TERTIARY CLIMATE CHANGES IN THE FAR EAST BASED ON PALAEOFLORISTIC AND PALAEOMAGNETIC DATA

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ABSTRACT

Temperate Arcto-Tertiary assemblages may represent a series of afforestation events with intervening deforestations introducing non-arboreal elements. Joint palaeobotanical and magnetostratigraphic studies of the most complete Palaeocene to mid-Miocene Khoyndjo Section (northwestern Sakhalin) and supplementary sections revealed 15 my climatic cycles of four phases: cold humid (CH), cold dry (CD), warm dry (WD) and warm humid (WH) repeated cyclically. Major floristic events fall at the WD/WH boundaries. These patterns seem typical of the northern hemisphere middle latitude climatic cycles. Moreover they are repeated on minor scales down to the Holocene, 10,000 years ago, and to even shorter cycles. A model of climatic cyclicity is proposed involving the maritime polar surges as a source of cyclogenesis (WH to CH), polar front advance over continents (CD), subtropical front outbreaks in the form of blocking anticyclones (WD) and the build-up of atmospheric CO_2 (CD-WD transitions). The model may have some predictive possibilities.

INTRODUCTION

An attempt is made in this paper to reveal the potential value of Arcto-Tertiary climatic events for climatic forecasting. Though the analysable Arcto-Tertiary events and the aims of present-day climate forecasting are of very different time scales, some inferences would seem justifiable if any structural similarity exists between the first order and subordinate climatic cycles. Moreover, the greenhouse and other forecasting models have to be adjusted to the natural patterns of climatic evolution recognisable in a sufficiently long geological record, otherwise they are of little value

The material for this paper has been collected since 1975 by the author and his collaborators in the Far Eastern Research Centre (Vladivostok) from Primorye, Amur Province, Kamchatka, Sakhalin and the Kuril Islands. A review of the Arcto-Tertiary floras and phytostratigraphy of these areas are given in Krassilov (1989a).

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ARCTO-TERTIARY FLORISTIC EVOLUTION AND CLIMATE

The concept of the Arcto-Tertiary geoflora was initially based on the 'temperate' plant assemblages from various northern localities described by Oswald Heer in his voluminous *Flora Fossilis Arctica*, and compared with the (then) best-known Miocene flora of Switzerland. Later it was shown that at least some of the temperate floras were of Palaeogene rather than Miocene age. Eventually it became clear that the Arcto-Tertiary assemblages belong to two successive 'temperate' stages divided by a much warmer stage. The latter is marked by a spread of the London Clay (or Poltavian in Russian terminology) elements reaching as far north as Alaska and Kamchatka. In Europe this warm stage is presently assigned to the Sparnacian-Lutetian (Chateauneuf, 1980; Plaziat, 1981; Boulter, 1984, etc.). Some thermophilous Eocene plants, such as mastixioid genera, have reappeared as dominant elements in the Miocene vegetation of Burdigalian age marking the second major (though short-lived) warming.

While the 'temperate' Arcto-Tertiary assemblages undoubtedly represent deciduous forests, the nature of the London Clay-type or mastixioid vegetation is less obvious. They are often compared with humid tropical or subtropical forests; but the average size of the leaves is much smaller, and they have thicker cuticles and less prominent drip-tips, suggesting an open shrubby vegetation rather than closed forests. Moreover the preponderance of fruits over leaf remains, especially among the Cornales, might seem to be indicative of shrubs rather than tall trees such as extant *Mastixia*. Even mangrove palms and *Taxodium-Nyssa* mire forest might thrive in a relatively dry climate (as in Florida today) bordering on vast open landscapes.

Paradoxically, in the Pacific region, Eocene 'palm horizons' are more frequent in Alaska and Kamchatka than in middle latitudes, perhaps reflecting a more open vegetation in the north. Their patchy distribution there perhaps reflects a mosaic of forested and open landscapes.

By this reasoning the temperate Arcto-Tertiary stages might correspond to widespread afforestation events. During the first of them the betuloid, fagoid, ulmoid and other precursors had been selected from Maastrichtian plant communities, and they evolved into the dominant components of the Arcto-Tertiary forests. The basal Palaeocene mixed conifer broad-leafed assemblages from various Far Eastern sites are conspicuously different from each other in their broad-leafed components. For instance, in the hinterland Tsagajan Formation of the Amur Province they are dominated by *Tiliaephyllum*, in the volcanic Sikhote-Alin intermontane depressions by various Ulmaceae and Betulaceae, and in the western Sakhalin and Kamchatka coastal environments by *Corylites*, Fagaceae and Juglandaceae (Krassilov, 1975; 1976a; 1976b; 1979; 1989b). Later, these local centres have been integrated into a homogeneous temperate deciduous forest biome.

At the same time the interzonal *Taxodium-Nyssa* swamp forests, *Arundo-Phragmites*, marshes and *Potamogeton - Hydrocharis - Nuphar* aquatic communities were already present in the early Palaeogene Tsagajan stage (Krassilov, 1976a).

The intervening global warmings served as a pump, drawing thermophilous species to higher latitudes along the shrublands or grassland corridors which dissected the primeaval Arcto-Tertiary forests. During the next afforestation wave their modified descendants have enriched the Arcto-Tertiary vegetation, notably as its successional salicoid, rosoid and legume components.

Soil moisture is critical for afforestation, in turn depending on seasonal precipitation ratios. At present the deciduous broad-leafed forest boundaries with various vegetational types such as evergreen forest, woodland, shrubland or steppe are mostly confined to the summer wet – summer dry transition zones which are longitudinal as well as latitudinal.

Major vegetational changes through time are thus caused primarily by the seasonal shifts in precipitation and only indirectly by concomitant changes of temperature. When dealing with past vegetational changes of this kind, it would seem preferable to use several criteria rather than a single one, such as leaf margin morphology. The following set of climatic criteria was applied to the Far Eastern Arcto-Tertiary assemblages:

Climate	warm humid	warm dry	cool humid	cool dry
Species diversity	high	high	high	low
Dominance	poly	poly	oligo	oligo-mono
Modern analogue	thermophilous	thermophilous	temperate	temperate
Leaf breadth*	c. 60 mm	c. 35 mm	c. 45 mm	c. 30 mm
NA element	rare	common	rare	common
Taxodiaceae	common	rare	common	rare
Pinaceae	rare	rare	common	common

*of dominant species

Leaf margin morphology and sedimentological features have been used as additional climatic indicators. Stratigraphical succession could be informative as evidence of a vegetational response to climate changes, e.g. lowering of altitudinal belts. For instance, a *Fagus*-dominated assemblage might suggest cooling when found stratigraphically above a *Castanea*-dominated assemblage since *Fagus* woods frequently occur at higher altitudes than those dominated by *Castanea*.

GEOLOGICAL SETTING

The Russian Far East, east of the Siberian Platform, is a mosaic of cratonic 'massifs' welded by igneous ophiolitic suture belts. Cretaceous sedimentary basins occurred mostly on the massifs' sagging margins and in the residual suture troughs. A new structural pattern commenced on the emergence of the mid-Cretaceous volcanic belt which stretched indiscriminately over the cratonic blocks and their napping sutures. Concomitant napping has occurred in the geosyncline zone further east, but volcanic island arcs did not appear until the KT boundary (Krassilov *et al.*, 1988).

This structural framework, which prevailed since the terminal Cretaceous, consisted of (1) a terrestrial volcanic belt extending from Chukotka to Primorye and farther south to Korea and China, (2) a paralic belt of flyschoid marginal marine and non-marine clastic deposits, traceable from the Anadyr River in the north to western Sakhalin and along the median zone of Japan, and (3) an island arc belt of eastern Kamchatka, eastern Sakhalin and the Kuril Islands. Major Tertiary coal basins occur in cratonic depressions west of the coastal ranges (e.g. the Raychikhinsk and Retikhovka Basins) and in the paralic belt (Penjin Gulf and Western Sakhalin) while the terrestrial volcanic belt is traversed by a series of intermontane transcurrent fault-bound depressions filled with mollasoid volcanoclastics (e.g. Sovyetskaya

Gavan', Bikin, Kavalerova, and the Tavrichanka and Posyet Basins). The island-arc belt contains the fore-arc volcanics of Palaeocene and younger ages.

Major centres of deposition in the paralic belt have been confined in the Tatar Strait Trough, the eastern flank of which is now raised as the western Sakhalin coastal ranges. The trough has been filled with deltaic clastics coming from the former Okhotsk Land in the north and periodically encroached by the sea from the south. It was temporarily raised during the KT boundary tectonic restructuring leaving a few depositional loci. Subsequent subsidence has restored the previous structural pattern, though the Palaeogene non-marine deposits prograded further south than in the Cretaceous. The zone of their interfingering with marine strata at about 50 °N is of a special interest for interfacies correlation.

KHOYNDJO SECTION

For most basins we have composite Cenozoic sections, fragments of which came from occasional outcrops, boreholes or coal quarries. The coastal Khoyndjo Section of northwestern Sakhalin (1 in Fig. 1) is exceptional in spanning all the stages from Senonian to mid-Miocene in a monoclinal sequence deepening to the north. The section is exposed by a series of continuous outcrops extending about 10 km south and north of Khoyndjo Point. It was divided into a number of lithostratigraphic units by Kryshtofovich (1936), who recognised the floristic assemblages of Eocene and Miocene ages in what was described a century ago by Heer as a single fossil flora. Subsequent studies revealed more floristic horizons (Borsuk, 1956; Krassilov, 1973; Fot'janova and Serova, 1977; Akhmet'iev, 1978; Krassilov and Kundyshev, 1982). The following analysis is based on the joint palaeofloristic and magnetostratigraphic research by Krassilov, Schmidt and Remisovskiy (1986).

Schematically, the Khoyndjo Section consists of the following lithostratigraphic units each characterised by one or more fossil assemblages:

(1) Cretaceous marine shales with inoceramid shells, more than 20 m.

(2) Sandstones with thin coal lenses, 4 m thick, unconformable on (1), containing *Metasequoia – Trochodendroides* assemblages.

(3) Conglomerates and coarse detrital sandstones, about 100 m thick, with several floristic horizons assigned to a single *Dryophyllum–Trochodendroides* assemblage.

(4) Coarse to fine-grained sandstones, 25–30 m, with a *Magnoliaephyllum – Dryophyllum* assemblage.

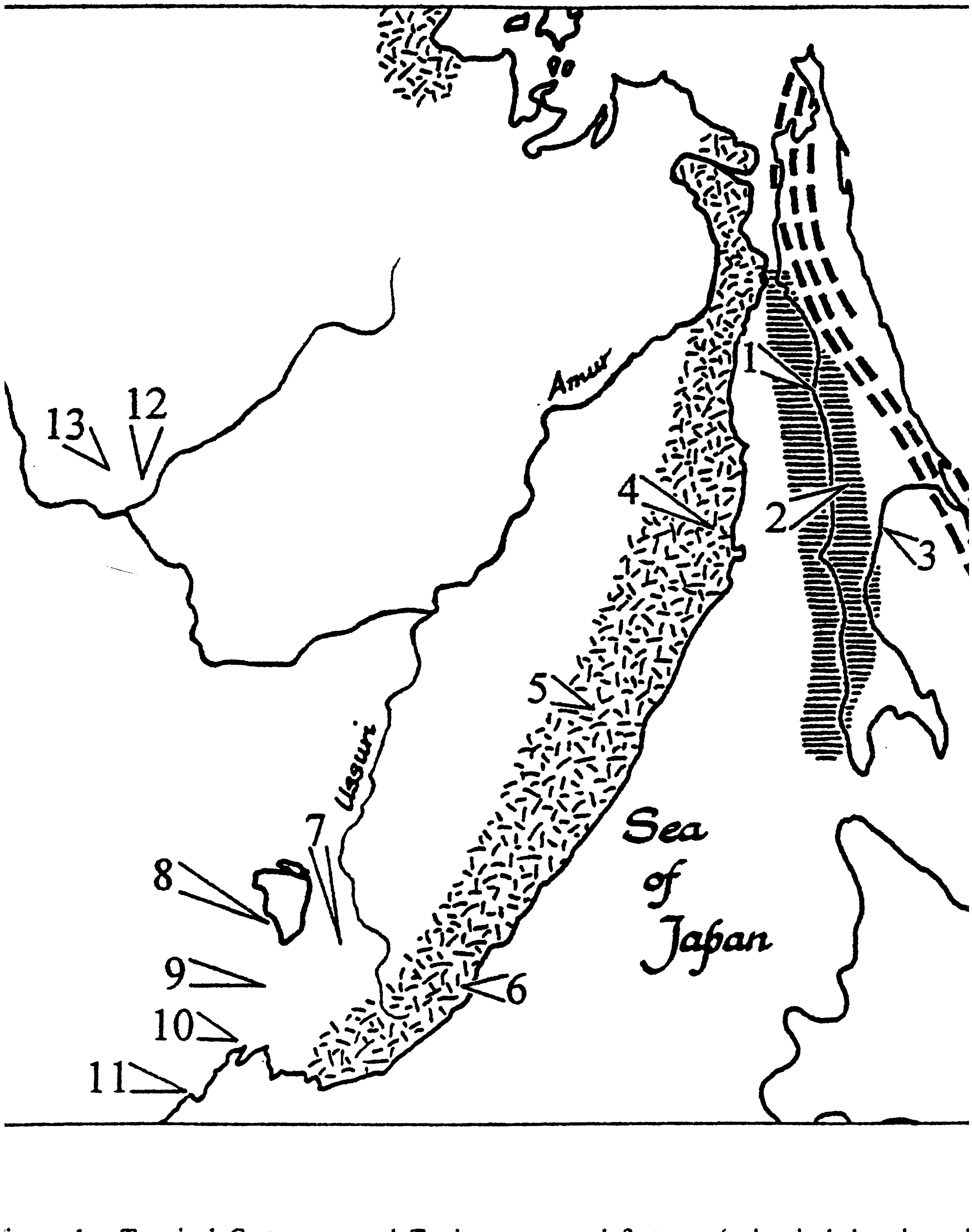
(5) Coal beds, 15 m, with three major coal seams separated by ferruginous shales yielding three successive assemblages: *Platanus – Aesculus*, *Alnus omorica – Populus celastrophylla*, and *Metasequoia – Zelkova ungeri – Trochodendroides.*

(6) '*Gennoishi*' (sanidine crystals) shales with marine bivalves of Oligocene age, in a sharp slickensided contact with (7), about 80 m.

(7) Basalts with pillow structures, tuffs, about 60 m, overlaid by coarse-grained tuffaceous sandstones, 3 m.

(8) Black shales with conglomerate interbeds, 25 m, containing a *Picea – Betula – Ulmus protojaponica* woody assemblage and grass remains.

(9) Sandstone/shale alternation of about 80 m, with thin coal beds and up to 7 plant beds of an *Acer – Ulmus – Carya* broad-leaved assemblage.



igure 1. Terminal Cretaceous and Tertiary structural features (volcanic belt - irregul hading, flysh trough - horizontal shading, island arc - thick dashes) and localities mention ı the text : 1 - Khoyndjo, 2 - Augustovka, 3 - Krynka River (Zaliv Terpeniya), 4 ovetskaya Gavan', 5 - Bikin, 6 - Kavalerovo, 7 - Retiikhovka, 8 - Lake Khanka, 9 .asdolnaya River, 10 - Rechnoy Peninsula (Tavrichanka Basin), 11 - Posyet, 12 - Tsagaja 3 - Raychikhinsk.

(10) Ferrugineous sandstones and shales, 12 m, with *Quercus furuhjelmii – Castanea miomollissima* assemblage.

(11) Coal beds, more than 50 m, with *Corbicula*-bearing brackish shales above coal seams and numerous floristic horizons comprising *Fagus antipovii – Acer – Byttneriophyllum* woody and *Nelumbo – Hemitrapa* aquatic assemblages.

SUPPLEMENTARY DATA AND INTERPRETATION

The Khoyndjo section represents two large non-marine sedimentary cycles divided by marine clastic and volcanic sequences. Each cycle ends with coal beds and a marine transgression, but the coarse-grained basal member is much more prominent in the lower cycle. It has to be noted also that the Khoyndjo section is condensed: its units are mostly less thick than their stratigraphic equivalents in other Sakhalinian sections.

The lower cycle is bounded by marine Cretaceous and Oligocene deposits. However the KT boundary is unconformable. The upper cycle rests on non-fossiliferous volcanic rocks. The floristic succession is thus interrupted at the base of both cycles. These gaps have to be filled by data derived from supplementary sections.

KT Boundary

In the Far East the basin-wide KT unconformities are caused by tectonic uplifts, regression and igneous activity which spread over the flysch trough while the lesser Kuril Islands first emerged as a volcanic arc (Krassilov *et al.*, 1988). The basal non-marine Tertiary deposits occur in a few graben-like depressions filled with lacustrine shales or tuffs. One such site is located 100 km south of Khoyndjo Point, along the Augustovka River where marine Maastrichtian shales are overlaid by the uppermost Maastrichtian paralic sandstones with a *Parataxodium – Trochodendroides* assemblage and fine-grained tuffs with a *Metasequoia – Corylites – Trochodendroides* assemblage still retaining *Nilssonia* and some other Cretaceous relics (Krassilov, 1979). Further south they are replaced by the marine Sinegorsk Beds of the Lower Palaeocene *Rzehakina epigona* zone (Kalishevich *et al.*, 1981).

Transitional macrofossil and palynological assemblages of the Lesser Kuril Islands came from marine beds belonging to the same foraminiferal zone. Their palynoflora, dominated by *Tricolpopollenites*, *Myricites*, *Ulmoideipites*, etc. still contains *Aquilapollenites* spp., *Orbiculapollis*, *Cranwellia* and other Cretaceous elements amounting to about 11 % of all species (Krassilov *et al.*, 1988).

A relatively complete non-marine KT succession is known from the Tsagajan Formation in the Amur Province where a Maastrichtian *Sequoia – Platanus* assemblage from dinosaur beds are succeeded by transitional *Taxodium – Trochodendroides – Nordenskioldia* macrofossil and *Tricolpites – Ulmoideipites* microfossil assemblages with *Protophyllum*, *Triatriopollenites*, *Triprojectacites*, *Orbiculapollis*, etc. from the overlying clay beds, in turn giving way to a less diverse *Trochodendroides – Tiliaephyllum* assemblage lacking Cretaceous relics (Krassilov, 1976a, Zaklinskaya *et al.*, 1977).

While the transitional Lower Palaeocene stage is perhaps lacking in the Khoyndjo Section its lowermost plant assemblage might correspond to the upper Tsagajan flora.

As a whole, the early Palaeocene floras, dominated by broad double-serrate leaves seem more 'temperate' and more 'humid' in their ecological requirements than the preceding Late Cretaceous floras. In particular, the basal Palaeocene horizons at Augustovka and other localities contain abundant ferns and taxodiaceous conifers as well as a peculiar cupressoid conifer related to *Libocedrus*. At many sites these horizons are coal-bearing. In contrast, the upper Tsagajan coarse-grained facies with clay boulders and less diverse floristic assemblages might represent an abbreviated CD climatic phase.

Eocene – Oligocene boundary

The Khoyndjo unit (2) assemblage is dominated by narrow, serrate leaf types containing also a substantial lauroid element, notably the thermophilous *Cinnamomum*, while conifers are rare. In the western North American Palaeogene such lauroid morphotypes are absent north of central Wyoming (see Brown, 1962). These features suggest a WD phase in accord with a high frequency of the coarse poorly sorted arenitic temporary torrent or mudflow facies with lenticular clay beds and clay pebble conglomerates. However, precipitation was enough for occasional thin peat accumulation.

This part of the section can be correlated with the Rechnovskaya Formation of southern Primorye and perhaps the 'palm horizon' of western Kamchatka (Budantsev, 1983; Fot'janova, 1989).

The next unit (3) assemblage has an even more prominent lauroid element (including *Magnoliaephyllum*) probably representing a somewhat more humid phase. Major floristic change occurs above the lower thick coal seam, from the roof of which came a large-leaved assemblage dominated by arboreal genera of warm temperate affinities with double-serrate leaves, as in *Aesculus magnificum* or *Platycarya hokkaidoana*. The lower coal seam is 2.5–3 m thick, suggesting a rising water table necessary for the acccumulation of a thick peat bed which requires ample, year-round, precipitation. The second coal seam is 5–6.5 m thick with fern leaves in the roof, and splits. A woody plant assemblage coming from the border of the mire is floristically similar to the one below it, but less diverse and with comparatively small-leaved dominant species.

In the uppermost plant beds leaf sizes rise and fall again suggesting rapid second-order climatic fluctuations. The calculated sedimentation rates for the coal-bearing strata was 7 mm per 10.4 years which gives the fluctuation scale of about 0.4 My, comparable with the glacial cycles (Krassilov *et al.*, 1986).

It would seem natural to draw the Eocene-Oligocene boundary at the base of the large-leaved plant bed above the lower coal seam. However, magnetic polarity evidence would rather suggest that its position lies somewhat lower in the section. The lower coal seam falls in the polarity zone A44N (anomaly 13) while the boundary is currently placed either in A45 between the anomalies 15 and 13 (Poore *et al.* 1982) or even in A46N, anomaly 16 (Ness *et al.* 1980).

Oligocene – Miocene transition

Non-marine equivalents of the Khoyndjo Oligocene shales (Gennoishi Formation) are poorly known. In southern Primorye they seem to be represented by the Nadezhdinskaya Formation, overlying the coal-bearing Uglovskaya Formation. In the Rechnoy Peninsula

Section, the Nadezhdinskaya Formation siltstones contain a taxonomically diverse polydominant *Zelkova ungeri* – *Ulmus plurinervia* – *Laurophyllum* assemblage with occasional *Liquidambar* and supposedly non-arboreal *Zizyphus harutoriensis* (Krassilov and Alexeyenko, 1977). All the dominant elements are small-leaved. This assemblage is assigned to a WD (Rupelian ?) phase.

In Sakhalin the widespread Oligocene transgression has deposited flyschoid sequences, upper members of which are essentially volcanomictic. Profuse eruptions like those at the Khoyndjo Point are known at several sites both in western and eastern Sakhalin, as well as in eastern Kamchatka (Uspenskaya Formation) and the Greater Kuril Islands. This volcanic activity was confined primarily in transcurrent fault zones extending over the miogeosyncline to the continent.

Several Oligocene-Miocene sections along the rivers flowing into Terpeniya Bay on the eastern coast have been studied by the same team that worked on the Khoyndjo Section (Krassilov *et al.*, 1984). They discovered a new plant locality in the white tuffs of the volcanic sequence (Chekhovskaya Formation) in the Krynka-Shakhtnaya River Section. Marine bivalves were found below and above the plant-bearing beds. The fossil flora consists of abundant ferns (*Osmunda sachalinensis* and *Woodwardia arctica*), conifers (*Glyptostrobus* and *Pityostrobus*) and angiosperms (*Ceratophyllum*, *Myrica*, *Fagus*, *Corylites*, *Nyssa*, *Fraxinus* etc.), interpreted as a lowland swamp cypress – gum forest with ash and bay, perhaps bordering a lagoon. *Osmunda* and hazel shrubs might have covered charred clearings upslope. Coal-bearing strata above the volcanic Chekhovskaya Formation contain several floristic horizons correlating with units (8) – (11) of the Khoyndjo Section. Notably, *Pityostrobus* is abundant in the lowermost horizon.

The plant-bearing white tuffs fall in a reversed polarity interval while the massive tuffs and tuffaceous conglomerates above them (60 m) belong in a mixed polarity zone correlating with the standard scale zone 21 (Theyer and Hammond, 1974). A long normal interval in the lower part of the overlying coal-bearing strata was assigned by V.I. Remisovskiy to polarity zone 19 which is detectable in all the Miocene sections.

Miocene

The basal Miocene *Pityostrobus*-beds above volcanites in the Krynka-Shakhtnaya Section could be equivalent or somewhat lower than Khoyndjo unit (8). They might represent a short-living CH phase of the lowland spruce forest. The unit (8) black shales with intervening conglomeratic tongues, seem to have been deposited in a lake of the transcurrent fault zone rift valley. The plant remains are scattered throughout the deposit, rather than concentrated in a few layers as in other units. Small betuloid and ulmoid leaves predominate, associated with spruce and fir seeds as well as grass achenes. A high proportion of wind-borne débris suggests open vegetation, grasslands and sparse woodlands, with a conifer forest on adjacent slopes. This assemblage is polydominant but on the basis of the prevailing leaf morphologies, pinaceous conifers and non-arboreal element, it seems assignable to a CD phase and correlated with the Aniai Formation of Japan, and the 1 My long Aquitanian cooling (Alvinerie, 1980). Subsequent plant assemblages suggest a much milder climate, with a narrow-leaved *Quercus* – *Castanea* assemblage of unit (10) perhaps representing a drier episode. It is followed by a diverse polydominant flora of the coal-bearing sequence with *Fagus* among the most common arboreal genera.

In the literature the '*Fagus* horizon of northeastern Asia' is often associated with the mid-Miocene (Burdigalian to Langhian) climatic optimum (e.g. Fradkina, 1983). However from the altitudinal position of the beech and chestnut belts in Japan and other countries one can surmise that *Fagus* abundances are due to a shift to lower altitudes and, therefore, these floras are in fact post-optimal (Langhian to early Serravallian).

In Primorye, *Fagus* has also replaced *Castanea* as a dominant tree genus. The Lake Khanka flora near the Chinese frontier has abundant morphologically-variable *Fagus* leaves (40 %) in association with *Ailanthus* and other 'Mediterranean' elements. It is succeeded by the Late Miocene (late Serravallian – Torotonian ?) Rasdolnaya River flora, which suggests a rapid decline of the lowland beech forests (Krassilov and Alexeyenko, 1977).

CLIMATIC PHASE PATTERN

Generalising from the preceding discussion we can see evidence that the **WH-CH-CD-WD** succession is typical for the 15 My long middle latitude climatic cycles (in turn constituting two 30 My long primary cycles of the Tertiary). Their interpretation would seem to be derived from the theory of atmospheric disturbances (Lorenz, 1967; Palmen and Newton, 1969; Wallace and Blackmon, 1983). Here an attempt is made to present the typical sequence of climatic events in a grossly simplified model.

WH: the preceding WD stage caused extensive seaborne glacier melting which stimulated maritime polar front surges, resulting in active middle latitude cyclogenesis. The eustatic sea level rise later in the WH phase or in the next CH phase brought transgression, which in turn contributed to the cyclonic activity.

CH: in the middle latitudes, cyclones moved poleward bringing more snow to the northern land masses. In effect the polar front (strongly influenced by the extent of snow cover) has been shifted southward. Atmospheric CO_2 might decrease in association with the sea level rise and increased precipitation.

CD: with further advance of the polar front over continents, arctic air surges pushed cyclonic vortices to lower latitudes forming stable meridional anticyclone-cyclone couples (Wallace and Blackmon, 1983) which blocked mid-latitude westerlies while bringing more precipitation to subtropical regions. Later in the phase continental glaciers shrank as a consequence of reduced snowfall.

WD: during the CH-CD phases less North Atlantic Deep Water is formed resulting in sluggish oceanic circulation, shallow equatorial thermoclines, and sea surface heating as a prerequisite for atmospheric CO_2 build-up (actually observed during El Niño events) and weaker monsoonal circulation (also associated with El Niño). This results in heating of the tropical air and steeper meridional thermal gradients. The latter might cause extensive subtropical front outbreaks, forming warm blocking anticyclones which shifted subtropical highs to mid-latitudes, while the polar front moved far poleward. (Pronounced blocking in the northern mid-Latitudes was observed during the 1987 El Niño event: see Davidson *et al.*, 1990.)

The model implies that the most dramatic climatic changes occur while the ocean-atmosphere interactions produce long-lived zonal temperature anomalies resolved by means of atmospheric disturbances steering interzonal heat exchanges. The climatic phases would then differ mainly in the mid-latitude blocking frequencies governing the weather régimes, with rapid transition from one phase to another.

This mechanism would explain the abruptness of the major climatic changes (Lamb, 1977; Zubakov, 1990) the rates of which are comparable to if not exceeding any anthropogenic processes. The atmospheric CO_2 fluctuations are here conceived as an integral part of these processes. Other feedback loops not considered in the model might determine relative intensities and durations of phases. Though all the phases of a typical cycle are compulsory in this model, in the actual sequences some of them could be reduced beyond resolution of palaeoclimatological methods. Such phases would be deleted from the geological record. Moreover, since climatic cycles are hierarchical, their stages would in turn have a cyclical structure while their generalised characteristics – WH, WD, etc. – would depend on the relative prominence of respective stages in subordinate cycles. The typical pattern seems to have been repeated down to 10,000 year (younger Dryas CD, Boreal WD, Atlantic WH, Subboreal CH to CD, Subatlantic CD to WD) and even shorter cycles. For instance, a crude climatic scheme for the last two millennia would include:

Century A.D.		
I–III	First Little Ice Age	CD
IV–VIII	Great Migration of Peoples	WD
IX–XII	Viking Warming	WH
XIII–XVIIII	Second Little Ice Age	CH to CD
XIX–XX	Modern	CD/WD transition

By this scheme we have about two centuries of the middle latitude WD before us (the present day warming repeats that of the 1940's with a cooling in between: while these temperature fluctuations occur against the steady rising CO_2 emission it is obvious that anthropogenic influences are hardly capable of altering even minor natural cyclicity).

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