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PLIOCENE CLIMATES OF THE NORTHERN HEMISPHERE:

Abstracts of the Joint US/USSR Workshop on Pliocene Paleoclimates,

Moscow, USSR, April, 1990.

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Editor of English Language Version

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Introduction

A joint US-USSR workshop met at the Laboratory of Paleogeography of the Academy of Sciences of the USSR in Moscow from April 20th to 23rd, 1990 to discuss Pliocene paleoclimates and to develop a joint long-term research program. Soviet participants included more than fifteen scientists from across the USSR, and the United States was represented by four scientists from the U.S. Geological Survey (Table 1). As with the 1989 Denver Pliocene workshop (Gosnell and Poore, 1990), the objectives of the 1990 Moscow workshop included establishing the chronology and amplitude of Pliocene climatic changes, mapping the spatial patterns in these variations, and determining the biologic responses to climatic change (see also Cronin and Dowsett, 1991, for further Pliocene paleoclimatic studies). These data will form the basis for explorations of General Circulation Model simulations of Pliocene paleoclimates and will provide insights into the nature of climatic circulation in a warmer-than-modern mean global climate state.

Workshop participants discussed data pertaining to the estimation of Pliocene climatic conditions in the Northern Hemisphere, and abstracts in this volume present information on continental environments in the European USSR, the Trans-Caucasus, western Siberia, the Soviet Northeast, Kamchatka, western and arctic North America, and Iceland (see fig. 1 for study regions within the USSR). Marine data presented here are from the margins of the Northern Pacific and from the northern and western margins of the Atlantic. Collectively, these records indicate that for hundreds-of-thousands of years during the early and middle Pliocene, conditions in middle and higher latitudes of the Northern Hemisphere were generally much warmer and moister than today. The deviations from modern conditions were more pronounced at higher latitudes, a phenomenon apparent in other warm climate episodes. Although the climate was generally warm from before 4 Ma to ca. 3 Ma, there were episodes of relatively cool conditions. Soviet participants focused on the period near 4 Ma for the Pliocene thermal "optimum", whereas American scientists concentrated more on the time ca. 3 Ma, a period with greater biotic links to today and with finer age controls (*e.g.* Barron, this volume). Participants from both countries cited evidence for major Northern Hemisphere cooling after 3 Ma, with major glaciations beginning by ca. 2.4 Ma.

A second focus of the workshop was on the quantitative techniques used in paleoclimatic reconstructions. Soviet scientists working with Pliocene paleobotanical data discussed methodologies which estimate paleoclimatic conditions from modern plant distributions (climatograms) and which identify modern sites where plant communities live that are

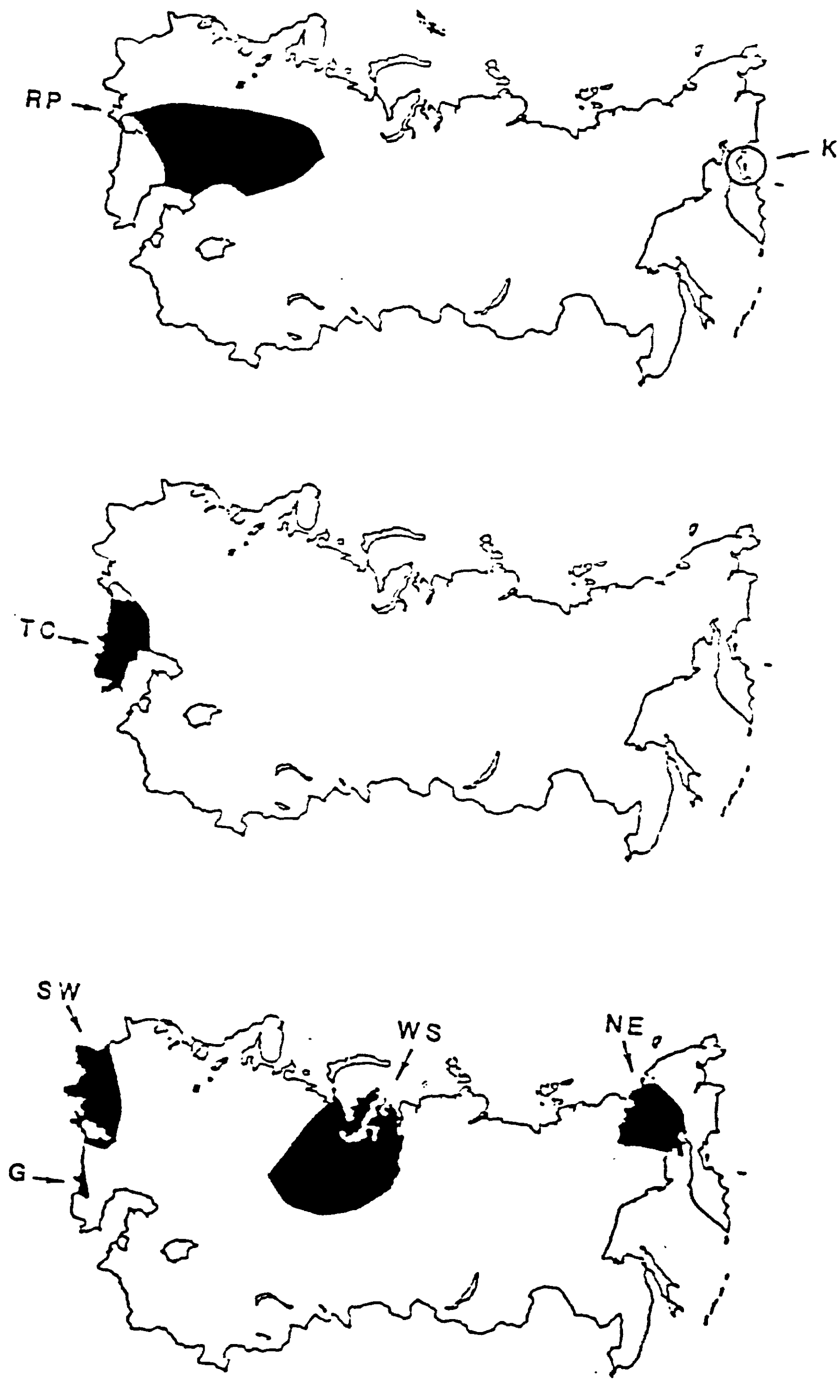

Figure 1. Pliocene study regions in the Soviet Union. Key to regions (authors of abstracts covering each region are in parentheses following the region): Upper Panel - RP = Russian Plain (Borisova; Grichuk): Middle Panel - TC = Trans-Caucasus Region (Mamedov); Lower Panel - SW = Southwestern European USSR (Syabryaj and Svetlitskaya); G = Georgia (Shatilova *et al.*); WS = West Siberia (Volkova); NE = Far North-East of the USSR (Fradkina).

similar to the Pliocene plant communities (arealograms). American scientists presented preliminary results of response surface methodology for paleobotanical data. For paleoceanographic studies, participants discussed paleoclimatic estimates based on numerical analyses of foraminiferal, ostracode, and diatom assemblages, as well as interpretations of oxygen-isotope analyses.

Workshop members concluded that future US-USSR joint research activities should continue to focus on the Pliocene as one warm interval in earth history that could be used to understand the response of geologic and biologic systems to global warming. Toward this goal, it was proposed that key sections be studied over the next three years to provide the basis for inter-regional correlations and comparisons across the Northern Hemisphere. It was agreed that methodological comparisons were necessary and that all data should be organized into databases for joint use. These data sets will provide the basis for large-scale interpretations of climatic and biological changes during the Pliocene. As part of this effort, the Soviet participants prepared a template for their Pliocene researchers (fig. 2), which is designed to assure uniformity in their data collections and presentations. American readers should be careful to note that not all Soviet workers use the same age boundaries as their western counterparts. For example, Shatilova *et al.* (this volume) place the Pliocene/Pleistocene boundary at 0.7 Ma, a million years younger than its current placement in the western literature.

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Acknowledgments

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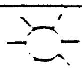
Paleobotanic data	
	pollen and spores
	leaves (leaf prints)
	carpological data
Paleofaunistic data	
	mammals
	rodentia
	molluscs
	diatoms
	foraminifers
	radiolaria
	ostracodes
Dating	
TL	Thermoluminescent - dating
FT	fission - track method
K/AR	K/AR method

Figure 2a. Explanation of the Soviet table for a "General climastratigraphic description of a key-section". This table is intended to provide guidelines for a common approach to the description of key sections. The columns of the table should be only when data is available, otherwise they should be left open. The table contains: A) a chronological scale (based on paleomagnetic, biostratigraphic and radiometric data); B) the paleontological data obtained; C) the paleoenvironmental zones reconstructed (on land or on sea); D) the assessment of paleoclimates (qualitative - with respect to present-day characteristics, and quantitative). Readers should note: 1)) the Kaena and Mammoth events are not illustrated, and 2) the foraminferal zone boundaries do not match standard western usage.

Figure 2b. General climastratigraphic description of a key-section (guidelines for Soviet Pliocene paleoclimatic research)

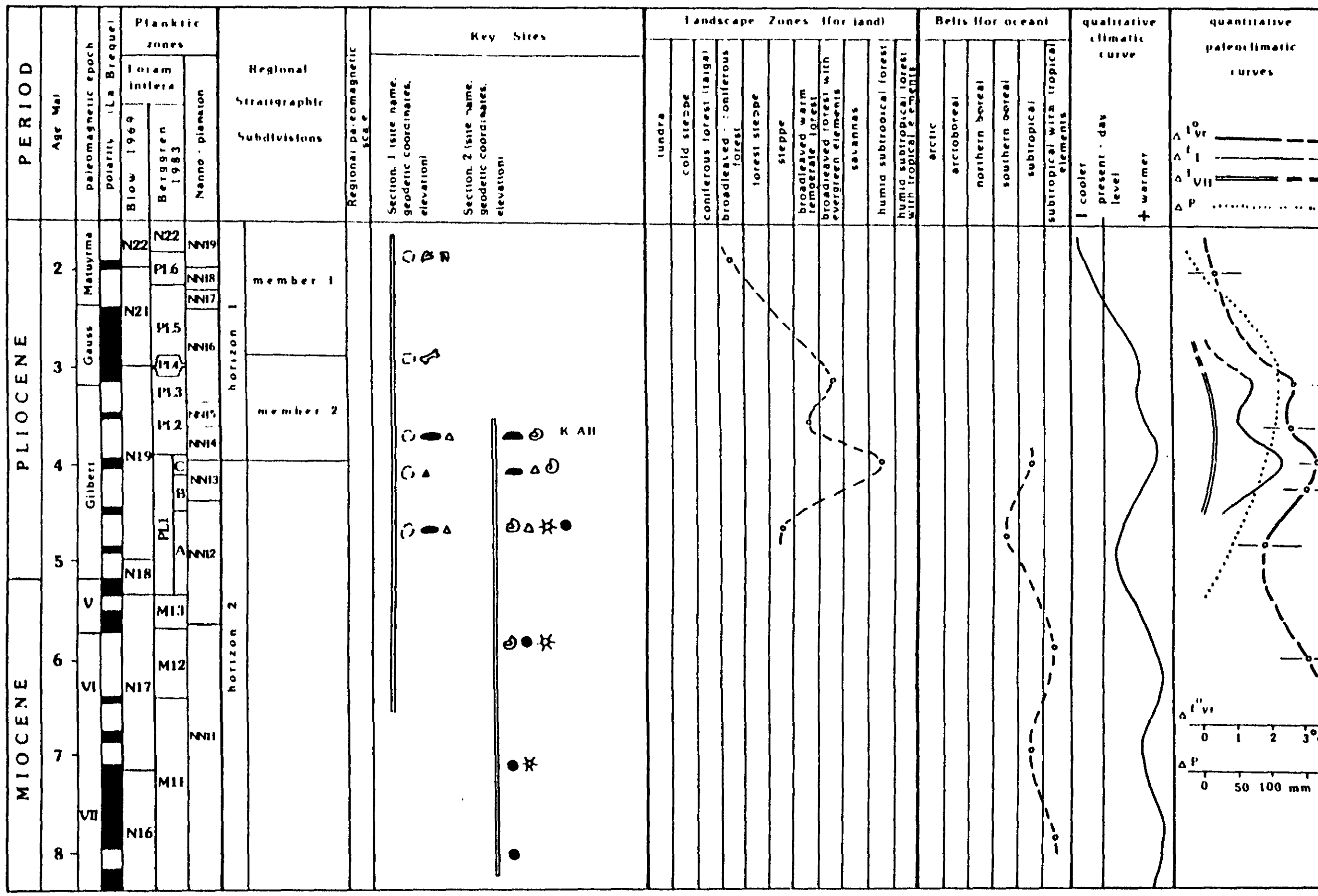


Figure 2b. General climastratigraphic description of a key-section (guidelines for Soviet Pliocene paleoclimatic research)

Flora, Vegetation, and Climate of Iceland during the Pliocene

M.A. Akhmetiev

Pliocene volcanic units cap "Tertiary plateau basalts" in the western, northern and eastern parts of Iceland, and comprise the bulk of the "ancient grey basalts" complex exposed over the periphery of the neo-volcanic zone. On the Tjornes Peninsula, the Pliocene is represented by the full scope of the Tjornes marine sequence, ranging from basal hyaloclastics that outcrop at the mouth of the Kaldakvisl River to the tillites and basalt flows that formed at the time of the Pliocene-Pleistocene boundary at Furuvik Cape. Paleobotanical remains from these Pliocene units may be grouped into two interregional horizons: the Sleggjulaekur (early Tjornes) and the late Tjornes. The Pliocene also incorporates the upper part of the Hredavatn horizon, which encompasses those flows of Tertiary plateau basalts younger than 5.5 Ma. Throughout the island, these basalts enclose beds of flora-bearing tuffaceous sedimentary rocks which attain their maximum thicknesses and stratigraphic completeness in the north and in the east.

The first late-Cenozoic cooling pulse in Iceland occurred in the latter half of the late Miocene (late Hredavatn time, ca. 6 Ma) when the beginning of degradation of taiga-type spruce-fir forests suggests that mean annual temperatures fell by 5°C to 6°C. Forest composition at the end of the Miocene was far from homogeneous, as indicated by high variability in the pollen spectra of conifers and woody small-leaved (parvifoliate) angiosperms (tree-*Betula*, *Alder*, and *Salix*).

Open *Betula-Alnus* forest and *Betula*, *Alnus*, and *Salix* shrub communities dominated the vegetation of Iceland during Sleggjulaekur time. The climate was moderately cold, with mean annual temperatures 2°C to 3°C above modern levels in the southern part of the island. Local peaks in the proportions of pollen of woody *Alnus* and *Betula* in palynospectra from the "D" and "F" beds of the Tjornes sections suggest brief warming phases occurred between 4.5 and 3.2 Ma. The "F" bed also contains branches and cones of *Abies*, *Picea*, *Larix*, as well as leaves of *Myrica* and woody *Alnus*.

An important change in the vegetation of the island occurred at the boundary between the Sleggjulaekur and Upper Tjornes horizons when parvifoliate forests and open forests gave way to a grass and shrub community resembling tundra. The same level is marked by the first occurrence of sheet tillites on the island, correlated to the Mammoth episode of the paleomagnetic scale. In the late Pliocene, with the onset of glaciers on Iceland, the establishment of hypo-arctic and arctic floras led to the dominance of tundra and high arctic phytolandscapes. The closest living relatives of the majority of late-Pliocene plants are concentrated either in the Atlantic sector of the Arctic or are circum-polar (*Alnus viridis*, *Betula nana*, *Salix herbacea*, *S. phylicifolia*, *Polygonum viviparum*, *Dryas octopetala*, *etc.*). The climates of the late Pliocene and early Pleistocene differ little from that of today.

Mollusks And Climatic Changes In The Pliocene Of Northeastern Kamchatka

Barinov, K.B. and Basilyan, A.E.

Detailed examinations of key stratigraphic sections from around the world are central to paleogeographic and paleoclimatic reconstructions. Investigations of sections from the northern Pacific region incorporate data from various paleontological groups, paleomagnetism, and paleoclimatology, to provide a reliable chronology of major events since 6 Ma. The most complete Pliocene section in the Far-East of the USSR is the suite of marine strata on Karaginsky Island, off northeastern Kamchatka. Due to its unique geographic position, it is possible to correlate Pliocene sediments from this site on the Asian periphery with those from the western margin of North America and subsequently to outline major routes of late Cenozoic migration of benthic Mollusks. The Karaginsky section has been previously examined by Y.B. Gladenkov and O.M. Petrov (mollusks), T.V. Oreshkina and R.M. Guseva (diatoms), I.M. Khoreva (foraminifers), among others. Gladenkov divided this section upward into the Limimtevayam suite (sequences 10, 11, 12; conglomerates, tuff sandstones and tuff diatomites, 290 m); the Ust-Limimtevayam suite (sequence 13, sandstones and tuff diatomites, 80 m); and Tusatuvayam layers (sequence 14; conglomerates and sandstones, 13 m). Paleomagnetic data also refer the upper part of the Yunyunvayam suite (which underlies the Limintevayam suite) to the Pliocene (sequence 9; tuff sandstones and tuff diatomites, 110-123 m). Biostratigraphic studies of Karaginsky sections delineated seven consecutive mollusk stages, which can be grouped according to modern biogeographic affinity, and on this basis the major changes in Pliocene benthic communities can be deduced.

The first stage, paleomagnetically dated between 5.4 and 4.5 Ma, is characterized by predominance of boreal elements in mollusk communities and by the total absence of southern-boreal forms. The assemblages at the time are dominated by species of Asian origin, whereas high-latitude endemics and North American immigrants are represented at lower levels. Apparently, this period was distinguished by bilateral exchange of boreal faunas in the high latitudes of the Asian and North American shelves along the Beringian margins.

The second stage (4.5 to 4.05 Ma) is associated with the onset of a vast transgression that invaded large areas adjacent to Kamchatka. It is distinguished by largely one-way migration of mollusks along the Asian coasts from southern boreal and boreal regions to high latitudes. Boreal species were dominant in the mollusk assemblages of the northeastern Kamchatka shelf, while subtropical and lower-boreal species accounted for

8.0 to 8.3% of the assemblages. In the Karaginsky sections, the second stage corresponds in time to accumulation of sequences 10-11 of the Limimtevayam suite, which in addition contain southern-boreal *Fortipecten kenyoshiensis*, *Callithaca adomsi*, *Pandora pulchella*, etc., indicating climatic warming.

A drastic reordering in benthic communities occurred at 4.05 Ma. This event is demonstrated by the quantitative predominance of arctic-boreal and high-boreal species in the assemblages of sequence 12 of the Limimtevayam suite, paleomagnetically dated between 4.05 and 3.8 Ma. Southern-boreal forms represent 6% of the communities of this time. Of interest is the entry of *Elliptica* subgenus, previously unknown in the Pacific, and a probable migrant from the Arctic basin due to the inundation of Beringia. This is confirmed also by the presence of *Fortipecten hallae* in the Karaginsky section, together with the first *Astarte*. The same phenomenon has been noted in Alaska near the town of Kiwalina, north of the present Bering Strait.

Mollusk communities of the Ust-Limimtevayam time (3.6 to 3.25 Ma) suggest further cooling, as southern-boreal forms are reduced to 5% while high-boreal and arctic-boreal species predominate. This stage has large numbers of endemic species in the genera *Astarte*, *Chlamys*, and *Clinocardium*, which developed independently in the high-latitude subarea and are known only from the northeastern areas of Kamchatka and northwestern Alaska. At the same time, the entry of *Astarte*, subgenus *Tridonta*, and genus *Cyrtodaria* at this level in the Karaginsky strata suggests a stable exchange of faunas between the Pacific and Arctic basins. Some experts on the Pliocene strata of this region believe that this was the time of mass expansion of Pacific species into the North Atlantic and Arctic.

The last stage (Tusatuvayam time: 2.2 $\pm$ 0.03 Ma) is marked by considerable cooling. The number of southern boreal forms is reduced to 3%, and the communities now contain arctic forms (6%) and are dominated by boreal-arctic species. It is not yet possible to accurately reconstruct the direction of faunal exchanges during this period, due to the scarcity of data on strata from near the Neogene/Quaternary boundary in the Pacific and Arctic regions.

In summary, Pliocene data from Karaginsky Island suggest a relative warming of the climate in the northeastern Kamchatka region between 4.5 and 4.05 Ma, with subsequent progressive cooling in the late Pliocene.

Pliocene Paleoceanographic Events in the North Pacific Ocean

John A. Barron

Oxygen isotope studies suggest that a major cooling of high-latitude areas occurred at 2.4 Ma (late Pliocene) resulting in increased glacial-interglacial variations and Northern Hemisphere ice sheets that were on average about half as large as those of the late Pleistocene. The magnitude of this climatic step is apparent throughout the world: sea ice increased markedly in Antarctic waters, trade winds and upwelling increased in the eastern equatorial regions, aridity increased in the middle latitudes, and the subarctic front migrated southward in the North Pacific. Investigation of Pliocene periods of climatic warmth as a possible scenario for mid-21st-century climate due to build up of CO_2 gases in the atmosphere should therefore concentrate on the interval prior to 2.4 Ma.

Detailed oxygen isotope records on deep sea cores are generally limited to the last 3 to 4 million years. Studies such as those of W.L. Prell (1985), K.M. Elmstrom and J.P. Kennett (1986) suggest that relatively warm conditions prevailed between 4.6 and 3.8 Ma with generally low amplitude fluctuations compared with conditions of the late Pliocene. Most studies show increasingly fluctuating conditions in the middle part of the Pliocene with many cooling events (*e.g.* 3.6 to 3.5 Ma, 3.2 Ma, 2.7 Ma, 2.6 Ma). In a broad sense, a climatic optimum of relatively warm Pliocene paleotemperatures at middle and high latitudes probably occurred between about 4.6 Ma and 3.8 Ma, but detailed studies are lacking for this interval and conditions probably fluctuated. On the other hand, high-resolution isotope studies all point to a period of relative warmth centered on about 3.0 Ma; this period is bracketed by the Kaena and Mammoth reversed events of the Gauss magnetic chron, and therefore, it is relatively easy to identify in both continental and marine sequences.

Diatoms, which are abundant and diverse in the high-latitude oceans, offer an excellent means of correlation in low energy (typically outer shelf and deeper) marine environments. Diatom biostratigraphic zonations are generally well developed and calibrated to magnetic stratigraphy for the Pliocene of the middle- to high-latitude North Pacific, the equatorial regions, and the Southern Ocean. Consequently, marine diatoms can be very helpful in identifying prospective time slices during the Pliocene climatic optimum.

Diatoms are typical of regions of cooler surface waters; there cool waters actively mix with intermediate waters (200m to 1500m depth), which are enriched in nutrients such as phosphorus, nitrogen, and silica relative to surface waters. Consequently, diatoms are found in high-latitude regions and areas characterized by upwelling, such as the equatorial Pacific and along the eastern coasts of the continents. During periods of high-latitude cooling, one would expect increased winds and intensified blooms of diatoms in these upwelling regions. Conversely, during periods of relative climatic warmth, diminished winds and reduced upwelling might be expected, especially in regions of marginal upwelling.

During the middle part of the Pliocene between about 4.5 and 2.5 Ma, diatom production decreased markedly in the waters off southern California as evidenced by the presence of sparse and poorly preserved diatom assemblages in strata of this age at DSDP (Deep Sea Drilling Project) Sites 467 and 469 as well as in strata exposed onshore. Planktonic forminfers document a period of relatively warm surface waters during this time and presumably upwelling was greatly diminished. Studies of more northerly DSDP sections off northern California and in the Gulf of Alaska are presently underway in order to document the timing and character of this period of increased climatic warmth in the Pliocene.

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Neogene Temperature Fluctuations on the Southeastern Russian Plain

O.K. Borisova

Neogene deposits of are widespread on the southeastern Russian Plain and paleobotanic studies of pollen, seeds, and leaves from these sediments have been carried out over the past 40 years. Data for Neogene paleotemperature reconstructions for this region are available in paleobotanical reports by E.N. Ananova, V.P. Grichuk, Z.P. Gubonina, P.I. Dorofeev, E.D. Zaklinskaya, P.A. Nikitin, I.M. Pokrovskaya, A.A. Chiguryaeva, among others. For this report, paleotemperature estimates were made by the climatogram method, employing a modification of this technique developed for reconstructions based on late Cenozoic fossil tree floras(Grichuk, Zelikson, and Borisova, 1987). For each genus of the fossil tree flora, a climatogram graph was constructed showing all possible combinations of the mean modern temperatures of the warmest and coldest months where the aggregate of species of this genus grow naturally today. The paleotemperate estimates for a given fossil assemblage were obtained by overlapping the climatograms of all genera represented in a given paleoflora. By this method, it is believed that summer temperatures may be reconstructed with an accuracy of ± 2°C. Winter temperatures may be more difficult to estimate, as most plants are dormant during the coldest months and thus may not react to the severity of this season. However, many evergreen plants cannot withstand even short-term frost, while some trees such as spruce apparently require a cold dormant period for survival. These factors permit some general statements about winter conditions to be interpreted from fossil floras.

The paleotemperature record indicates a long-term progressive cooling through the Neogene on the southeastern Russian Plain. Mean January temperatures fell from +7°C to +10°C down to -3°C to -1°C, while mean July temperatures declined from +24°C to +26°C down to +18°C to +20°C. These changes reflect a trend from nearly tropical conditions in the early Miocene to moderately warm climates by the late Pliocene. This fall of temperature was not smooth and steady, as can be seen in the profound changes that occurred in floral composition at the middle to late Miocene boundary and at the beginning of the late Pliocene (Grichuk, 1959). Upper Miocene deposits are rare on the southeastern Russian Plain, and thus it is difficult to determine the nature of the paleoclimatic changes associated with the floral impoverishment that occurred at the middle to late Miocene transition. The climatic change associated with the late Pliocene disappearance of the arboreal genera *Keteleeria*, *Taxodium*, *Libocedrus* (among others) probably included the first occurrence of mean temperatures for the coldest month below the freezing point.

The identification of shorter-time climatic fluctuations imposed on the long-term trend toward cooler temperatures through the Neogene calls for further analysis of the paleofloristic data and better correlations among stratigraphic sections.

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Pliocene Marine Climates of the Western North Atlantic

Thomas M. Cronin

The Neogene geologic record of the U.S. Atlantic Coastal Plain is characterized by marine transgressions alternating with periods of emergence and fluvial erosion. One of the most extensive periods of submergence occurred during the middle Pliocene, between about 4.0 and 3.0 Ma, when the Yorktown, Duplin, Raysor, and Goose Creek Formations were deposited (figure 1). Dowsett and Cronin (1990) correlated this transgression with a period of global warmth and reduced polar ice, and estimated that eustatic sea level during this interval was 35 m $\pm$ 18 m above present sea level.

Marine Ostracoda occur commonly as fossils in Pliocene deposits of the Coastal Plain. Many ostracode species have modern geographic ranges limited by water temperatures, making these species useful for paleoceanography. Using the factor analytic transfer function method, Cronin and Dowsett (1990) quantitatively estimated February and August water temperatures for Pliocene deposits from several regions of the Coastal Plain. Cronin (1991) extended this study to produce the paleotemperature estimates given in Table 1 for five regions of the Coastal Plain where Pliocene deposits outcrop. See Cronin and Dowsett (1990) and Cronin (1991) for details on the five regions.

The results indicate that Pliocene ocean temperatures were warmer than today north of Cape Hatteras, North Carolina (north of 35°N) but were about the same or slightly cooler off the southeastern US.

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Table 1. Paleotemperatures for Pliocene deposits determined by ostracode transfer function.

Area	Latitude North	Pliocene Temperature Feb°C	Pliocene Temperature Aug°C	Difference from modern Feb°C	Difference from modern Aug°C
1. SW Florida	27-28°	15.4	24.6	-0.6	-2.4
2. SE Florida	24-25°	18.1	25.6	-2.1	+2.2
3. Southeast US	31-35°	14.1	23.1	-1.0	-0.4
4. Mid Atlantic	35-38°	12.2	20.1	+2.8	+3.6
5. Massachusetts	40-41°	9.5	20.3	+2.8	+8.9

PLIOCENE FORMATIONS OF THE ATLANTIC COASTAL PLAIN

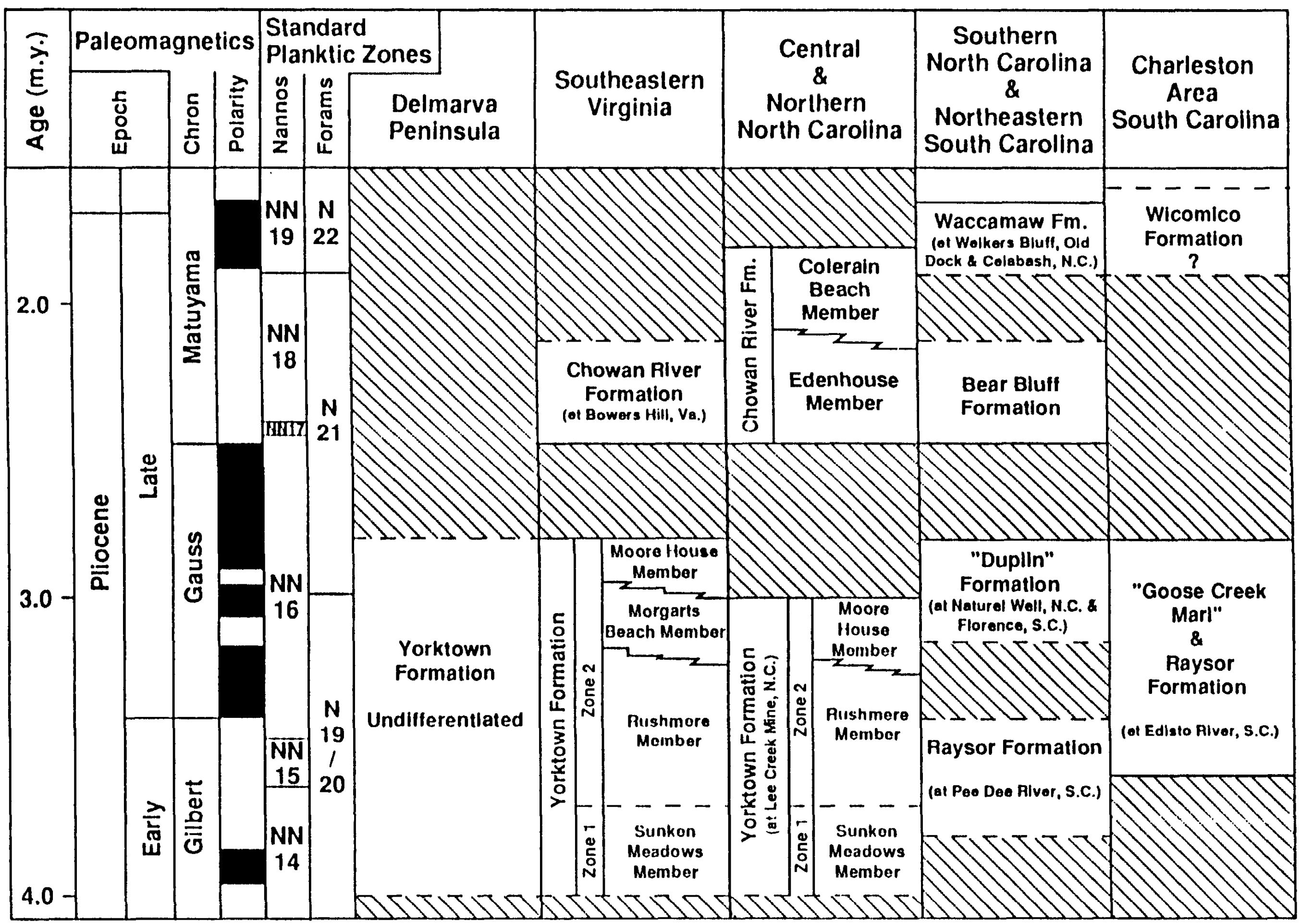

Figure 1. Stratigraphic correlation chart of Pliocene formations of the Atlantic Coastal Plain. Zones 1 and 2 of the Yorktown Formation are informal subdivisions used by early workers to divide the unit. Zone 1 corresponds to the Sunken Meadows Member; zone 2 corresponds to the Rushmere, Morgarts Beach, and Moore House members.

3.0 Ma Sea-Surface Temperature Estimates from the North Atlantic Ocean

H.J. Dowsett and R.Z. Poore

As part of the USGS investigation of Earth system response to global warming, we are documenting the magnitude and variability of North Atlantic Pliocene marine sea-surface temperature (SST) changes through intervals considerably warmer and cooler than modern conditions.

Our SST analyses are based upon analysis of planktic foraminifer assemblages with a major modification of the transfer function technique pioneered by Imbrie and Kipp (1971). This technique relies on a taxonomic simplification of the modern North Atlantic planktic data (from 223 core top samples) and a secondary regrouping of fossil data to account for fossil taxa not present in the modern data set (Dowsett and Poore, 1990; Dowsett, 1991). This regrouping has the effect of reducing the approximately 29 planktic foraminifer species presently living in the North Atlantic to 18 taxonomic categories with relatively little loss of information.

Factor analysis of this regrouped and condensed data set from 223 core top localities results in 5 factors or foraminifer assemblages which account for over 94% of the original data: tropical, subtropical, polar, subpolar, and gyre margin. Stepwise multiple regression of these factors or assemblages against physical oceanographic data like temperature and salinity produce the transfer function (GSF18) which can then be used to estimate paleoceanographic conditions. Tests on this transfer function suggest it is useful from the early Pliocene (approximately 4.0 Ma) to the Holocene.

Application of GSF18 to long time series through the Pliocene between 4.5 and 2.0 Ma at several North Atlantic DSDP Sites (552, 548, 603, and 606) show an interval of time around 3.0 Ma when mid latitude SST was elevated 3°C to 6°C with respect to modern temperatures.

We have determined the position of the 3.0 $\pm$ 0.15 Ma time level in a number of DSDP cores and several land sections and plotted the temperature change from modern conditions on Figure 1. All sites were correlated through a combination of paleomagnetic stratigraphy, and planktic foraminifer and calcareous nannofossil biochronology following Berggren *et al.* (1985) and Dowsett (1989). The results of this preliminary reconstruction support the notion of amplification of warming at higher latitudes as has been suggested by the results of most GCM simulations of the effects of increased atmospheric CO_2.

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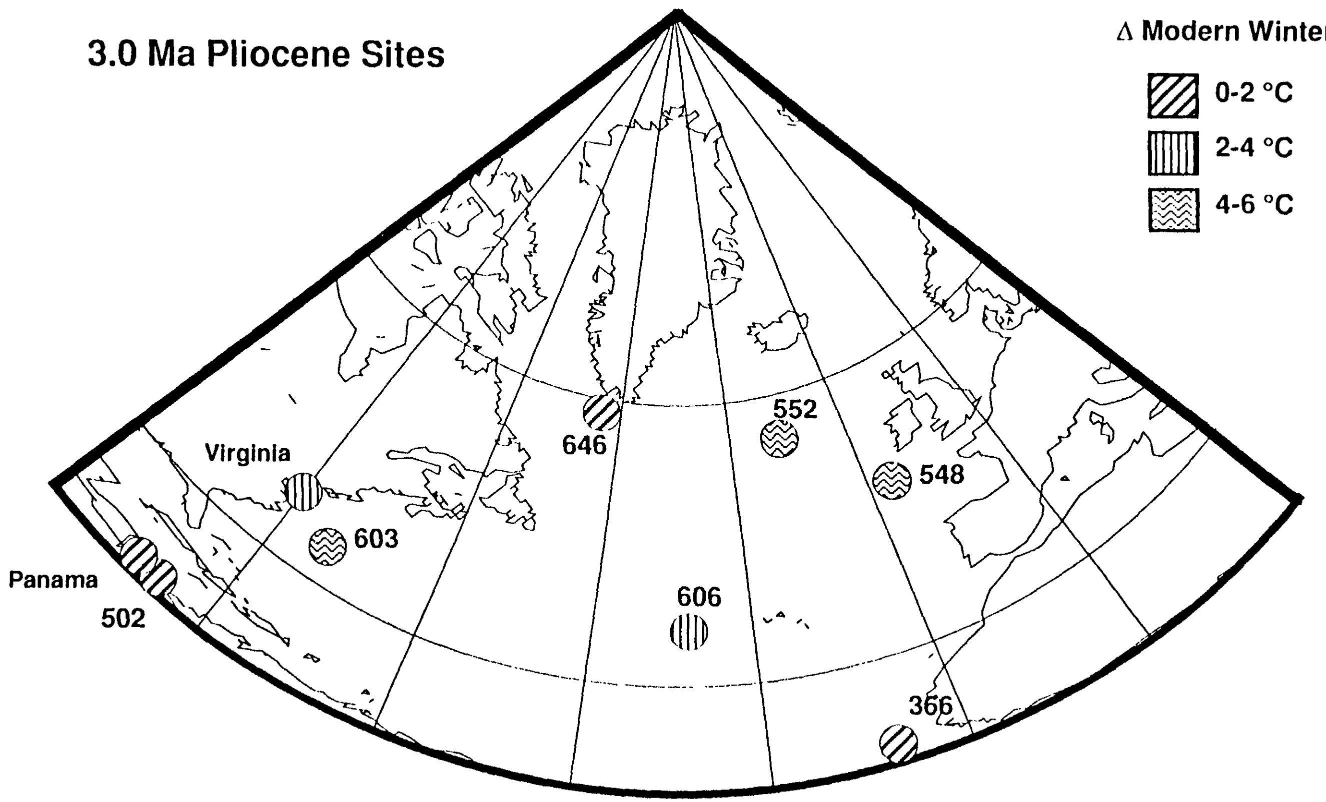

Figure 1. Location of Deep Sea cores and coastal sections with 3.0 Ma winter SST estimates.

Pliocene Climatic Fluctuations in the Far North-East of the USSR

A.F. Fradkina

Through many years of investigations in the region from the Verkhoyansk Mountains to Chukotka and the northern coast of the Okhotsk Sea it has been determined that the oldest Pliocene rocks are those of the Begunovsky regional horizon. These sediments have been studied in detail in sequences along the Kolyma River, and their early Pliocene age is inferred from palynological and plant megafossil data. Based on the paleomagnetic data from boreholes along the lower Kolyma, they are assigned to the Gilbert Epoch. Paleobotanical assemblages suggest that the vegetation of this time was a taiga-type forest with *Picea*, *Pinus*, *Larix*, *Betula*, *Alnus* with rare *Myrica*, *Carpinus*, and *Corylus*. The climate was temperate and humid, without sustained frosts. The mean annual temperature is estimated to have been less than +3°C (-13°C to -17°C in winter, +14°C to +17°C in summer). On the basis on studies of small rodents, the Kutuyakhskaya Formation (early Matuyama Chron or middle Villafranchian) and the lower Olerskaya subformation (late Matuyama Chron) are assigned to the late Pliocene. During this period, the coverage of forests decreased sharply and hypoarctic and arctic vegetation (including shrub-*Betula* and *Alnaster*, moss, and grass) became dominant. Temperatures are inferred to have declined to subarctic and arctic levels characterized by mean annual temperatures below freezing, with sharp differences between summer and winter temperatures. Despite this general decline in temperature through time, there were apparently at least two short periods of warmer temperatures within the late Pliocene (fig. 1). In summary, the first half of the Pliocene in the Far North-East of the USSR was warm, and a pronounced decline in temperature after 2.4 to 2.5 Ma.

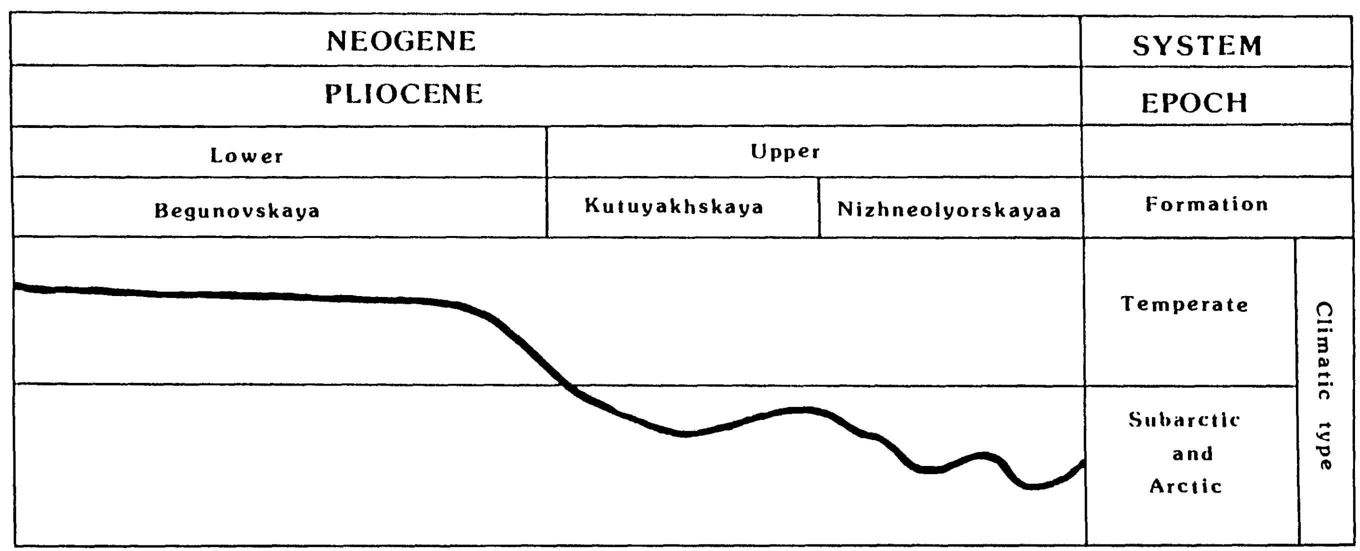

Figure 1. Inferred Pliocene environmental changes in the Soviet Far North-East.

The Pliocene Climatic Optimum in Northern Regions

Y.B. Gladenkov

The Geological Institute of the Academy of Sciences of the USSR has conducted research on late Cenozoic sequences of the North Pacific, North Atlantic and Arctic for many years. As a result, a climatic sequence with three major Neogene optima has been established, with the youngest optimum encompassing the lower Pliocene (Gladenkov, 1984). Research on a 460 m section of Pliocene sandstones, conglomerates, and tuffs in Iceland have shown that the warmest marine assemblages and most thermophilic floras are associated with Tapes-Mactra zones of the Tjernesian beds. This level in England corresponds to the Coralline Crag, which is characterized by warm-water assemblages. Correlation of geologic data suggests a relative warming across northern Europe in the early Pliocene (ca. 4 Ma) (Gladenkov, 1978).

Studies of a 500-m-thick Pliocene sequence of sandstones, conglomerates, and diatomites on Karaginsky Island off eastern Kamchatka have shown that the lower Limimtevayam suite contains fossils of relatively warm-water assemblages that are replaced in the upper part of the suite with cold-loving forms (Gladenkov, 1972). A similar picture is found in Sakhalin and in Japan, as well as in Alaska-California region. It follows from these data that warming in the early Pliocene (ca. 4 Ma) also occurred in these regions.

These data, in concert with deep marine sediment records (*e.g.* Barron, this volume), indicate that a climatic optimum occurred across the northern regions during the early Pliocene. Although this event was of much smaller magnitude than Miocene optima in these regions, the associated migration of thermophilic assemblages northward from tropical and lower boreal latitudes was quite distinct, with latitudinal shifts in the paleogeographic provinces in both the northern Atlantic and Pacific regions of 10° to 20°. Pliocene warming should be considered in correlation with other geologic events (eustatic oscillations of the ocean, tectonic events, emergence of water-ways or destruction of physical barriers, etc.). Without such correlations, interpretations of the paleoclimatic situation in each of the regions may be inaccurate. Confirmation of the paleoclimatic conclusions requires new comparative materials with an emphasis on detailed studies of various paleontological groups. This effort should result in the detection of the true patterns of paleoclimatic fluctuations; documentation of their manifestations in three major paleo-ecosystems (marine, continental shelf, and continental); and the application of these results to the estimation of future climatic variations.

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Vegetation And Climate Of The Middle Akchaghylian (Late Pliocene) On The Russian Plain

V.P. Grichuk

Palynological studies provide the majority of information on the vegetation and climate of the Russian Plain during late Pliocene (Akchaghylian) time. This research indicates that forests covered this region, except for a narrow latitudinal belt of steppe in the Azov region. Conifers dominated these Pliocene forests, with *Pinus* spp. more dominant in the western portion and *Picea* spp. to the east of 45°E longitude. *Abies*, *Tsuga*, *Juglans*, *Pterocarya*, *Liquidambar*, *Carya*, *Ilex*, *Fagus*, *Castanea* and many other genera were also present: the presence of over 30 arboreal genera in Akchaghylian deposits testifies to the high diversity of the forests. In this region, Holocene deposits typically contain only 9 to 11 genera.

Despite the predominance of conifers, the forest formations of the Akchaghylian time were not analogous to modern taiga forests. As illustrated in figure 1, the climatic tolerances of the primary indicator genera of modern dark-coniferous formations - *Picea* and *Abies* - are considerably broader that the distributional limits of taiga and subtaiga forests. In the remaining part of their ranges these taxa are in associations with genera alien to the modern taiga, such as *Vitis* and *Pterocarya*. Arealogical analyses indicate that the closest modern analogues for the Akchaghylian flora of the Russian Plain occur in eastern China where warm-moist climates support pine forests with a great diversity of broad-leaved and evergreen arboreal species. However, one should exercise care when using formation analogues in the process of paleogeographic (paleoclimatic) reconstructions for various epochs of the late Cenozoic, including the Pliocene.

The climatogram method was employed to obtain paleotemperature estimates for the Akchaghylian optimum. This method does not select any specific modern regions as analogues and, consequently, does not artificially read into the past any modern combination of environmental factors or competitive relations among taxa. Figure 2 illustrates the paleotemperature estimates for twelve Pliocene sites on the Russian Plain. The Pliocene climate across the region was relatively uniform, but with a trend toward declining winter temperatures and, consequently, a greater range in seasonal temperatures, to the east. Mean July temperatures (18°C to 20°C) was the least variable across the region, and only in the Azov region did it reach 24°C. In summary, during the late Pliocene the climate was nearly subtropical and varied only slightly across most of the Russian Plain.

Figure 1. Climatograms for four genera found together in Pliocene assemblages from the Russian Plain.

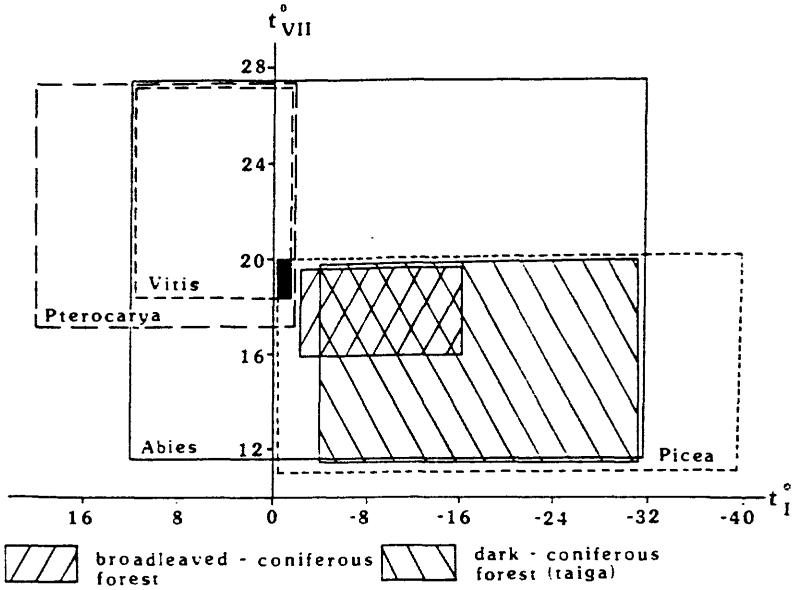

Figure 1.

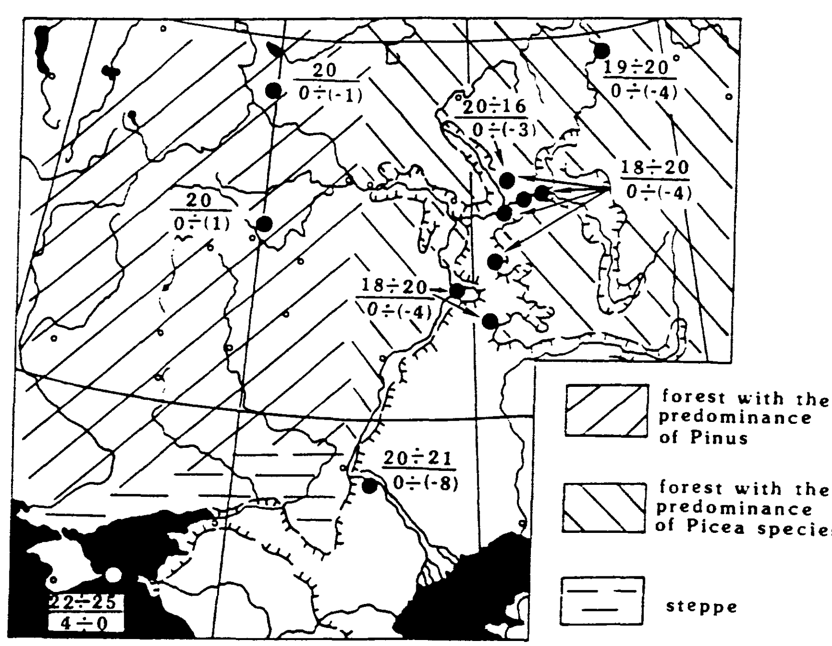

Figure 2.

Figure 2. Pliocene paleotemperature estimates for the Russian Plain. Numbers above the bar at each site represent the range of summer temperature estimates, while numbers below represent winter temperature estimates.

The Paleogeography of the Trans-Caucasus Region During the Pliocene Climatic Optimum

A.V. Mamedov

This short report presents the initial results of an investigation of the climate and landscape of the Trans-Caucasus region during the Pliocene optimum. Numerous biostratigraphical, paleontological, palynological, and geochemical investigations are synthesized for this reconstruction, and new focused integrated research was conducted on a number of selected sections. Special attention was paid to stratigraphic correlations of events in this region with those in other nearby areas. More than 30 tephra layers were deposited in the Trans-Caucasus during the late Neogene, and fission-track dating of these deposits has made it possible establish a radiometrically based Pliocene chronology for the region (Chumakov *et al.*, 1988). This chronology can thus be correlated with the Pliocene standard scale of the Mediterranean region, with zonal stratigraphical schemes of the world ocean, and with the paleomagnetic scale (fig. 1).

Paleoclimatic reconstructions based on the interpretation of paleobotanical data by the arealogram and climatogram methods place the temporal bounds of the Pliocene climatic optimum within the period between 4.0 and 3.5 Ma (Mamedov and Rabotina, 1984; Shatilova, 1974). Stratigraphically it corresponds to the upper part of Early Pliocene, i.e. the upper Kimmerian and Balakhanian. Deposits from this period contain the greatest abundance and diversity of thermophilous plants, with more than one third of the 60 floral genera found in the Upper Kimmerian deposits of western Georgia belonging to this group. These taxa include *Ginkgo*, *Myrica*, *Comptonia*, *Platycarya*, *Engelhardtia*, *Magnolia*, *Laurus*, *Liriodendron*, *Corylopsis*, *Sycopsis*, *Alangium*, *Aralia*, *Sabal*, *Eucalyptus*, *Cryptomeria*, and *Ficus* (Shatilova, 1967, 1974). The remaining two thirds of this flora are deciduous and coniferous trees, however many of the latter taxa can be found today in warm subtropical areas. At present, more than 70% of the flora of the Upper Kimmerian deposits of western Georgia grow together in south-eastern coastal China where the mean January temperature is between 10°C and 15°C, mean July temperature is 22°C and 24°C, and mean annual precipitation is approximately 2500 mm.

A compositionally similar flora is also present deposits from the Pliocene climatic optimum in Azerbaijan. Sediments of upper Balakhanian age here contain *Pinus*, *Picea*, *Podocarpus*, *Cedrus*, *Taxodium*, *Abies*, *Thuja*, *Juniperus*, *Fagus*, *Zelkova*, *Ulmus*, *Pterocarya*, *Laurus*, *Cinnamomum*, *Nyssa*, *Aralia*, *Ginkgo*, and *Rhododendron*. This floral assemblage differs from that of the western Trans-Caucasus region mainly in the absence of the most moisture-loving elements (Palmae, *Ficus*, *Myrica*, *Eucalyptus*, *Cryptomeria*, and others). This Pliocene assemblage also greatly differs from the modern flora of Azerbaijan, with more than two-thirds of its elements lacking in the present-day flora. These plants do grow together now in eastern Asia and eastern North America. The presence in the Pliocene floral complex of apparently ecologically-incompatible species, such as coniferous, broad-leaved, and evergreen plants (which today are restricted to different elevational belts) indicates that during this period there was strongly pronounced vertical climatic and landscape zonality in the Trans-Caucasus region. The paleogeography and paleoclimate of the Trans-Caucasas region during the Pliocene climatic optimum can be reconstructed from sedimentary, floral, and faunal data. As illustrated in figure 2, forests covered this region and the modern steppes and semideserts were absent. In the arid areas of Azerbaijan in the foothills of the Great and Lesser Caucasus and in the Kura Depression, there were savannas with varying degrees of forest cover. The mountains were almost completely covered by forests, with broad-leaved communities with many evergreen species at lower elevations and polydominant coniferous assemblages at higher elevations.

In the arid portions of Azerbaijan the mean January temperature during the Pliocene optimum was 8°C warmer than today, the mean annual temperature was 4°C warmer, and precipitation was twice modern levels. The Black and Caspian Seas, although separated, were larger than at the beginning of the Pliocene, having expanded to form shallow gulfs in the Rioni and Kura Depressions respectively.

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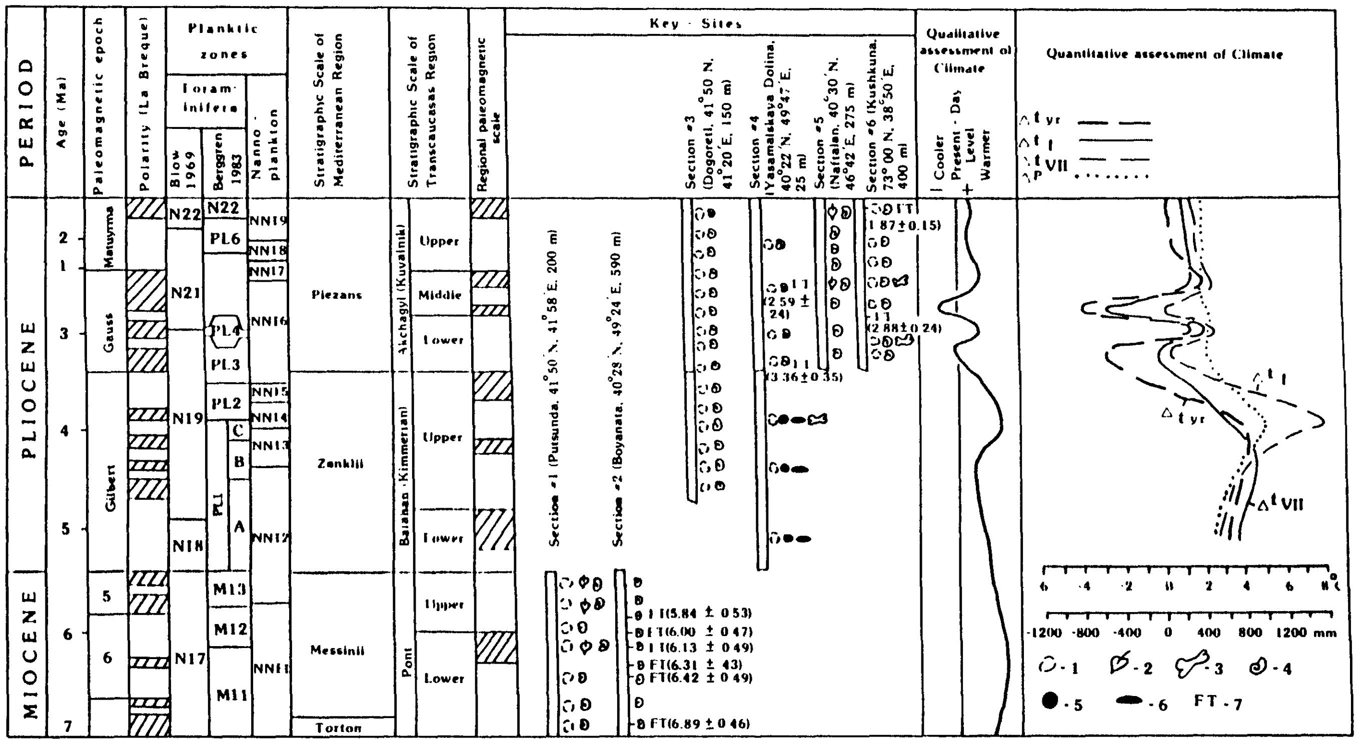

Figure 1. Paleoenvironmental sequences from the Trans-Caucasas Region correlated with stratigraphic schemes from the deep oceans and from the Mediterranean.

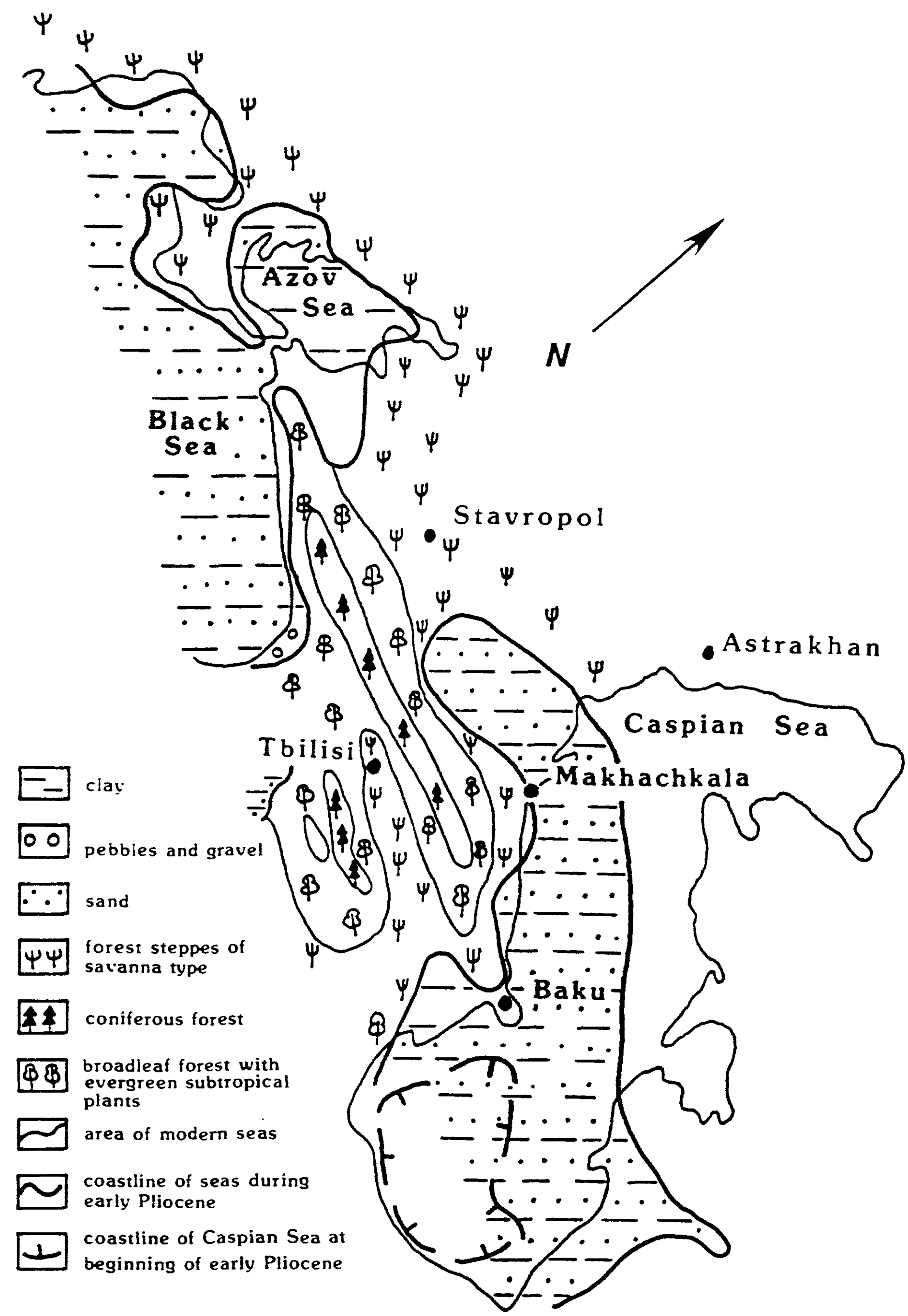

Figure 2. Paleogeographic reconstruction of the Trans-Caucasas Region for the Pliocene optimum.

Northeastern Pacific and Arctic Ocean Pliocene Marine Mollusks

L. Marincovich, Jr.

Deposits containing Pliocene marine mollusks are widespread along the margin of the northeastern Pacific Ocean and on the adjacent Arctic Ocean coasts of western and northern Alaska and northern Canada. These Pliocene faunas have been relatively well-studied only in the U.S. Pacific Northwest states of Oregon and Washington (Addicott, 1976). Much thicker Pliocene strata with abundant and diverse molluskan faunas occur in southern Alaskan formations, especially the Yakataga Formation, but they have been incompletely studied. Pliocene faunas in western and northern Alaska, associated with marine transgressions through Bering Strait, are now being comprehensively studied for the first time.

Pliocene molluskan faunas of the Quinlaut Formation in Washington State were used by Addicott (1976) to define the Moclipsian molluskan stage. This stage name has since been used for faunas in Oregon, northern California, and the Gulf of Alaska. Most mollusks used by Addicott (1976) to define the Moclipsian Stage have their first or last appearances in this stage, but few are known only in Moclipsian faunas. Addicott (1976) did not subdivide the Moclipsian Stage, so his biostratigraphic scheme does not permit the differentiation of early Pliocene from late Pliocene faunas. Moclipsian faunas of northern California, Oregon, and Washington share numerous species, but only one characteristic Moclipsian species in those faunas, *Lituyapecten dilleri*, has been found in southern Alaska, in the upper part of the Yakataga Formation.

On the basis of limited published information and unpublished studies of U.S. Geological Survey mollusk collections, the Gulf of Alaska formed a distinct cold-water faunal province during the Pliocene. In the eastern Gulf of Alaska, Pliocene mollusks occur in the upper part of the Yakataga Formation, and in the western Gulf of Alaska Pliocene mollusks are thought to occur in the lower part of the Tugidak Formation. Addicott and others (1978) indicated that Pliocene strata within the Yakataga Formation are up to 2,050 meters thick. Mollusks are the best known fossils from this formation, but diatoms and planktonic and benthic foraminfers also occur in it. It is clear that a detailed study of Yakataga Pliocene faunas is needed, to learn exact ages of the faunas and to provide precise data for high-latitude northeastern Pacific paleoclimatic interpretations.

Pliocene Tugidak Formation molluskan faunas are of somewhat warmer-water aspect than those in the Yakataga Formation. Probably because of this paleotemperature difference, some eastern Asian species are present in the Tugidak fauna and allow the possibility of correlating from the western Gulf of Alaska to the Far-eastern USSR and northern Japan.

Some Tugidak and Yakataga species also are present in the Bering Strait region, where a series of six or eight marine transgressions ranges in age from late Pliocene to late Pleistocene (Hopkins, 1967). Among the extinct Pliocene mollusks in the Bering Strait region is *Fortipecten hallae*, which is clearly related to east Asian species such as *F. takahashii* and *F. kenyoshiensis*. The precise age range of *F. hallae* is now under study, but this species also is present in the Gubik Formation of northern Alaska. Using this species and others it should be possible to correlate between Pliocene faunas of the Bering Strait region and those of the Gubik Formation in northern Alaska. Paleotemperature fluctuations now recognized within faunal sequences of both western and northern Alaska could then be understood in a regional context.

An effort by several American workers is now underway to date Pliocene faunas of western and northern Alaska, using the relative-dating technique of amino acid racemization and the more precise technique of strontium isotope measurements.

A principal objective of studying North Pacific and Arctic Pliocene faunas is to more exactly date the opening of Bering Strait. The marine transgression that formed this seaway presumably occurred during a warm climatic interval, perhaps at the peak of early Pliocene global warming. The best dating of this seaway's opening is based on the first appearance of Pacific mollusks in Iceland at about 3.35 Ma (Gladenkov and others, 1980). However, it would be desirable to date this opening based on faunas that are geographically closer to Bering Strait, in Alaska or the Far-eastern Soviet Union.

In addition to the Gubik Formation, two other Arctic Ocean deposits contain Pliocene mollusks. These are the Nuwok Member of the Sagavanirktok Formation of northeastern Alaska and the Beaufort Formation of northern Canada. Molluskan faunas of these two formations differ from those discussed earlier, because they contain only taxa of Atlantic origin, so they likely predate the opening of Bering Strait. Although little-studied, mollusks have been collected from the Nuwok beds (70°N) and collections from the Beaufort Formation on Ellesmere Island and Meighen Island (80°N) will soon be studied. The presence of the mid-latitude northwestern Atlantic bivalve *Chesapecten* in the Nuwok fauna implies a relatively warm early Pliocene Arctic Ocean. A late Oligocene age for the Nuwok beds (McNeil and Miller, 1990) is based on one strontium isotope age of a mollusk from a bed in which all fossils have been diagenetically altered, and on one benthic foraminifer species considered herein to be reworked. Comparisons of these two Arctic Ocean Pliocene faunas with coeval North Pacific faunas will hopefully provide insights into latitudinal paleotemperature gradients during the early Pliocene.

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The Pliocene Climate of Western Georgia

I.I. Shatilova, N.V. Macharadze, and L.S. Davitashvili

The western Georgian Colchic region, along the eastern Black Sea, is an isolated botanical province where some Tertiary floral elements have persisted until today. From the geological perspective, this area is a stratotypical region where all Neogene deposits of Black Sea are represented. The rich paleontological assemblages from sediments provide the basis for the chronostratigraphic regional subdivisions of the Neogene. Here, the Pliocene is divided into the Pontian (ca. 6.3 to 5.0 Ma), Kimmerian (ca. 5.0 to 3.1 Ma), Kuyalnikian (Egrissian, ca. 3.1 to 1.8 Ma) and Gurian (ca. 1.8 to 0.7 Ma), the top of which is the boundary between the Pliocene (Eopleistocene) and Pleistocene.

The climatogram method was employed with paleobotanical data to produce an inferred temperature curve for the latest Miocene, Pliocene, and lower Pleistocene (Tschaudian). This climatic chronology begins with the Meotian, because the later Miocene was a major turning point in the geological history of Caucasus. This was the time when mountain-building formed the Colchic refuge, where warm and humid conditions persisted through the Pliocene. Following the Sarmation, a great number of plant taxa disappeared from the floral assemblages of western Georgia. These included primarily ancient lineages of ferns, conifers and thermophilous angiosperms, the bulk of latter being predominantly members of the Lauraceae. Due to these extirpations, the Meotian flora more closely resembles younger (Pliocene) assemblages than the older Samartian (Miocene) ones.

The warmest temperatures of the Neogene in western Georgia occurred during the Meotian, Pontian and early Kimmerian (fig. 1). During this time-span subtropical vegetation present during the Samartian persisted at lower elevations. In the mountains, this vegetation was replaced by deciduous and coniferous forests. The first sharp temperature reduction occurred in the Upper Kimmerian, and after this time the entire scope of natural processes was different and climatic variability greatly increased. In the Kuyalnikian there were two warm and two cold phases. During the cold episodes, coniferous replaced deciduous communities across the elevational gradient in the mountains. The warm episodes were characterized by the predominance of the polydominant conifer and deciduous communities which lacked subtropical elements. The extinction of the latter taxa continued through Pontian and Kimmerian times, with the result that evergreen vegetation completely disappeared from western Georgia.

The Gurian was a time of less climatic variability, but during this time the structure of vegetation changed radically. The vertical typical Quaternary vegetation zones formed as in the upper and middle elevational zones the polydominant formations were replaced by monodominant forests.

All of the vegetational and climatic changes discussed above were connected to tectonic movements, which created the modern Greater and Lesser Caucasus by the end of the Pliocene. Mountain-building created new ecological niches, a process that favored the wide distribution of temperature plants and the formation of new monodominant forests not characteristic of the Neogene.

The vegetation and climate of the late Gurian and the early Tschaudian were much alike, and major temperature changes occurred only in the Late Tschaudian. Climatic instability characterized Tsermagalian time, by which it can be distinguished from the previous and following periods of Pleistocene.

In summary, the gradual climatic changes that began in the Meotian led to early Pliocene subtropical climates being replaced warm-temperate conditions, which continued through the Pleistocene. This general climatic trend was punctuated by sharp temperature fluctuations which became more distinct after Kimmerian time.

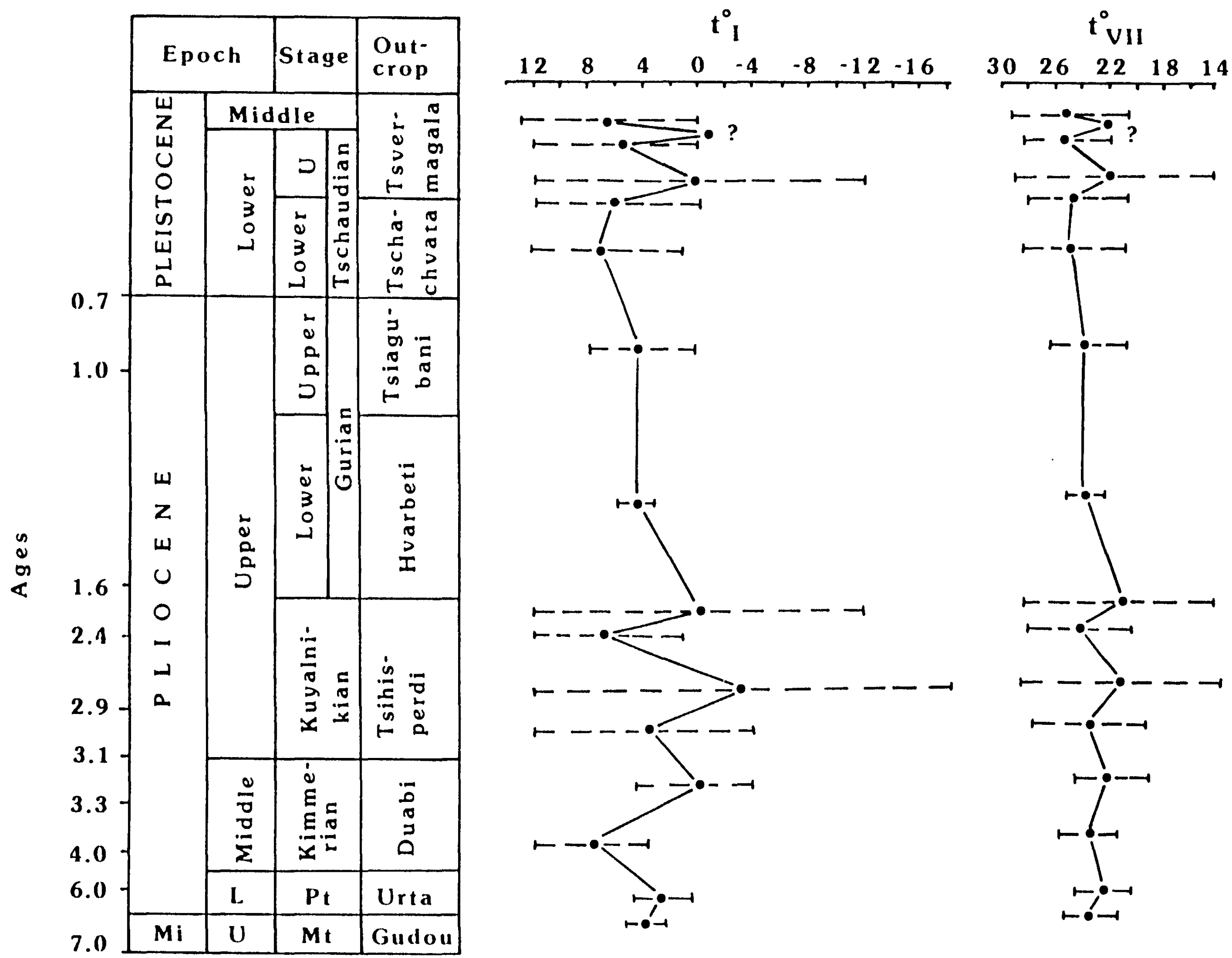

Figure 1. Paleotemperature estimates for western Georgia for January (T^{o}_{I}) and July (T^{o}_{VII}) for the last 7 Myr.

Pliocene Paleolandscapes and Paleoclimates of the Southwest of the European Part of the USSR

S.V. Syabryaj and T.V. Svetlitskaya

An integrated study of paleobotanical, paleozoological, and paleomagnetic investigations in the southwestern European territory of the USSR has made it possible to define the main trends in the Pliocene paleogeography of this region. Quasi-rhythmic climatic fluctuations were imposed on the general trend toward cooler/drier conditions through this period. The currently available data indicate that the post-Miocene vegetation history varied across this area, with three primary apparent divisions: 1) the region west of the Dnieper River, where forests were dominant, 2) the region east of this river, where open vegetation dominated, but with pockets of forest cover, and 3) the mountains, where dark coniferous forests played an important role.

During the late Pontian, temperatures were generally warm, with relatively arid conditions in the east. The mountainous regions experienced lower temperatures, more humid conditions, and higher soil moisture. Paleobotantic data from Kimmerian sediments, supported by molluskan and large mammal records, indicate a warmer and more humid climate than previously. During the first half of the Kimmerian, the percentage of subtropical genera in the flora (*Pittosporum*, *Parrotia*, *Nyssa*, *Aralia*, *Magnolia*, *Staphylea*, *Taxodium*) increased over the late Pontian level, reflecting the rise in temperature. The maximum temperature increase occurred during deposition of the sediments of the Kamyshburun horizon (4.2 to 4.0 Ma). Mean January temperatures rose by almost 2°C (to 6°C) and mean July temperature rose from 22°C to 23°C. The spatial differentiation of the landscape types remained the same as in Kimmerian. Forests, especially broad-leaved warm-temperate communities, remained common. Open vegetation also occurred, but swamp-meadow complexes replaced steppe in most non-forested areas, and halophytic plants occupied vacated parts of sea-shelves. In the mountains, broad-leaved and swamp forests (the latter with a dominance of *Taxodium* and *Nyssa*) expanded, indicating a warm-humid climate with greater warming in the south. Similar temperature increases took place over considerable areas of eastern and east-central Europe, where greater moisture availability gave a mesophytic cast to the vegetation than in the USSR.

A trend toward cooler temperatures and a more continental climate developed by the end of the Kimmerian. This trend intensified in the late Pliocene and was strongly manifest in the southern part of the European USSR, as forest-steppe vegetation became dominant. In the open areas existed more xerophilous steppe species, reduced areas of forest, and fewer broad-leaved trees. These vegetational changes also induced major changes in faunal communities. In the mountains, due to existence of a warm internal lake-bog basin, the climate did not become as continental, and the floral and faunal changes at the beginning of the late Pliocene were insignificant.

On the basis of the data presented here, despite regional differences, we affirm that Pliocene optimum occurred during Kimmerian time (approximately 4.2 to 4.0 Ma) across the entire region under investigation.

Pliocene Environments of North America

Robert S. Thompson

Evidence for environmental conditions during the early and middle Pliocene (ca. 5.0 to ca. 2.4 Ma) in North America is available from a variety of fossil groups, including pollen, plant macrofossils, vertebrates, diatoms, and ostracodes. The majority of the available data for this generally warmer-than-present period in Earth history is from the Arctic and the western United States. Much remains to be done, particularly in regard to resolving discrepancies in dating and in the development of improved means of paleoclimatic interpretation.

In the Canadian Arctic archipelago as far north as 80°N, plant macrofossil assemblages of apparent Pliocene age contain a mixture of extinct species, plants that now grow only far to the south, and modern arctic forms (Matthews, 1989, 1990). The inferred temperature anomalies (departures from modern) are larger than those in the middle latitudes. Palynological study of early and middle Pliocene sediment cores from the Labrador Sea indicates that a cool temperate coniferous forest including *Pinus, Picea, Tsuga,* and *Sciadopitys* grew in an area now covered with tundra and glacial ice (de Vernal and Mudie, 1989a). Pliocene pollen from marine sediments in Baffin Bay reflect an open coniferous forest and forest tundra, again including relatively temperate elements such as *Abies* and *Sciadopitys* (de Vernal and Mudie, 1989b).

In the western United States, large lake systems existed in the now semiarid interior from eastern Oregon and southern Idaho to Arizona and southern California (Thompson, 1991). Conifers dominate the palynological records from this region, where steppe and desert plants are now prevalent (Leopold and Wright, 1985; Thompson, unpub. data). These data indicate that much higher-than-modern levels of effective moisture prevailed through much of the Pliocene. Pollen and diatom data from Tule Lake in northwestern California indicate generally warmer-than-modern temperatures from 2.9 to 2.6 Ma, as the modern analogs for this period are located ca. 2° latitude south of the coring site (Adam *et al.*, 1990). Pliocene plant macrofossil assemblages from northwestern California, northwestern Oregon, and northern Utah have been interpreted in paleoclimatic terms through numerical analyses of leaf-physiognomic parameters (Wolfe, 1990). Wolfe concluded that Pliocene temperatures were 2°C to 4°C warmer than modern at all sites, and precipitation levels were higher than today in California and Utah, but lower than today in northwest Oregon.

Although absolute age controls on climatic variations are lacking from many sites, it appears that a general trend toward cooler and drier conditions (with embedded short but significant reversals) developed during the late Pliocene across North America. In the Labrador Sea and Baffin Bay regions, temperate trees dropped out of the vegetation assemblages as boreal forest developed. The first continental scale glaciation occurred near 2.4 ma, with glaciers advancing as far south as Iowa (Easterbrook and Boellstorff, 1984). In western North America, the major drying and/or cooling occurred soon after 2.5 to 2.4 Ma (*e.g.* Smith, 1984; Adam *et al.*, 1990)

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Cenozoic Paleoclimates and Prospects for Forecasting

A.A. Velichko

The possibility that human economic activities may lead to global climatic changes in the 21st Century (the greenhouse effect) has drawn the attention of many specialists to the examination of data on climatic conditions in the geological past. The results of paleoclimatic investigations are necessary for: 1) working out the scenarios of the future states of the climate and the environment; 2) determination of the predictable aspects of natural climatic variations; and, 3) verification of climatic simulations of numerical climatic circulation models.

According to current estimates, the mean global temperature of the near-surface layer of the atmosphere will rise by 1°C by the year 2000, by 2°C by 2025, and by 4°C to 5°C by 2050. The wide spectrum of thermal fluctuations that occurred through the Mesozoic and Cenozoic includes variations of similar magnitudes to these predictions. Calculations indicate that global temperature anomalies of +1°C occurred during the Holocene optimum (5.5 ka) and that anomalies of +2°C occurred during the optimum of the last interglacial at about 125 ka (this is known variously as the Eemian, Sangamon, or Mikulino interglacial and correlates with marine isotope stage 5e). Spatial reconstructions of climatic parameters for 5.5 ka and 125 ka have a relatively high degrees of reliability since they are based on a network of terrestrial as well as marine sites. It should be noted that the spectrum of terrestrial biota now provides a series of quantitative paleoclimatic estimates on a scale previously available only in the oceans.

Scientific studies over the last 10 to 15 years at sites in many countries, including our laboratory of paleogeography, have determined that paleoclimatic reconstructions based on paleobotanical data have the highest resolution and the most widespread applicability of any of the methods available for continental studies. As the quantitative methods employed are based on modern relationships between climatic parameters and vegetation, reconstructions for the late Quaternary (when the flora is nearly identical to modern) have better resolution than those for earlier periods. The accuracy of these methods for the late Quaternary falls within 1°C for temperature and within 25-50 mm precipitation per year. As the number of extinct taxa increases with progressively older floras, the linkage between modern plants and climatic parameters becomes more tenuous and the uncertainty associated with the paleoclimatic reconstructions increases. However, special methodological investigations carried out in our laboratory indicates that these obstacles can possibly be overcome through the application of the climatoagram method. A reconstruction of conditions during the Eocene optimum based on climatograms constructed at the generic level apparently has an accuracy in the temperature estimations of within 2°C. Based on this example, there are grounds to suppose that the accuracy of reconstructions for the Pliocene optimum will be not less than 2°C.

Paleoclimatic reconstructions of the Pliocene optimum (3.5 to 4.0 Ma) are of special interest for the identification of scenarios for climatic warming associated with the greenhouse effect. Based on preliminary data, the global temperature difference between today and the Pliocene climatic optimum was similar to that expected with a future doubling of atmospheric CO_2. The development of qualitative spatial reconstructions will make it possible to compare scenarios based on paleodata with simulations from numerical climate circulation models.

Information on past climates are available now and form the basis of deductions about key aspects of major climatic changes, such as the similarity of variations in the pole-to-equator temperature gradient during past periods of global warmth. In all warm episodes from the Holocene optimum to the Eocene optimum the largest increases in temperature occurred in higher latitudes, even though the amplitude of the temperature anomalies were quite different (in the middle Holocene, January temperatures differed from those of today by +3°C to +4°C, in the Eemian by +6°C to 10°C, and in the Eocene by +30°C to +40°C). In the middle latitudes the amplitude of the temperature anomalies decreased with decreasing latitude. In the low latitudes the temperature anomalies were generally negligible, or even negative in some regions. The occurrence of warm temperatures across the latitudinal gradient during the powerful Tertiary thermal optima provides evidence for the conclusion that the "Milankovich mechanism" cannot account for these climatic changes.

The pattern of fluctuations in mean annual precipitation were not as similar as the temperature variations among the Cenozoic thermal optima. Although during all of these warm periods the total sum of precipitation increased, there were regions were precipitation decreased as the global mean temperature increased by 1°C. However, overall precipitation increased proportionate to the rise of the global temperature. During the Eocene optimum, the increased moisture levels made it possible for the arboreal vegetation with tropical elements to grow at high latitudes. This data-based interpretation of higher levels of effective moisture during the Eocene differs from the conditions simulated by numerical climate models, which calls for a joint discussion by experts representing both points of view. It is clear that paleogeographic reconstructions from past warm periods, such as the Eocene and Pliocene, cannot be taken as literal predictions of future "greenhouse" conditions.

Pliocene Climates of West Siberia

V.S. Volkova

Palynological and paleontological evidence provide the basis for the estimation of seasonal temperatures and annual precipitation for the Pliocene of west Siberia. Climatic conditions changed repeatedly through the Pliocene in this region, and the major stages of climatic change are presented below.

Early Pliocene. During the first stage (Novostanichny time, 5.3 to 4.0 Ma), the flora was dominated by conifers with a few broad-leaved trees (*Corylus*, *Ulmus*, *Quercus*, *Juglans*, and *Carpinus*) and abundant water plants. The climate was warm and temperate with mean January temperature near -8°C, mean July temperatures in the range of +18°C to -22°C, and mean annual precipitation between 300mm and 350mm. The second stage (Bitekeisky time, 4.0 to 3.5 Ma based on paleomagnetic data) corresponds to Pliocene optimum, and deposits of this age contain thermophilic mollusk communities with Sino-Indian elements, and late Ruscinian small rodents, spores and pollen. Palynologic data from the early Pliocene indicate repeated climatic fluctuations (fig. 1), ranging from warm-temperate to arid and semiarid. The temperature regime was heterogeneous and differed greatly from the present one. According to the palynologic evidence, the mean temperature in January varied from -8°C to +6°C to +8°C, and in July from +20°C to 24°C. The climate in southern West Siberia was warmer than present time and the mean temperature was similar to modern conditions at Shanghai (China), in eastern North America between 40° and 50° North latitude, in northern India, and in some portions of Soviet Central Asia.

Late Pliocene. During late Pliocene time (the Kochkovsky and Ubinsky horizons in the Matuyama and Gauss Chrons, 2.5 to 1.65 Ma) the climate varied from temperate-boreal to subarctic and arctic. Beginning near 2.5 Ma, arctic and subarctic elements increased in both the flora and the fauna. Particularly profound climatic cooling occurred between 1.65 and 1.2 Ma, as arctic and subarctic landscapes came to dominate the entire southern region of the West Siberia. The first continental glaciation of Siberia is assigned to Ubinsky time.

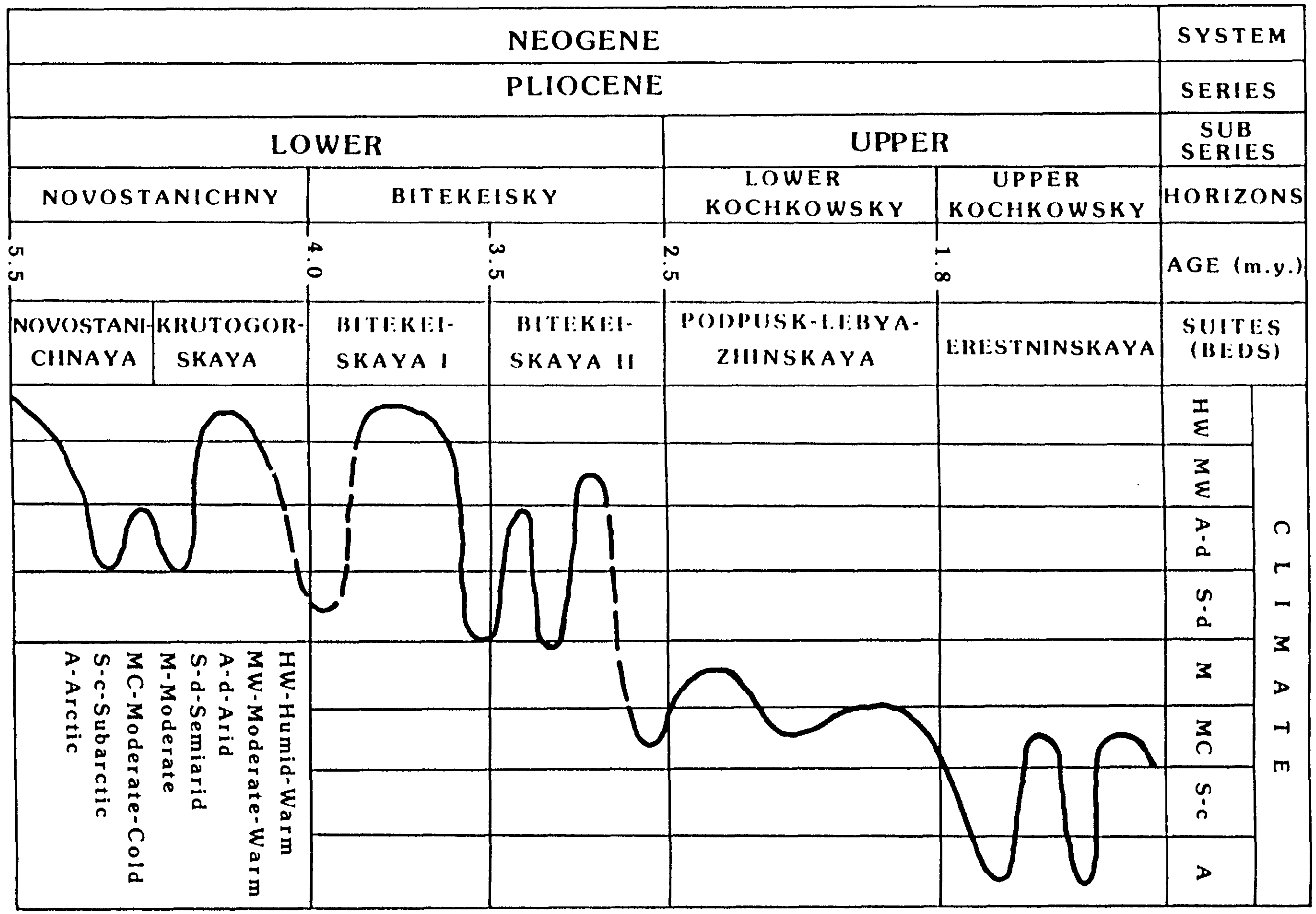

Figure 1. Estimated changes in paleoclimatic conditions in western Siberia during the Pliocene.