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POLLEN *CLASSOPOLIS*: INDICATOR OF JURASSIC AND CRETACEOUS CLIMATES

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ABSTRACT

Pollen *Classopollis* belonging to extinct coniferalean family Cherolepidiaceae are widely spread in the Jurassic and Cretaceous. The material from the USSR provides the most detailed data on the quantitative distribution of the pollen. A low content (1-10%) of *Classopollis* suggests temperate climatic conditions, whereas a percentage (20-50%) reveals warm subtropical one. The highest content attaining 60-75% even 90% (in Oxfordian of the USSR southern regions) testifies to an arid climate. Thus the distribution of the pollen plotted against that of lithological indicators of the climate allows to reveal climatic belts for different epoch of the Jurassic and Cretaceous and to establish climatic fluctuation during this time.

Key-words — Palynology, *Classopollis*, Cheirolepidiaceae, Jurassic, Cretaceous. USSR.

सारांश

क्लासोपोलिस परागकण : जुरेसिक एवं क्रीटेश्यस कालीन जलवायु के सूचक – व्सेवोलोद ऐंन्द्रियविच वाखरामिश्रॅफ़

विलुप्त कोनिफ़रेली के काइरोलेपिडिएसी कुल से संबन्धित क्लासोपोलिस परागकण जुरेसिक एवं क्रीटेश्यस काल में दूर-2 तक फैले हुए हैं। परागकणों के परिमाणात्मक वितरण पर सबसे अधिक विस्तृत आँकड़े सोवियत संघ से एकत्रित सामग्री से मिले हैं। क्लासोपोलिस की अल्प मात्रा (1 से 10 प्रतिशत तक) शीतोष्ण जलवायवी परिस्थितियाँ व्यक्त करता है परन्तु 20 से 50 प्रतिशत तक यह उष्ण-उपोष्ण जलवायु प्रदर्शित करता है। इसकी 60 से 70 प्रतिशत अथवा 90 प्रतिशत तक उच्चतम् मात्रा (सोवियत संघ के दक्षिणी क्षेत्रों के ऑक्स-फोर्डियन में) शुष्क जलवायु प्रदर्शित करती है। इस प्रकार पराग तथा जलवायवी आश्मिक-सूचकों का प्रति-वितरण जुरेसिक एवं क्रीटेश्यस के विभिन्न युगों के लिए जलवायवी कटिबन्धों को व्यक्त करने तथा इस काल में जलवायवी उच्चावचन को निश्चित करने में सहायक हैं।

POLLEN *Classopollis* became extinct at the beginning of the Palaeogene. The data accumulated during the last decade confirmed the previous opinion of the author (Vakhrameev, 1970) on dependence between content of *Classopollis* in miospore assemblages and of palaeoclimates.

Shoots with male cones yielding the *Classopollis* pollen have different appearance, and hence were described under various genera: *Cheirolepidium*, *Frenelopsis*, *Pseudofrenelopsis*, *Tomaxiella* and partly, *Masculostrobus*. These shoots are most densely covered by tightly adpressed scale-like or incurved spine-like leaves. When isolated, they are assigned to the form-genera *Brachyphyllum* (scale-like leaves), *Pagiophyllum* (short incurved leaves) and *Elatocladus* (longer incurved leaves). Isolated shoots of *Pagiophyllum* and *Elatocladus* in general habit are similar to those of extant Araucariaceae.

The study of epidermis and cones found together with some of the above shoots, Krassilov (1975, 1978), showed that they belong to the latter family. Nevertheless, it would be erroneous to insist on belonging of all isolated shoots attributed to form-genera *Brachyphyllum*, *Pagiophyllum* and *Elatocladus* to Cheirolepidiaceae or Araucariaceae only. Noteworthy is that the pollen of both the families, as well as male cones, are well distinguished from one another.

Frenelopsis and *Pseudofrenelopsis* have articulate shoots. In their nodes there are one (*Pseudofrenelopsis*) to three (*Frenelopsis*) short triangular leaves adpressed to the axis. The male cones born on shoots of this structure yielded *Classopollis* pollen only (Watson, 1977; Alvin *et al.*, 1978; Doludenko, 1978). Thus, these genera belong to the Cheirolep˙diaceae family.

Especially abundant material on the *Classopollis* content in the Jurassic and Cretaceous was obtained by Soviet Palynologists who provided the percentage of the pollen in miospore assemblages. This enabled me to draw the curves showing changes of the *Classopollis* content throughout Jurassic and Cretaceous plotted against latitudinal belts crossing the vast territory of the European part of the USSR, West and Middle Siberia, Kazakhstan, Middle Asia and the Caucasus. These curves are based on published data of Alekseeva, Alimov, Barkhatnaya, Blyakhova, Bondarenko, Danilenko, Dobrutskaya, Fokina, Ivanova, il'ina, Khachieva, Klimko, Kotova, Kosenkova, Kuvaeva-Smirnova, Markova, Nesterova, Orlova, Petrosyants, Pogodaeva, Perfilieva, Polumiskova, Ponomarenko, Rovnina, Sakulina, Shramkova, Shugaevskaya, Tarasova, Terekhova, Voittsel, Yaroshenko and some others. Reference to their publications are given in Vakhrameev (1970, 1978) and Vakhrameev and Doludenko (1976).

Palynologists from other countries do not give, as a rule, the percentage of these or other pollen genera and species; they only mention their frequent or rare occurrence. This fact does not enable a construction of curves of the quantitative content according to their data.

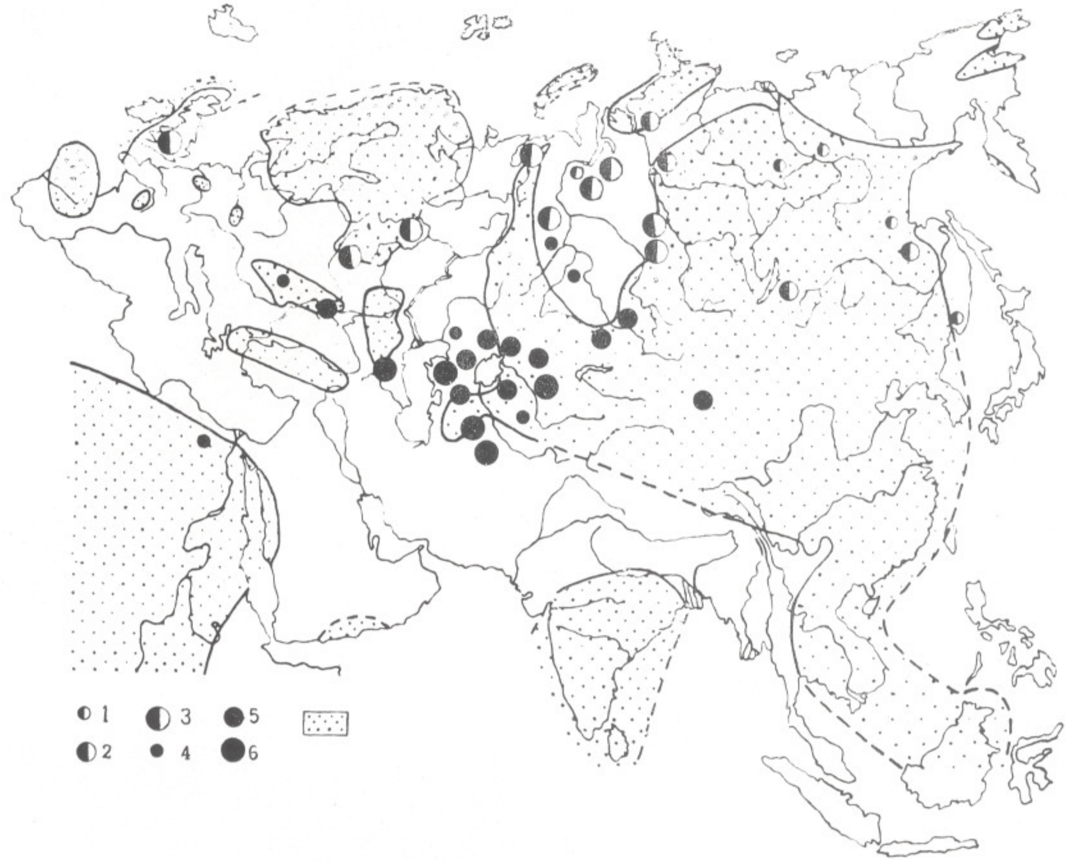
Before analysing the above mentioned curves and elucidation of their relation to climatic changes, the spatial distribution of *Classopollis* over the greater part of Eurasia for the Late Jurassic epoch should be attempted (Text-fig. 1). This time is particularly favourable for establishing dependencies between the *Classopollis* percentage and disposition of climatic belts. It is Upper Jurassic deposits that yield maximum amounts of the pollen, and the quantitative distribution of the latter, and hence, distribution of conifers producing them (Cheirolepidiaceae) seems very convincing. Text figure 1 shows that the *Classopollis* pollen content increases gradually southwards.

Paleoclimatic reconstructions for the Late Jurassic compared with the distribution of lithological indicators of climate and plant remains (Strakhov, 1960; Vakhrameev, 1964; Sinitsyn, 1966) show that the northern part of Eurasia was a belt of temperate-warm and humid climate. The *Classopollis* content does not exceed here 6-10%. In the Lena River Basin and in the north-east of the USSR, where the Upper Jurassic is represented by coal-bearing deposits, the *Classopollis* pollen either occurs as solitary grains, or is missing at all.

Southwards, in West Europe, the central part of the Russian platform and in the south of West Siberia, the climate was warmer and its humidity was seemingly decreasing. The content of *Classopollis* pollen in the Upper Jurassic varies here from 10 to 30-40%. In Moldavia, Crimea, Caucasus, South Kazakhstan and Middle Asia (a belt of semiarid and arid) hot climate is situated; this being evidenced by wide distribution of gypsum, and locally presence of rock salt. The content of *Classopollis* pollen is over 50% here. Such a regularity supports the opinion of many workers claiming that the Cheirolepidiaceae producing *Classopollis* pollen were thermophilic.

The second peculiarity in distribution of *Classopollis* pollen is its enormous quantities in rocks sediments deposited in the belt of semiarid and arid climate. As it has been already mentioned, the content of this pollen within this belt exceeds 50% everywhere, and that in Oxfordian deposits reaches 90%. Such a percentage of *Classopollis* pollen suggests that Cheirolepidiaceae survived well in dry climate, whereas the role of other plant groups in vegetation, especially ferns, abruptly decreased with aridity of climate up to their complete disappearance.

The *Classopollis* pollen is related to mostly shallow-water, near-sea-shore and deltaic sediments. It is distributed in lacustrine deposits of intermontane depressions as well (Karatau ridge in South Kazakhstan, etc.). Text-figure 1 clearly shows that the content of this pollen appreciably decreases from the West Siberian lowland occupied by a shallow water sea in the Late Jurassic in the eastern direction, where Upper Jurassic and Lower Cretaceous coal-bearing deposits are developed filling some depressions (Vilyui, Zyranka, etc.). In the continental Upper Jurassic of the Transbaikalian



TEXT-FIG. 1 — Contents of *Classopollis* pollen in palynological samples. Symbols: **1** — solitary grains **2** — from 1 to 2%, **3** — from 6 to 10%, **4** — from 30 to 40%, **5** — from 50 to 70%, **6** — 75 to 90%, **7** — land. Land and sea boundaries are given for Oxfordian age (Atlas of lithologo-paleogeographical maps of the USSR, v. III, 1968, and other sources).

area, and Bureya depression the *Classopollis* pollen content does not exceed 1-2%. The same pattern of the *Classopollis* pollen content in synchronous near-sea-shore and coal-bearing deposits was established by Yaroshenko (1965) for the Pliensbachian of the North Caucasus. The Cheirolepidiaceae producing *Classopollis* pollen seem to have avoided swampy overflooded habitats, preferring to grow on drained slopes or peneplated uplands.

This fact is likely to explain an increase of *Classopollis* pollen in transgressive portions of successions (Upper Jurassic of the Russian platform & West Siberian lowland). The sea, while transgressing over near-sea-shore lowlands covered by moisture-loving vegetation with prevailing ferns, approaches higher drained of the forested land. The Cheirolepidiaceae played a considerable role in the composition of the latter. It is natural that the *Classopollis* pollen content in near-sea-shore sediments increases considerably. This peculiarity of ecology of Cheirolepidiaceae somewhat disturbs the regularity of their distribution in climatic zones.

An opinion that Cheirolepidiaceae were an analogue to the recent mangrove plants growing in a very narrow shore intertidal band (Kondratiev, 1970; Hughes & Moody-Stuart, 1967), causes a serious objection. This analogy is opposed by considerable content of *Classopollis* pollen (50-70%) in Upper Jurassic continental deposits in north and north-east Kazakhstan accumulated at a large distance (about 500 km) from the shore line and especially in north-west China that had never been overflooded by Mesozoic seas.

Distribution of *Classopollis* pollen (Text-fig. 1) agrees well with the distribution of rainfall in the Jurassic and Cretaceous periods with Eurasia as reconstructed by Sinitsyn (1966). His maps show a belt of arid and semiarid climate stretching from the Arabian peninsula to western China and further pinching out eastwards. The belt embraces the southern part of the USSR. The northern and eastern parts of the USSR were within humid climate and it is here where the *Classopollis* pollen content proved minimum.

Summing up the data one can say that the Cheirolepidiaceae producing *Classopollis* were thermophilic plants as evidenced by a rapid decrease of the pollen from south to north. During the conditions of humid climate such groups of gymnosperms as Ginkgoales, Czekanowskiales, Podozamitales and older Pinaceae were successfully competing with the Cheirolepidiaceae. The latter avoided swamped lowlands within which coal-bearing beds were formed. They gave preference to drained slopes, and likely flattened peneplated uplands. Therefore, in East Siberia and in the Far East, where humid climate was predominant and the coal formation took place (Sinitsyn, 1966), the Cheirolepidiaceae were not in appreciable amounts in vegetation throughout the Jurassic and Cretaceous. Sediments with abundant *Classopollis* pollen gravitate most frequently toward in intercontinental basins (depressions) as well.

The Cheirolepidiaceae resisted the change of humid climate for semiarid or even arid one, becoming in this case monodominant. This process resulted in an abrupt decrease of ferns that could not survive in dry conditions and the aforesaid hygrophilic gymnosperms. Along with Cheirolepidiaceae forms, as the author believes in low sparse forest, many Bennettitales also grew.

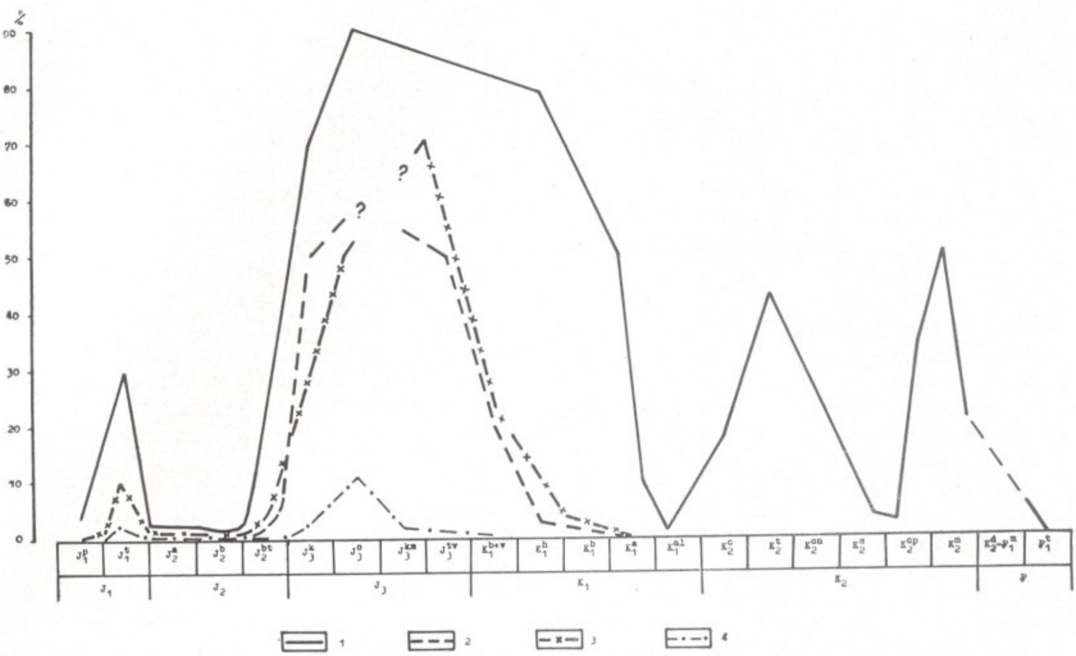
Under conditions of warm and hot climate, but humid, the Araucariaceae could grow together with Cheirolepidiaceae. The distribution of extant representatives of the former family growing in the southern Hemisphere, is confined to areas of humid climate. In regions of semiarid and arid climate abounding in Cheirolepidiaceae due to elimination of hygrophilic plants, the Araucariaceae did not grow in somewhat appreciable amounts. Further studies of both the epidermis of isolated shoots, and pollen of fossil Araucariaceae are necessary for a more accurate delimitation of areas of these two families in the Mesozoic.

While passing from Pliensbachian to Toarcian a considerable increase of the *Classopollis* content is observed (Text-fig. 2). The Toarcian peak is marked in all three curves; for the southern regions (Caucasus) the peak is better pronounced, whereas in North Asia (Vilyui & Khatanga depressions) the *Classopollis* content does not exceed 10-15%.

The dependence between the *Classopollis* content in the Toarcian and warming of climate is supported by other data as well. This time was characterized by penetration of some thermophilic ferns and bennettites to the north. For instance, along with *Classopollis*, spores of *Matonisporites*, *Marattiosporites*, *Contiguisporites*, usually confined to more southern regions, were found in Toarcian of the Vilyui depression and on the Anabar River. In the Kolyma River Basin imprints of *Thaumatopteris* and *Ptilophyllum*, in South Alaska — *Otozamites* and *Dictyophyllum*, and in the Kuznetz and Kansk-Achinsk basins — *Phlebopteris polypodioides* and *Marattiopsis muensteri*, were found.

The warming in the Toarcian time caused considerable advance of subtropics northward reaching the southern regions of Siberia and South Alaska. The breadth of the tropical and subtropical belt considerably increased. At the same time, the Toarcian warming did not cause appreciable expansion of arid climate, traces of which have been found neither in the Soviet Union nor in South Europe. This is evidenced by a complete absence of evaporites in Toarcian deposits of these regions, and a much lesser content of *Classopollis* pollen (less than 30-40%), as compared to the Upper Jurassic.

In Aalenian and Bajocian the *Classopollis* pollen content abruptly decreased everywhere to 1-2%, and eventually to complete disappearance. This is well-correlated to the cooling and moistening of climate, reaching maximum value in Bajocian. The northern boundary moved southward. Miospore assemblages, especially Bajocian ones, begin to abound in spores. Process of coal accumulation was widely distributed.



TEXT-FIG. 2 — Curves of *Classopollis* pollen contents in Jurassic and Cretaceous deposits. Symbols: **1** — curve for USSR southern regions (Moldavia, Crimea, Caucasus, South Kazakhstan, Middle Asia). The right part of curve embracing Upper Cretaceous is drawn according to samples from Middle Asia, **2** — curve for central part of Russian platform (Moscow Basin, Vyatka-Kama depression, etc.), **3** — curve for West and Middle Siberia (Vilyui depression), **4** — curve for the northern margin of Asia (Ust-Yenisei and Khatanga depressions).

In Bathonian, southern regions of the USSR show a gradual increase of the *Classopollis* content (up to 20-30%). In Middle Asia, particularly in Ferghana, one can observe impoverishment of the floristic composition in plant megafossils, at the expense of falling out of more hygrophilic forms. Representatives of some genera have appreciably reduced leaf laminae. In more northern regions, for instance, in the central part of the Russian platform and in West Siberia the increase of the *Classopollis* content is negligible. No increase of *Classopollis* pollen was recorded along the northern margins of Eurasia. Changes recorded in southern regions are related to the first hardly noticeable phase of the climate warming pronounced rather clearly in the south of the Soviet Union only (Crimea, Caucasus, Middle Asia). In Middle Asia this warming was accompanied by the aridization of climate, evidenced by the reduction of leaf laminae and cease of coal accumulation.

In Callovian deposits the *Classopollis* content begins to increase. Even in the northern region (Ust-Yenisei depression, etc.) it increases in the Upper Callovian and Oxfordian from solitary grains in a sample to 10%. In the central parts of the Russian platform and West Siberia the *Classopollis* content becomes very significant (>50%), but especially high in southern regions (80-90%). In some samples taken from Oxfordian deposits the spore-pollen spectra consist practically of only *Classopollis* pollen (Text-fig. 2).

In the Oxfordian there was one of the largest transgressions in the Northern Hemisphere coinciding in time with the warming of climate. This can be evidenced by a significant northward advance of coral constructions recorded for Europe. Aridization of climate, as compared to the Callovian, became still stronger, as shown by the appearance of gypsum and, locally, rock salt. The wash down of clastic material from land framing in the north the Tethys and Paratethys seas sharply decreased. This was most probably associated with aridization of climate and drastic shrinkage of the surface drainage. This resulted in deposition of carbonate rocks in some regions near the shore line.

In Kimmeridgian-Tithonian deposits, as in the Oxfordian, represented by shallow-water or near sea-shore sediments the absolute content of *Classopollis* pollen somewhat decreases. The latter takes place mostly at the expense of great amounts of marine dinoflagellates. The latter are frequently observed along with spores and pollen of land plants. Therefore we had to interrupt the curves for this time.

While passing to the Cretaceous, the *Classopollis* content invariably decreases, reaching its minimum in the Albian. However, for various regions this part of the curve is not identical. In the north of Eurasia *Classopollis* disappears as early as in Berriassian-Valanginian. In the central part of the Russian platform, Mangyshlak peninsula and West Siberia the *Classopollis* content abruptly decreases not exceeding 20-25% in the Berriassian-Valangnian; its amounts in the Hauterivian become negligible (a few per cent), and in the Lower Aptian deposits it practically disappears.

The cooling of climate is evidenced by penetration of buchias (aucellas) to the south, up to the Mangyshlak and North Caucasus. These buchias are widely distributed in Late Jurassic and Early Cretaceous on the northern margins of Eurasia and North America, and gravitate towards the belt of temperate or temperate-warm climate. Increase of fern spores in miospore assemblages, and disappearance of evaporites testifies to humidization of climate.

The situation is different in Middle Asia where the *Classopollis* content remained high up to the Upper Aptian (Text-fiig. 1). This appears to be related to the fact that in this region, where continental red beds with dolomite and gypsum were still accumulating, the climate was dry enough preventing from distribution of ferns. This is also confirmed by a negligible amount of spores in the deposits of this age.

The minimum content of *Classopollis* accounts for the Albian (Text-fig. 2). This is well-confirmed by the curves made separately for the Crimea, South-East Caucasus, Uzbekistan and Turkmenia (Vakhrameev, 1978). The Albian lowering of temperature was likely global. In the southern hemisphere it was recorded in Australia (Douglas, 1976) and South Atlantic (McLachlan & Pieterse, 1978). However, the decrease of temperature in the near-equatorial belt did not appear to be appreciable, as the *Classopollis* content in Albian deposits remains significant. It can be judged from the palynological investigations of core material from some deep sea holes drilled by D. V. "Glomar Challenger" in the Marocco Basin and the Cape Verde Basin (Kotova, 1978). The *Classopollis* content in Aptian and Albian deposits reaches 80% (in Neocomian — 70%, and in Cenomanian — 60-65%).

The Albian age coincides with dispersal of angiosperms, and especially broad-leaved forms of this group. Noteworthy is that in all northern and central regions the *Classopollis* pollen in post-Albian deposits disappears. In the Upper Cretaceous of the USSR southern regions the pollen are still observed in great amounts in Middle Asia and South Kazakhstan. In the Crimea and Caucasus typically marine, mostly carbonate deposits are nearly devoid of miospores. In Middle Asia the *Classopollis* content, being minimum in the Albian, begins to increase in Cenomanian reaching its maximum in the Turonian-Coniacian and decreasing in Santonian. The last rise of *Classopollis* accounts for Campanian-Maestrichtian. Then the curve descends. In the Upper Palaeocene the Cheirolepidiaceae disappear from the Eath's surface, this being confirmed by complete disappearance of *Classopollis*.

The Turonian-Coniacian corresponds maximum to a rise of temperature and an increasing aridization of climate. This is asserted by appearance of red beds and gypsum in Middle Asia. The second maximum relates to well-known warming in the Campanian age. The available data on the *Classopollis* content in the Upper Cretaceous of Middle Asia and in other regions are insufficient. The distribution of this pollen is not clear enough due to two factors: (i) in samples from the Upper Cretaceous shallow-water marine deposits, these being predominant, there are numerous unicellular algae forcing out miospores from palynological spectra, (ii) appearance of *Gnetaceapollenites* pollen belonging to gymnosperms in Upper Cretaceous deposits. Requirements of these plants to the environment were similar to those of Cheirolepidiaceae. The competition between both groups influenced on their proportion in miospore spectra.

On the whole, the curves of the *Classopollis* content show good agreement with paleotemperatures measured by Ca/Mg ratio (Yasamanov, 1975, 1976), with the data on plant megafossils (Vakhrameev, 1978; Vakhrameev & Doludenko, 1976), as well as with distribution of lithological indicators of climate (Ronov & Khain, 1962; Khain, Ronov & Balukhovsky, 1975). Warmings in the Toarcian, Late Jurassic and Campanian time, and a cooling in the Albian can well be traced throughout the northern hemisphere. The Albian pessimum is recorded in the southern ehmisphere (Australia) as well.

It may be said again that in climatic interpretation of the *Classopollis* content the lithological composition of beds yielding samples are to be considered. It is necessary to remember that samples from coal-bearing beds deposited even under conditions of subtropical or tropical climate contain, as a rule, small amounts of *Classopollis* (Jurassic & Lower Cretaceous of India). Therefore according to this feature they should not be used for reconstruction of changing paleotemperature. The *Classopollis* content in shallow-water, near-sea-shore and continental (but not coal-bearing) deposits is a reliable indicator of climate, and can also be used for stratigraphic correlation purposes, particularly when deposits are poor in other organic remains.

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