THE CLIMATES OF THE NORTHERN HEMISPHERE IN THE CRETACEOUS IN THE LIGHT OF PALEOBOTANICAL DATA

V.A. Vachrameev (Vakhrameyev)
Geological Institute, USSR Academy of Sciences

ABSTRACT: The following climatic zones are distinguished in the Northern Hemisphere on the basis of paleobotanical data and the distribution of the rocks as indicators of the climate: humid temperate-warm, humid subtropical, arid (predominantly subtropical) and humid equatorial. It is established that a number of Early and Late Cretaceous plants are indicators of temperate-warm and subtropical humid climates. A high content of Classopollis pollen (50-90%) is an indication of aridity. The climatic changes that occurred during the Cretaceous are considered.

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The information that has been accumulated in recent decades concerning the distribution of fossil remains of Cretaceous plants over the Earth's surface has made it possible to establish the climatic setting that was most conducive to the flourishing of some of these plants. Plant indicators of a humid or dry, and of a temperate or subtropical (tropical) climate have been established. A significant contribution has been made to this research by data on paleotemperatures and on the distribution of rocks as climatic indicators, as well as by data on the distribution of some groups of the fauna that react sensitively to an alteration of the thermal regime (colonial corals, rudistans, dinosaurs).

The only way to reconstruct the climates of past geological periods, including the Cretaceous, is, of course, to use and cross-check the data yielded by all the above methods. The key works and the most recent works dealing with reconstruction of the paleoclimates of the Cretaceous are those of Strakhov (1960), Sinitsyn (1966, 1967), Khain et al. (1975), plus a number of studies in which the Cretaceous climates of extensive regions are reconstructed (Naydin et al., 1966; Paleoclimates of Siberia. . . , 1977; Yasamanov, 1975).

On the basis of information on the distribution of rocks as climatic indicators, a more northerly humid zone and a more southerly arid zone may be distinguished in the Cretaceous of the Northern Hemisphere, as in the Jurassic. The first of these zones is noteworthy for the extensive distribution of coal measures, and in its more southerly half of bauxite and bauxitic rocks, while the second is noteworthy for redbeds, gypsum and less frequently encountered salt deposits. The more southerly arid equatorial humid zone occupied only a narrow strip of the Northern Hemisphere, taking in the south of West Africa, India, Indo-China and Indonesia. It is noteworthy for coal measures and the presence of iron ores of sedimentary origin.

Two major paleofloristic regions may be distinguished on the basis of paleobotanical data (Vachrameev et al., 1970): a more northerly Siberian-Canadian region and a more southerly Indo-European region. The boundary between these phytogeographic regions lies within the northern humid zone. The distribution of the remains of certain groups of plants, many of which are indicators of climatic conditions, is the basis for the distinguishing of these regions. For the Siberian-Canadian region the plants concerned are members of the genera Czekanowskia and Phoenicopsis, combined in the order Czekanowskiales. The fact that the Czekanowskiales and some conifers (Podozamites) were deciduous, taken in conjunction with the presence of annual rings in the trees, is an indication that the climate in this region was of a seasonal nature. The trunks of Czekanowskiales, like those of a number of other trees that flourished in the Siberian-Canadian region (ginkgos, conifers), were of what is known as the pycnoxylic type, in which secondary wood is greatly predominant. Trees with trunks of this type are well able to withstand subzero temperatures.

That the climate of the Siberian-Canadian region was temperate-warm is indicated by the poorer composition in terms of genera and species, less than half the number (Vachrameev, 1964), and

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by the absence of plants confined to the more southerly Indo-European region, which are specific to a subtropical or tropical frost-free climate. These include the treelike ferns Tempskya, ferns (Matonidium and Phlebopteris) and the related Weichselia, and also cycadeoids, which had short barrel-shaped trunks. The treelike ferns and cycadeoids had trunks of the manoxylic type, made up predominantly of parenchymatous tissue consisting of thin-walled cells incapable of withstanding subzero temperatures. It is well known that the range of treelike ferns at the present time, like that of large-leaved Matoniaceae, which have a thick rhizome, is confined to the tropics and subtropics. Cycads related to extinct cycadeoids have a similar range.

Recent reports of the shoots of conifers belonging to the genera Frenelopsis and Manica, which are sometimes found with the cones attached to them, show that they can be used as indicators of a subtropical or warmer climate. They have been reported from Southern England, France, the Federal German Republic, Portugal, Czechoslovakia, Poland, the Ukraine, Tadzhikistan (Darvaz), E. China (Chow and Tsao, 1977), and also in the Sudan and on the Atlantic seaboard of the United States (Potomac). On the basis of the Classopollis pollen contained in male strobili, Frenelopsis and Manica belong to the family Cheirolepidiaceae.

The present author has demonstrated in earlier works (Vachrameev, 1970) that an appreciable content of this pollen in samples (> 10-15%) is a good indicator of a subtropical climate, especially subtropical arid.

When we examine the paleoclimatic map compiled by Khain et al. (1975) with the boundaries of the phytogeographic regions plotted on it (Fig. 1), we see that the boundary between the Siberian-Canadian and the Indo-European regions divides the humid climatic zone of the Northern Hemisphere into two latitudinally extended regions. This enables us to give a more detailed account of the climatic zoning of the Early Cretaceous epoch. It is readily apparent that the northern part of the humid zone coinciding with the Siberian-Canadian phytogeographic region is a zone of a temperate-warm humid climate, within which the temperature may at times have fallen below zero in the winter. There was a subtropical humid climate in the southern part of the humid zone, as is shown by the presence of treelike ferns and cycadeoids. It is of interest that all Early Cretaceous deposits of bauxite and bauxitic rocks are confined to the subtropical humid zone (Khain et al., 1975), a fact which is in good agreement with the generally accepted view of a connection between lateritic weathering and a subtropical or tropical humid climate.

The boundary between the humid and arid regions, which is clearly seen from the distribution of redbeds and evaporites, is also detectable on the basis of paleobotanical data (fig. 1). There is a noticeable reduction in the number of localities of plant remains within the arid zone. This is probably related to the thinning out of plant associations that is a feature of arid climatic regions and, consequently, to the conditions of interment. The xeromorphic fern Weichselia was well adapted here; localities are known in the arid zone from countries in North and East Africa, from the Near East, Texas and Peru. On the other hand, remains of the hygrophytic Matoniaceae do not extend into this zone. It is only in India and in the Malacca Peninsula that Early Cretaceous sites of fossil remains are known in the equatorial humid zone.

Variation in the content of Classopollis pollen in palynological spectra is an excellent paleobotanical criterion by which to delineate the boundaries of the subtropical and the arid zones, or to determine climatic change towards increasing aridity. This pollen, which is morphologically very characteristic, belongs to a group of Mesozoic conifers, the Cheirolepidiaceae, which became extinct at the beginning of the Cenozoic. It has been established both for Eurasia and for North America (Norris et al., 1975) that Classopollis pollen is either completely absent from the temperate-warm humid climatic zone, or present in very small quantity (1-3%). It is only for periods when the climate became abruptly warmer, for example, in the Late Jurassic, that its content may here be increased to 5-10%. It is noticeably more plentiful (10-20%) in deposits of the subtropical humid zone, and this is an indication of the thermophytic nature of the Cheirolepidiaceae that produced it. It should be noted that this distribution pattern is confined to rocks devoid of coal. The fact that the content of Classopollis pollen is never high (usually less than 10%) in coal measures and especially in coal or carbonaceous rocks is connected with an environmental peculiarity of the conifers that produced this pollen, which shunned waterlogged areas. The conifers that produced Classopollis pollen become distinct dominants in the arid climatic zone, thus the content of this pollen in palynological spectra of corresponding deposits increases to 50-70% or more.

A reduction in the percentage of Classopollis pollen is offset in most instances by an increase in the proportion of fern spores and, in part, of bisaccate pollen. An increase in the part played by fern spores is undoubtedly related to a climatic change toward increasing humidity.

The features described have been established for a vast area covering the Russian Platform, western and central Siberia, and also Kazakhstan, the Crimea, the Caucasus and Soviet Central Asia. Unfortunately, there are very limited quantitative data on Classopollis pollen content for European countries (apart from the European regions of the USSR) and for North America. However,

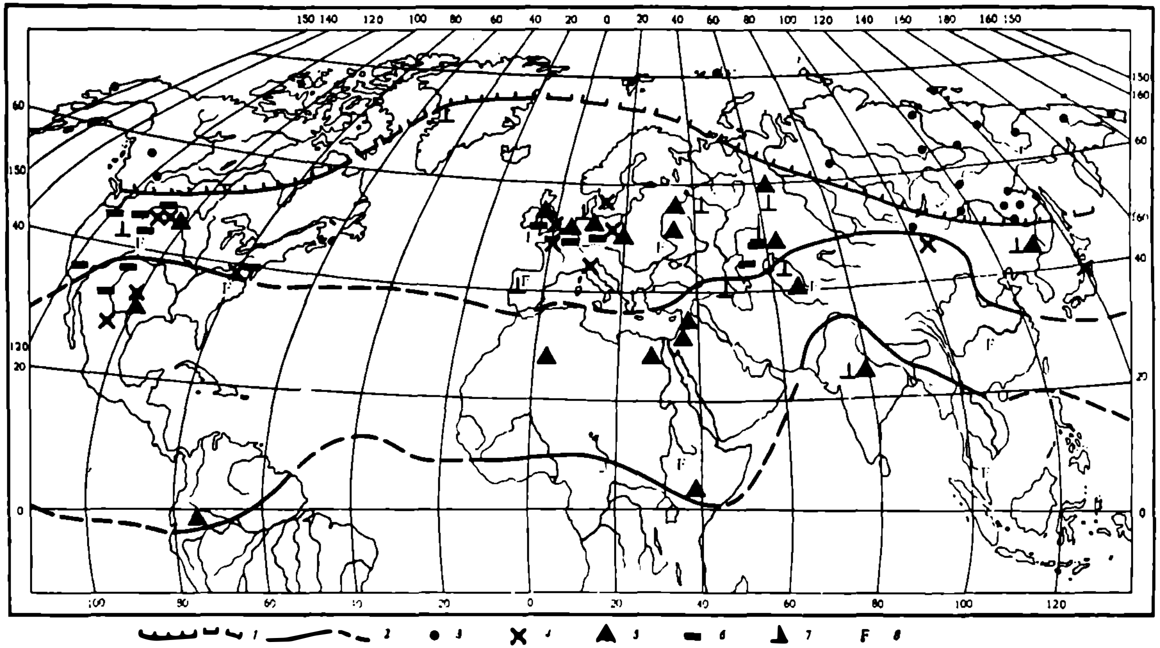

FIGURE 1. Early Cretaceous paleoclimates.

1 - boundary between temperate-warm and subtropical humid zones (as given by Vachrameev), 2 - northern and southern boundaries of the arid zone in the Northern Hemisphere (Khain et al., 1975), 3-7 - localities of plant remains that are climatic indicators; 3 - Czekanowskiales, 4 - Cycadeoidea, 5 - ferns (*Weichselia*), 6 - *Tempskya*, 7 - Matoniaceae (*Matonidium*, *Phlebopteris*), 8 - conifers (*Frenelopsis*).

even the limited information that exists confirms these features. It has been demonstrated in a recent study by I. Z. Kotova of Lower Cretaceous deposits, uncovered by deep drilling on the floor of the Atlantic Ocean in the vicinity of the Moroccan trench, that here also the Classopollis pollen content fluctuated between 70 and 80% in the Neocomian, Aptian and Albian. This is in good agreement with the location of this part of Africa within the arid zone according to lithological data (Khain et al., 1975). There is scarcely any information on Classopollis content for China and the Indo-Chinese Peninsula. This makes it impossible, in particular, to ascertain how frequently Classopollis pollen is found in rocks formed under the conditions of the equatorial humid zone. The few palynological analyses from the Cretaceous and Jurassic of India would appear to suggest that its content was very small in the Jurassic and Lower Cretaceous rocks of this zone.

Let us now consider the climatic changes in the Early Cretaceous. At the transition from the Jurassic to the Cretaceous the northern boundary of the arid zone in the Northern Hemisphere was shifted appreciably southward. The formation of evaporites and redbeds ceased in a number of regions of Western Europe, Poland and the North Caucasus. The sharp reduction in the amount of Classopollis pollen in the Berriasian-Valanginian (Wealdian) of Southern England and northern districts of France, Belgium, the Federal German Republic, Poland and the central region of the Russian Platform, compared with its content in Upper Jurassic rocks, is also evidence that the climate became increasingly humid. It should be noted that the northern boundary of the arid zone in the Mediterranean, indicated on fig. 1, does not correspond to the beginning of the Early Cretaceous but rather to its middle, since, judging from the very high content of Classopollis pollen in the Valanginian and Berriasian deposits of the South of France, the Crimea and the North Caucasus, the climate of Southern Europe still remained fairly dry.

During the transition from the Jurassic to the Cretaceous, the boundary between the humid and arid zones did not undergo any appreciable southward shift within Asia. This is confirmed both by the distribution of redbeds and by the high content of Classopollis pollen (up to 90%) in the Berriasian-Valanginian deposits of the Caucasus, S. Kazakhstan and Soviet Central Asia (Kuvayeva et al., 1964; Ponomarenko et al., 1973; Fokina, 1976). It remained almost as high (fig. 2) as in Upper Jurassic deposits. From the beginning of the Hauterivian the climate in the arid zone became gradually damper, and this continued up to the Albian, as is clearly seen from the curves of Classopollis content constructed from palynological records for the Crimea, the southeastern Caucasus, Turkmenia and the adjacent part of Uzbekistan. There was simultaneous disappearance of redbeds or gypsum units from the sections.

On examination of the curves (fig. 3) it may be noted that the content of Classopollis pollen decreases sharply immediately after the end of the Valanginian age in the Crimea (Kuvayeva and Yanin, 1973) and in the Caucasus (Kuvayeva et al., 1964), whereas this process does not begin until after the Hauterivian in Soviet Central Asia. The climatic changes are confirmed by the disappearance of redbeds on moving up the section in the south of Soviet Central Asia. The longer - retention of an arid climate in this area is related to the greater distance from marine basins by comparison with the Caucasus and the Crimea. The reduction in the content of Classopollis pollen depicted on these curves is an indication of an increasingly damp climate. Data confirming this trend also exist for more easterly districts. Thus, an appreciable Classopollis content is noted in the lower half of the Lower Cretaceous in Kansu Province in China (Hsü and Chow, 1956), whereas the content of this pollen does not exceed 10% in the uppermost Cretaceous of Mongolia. This feature agrees well with the disappearance of red rocks from the upper part of the Lower Cretaceous in Central Mongolia and the appearance of carbonaceous clays and coal interlayers in this part of the section.

All these facts indicate that the arid zone contracted in the second half of the Early Cretaceous, and that its northern boundary retreated southward of the line established for the beginning of the Early Cretaceous (fig. 1), leaving Tempskya in the humid zone in the Albian of the United States.

The increased dampness was also accompanied by some reduction in temperature. Yasamanov (1975), who measured the Ca/Mg ratio in bivalve mollusk shells from various stages of the Cretaceous system in Soviet Central Asia, demonstrated that temperatures were lowest in the Albian age. Thus, for the Gaurdak district temperature in the Albian was 14. 8° C, whereas it reached 20-21° C for the Valanginian (Al'muradian suite) in the same district. Admittedly, this high value was obtained for the shallow, well heated basin in which the sediments of the Al'muradian suite were deposited. The same author gives slightly lower values 17. 8° C for the Valanginian of Mangyshlak. The lowest temperatures (8. 5° C) are noted for the Upper Albian, also for Gaurdak.

Relatively low temperatures are also recorded for the Late Albian of the Russian Platform, the Caucasus and the Crimea (Naydin et al., 1966; Yasamanov, 1973). It should also be noted that bauxite formation, which had previously been prevalent (Aptian-middle Albian) on the eastern slope of the Urals, in the Mugodzhary mountains and in Southeastern Siberia, ceased in the late Albian (Paleoclimates of Siberia . . . , 1977). A certain amount of cooling in the late Albian and Cenomanian is also indicated by the prevalence of broad-leaved, mainly plane forests. Traces of their

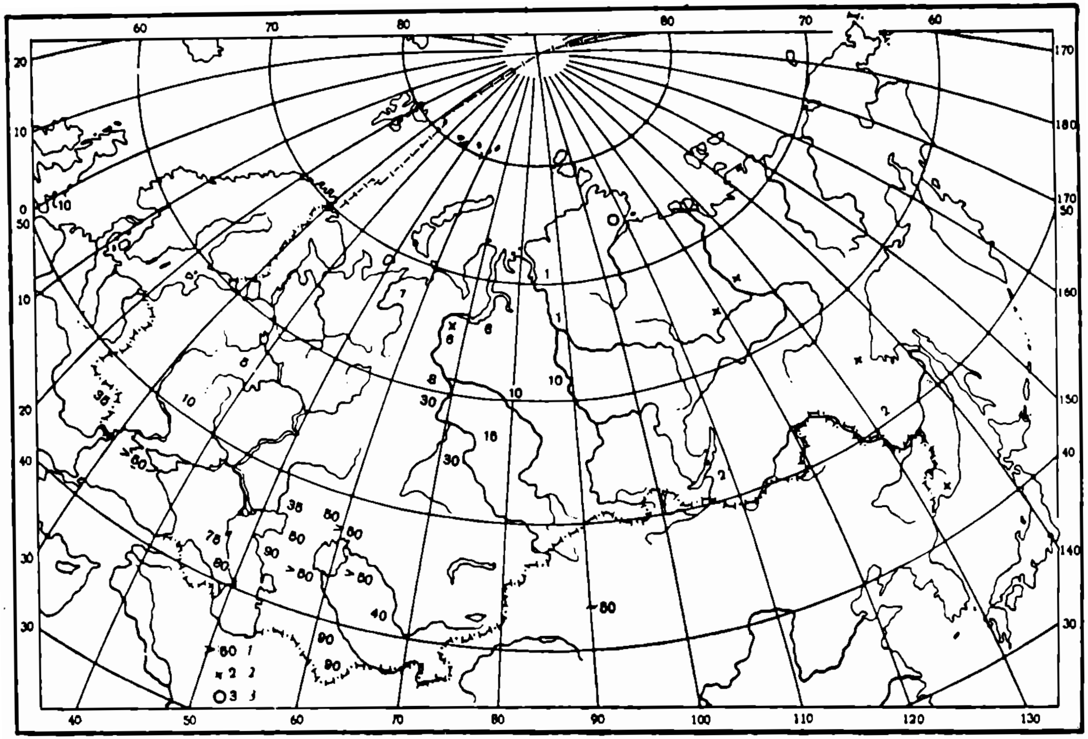

FIGURE 2. Average content of Classopollis pollen in Berriasian-Valanginian deposits in various regions of Eurasia.

1 - content of Classopollis pollen, %; 2 - isolated grains, 3 - no Classopollis pollen found.

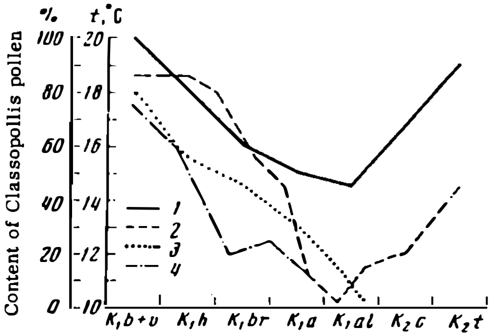

FIGURE 3. Relationship between paleotemperatures and the content of Classopollis pollen for the Berriasian-Turonian of southern districts of the Soviet Union.

1 - Paleotemperature curve for the marine basins of Soviet Central Asia (data of Yasamanov, 1975), 2-4 - curves of the average content of Classopollis pollen: 2 - for Turkmenia and the adjacent part of Uzbekistan (Fokina, 1976), 3 - for the southeastern Caucasus (Kuvayeva et al., 1964), 4 - for the Crimea (Kuvayeva and Yanin, 1973).

existence, in the form of considerable aggregations of leaf impressions, that are an indirect indication of their deciduous nature, have been found (Vachrameev et al., 1970) in the Middle and Southern Urals, in Kazakhstan and Western Siberia, and in the central states of the USA (North and South Dakota, Nebraska, etc.).

On examination of fig. 3 it may be noted that the temperature minimum, occurring in the late Albian, does not coincide with the relative minimum content of Classopollis pollen, the content of which is already lowest from the early Albian, but is even slightly increased at the end of the Albian. This discrepancy is apparently related either to insufficient palynological analyses, or to the fact that the minimum content of Classopollis pollen in this region was due not so much to the decline in the temperature as to the amount of precipitation, which may have been less in the early and middle Albian than in the late Albian.

An analysis of paleobotanical records for the Soviet Far East, which lay in the subtropical humid zone and was distinguished by varied and profuse vegetation, also provides evidence of some decline in temperatures after the Berriasian. In the opinion of Krasilov (1973), this is indicated by the reduction in the part played by cycads and Bennettitales, which was expressed in a gradual reduction of the cycadophyte index on moving from the Berriasian to the Albian. It was only in the Aptian that this index increased slightly, but then in the Albian its value became lowest. The penetration into Yakutia of the ferns Onychiopsis and Ruffordia, which are characteristic of the subtropical zone and which were found there throughout the Early Cretaceous, which was within the temperate-warm humid zone, was evidently related to some rise in temperature in the Aptian. The number of cycads and Bennettitales also decreased toward the close of the Albian in the floras of the Lena and Kolyma river basins (Samylina, 1974). It was maintained for slightly longer in the coastal region of the North Pacific (Penzhina Bay, the Koryak Upland, Alaska), a fact explicable by the warming action of the ocean waters. A reduction in temperature at the end of the Albian and beginning of the Cenomanian is evidently also indicated by the appearance of the Arkagalaian suite, a suite unusually rich in conifer remains, in the section of the Okhotsk-Chukotsk volcanic zone (Samylina, 1974).

Khain et al. (1975) note that the climate became increasingly arid in the Aptian, an assertion which they based on the formation of salts at this time in the inshore zone of Equatorial Africa and Brazil, i. e., on opposite sides of the South Atlantic. Judging by the nature of the Aptian deposits and their content of Classopollis pollen (fig. 3), it would appear that there was no increased tendency toward aridity in Southern Europe, the Caucasus and Soviet Central Asia; on the contrary, as we have just demonstrated, the climate gradually became damper from the start of the Early Cretaceous. It must be assumed that the formation of the salts did not result from an increase in the aridity of the climate, but from the formation in the Aptian of a narrow, shallow, semi-enclosed basin, the rudiments of the South Atlantic, open to the south, but still not connected to the already existing North Atlantic. It is natural that the appearance of a basin of such a type within an already existing arid zone should entail the formation of salt deposits. This basin was not yet in existence in the Neocomian, since Africa was closely adjacent to South America, and there was a series of grabens at their junction, in which continental deposits were laid down.

We know that floras throughout the world were appreciably modified in the course of the Albian as a result of the extensive spread of angiosperms and the accompanying degradation of Czekanowskiales, Bennettitales, and the greater part of the ginkgos and cycads. There was also an appreciable reduction in the number of ferns. However, the relatively slight reduction of temperature at the end of the Albian could scarcely have led to such an appreciable modification of the vegetation practically throughout the World. Many students (Golenkin, 1947; Teslenko, 1967) relate this modification to a change in the composition of the atmosphere, namely to a reduction in CO_2 content, which, by making it more transmissive, sharply increased insolation, which had an adverse effect on a number of shade-loving and hygrophytic plants.

Owing to the appreciable change in floristic composition at the end of the Early Cretaceous epoch, different plants, mainly from among the already developed angiosperms, must be sought as climatic indicators in reconstructing the climate of the Late Cretaceous. The indicators of a humid subtropical

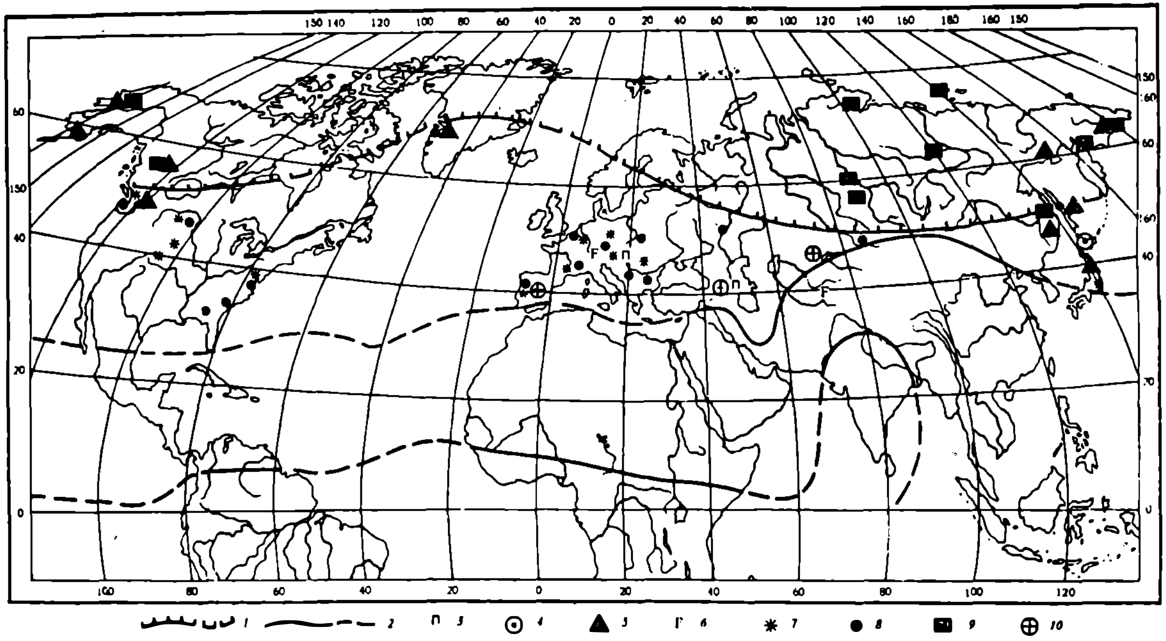

FIGURE 4. Late Cretaceous paleoclimates.

1 - boundary between temperate-warm and subtropical humid zones (as given by Vachrameev), 2 - northern and southern boundaries of arid zone in Northern Hemisphere (Khain et al., 1975), 3-7 - localities of plant remains that are climatic indicators: 3 - trunks of treelike ferns, 4 - Cycadeoidea, 5 - Nilssonia, 6 - conifers (Frenelopsis), 7 - palms, 8 - Dewalquea (Debeya), 9 - Pseudoprotophyllum, 10 - narrow-leaved and small-leaved angiosperms.

(and tropical) climate are first and foremost palms (although their remains are somewhat scarce in Upper Cretaceous deposits), the trunks of treelike ferns, leaf impressions of some Leguminosae (Bauhinites), and also, as recently demonstrated by Krasilov (1975), digitate leaves of Dewalquea (= Debeya). We also know that leaves with an entire margin and pinnate venation predominate under the conditions of a tropical or subtropical climate, whereas the leaves of most trees in the temperate zone have a dentate margin, and digitate venation is also prevalent among them (the rule of Bailey and Sinnot).

Large Pseudoprotophyllum leaves, which have digitate venation (fig. 4), may be used as climatic indicators for the humid temperate-warm zone. Czekanowskiales, which were so widely distributed in the humid temperate-warm zone in the Early Cretaceous, were preserved in this zone only in the northeast of the USSR, where they were represented by the genus Phoenicopsis, not ascending above the Cenomanian. The distribution of Nilssonia is interesting. In the Late Cretaceous Nilssonia were preserved only in the temperate-warm climatic zone, and also in the regions of the subtropical zone bordering on the temperate-warm zone (Sakhalin, Japan, Vancouver). All Late Cretaceous Nilssonia localities tend toward the coastal regions of the northern part of the Pacific Ocean, where judging from the abundance of ferns and large-leaved angiosperms, the climate was considerably damper and warmer in the winter than in regions remote from the Pacific seaboard.

Comparison of the successions of a number of Late Cretaceous floras originating from several regions in Asia and North America yields an outline of climatic changes both in time and in space. For this purpose we selected four regions in which the change in the systematic composition of the floras during the Late Cretaceous had been quite fully traced. These regions were Kazakhstan, Eastern Siberia, the northeast of the USSR and Western Canada plus Alaska. For a large part of the time Kazakhstan was in the arid (at times humid) subtropical zone, whereas the other three regions were in the more northerly temperate-warm humid zone.

The Late Albian and Cenomanian floras of Kazakhstan, rich in broad-leaved forms represented predominantly by Platanaceae, contain a few evergreen plants with entire leaves (Magnolia, Diaspyros, etc.), indicating that they flourished under conditions of a warm, probably already subtropical, humid climate. By the beginning of the Turonian age many evergreen elements represented by entire-leaved and hard-leaved forms (Laurophyllum, Daphnophyllum, Persea, Andromeda, Cocculus) appear in the floras of Kazakhstan. However, Platanaceae are also abundant (Kyzyldzhar).

The increase in the aridity of the climate in the central regions of Asia, with Kazakhstan on their periphery, was a process that continued in the Coniacian, Santonian and, partly, in the Campanian. Platanaceae and ferns disappear completely from floras of this age (Shilin, 1977) from the Shakh-Shakh and Taldy-say localities, but small-leaved and narrow-leaved forms of angiosperms (Celtidophyllum, Quercophyllum, Salix, Myrica, etc.) are abundantly represented. The appreciable increase in the amount of Classopollis pollen in the Turonian, Coniacian and Campanian of Turkmenia also confirms that the climate became more arid (Petros'yants and Tarasova, 1965; Ponomarenko, 1973). The amount of Classopollis is also increased in S. Kazakhstan, although not to the same extent. The content of Classopollis pollen declined in the Santonian, to increase once again in the Campanian. The increasing aridity is also indicated by the appearance of gypsum-containing units in the Turonian deposits of Fergana and the Tadzhik depression.

Floras of the second half of the Upper Cretaceous in Europe also contain many narrow-leaved and small-leaved forms. They include remains of leaves from the Senonian of the Carpathian region of the Ukraine and the Donets Basin (Vachrameev et al., 1970), and also southeastern Poland (Malicki et al., 1967). Localities of leaf remains of small-leaved and narrow-leaved angiosperms (Dryophyllum, Myrica, "Eucalyptus") belonging to various ages of the Late Cretaceous are also known in Transcaucasia (Daralagez), Italy and Portugal.

Impressions of exclusively aquatic or coastal plants (Quereuxia angulata, Nelumbites sp., Typha sp., Equisetites sp.) have been found at a number of points in the continental variegated Upper Cretaceous (Campanian) deposits of Fergana, which were accumulated in the arid zone of this epoch. It is, as a rule, remains of trees or aquatic plants that are interred. The absence of the former suggests that there was little arboreal vegetation, the simplest explanation for which is the aridity of the climate. The aquatic plants may have been connected with waters in treeless terrain. The data cited for Fergana apparently indicates this.

Leaf impressions have not as yet been found in the widely distributed Upper Cretaceous continental redbeds in Mongolia. At the same time fragments of large trunks have been found repeatedly in rocks of alluvial origin. This factor should be related to the aridity of the climate of Central Asia in the Late Cretaceous epoch. The wide expanses of plain land surrounding the numerous lakes and valleys in the lower reaches of the rivers, in which sedimentation occurred, were apparently covered at this time by herbaceous vegetation, which provided food for numerous herbivorous dinosaurs. There are scarcely any traces of this vegetation, since herbaceous plants are not usually interred in the fossil state, but rot as they stand.

Areas of forest were confined to the slopes of the uplands, where the upper parts of the river valleys were located, outside the sedimentation region. It is natural that leaves that fell into the rivers should have been worn away as they were transported, whereas the tree trunks were carried downstream and were interred far from the point where they had grown.

The foregoing data show that temperatures rose gradually and the climate simultaneously became more arid during the Late Cretaceous within the subtropical zone both in Asia and in Europe. This is well supported by measurements of paleotemperatures for the marine basins that covered Soviet Central Asia (Yasamanov, 1975). The lowest temperatures recorded here are for the Late Albian, the highest for the Campanian-Maestrichtian. A slight reduction is to be noted for the Santonian. A similar temperature curve has also been established for the Russian Platform (Naydin et al., 1966). It has not yet been possible to detect a reduction in temperature in the Santonian through paleobotanical data owing to the rarity of Santonian floras. However, we have already noted a reduction in the content of Classopollis pollen for the Santonian of Soviet Central Asia. The distribution of remains of terrestrial dinosaurs is limited in the north by the boundary of the Cretaceous subtropics.

Let us now turn to the history of the Late Cretaceous floras that flourished in the zone bordering the northern part of the Pacific. The best investigated floras of this area, incorporated in the humid temperate-warm zone, are those of Penzhina Bay (Kamchatka), of the Anadyr' River basin and the Koryak Upland, and also the floras of Western Canada and Alaska (Krasilov, 1975; Vachrameev, 1976). All the Late Cretaceous floras of these regions, from the Cenomanian to the Maestrichtian and the Danian, indicate a humid seasonal climate, as is suggested by the wealth of ferns, as well as by the presence of thick coal seams in the deposits containing plant remains. The relative abundance of Nilssonia, which did not disappear here until the beginning of the Paleogene, is an indication both of humidity and of a relatively warm winter made milder by the proximity of the ocean.

The disappearance of Nilssonia from the floras of Yakutia and other regions of Siberia at the beginning of the Late Cretaceous evidently must be related to the lower winter temperatures of the inner parts of the temperate-warm zone, while their absence from the arid subtropics of Southern Europe, the Caucasus, Kazakhstan and Soviet Central Asia must be related to the relative aridity of the climate in this zone, from which they had already disappeared when it was established at the beginning of the Late Jurassic.

The wide distribution in the Late Cretaceous floras of conifers (mainly Taxodiaceae with seasonally falling shoots and of angiosperms whose leaves have a dentate margin, including large-leaved Platanaceae (Pseudoprotophyllum, Platanus and "Credneria"), is evidence of a temperate-warm humid climate in the northern part of the Pacific zone. If we compare the composition of the floras whose remains are found in the various stages of the Upper Cretaceous, we are able to detect an appreciable warming up of the climate in the Campanian, as has already been noted by Krasilov (1975). Thus, there are many evergreen plants (Laurus, Cinnamomum, Dillenites, etc.), with palms among them, in floras of the Nanaimo group (Campanian of Vancouver Island). This flora should be regarded as already subtropical (Bell, 1957). Thus, the northern limit of the subtropics in the Pacific Ocean was shifted slightly northward for the Campanian. The warming up in the Campanian also affected the composition of the flora of the Zhonkiyerian suite (Central Sakhalin), lying approximately on the latitude of Vancouver (50° N) and the composition of the Chignik suite (Alaska), lying slightly farther north (around 55° N). A considerable number of plants having leaves with an entire margin, most of which were probably evergreen forms, appears in both floras.

The Late Cretaceous floras of Siberia (Vilyuy and Amur-Zeya depressions, and along the left bank of the Yenisey), which flourished far from the shoreline of the Late Cretaceous seas, differed in being considerably impoverished when compared with the floras of the Pacific seaboard. The few ferns (Asplenium, Cladophlebis) do not include the Gleicheniaceae, which are abundant in the floras of the Pacific seaboard (Sakhalin) gravitating toward the boundary between the temperate-warm and subtropical zones. Conifers are represented in Siberia, as on the Pacific seaboard, by various Taxodiaceae (Cephalotaxopsis, Sequoia). Metasequoia become abundant toward the close of the Late Cretaceous epoch. Forms with entire leaves are rare among angiosperms; medium-sized and large leaves with a dentate margin predominate among the interred leaves, namely various Pseudoprotophyllum, Platanus, "Credneria", Cissites, Menispermites, etc. Toward the close of the Cretaceous they were largely supplanted by members of the genus Trochodendroides, which had polymorphous leaves. It is only for the Vilyuy depression that Budantsev (1968) notes the appearance of large numbers of small leaves in the flora of the lower half of the Chirimyyskiian suite (Santonian-Campanian?), leaves belonging to genera found both lower down and higher up the section, but represented there by larger leaf blades (Menispermites, Zizyphus, Cissites, Macclintockia). Budantsev relates this small-leaved condition to a more arid climatic phase. However, no other evidence in support of this explanation has yet been found either in the Vilyuy depression itself, or in other regions.

There is an interesting discrepancy between the temperature curves for the Turonian age in Soviet Central Asia and Western Siberia. As has already been noted above, lithological and paleobotanical data indicate an increase in temperature accompanied by an increase in the aridity of the climate for Soviet Central Asia. At the same time there was an appreciable cooling in comparison with the Aptian-Albian in Western Siberia, lying directly to the north (Paleoclimates of Siberia. . ., 1977). This discrepancy is easily explained by the fact that a large transgression of the Arctic basin covering the whole of the West Siberian lowland is associated with the Turonian age. Naturally, the extensive southward spread of Arctic waters led to a fall in temperature on the land surrounding the marine basin that developed. Furthermore, no connection was established in the Turonian through the Turgay strait between the Arctic waters and the warm seas that covered Western Kazakhstan and Soviet Central Asia. This connection arose later in the Campanian-Maestrichtian and it led to a rise in temperature in Western Siberia, as is confirmed by the prevalence of carbonate deposits in the Maestrichtian of this region.

The foregoing example shows that against the background of synchronous global climatic changes, considerable deviations, due to the distribution pattern of transgressions and regressions and to the nature of the alteration in the topography of the land or of the sea and ocean floor, may develop for separate large regions. The disturbances of synchrony caused by these deviations may make it extremely difficult to correlate geological events on a climatic-stratigraphic basis.

The Danian age, which closes the Late Cretaceous epoch as currently accepted, is marked by a reduction of temperature detectable in the continents of the Northern Hemisphere. This is indicated by the appearance in the vegetation of the temperate-warm humid zone of the first members of such genera as Alnus, Betula, Corylus, Carpinus, Carya, Juglans, Ulmus, Zelkova, etc., which were to become widespread among broad-leaved coniferous-deciduous forests in the Paleocene (Vachrameev and Akhmet'yev, 1977). Palynological analysis confirms these data, because there is a sharp increase in the content of the pollen of anemophilous trees and shrubs, including members of the genera referred to above, at the transition from the Maestrichtian to the Danian and further to the Paleogene.

In Southeastern Kazakhstan the xerophilous subtropical flora of the Santonian-Campanian (Shilin, 1977) was replaced by a deciduous coniferous-broad-leaved flora (Tayzhuzgen, Ul'ken-Kalkan) with some evergreen elements (Dewalquea, Dryophyllum). In the western United States a subtropical, predominantly evergreen flora (Lance) was replaced at the transition from the Maestrichtian to the Danian by a flora in which deciduous elements began to play a large role (Fort Union).

A changed situation at the boundary between the Maestrichtian and the Danian, due in all probability to a reduction of temperature, is indicated by a heavy reduction in the systematic composition of the nanoplankton. Five families and 31 genera became extinct at this boundary (Shumenko et al., 1977). The southern boundary of the northern humid zone was shifted southward at the end of the Cretaceous. Coal measures appeared in Mexico, the South Sahara and the south of the Arabian Peninsula (Khain et al., 1975). As in the Albian, the increase in the dampness of the climate was accompanied by a decline in temperature.

On examination of the paleoclimatic maps of the Early and Late Cretaceous produced by Khain and his colleagues (Khain et al., 1975) we see that the northern boundary of the equatorial humid zone turns sharply northward in the Indian Ocean region, rounding the Hindustan Peninsula, and then descending steeply southward. The abrupt change in direction of this boundary is based on the presence in Hindustan of remains of a hygrophytic Cretaceous vegetation and of coal deposits, at the same present-day latitudes at which redbeds and gypsum of the same age occur in Africa, and which arose under arid climatic conditions. It seems to the present author that the simplest explanation of this abrupt change in direction of the northern boundary of the equatorial humid zone is continental drift, which shifted the Hindustan Peninsula far to the north in post-Cretaceous times, into latitudes which included an arid zone in the Cretaceous period.

In conclusion, we should say something concerning the general nature of the change in climate of the Northern Hemisphere in the Cretaceous period, having given a comparative description of the climate of the two epochs. The climate of this period had a well expressed zonal pattern (figs. 1, 4). The arid zone in Europe and North America was reduced in size at the beginning of the Early Cretaceous. Retreat of the northern boundary of the arid zone apparently occurred somewhat later in Asia: in the Hauterivian-Barremian. The temperature began to fall, reaching its minimum in the late Albian. Humidity increased simultaneously. The general reduction in temperature throughout the Early Cretaceous epoch was interrupted by some warming up in the Aptian, but it would be premature to make any assertion concerning the universality of this warming up.

In contrast to the Early Cretaceous, the first half of the Late Cretaceous was marked by an increase in temperature and by a northward advance of the northern boundary of the arid zone. The zonal climatic pattern was probably less sharply defined in the Late Cretaceous than in the Early Cretaceous, and especially than in the Late Jurassic. This is indicated by the gradual advance of the vegetation of the temperate-warm zone into the humid subtropical and, thereafter, into the arid zone, as well as by the absence of salt deposits from the arid zone and the presence of only comparatively thin gypsum units.

The temperature reached a maximum in the Campanian, after which there was cooling, that reached its greatest extent in the Danian age - the start of the Paleocene. This cooling gave rise to noticeable change in the terrestrial vegetation, impoverishment of the nanoplankton and a southward retreat of the northern boundary of the arid zone, which was particularly marked for the Western Hemisphere.

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