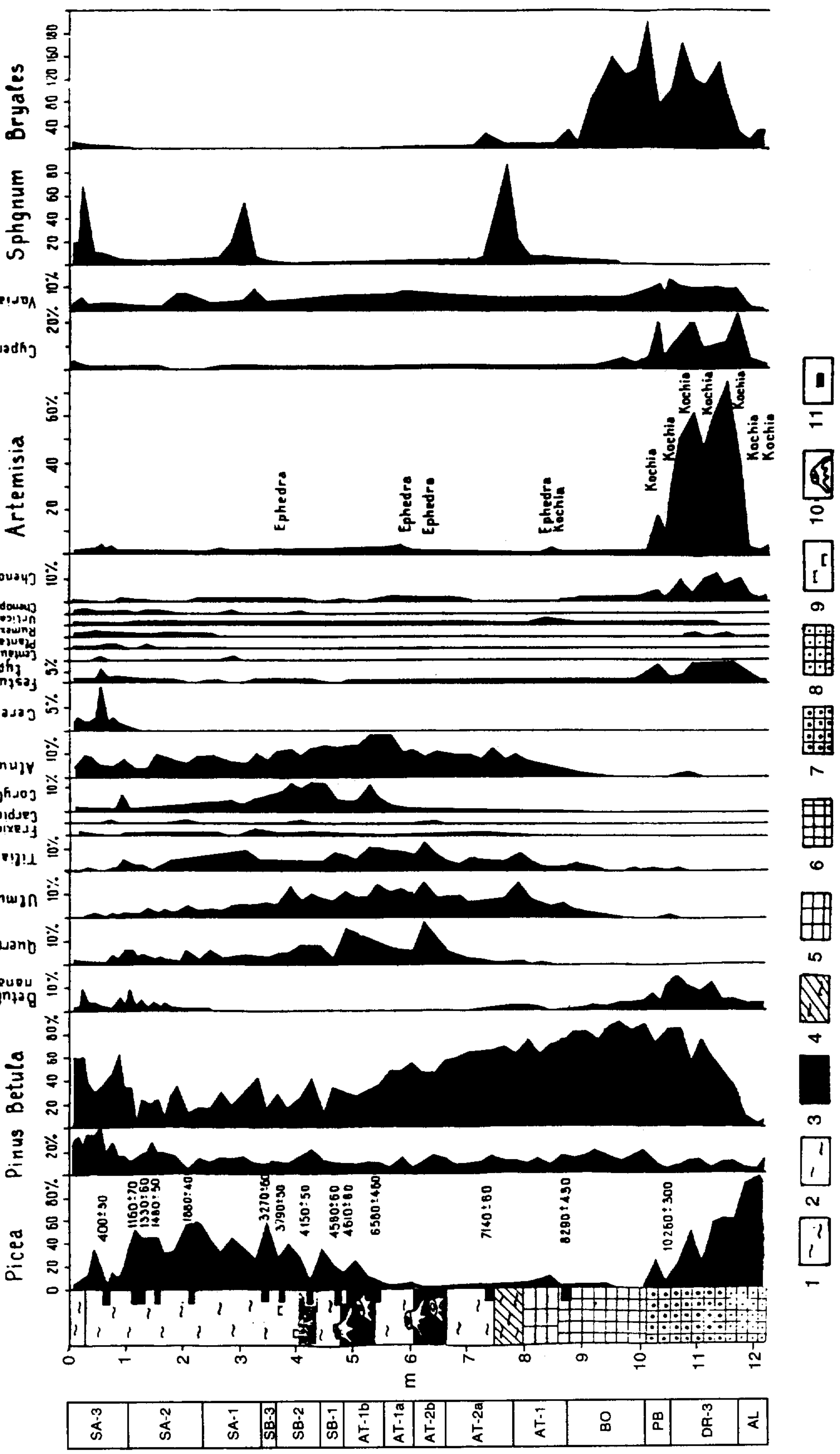

FIG. 12. Pollen diagram of Polovetsko-Kupanskoe section (Yaroslavl'region, 57°N, 39°E): 1—sphagnum peat; 2—complex sphagnum peat; 3—Eriophorum peat with pine remains; 4—sedge-sphagnum peat; 5—peaty gyttja; 6—algal gyttja; 7—calcareous-diatom gyttja; 8—high calcareous-diatom gyttja; 9—Eriophorum remains; 10—pine remains; 11—radiocarbon dated samples.

TABLE 2. 7 sites southern 57°N

Periods	Year BP	ΔT_{VII} 27°	37°	39°	57°	84°	125°	136°	ΔT_{I} 27°	37°	39°	57°	84°	136°	ΔPrecipitation (mm) 27°	37°	39°	57°	84°	125°	136°
SA	700	−1	−1	−2	−1.5	—	—	—	−1	−1	−2	−2÷3	—	—	0–25	−25	0	−25	—	—	−1
	1000	−1	−0.5	−0.5	−0.5	—	—	—	−0.5	−1	−1	−0.5	—	—	−25	0÷25	25÷50	−50	—	—	−0.5
	2500	−1	−0.5÷1	−1	−1.5	—	−1	—	−1	−1	0	−2	—	—	−25	÷25-÷50	0	0–25	—	÷50-÷75	—
SB	3500	1÷1.5	−1	−1	−1	−1	−1	1	−1÷1.5	−1	−2	−2	−1	−1.5÷2	÷25-÷50	−50	−25	0	0–25	−25	−50
	4500	−0.5÷1	−1	−1	−1.5	−1	−1	−2÷2.5	÷1.5-÷2.5	−2	−2	−1.5	−2÷2.5	−2÷2.5	0	−50	−25	−25	÷50-÷75	0	0
AT	5500	1÷1.5	−1÷1.5	−2	−2÷2.5	−2	−1.5	2	−1÷1.5	−1.5	−2÷2.5	−2.5	−2	2	0	−25	÷25-÷50	0	0	−50	−50
BO	8300	−1.5	−1	−1	−4÷5	−2.5	−1.5	−2.5	−2	−1.5	−1÷1.5	−6	−3	−2.5	−50	−25	−25	÷150-÷200	−125	0	−100
	8500	0	—	−0.5÷1	−2	1	−0÷0.5	1	−0.5	−0.5	0.5÷1	−3÷4	−1.5	−1.5	÷25-÷50	−25	−25	−75	−25	−25	−25
PB	9500	−2	—	−0.5÷1	—	−3÷4	−1.5	−4÷5	−2.5	−2	−1	—	−5	−8	÷25-÷50	÷25-÷50	50÷75	—	÷100-÷200	−50	—
	9900	−1	—	−0.5	—	—	−0.5	−2	−1.5	−1	0	−1÷1.5	−5	−50	−50	−50	—	—	—	÷25-÷50	−50
Dr-3	10500	−3÷4	—	−5÷6	—	—	—	−5÷6	−5		−9	—	−12	75÷100	—	—	—	—	—	÷75-÷100	−150÷175
All	11300	−0.5	—	−1	—	—	−1	−3	−1		−2	—	−9	÷25-÷50	—	—	—	—	—	÷25-÷50	−50÷75

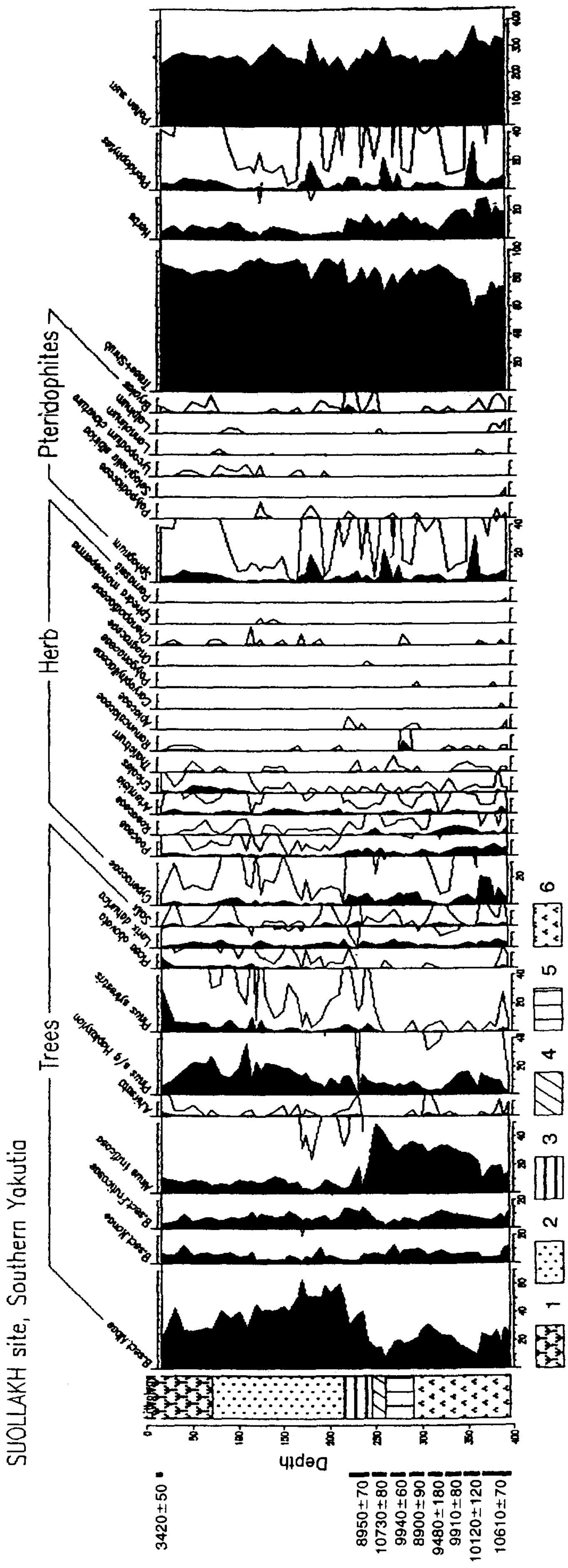

FIG. 13. Pollen diagram of Suollakh section (Southern Yakutia, 57°N, 125°E): 1—sphagnum peat; 2—woody-sphagnum peat; 3—sphagnum peat; 4—woody peat; 5—clayey sand; 6—sand.

southern western Siberia. Annual precipitation was lower than now in the European sector and particularly, in the Cisurals, exceeding the present values east of the Urals. The increase in precipitation in the Far East may be due to the increased activity of the Kuroshio current. The greatest deviations of temperature and precipitation during the cooling at the Boreal/Atlantic transition are acknowledged in the Cisurals, southern western Siberia and the Far East, i.e. in the same areas as previously.

The Atlantic period was the time-span most favourable for the development of forest-type vegetation in all the areas. Broad-leaved forests consisting of oak, elm, lime and hornbeam with the participation of coniferous species were dominant in Belarus. In the Ukraine, pine remained dominant in the first half of the Atlantic, although the proportion of broad-leaved elements was considerable. These proportions considerably increased during the second half of this period.

Broad-leaved forests elements reached their maximum in the Upper Volga, pine–birch forests being reduced. Lime became the dominant element in broad-leaved communities in the north of the central Russian Uplands, pine being dominant on sand soils. Mixed forests with a great importance of lime, oak and elm spread in the east of the Russian Plain (Nemkova, 1978).

Elm and lime appeared in pine–birch forests in the southwestern Siberia and Cisurals oak appearing towards the end of this period, and spruce, fir and Siberian pine retained importance. Spruce forests reached the maximum development along the Yenisei left bank in the Krasnoayarsk area, with pure forests of fir and Siberian pine emerging at that time (Glebov and Karpenko, 1988).

Birch forest with common pine, larch and wormwood-grass steppe occupied the southern slopes of the Enisei Range; spruce and fir forests masked the northern slopes. At the end of the Atlantic period the role of forests was increasing while the role of steppe gradually decreased.

Larch forests with birch, pine and spruce occurred at the beginning of the Atlantic period in southern Yakutia, pine forests dominating sandy areas starting ca. 6000 BP. Mixed birch–broad-leaved forests with the participation of wormwood-herb steppe were dominant in the Far East at the beginning of the Atlantic. During its second half, dark coniferous species appeared, and the areas of steppe formations were reduced.

During the maximum warming, 5000–6000 BP, temperature was universally higher than the present values, positive deviations of temperature and precipitation increasing from the west to the east. A marked increase in precipitation in Yakutia and the Far East may be due to the effect of the Kuroshio current, which became more active, shifting $\pm 1°C$ to the north.

The Subboreal period, particularly its beginning, was marked by less favourable environments for the development of forest-vegetation. Mixed broad-leaved forests spread in Belarus. Areas of broad-leaved forests diminished in the Ukraine, and the proportion of birch and pine rose in the mixed forests. The same is true for the Upper Volga, where the areas of spruce forests markedly increased during the second part of this period.

Birch forests with broad-leaved elements, alternating with bunchgrass-forb steppe, occurred in the central Russian Upland. The role of the broad-leaved species increasing in the second half of the sub-boreal.

The role of pine particularly increased during the colder stage in the east of the Russian Plain. The forests contained spruce, fir, lime and oak. Broad-leaved elements increased in importance during the warmer oscillations, diminishing during the colder ones (Klimanov and Nemkova, 1988).

Considerable reduction of elements of broad-leaved forests is seen in the Suburals. Siberian pine forests gained in importance further to the east, on the Yenisei left bank, where birch–pine forests remained dominant. On the Yenisei right bank, pine forests prevailed, with spruce, fir and larch (Savina *et al.*, 1988). Larch and pine forests with birch were dominant in southern Yakutia, spruce increasing in the middle phase. Birch–dark coniferous–oak forests with areas of forb-wormwood steppe were dominant in the Far East.

During the maximum Subboreal warming, ca. 3500 BP, the temperature remained above the present value, the deviations being less important than previously. The general trend is not clear, although the maximum rise of temperature and precipitation occurred again in the Far East. Considerable increases of January temperature (reaching 2°C) took place in the continental regions of eastern Europe, and precipitation increased in the central Russian Uplands.

During the Subatlantic period, the vegetation cover acquired its present features. A further decrease of broad-leaved elements is obvious in the forests of Belarus, the anthropogenic impact on vegetation becoming substantial (Yakushko *et al.*, 1988). In the Ukraine, an increase in broad-leaved elements has been noted for the first half of this period, the role of pine rising in its second half.

Spruce forests were dominant in the upper Volga during the first half of the period, pine and birch increasing in the second half, probably due to agricultural impact (Khotinsky, 1977). Oak forests were spread in the central Russian Upland, where they penetrated watershed areas. The anthropogenic impact rapidly increased during the last 2000 years (Serebryannaya, 1982).

Pine and spruce forests with birch, elm and lime were initially dominant in the east of the Russian Plain, an increase of broad-leaved elements starting with ca. 1000 BP indicating a significant amelioration of climate. Spruce–pine and pine–birch forests remained dominant in western Siberia, where the role of Siberian pine markedly diminished. Elm and lime totally disappeared after 1000 BP.

Pine and spruce–fir forests were dominant in the Yenisei Ridge. Larch and pine forests with birch and spruce prevailed in southern Yakutia (Mochanov and Savvinova, 1980). In the Far East Maritime Province dark coniferous forests was dominated by Korean pine and included oak, with areas of meadow-steppe vegetation including wormwood (Shumova and Klimanov, 1989).

Reliable quantitative estimates are lacking for Siberia and the Far East. One may note, however, the rise in

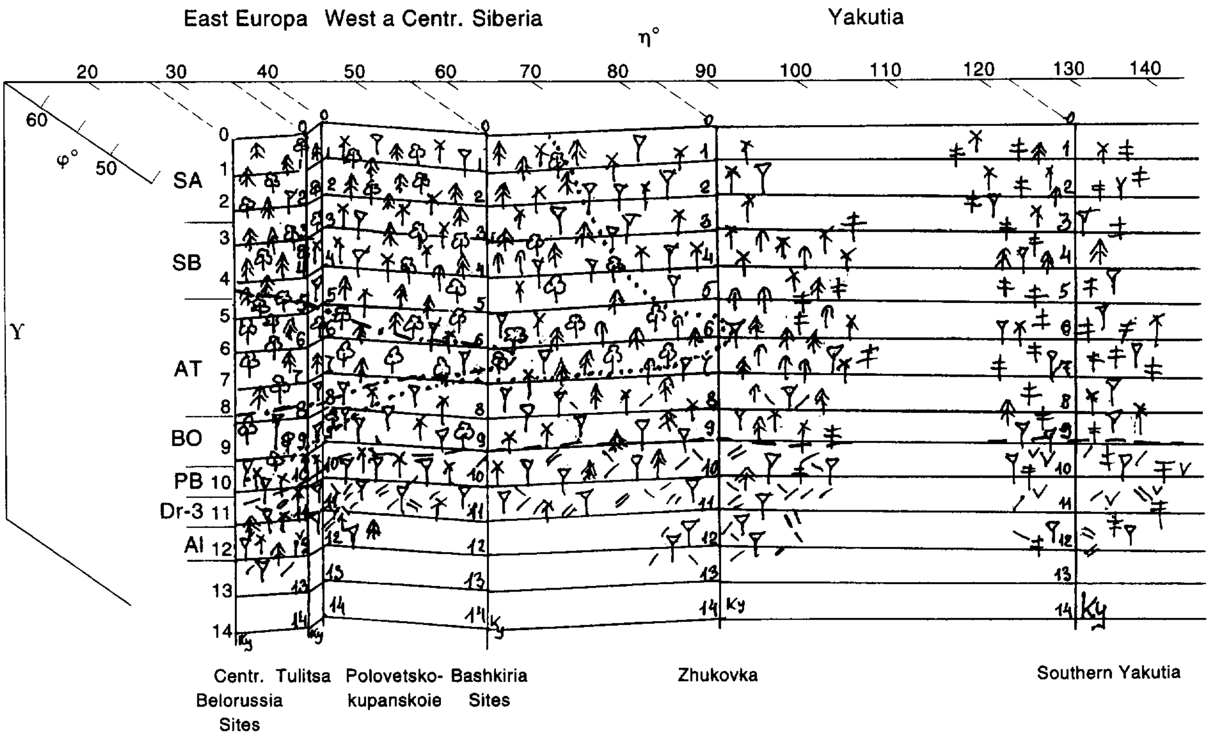

FIG. 14. Vegetation dynamics in forest zone (south of 60°N) during Holocene and Late Glacial time. For the explanation see Fig. 6.

temperature deviations of cooler phases from west to the east in eastern Europe. No trend for warmer phases may be recognized. During the warm phase of ca. 1000 BP, precipitation totals were above the present values, with the deviation gradient increasing from the west to the east.

The dynamics in the vegetation development of this zone are much clearer than in the other areas (Fig. 14). The initial proliferation of forests occurred during the Alleröd: spruce, birch and pine forests in western Siberia, open birch–larch forests in southern Yakutia. The Younger Dryas cool phase was equally clear in the reduction of forests in eastern Europe and western and central Siberia, *yernik* formations prevailing in Yakutia. Forests were restored, starting from Preboreal time, with broad-leaved elements appearing in Belorussia and Ukraine. These elements gained in importance during the Boreal. They became dominant in the forests of western areas, at the Atlantic stage, penetrating into the forests of southwestern Siberia. Modern forest vegetation started forming following the early Subboreal cooling.

CONCLUSION

The palynological data cited above permit recognition of the changes in climate and vegetation within the tundra and forest zone throughout the whole of late glacial and Holocene time. However, the investigations were not equally extensive in different regions. Climatic characteristics derived from individual sections enable us to present, in broad outlines, both general regularities and regional variations in climate change within the vast Arctic–Boreal area of northern Eurasia during the late glacial and the Holocene.

Among most general features, special attention should be paid to manifestations of the late glacial cooling correlated with the Younger Dryas (Dr-3). The "signal" of this cooling is noticeable both in inner areas of Siberia and in the Far North, though it is more attenuated in Siberia as compared to eastern Europe. At least in part, this may be due to the fact that climatic fluctuations were more dramatic in character in the east European sector. They resulted (and result at present) from repeated invasions of air masses from the Atlantic. The climate of western Europe is referred to as "allochthonous", as it forms under the influence of incoming air masses. In contrast to that, the Siberian climate is controlled mainly by local air masses and therefore belongs to "autochthonous" type. The climate of eastern Europe may be defined as "transitional" (Velichko, 1984).

Essential thermal fluctuations within this intermediate sector occurred as a result of alternating dominance of the allochthonous (West European) type of climate during warmings and the autochthonous (Siberian) type during colder phases. In the Siberian sector the cold autochthonous climate was permanent, and deviations towards cooling were not so drastic. Deviations towards warming at the beginning of the Holocene were most distinct in the Siberian sector. The signal was amplified, in summer in particular, probably due to greater continentality of climate in the northeast of the region, as the coastline of the Arctic seas was 500–600 km north of its present position. At present, water depths over this zone of the shelf do not exceed 40 m, and at the very beginning of the Holocene the global transgression of the ocean was only approaching this hypsometric level, while a considerable portion of the shelf was still dry. The main phase of warming, however, occurred in the mid-Holocene, (late Atlantic time), both in the East European and Siberian sectors, as demonstrated by evidence from West Siberia, East Siberia and the Far East.

However, the inner regions of Siberia and its eastern margins (which are similar to the intracontinental territories in climatic characteristics) do not show a trend towards cooling in the second half of the Holocene as distinctly as do other regions. This regional characteristic may be attributed to the fact that relatively small-amplitude coolings were not so conspicuous in the Siberian type of climate where low temperatures were most common.

Farther to the south, the maritime regions of the Far East are distinguished by sharp changes in climatic regime, with the monsoon type dominant in summer and the anticyclonic type in winter. The temperature curves display "classic" well-established forms.

On the whole, it may be noted that despite all the regional deviations, the principal regularities of global climatic change are shown in the arctic–boreal territories of eastern Europe and Siberia during the late glacial and Holocene time. One of the noteworthy features is that the peak of warming occurred in the Middle Holocene.

Both general and regional characteristics of climatic changes are easily seen if we consider temperatures within individual latitudinal belts. The regularities are most evident by comparing modern temperatures with those reconstructed for each of the past climatic phases along latitudes (Fig. 15). The curves may be called "chronotherms" to distinguish them from "isotherms".

The spectra of temperature curves plotted in this system permit identification of two principal features. The first one is that within each latitudinal belt along its full length the temperatures were lower during the first half of the Holocene than during the second half.

The second characteristic is that latitudinal temperature curves of individual phases of the second half of the Holocene follow the trend of the modern temperatures at the same latitudes, whereas during the first half of the Holocene the temperature curves differed considerably from the modern ones. The stated differences suggest that the climatic conditions (including the circulation pattern) began to resemble those of today only from the late Atlantic period, though thermal levels were different.

During the first part of the Holocene the climates were controlled by factors which partially account for essential differences from the present-day climatic system. The principal distinctive features are found in the western half of the area under consideration. In addition, resemblances between temperature curves of the first half of the Holocene and those of the second half seem to be more pronounced in the north than in southern regions.

North of 60°N the temperatures were well below the present-day values over the whole East European sector before the Atlantic period. The most conspicuous negative deviations are recorded in the west (Karelia), probably due to a cooling influence of the still existing (though reduced) Scandinavian ice-sheet. Lower temperatures persisted also in the east of Europe (areas adjacent to the White Sea and farther east). Even at present, the warming influence of the Gulf Stream is blocked from these regions; as a result, winter is colder there than farther east or west, and the White Sea is frozen each winter. The Gulf Stream influence was even more limited during the early Holocene. This situation may be responsible for even more contrasting climatic conditions in the regions farther south. Judging from the temperature curves related to the early Holocene, the remnants of the Scandinavian ice-sheet could hardly induce a considerable cooling in the west of the East European sector; negative deviations in temperatures were relatively small even in Belarus.

In the east of the European sector (in Bashkiria, west of the Ural mountains) the temperature dropped significantly, and the chronotherms even took up a position opposite to that attributed to the second half of the Holocene. It is believed that the main factor in control of the situation was the continuous inflow of colder Arctic air masses which formed over the Arctic Ocean. The latter remained frozen throughout most of the year, as the Gulf Stream influence was still limited in the region. As well, vast areas of the shelf remained emerged, thus blocking the Nordcap branch of the Gulf Stream from bringing warmth to the northeast of the Russian Plain. Only the Spitsbergen branch could be active under these conditions.

On the whole, both present and the Holocene temperature fluctuations decreased in a range eastward. This fact indicates the considerable importance of western air transfer in the atmospheric circulation throughout the late glacial and the Holocene.

The temperature ranges appear reduced most distinctly from west to east in high latitudes. Farther south the chronotherm pattern was more complicated, though comparison between the median and eastern sectors reveals the same trend. The Maritime Far East region is an exception, because it is located much farther south and lies within another climatic province.

Warm phases were marked by more pronounced rises in summer (July) temperatures, whereas during the cold phases the drop in winter (January) temperatures was more conspicuous.

The warm and cold phases differed also in rainfall distribution. In northern regions (north of 65°N) precipitation increased during warm phases and decreased during cold ones throughout the late glacial and Holocene. In southern regions (south of 50°N) an increase in rainfall is recorded both in warm and cold phases, during the late glacial and the first half of the Holocene. Later (during the second half of the Holocene) precipitation shows a decrease during warm phases. At that time in middle latitudes the peak of rainfall occurred during transitional phases between maximum warming and maximum cooling.

In the high Arctic, on coastal plains and islands, environments changed markedly, becoming more favorable for plant communities in the early Preboreal period. As warming occurred the areas were still part of a large

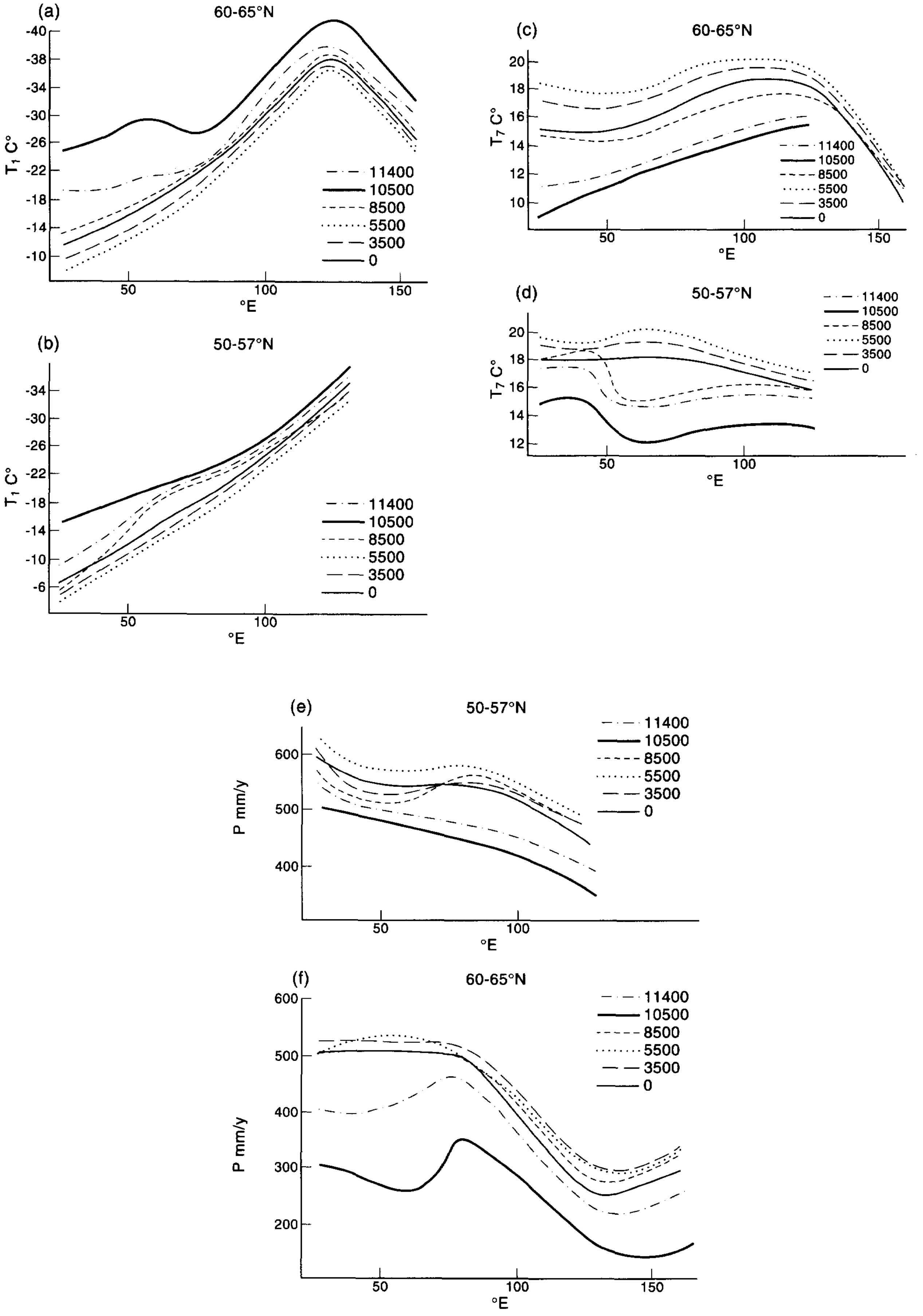

FIG. 15. Climatic characteristics calculated for different time intervals of the Holocene for latitudes 60–65°N and 50–57°: a, b—January mean temperatures; c, d—July mean temperatures; e, f—annual precipitation.

land area, distinguished by an extremely continental climate, which permitted shrub tundras to exist within today's areas of polar deserts and tundras. Later warmings occurred against the background of oceanic influence and, therefore, had no pronounced effect on vegetation of these regions.

In the forest and forest–tundra zones, the most favorable time for vegetation came later, its peak coinciding with the late Atlantic period, about 5000–6000 BP. At that time tree species extended their ranges northward and eastward. Broad-leaved species were important in the vegetation in eastern Europe and Siberia east of the Urals. The best conditions for broad-leaved trees existed in the west of the Russian Plain where they appeared in small proportions as early as the Alleröd. They became more scarce eastward.

On the whole, before 13–14 ka BP (that is before the transition to the Holocene) the vegetation was rather uniform all over northern Eurasia. In the dominant periglacial formations tundra and steppic elements prevailed, with some forest species (birch and larch in Siberia, pine and birch on the Russian Plain). From those starting positions began the restoration of differentiated vegetation zones. Within the zones, composition of plant communities during the first half of the Holocene was essentially different from their composition during the second half of the Holocene.

It is worth noting that vegetation similar to present-day had been formed before the Subatlantic period in a majority of regions. Forest vegetation increased and decreased in importance, simultaneously, in all the regions as a result of synchronous climatic fluctuations.

As indicated by the vegetation changes throughout the Holocene, the western part of the territory was subjected to most dramatic changes. Evolution of the vegetation was strongly influenced by the presence of broad-leaved species refugia within the western area or in its vicinity. Individual broad-leaved elements are documented in Karelia as early as the mid-Boreal period, while they do not occur in West Siberia until the late Atlantic. This may be partly attributed to a considerable increase in continentality eastward.

ACKNOWLEDGEMENTS

The authors are very grateful for the financial support from the US "Man and Biosphere Program" grant no. 1753-300223 used during the preparation of this paper.

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