The nonmarine Cretaceous of the U. S. S. R. : a review

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ABSTRACT

Nonmarine Cretaceous deposits in the U. S. S. R. accumulated along the margins of the East Europe and West Siberia shields. In the south, these deposits are found in the Tethys region as well as in the intracontinental basins and troughs behind the rising volcanic ranges of the Circum-Pacific belt and its continuation into Transbaikalia and Mongolia. A brief overview of the stratigraphy of these deposits is presented. A number of biological and climatic events defining inter-regional correlations are recognized.

INTRODUCTION

During the Cretaceous, the U. S. S. R. was covered by Tethyan geosynclinal seas transgressing from the south and southwest, while an almost continuous chain of island arcs and trenches bordered the east. Areas west of 90° East were, for the most part, covered by epicontinental seas which extended into the Arctic Ocean. A few island masses emerged above sea-level in the East Europe shield, but the shallow West Siberia and Kazakhstan seas exposed large areas of continental and paralic facies during their periodic retreats. To the east there was, perhaps, the largest known realm of continental sedimentation located in troughs and basins between and behind volcanic ranges that developed along the Pacific margin and extended into Transbaikalia and Mongolia. The locations of the principal basins where nonmarine Cretaceous strata occur are given in Fig. 1.

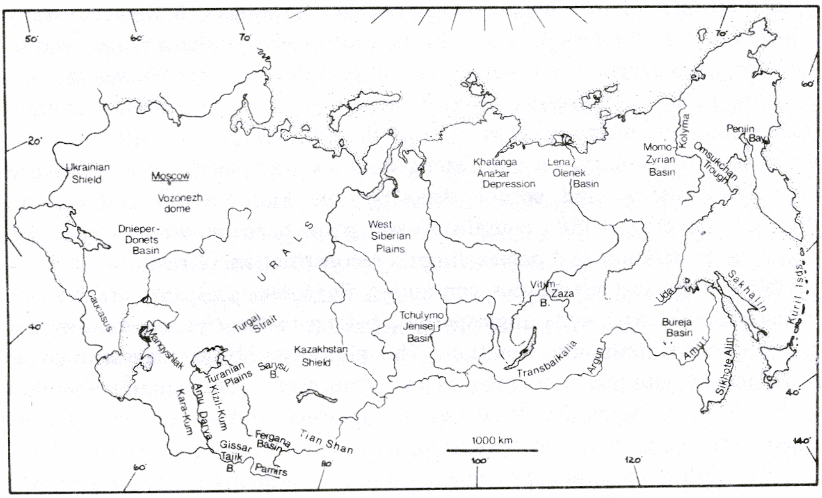

Figure 1. A generalized map of the U. S. S. R. showing the location of principal basins discussed in this paper.

Here, we outline the nonmarine Cretaceous stratigraphy of the U. S. S. R. as it appears today using a minimum of stratigraphic nomenclature and references to the extensive literature.

EUROPEAN REGION AND CAUCASUS

The nonmarine Cretaceous of the western regions usually contain marine intercalations which enable confirmation of age assignments based mostly on spore-pollen and plant macrofossil data. The Jurassic-Cretaceous boundary is marked by a regression of epicontinental seas. The Berriasian variegated kaolinitic clays occur locally in the Dnieper-Donets basin, on the Voronezh dome, and in the Moscow syncline. These clays contain a Wealden-type spore-pollen assemblage in which *Cicatricosisporites* is the most prominent spore morphotype, with *Classopollis* attaining 10—15% of the total content.

The Valanginian and Hauterivian deposits consist of similar lithologies and cover the Dnieper-Donets basin and northern Crimea where plant localities contain *Gle-*

ichenites and *Zamiophyllum* as dominant macrofossil components, while *Classopollis* dominates the pollen elements.

The Barremian kaolinitic bauxite clays onlap the Precambrian Ukrainian shield and, in places, they interbed with bituminous shales. In the Black Sea coastal areas, Barremian clays and sandstones with plant debris fill local tectonic downwarps. In the Dnieper-Donets basin, kaolinitic clays of this age contain abundant fossils of the fern *Gleichenites*, *Onychiopsis*, the conifer *Cyparissidium*, and the hirmerellean *Frenelopsis*. Characteristic features of the Barremian palynoflora include a great diversity of fern spores and monosulcate cycadalean pollen grains, and a decline in *Classopollis* with the first appearence of angiosperms.

Aptian kaolinitic clays and bauxites occur on the Ukrainian shield and Asov dome. The northern part of the Dnieper-Donets basin was subject to a marine transgression, while continental facies prevailed in the central and southern parts, and locally in the Voronezh-Kursk area where the characteristic ferns *Nathorstia* and *Murosporoides* are found. Transgressions from both the north and south gradually advanced during the Aptian and covered most of the Ukraine by Albian time.

In the Crimean mountains, on the Katcha-Bodrack watershed, upper Albian to middle Cenomanian marine and paralic deposits (see Marcinowski and Naidin, 1976; Naidin and Alexeev, 1980) contain several plant horizons which are important for interfacies correlation and palaeoclimatic reconstruction (Krassilov, 1984). The upper Albian clays and sandstones containing *Ruffordia goeppertii*, *Gleichenites zippei*, *Geinitzia cretacea*, and some angiosperms, belong to the *Hysteroceras varricosum* zone of the standard ammonite zonation. This plant assemblage suggests a cooler temperature compared with the Neocomian of the same area which contains abundant bennettites. The lower Cenomanian plant assemblage from marls of the *Mantelliceras mantelli* standard zone consists of mostly cosmopolitan species, such as *Anemia dicksoniana*, which also indicate cooling. However, middle Cenomanian *Turrilites costatus* zone shows a considerable increase in floral diversity, notably of cycadophytes and thermophilous ferns. The angiosperms *Rogersia*, *Sapindopsis*, *Celastrophyllum*, and *Celtidophyllum* are exceptionally small-leaved. Fish scale growth increments from these beds show typical temperature patterns in the late Albian, but with short adverse (i. e., dry) seasons during the middle Cenomamian (Krassilov, 1983).

The Caucasus and the adjacent margin of the Scythian platform were covered by geosynclinal and epeiric seas with volcanoclastic and carbonate deposits in which traces of terrestrial life have been found. Seas covering what is now the Greater Caucasus were divided from those of the Lesser Caucasus by the Transcaucasian median massif which prevented faunal exchange during the Neocomian. On the western margin of the Georgian block, an uplifted part of the Transcaucasian massif, a dolomitic limestone contains tracks of a carnosaur (*Satapliasaurus*) and, in the overlying bed, tracks of ornithopods (Gabunia, 1956). These occur in the lower Hauterivian ammonite zone *Speetoniceras inversum-S. auerbachi* (Kotetishvili, 1986).

MIDDLE ASIA AND KAZAKHSTAN

In Soviet Middle Asia continental and lagoonal facies are widespread on the Turanian plate and in the intermontane basins in the Tian Shan and Pamir ranges

(Gabrielanz, 1965; Sochava, 1968; Andreev, 1972; Aliev, 1979; Prosorovsky, 1979; Verba, 1979). Along the Caspian Sea and in the Karakum Desert, the Neocimmerian tectonic cycle closed with deposition of variegated clastics, carbonates, and sulphatic molasses of Oxfordian to Berriasian age. They are overlain by alluvial red beds passing upwards into clayey gypsiferous lagoonal facies, the ages of which are mostly Berriasian to Hauterivian south of Krasnovodsk (40°N), and Hauterivian to Barremian north of this where they onlap the Palaeozoic to Jurassic basement on the Mangyshlak peninsula. In the central Karakum, equivalent beds are mostly lagoonal with some freshwater interbeds.

Because of fluctuating shorelines, the marine, lagoonal (estuarine) and freshwater facies contacts are generally diffuse and migrational. Several transgressive-regressive cycles are recognized in the Amu Darya Basin and to the east, where extensive Hauterivian to Barremian red bed horizons occur.

In the Afgano-Tajik Basin, alluvial red beds and variegated lagoonal gypsiferous clays prevail in Upper Cretaceous strata, with marine carbonates wedging out to the east until only Turonian and Maastrichtian marine intercalations remain along the Tadjik-Kirghiz borders. In the Fergana area, Lower Cretaceous and Cenomanian strata (180—250 m thick) consist of freshwater red beds intercalated with dolomitic marls, limestones, and gypsiferous clays passing eastward into a coarse clastic molasse some 400 m thick (Fig. 2). Lower horizons contain *Martinsonella* bivalves known from the Hauterivian of China. The upper Cenomanian to Turonian deposits are predominantly marine oyster facies marking a transgressive event. Above these, the Coniacian to Maastrichtian interval reverts to a red bed-lagoonal complex with marine carbonate intercalations from the west, the uppermost of which contain *Hoplitoplacenticeras marroti* ammonites of late Campanian age.

Interbasinal correlation in Middle Asia relies on lithological markers, ostracod zonation, and a few stratigraphically important bivalve (Martinson and others, 1986) and vertebrate fossils. The most important lithological markers reflect short-lived, but widespread transgressive events. These are: 1—carbonate-sulphatic horizon of mid-Berriasian age (Shakhpakhtinskaja Formation) traceable from the Mangyshlak to Gissar ranges; 2—celestite-barytic nodule horizon in the Transcaspian region and Karakum, marking an early Hauterivian transgression; 3—carbonate shale member in the Gaurdak area, with variegated shales to the east, containing *Deshayasites weissi* of early Aptian age; 4—deep-sea black shale facies of late Aptian age. In the Upper Cretaceous, Turonian and Maastrichtian oyster beds are useful in tracing shorelines.

Ostracods provide 17 datum-levels, 12 of which are in the Lower Cretaceous, and five in the Upper Cretaceous (Andreev, 1984) (Table 1). In particular, *Cypridea* s. s. makes its last appearence in the lower to middle Albian, while the brackish-water genus *Sarlatina* is an important guide fossil for the upper Cenomanian and Turonian.

Among vertebrate fossils, selachians have proved most useful for interfacies correlation since they often inhabited estuarine areas where their remains mixed with terrestrial detritus. In the upper Albian Kizylkala Formation, the selachian *Eoanacorax dalinkevichiusi* and *Pazaisurus* sp. were found together with Pappotheriidae mammals related to the contemporaneous 'Trinity' fauna of North America (Nessov and Mertiniene, 1986). In the lower Cenomanian (upper part of the Chodzhakul For-

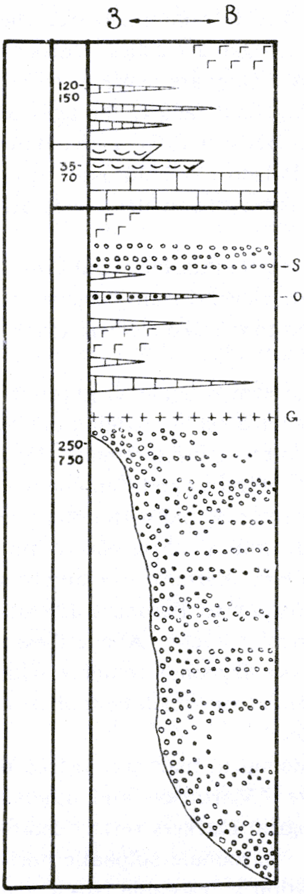

Figure 2. generalized nonmarine Cretaceous section in the Fergana depression. Circles-conglomerates-gravels; arched hachures-green clays with shell beds; vertical lines-carbonates; angles-red beds with gypsum. Marker beds; G—— blue copper shales; O—— oncolitic limestone; S——pyritic gravels (by Ju. L. Verba).

mation; Fig. 3a) exceptionally large archaic mammals, Palaeoryctidae, associate with the dinosaur *Microceratops* known otherwise from China (Bohlin, 1953; Young, 1958).

Estuarine beds deposited after the early Turonian transgression also contain a selachian chronofauna; for instance, the late Turonian *Palaeoanacorax* which occurs in Tajkarshin sandstone beds with platanoid leaves in the Kizil-Kum deserts (Fig. 3b); also, *Ptychocorax aulaticus* which, in the Coniacian, associates with *Parapalaeobates* and other rays. Contemporaneous freshwater and terrestrial vertebrate faunas underwent considerable changes. In particular, the turtle *Kizylkumemsis schultzi* and primitive ankylosaurs which were dominant in pre-Turonian assemblages, were replaced by *Lindholmemys* and heavily armoured ankylosaurs (Nessov and Krassovskaja, 1984). A similar succession of dominant faunas in the Bain Shirein Formation in southern Mongolia suggest a bipartite division, both in Middle Asia and Mongolia into early Cenomanian-early Turonian and late Turonian-Santonian ages.

Mongolian Cretaceous basins are traditionally viewed as lacustrine, although selachians have been found here also. However, the absence of *Shachemys* and the

Table 1. Coenozones of ostracods in nonmarine deposits of the Cretaceous of Central Asia.

Zone index	Assemblage of zonal taxa [(+) — brackish water forms]	Stage, horizon, suite
Zh1 + Zh2	*Scheda* sp. ; *S. polita*	K1b-? v, Karabi l
Zh3	*Scheda* sp. ; *Cypridea brevirostrata*;	K1b-? v, Karabi l-2
Zh4 + Zh5	*C. inversa lectipunctata*; *Limnocypridea pelucida almuradensis*; *Asciocythere* sp.	K1v-h, Almurad
K2	*Cypridea karatajgysensis*; *C. valdensis brevidorsuma*; *C. koskulensis*; *C. mera*; *C. angulata viva*; *Fabanella reticulata*; *Rhinocypris polikovi*; *Darwinula leguminella contracta*.	K1h2-br1, Kizilkir, Kugusem, Kiziltash.
K3 + K4	"*Cypridea*" *kiziltashensis*; *Cypridea valdensis brevidorsuma*; (+) *Asciocythere babatagensis*.	K1br, upper Kiziltash-lower Okuzbulak.
J1	*Ziziphocypris costata medasiatica*; *Cypridea priva gissarensis*; *C. dorsocornuta*; *C. tagigaliensis localituberculata*	K1a2, Kaligrek.
J2	*Drielba nova*; *Ziziphocypris simacovi*; *C. cylia*; *C. mera atuberculata* *Herpetocypris fabaeformis guzanensis*; *Mantelliana*? *grammi*.	K1a3, Karakuz.
JE1	*Cypridea sangardakensis*.	K1al. , Derbert.
E5	(+) *Sarlatina faizabadensis*; *S. mandelstami*.	K3c3, Gazdagana.
E6	(+) *Sarlatina leguminoformis*	K2t2, Dasgiriak.
E7	(+) *Neocyprideis hiascens*; *Valdonniella sp.*	K2m2

late survival of Nanhsingchelyidae, suggest against direct correlation with marginal basins in Soviet Middle Asia.

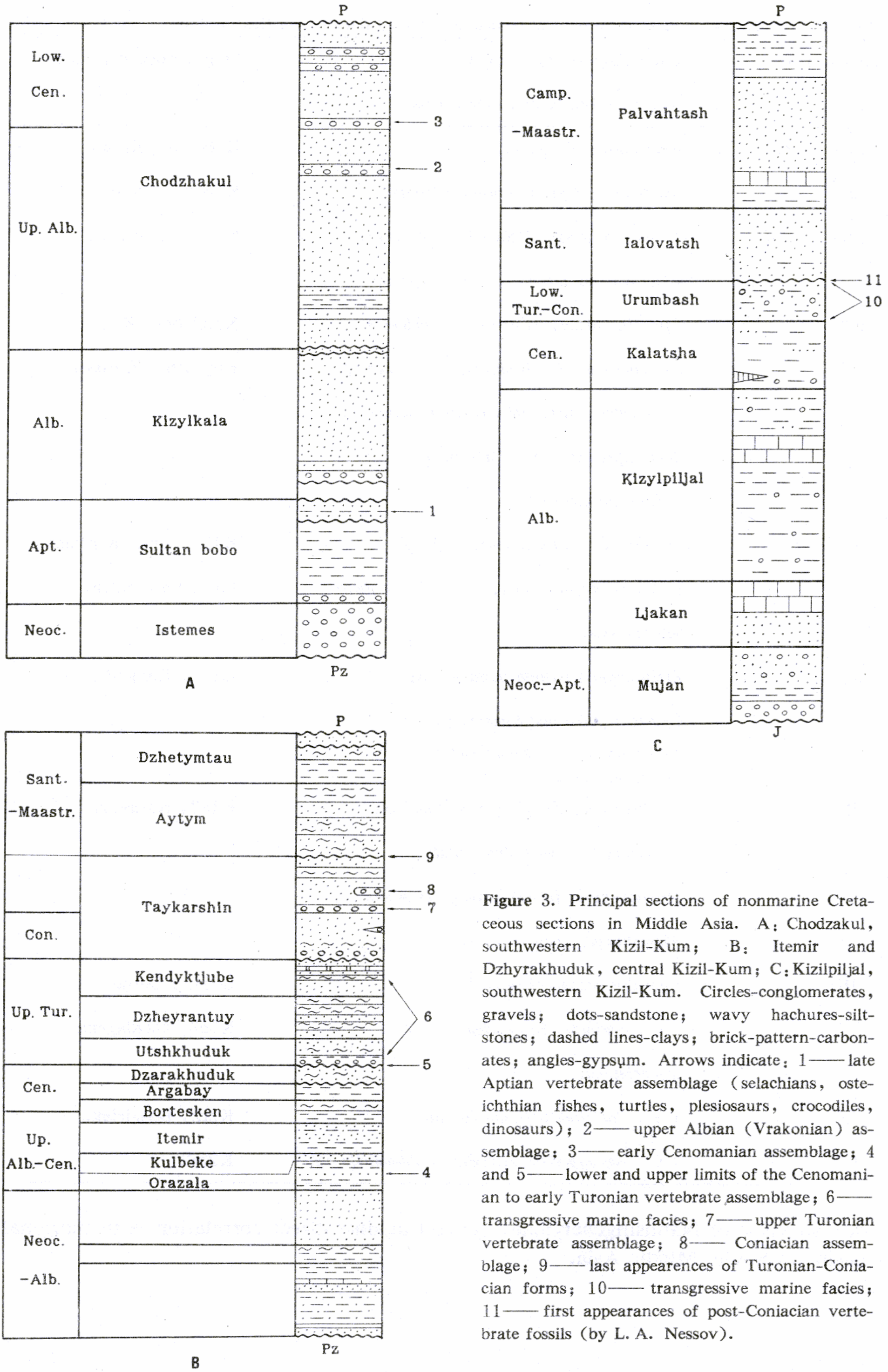

Figure 3. Principal sections of nonmarine Cretaceous sections in Middle Asia. A: Chodzakul, southwestern Kizil-Kum; B: Itemir and Dzhyrakhuduk, central Kizil-Kum; C: Kizilpiljal, southwestern Kizil-Kum. Circles-conglomerates, gravels; dots-sandstone; wavy hachures-siltstones; dashed lines-clays; brick-pattern-carbonates; angles-gypsum. Arrows indicate: 1——late Aptian vertebrate assemblage (selachians, osteichthian fishes, turtles, plesiosaurs, crocodiles, dinosaurs); 2——upper Albian (Vrakonian) assemblage; 3——early Cenomanian assemblage; 4 and 5——lower and upper limits of the Cenomanian to early Turonian vertebrate assemblage; 6——transgressive marine facies; 7——upper Turonian vertebrate assemblage; 8—— Coniacian assemblage; 9——last appearences of Turonian-Coniacian forms; 10—— transgressive marine facies; 11——first appearances of post-Coniacian vertebrate fossils (by L. A. Nessov).

eIn the middle Tajkarshin beds of Coniacian age, based on selachian evidence, ichthyornithiform birds and large azhdarchid pterosaurs with North American affinities are present (Nessov, 1986); primitive hadrosaurs, common in the Iren Dabasu fauna in China, suggest a Turonian-Coniacian age instead of an earlier Cenomanian age proposed by Maryanska and Osmolska (1981).

It is worth noting that dinosaur egg shells from the Santonian Jalovatch Formation of the Fergana area (Fig. 3c) are similar to *Oolithus chingkangkouensis* from the upper Wangshi Formation, Shandong Province, China (Chao and Chiang, 1974), but differ from Campanian eggs occuring in overlying beds elsewhere.

In northern and central Kazakhstan, differential tectonic movements at the Jurassic-Cretaceous boundary resulted in uplift of the Kazakhstan shield and subsidence of the Turgaj trough (linking the Turanian and West Siberia sedimentary basins). During the Lower Cretaceous this region emerged as part of the Uralo-Kazakhstanian continent where red beds accumulated in local basins. By the late Albian-Cenomanian, and possibly early Turonian time, substantial thicknesses of variegated lignitic bauxitic clays and sandstones were deposited in the Turgaj trough and other basins around the Kazakhstan shield (Kalmeneva and others, 1986; Levina and others, 1986). These beds contain tricolpoporoid pollen together with the spores *Divisisporites, Cingulatisisporites, and Foraminisporites.*

To the south, in the Jeskazgan-Sarysu basin, equivalent deposits consist of gypsiferous beds with xeric plant assemblages similar to those of Middle Asia. It might be that the crest of Kazakhstan shield acted as a rain shadow causing a more arid climate to the south. The Turonian transgression penetrated the Turgaj trough, while the Kazakhstan shield emerged as a peninsula along the northern and western margins. This latter area was subject to a humid climate with intense lateritic weathering, resulting in major bauxite deposits of Senonian age. This climatic zonation persisted throughout the Late Cretaceous in the southern arid province with variegated deposits in the Jeskazgan-Sarysu basin containing the auriculate pollen *Auriculiidites*, abundant gnetalean grains, and the endemic *Betpakdalina*. In the Maastrichtian, the northern province was further subdivided into an eastern *Triprojectacites*, and a western *Normapolles* subprovinces of Siberian and European floral affinities, respectively (Zaklinskaya, 1970).

Continental deposits of northern and central Kazakhstan contain rich plant fossil localities (Vachrameev, 1952; Shilin, 1986). The middle Albian gymonspermous assemblages also contain of a few important angiosperm fossils, among them the flowering shoots of *Caspiocarpus* and *Hyrcantha* (Krassilov and others, 1983). Late Albian-Cenomanian floras are dominated by platanoid leaves, while in the Turonian the latter is accompanied by substantial numbers of lauroid species and the first appearence of the fagoid *Castanosis*. The Santonian-Campanian plant assemblages are characterised by an increased proportion of myricoid and fagoid narrow serrate leaves, and in the Maastrichtian the latter prevail, indicating a more arid climate.

SIBERIA

Nonmarine Cretaceous deposits crop out along the western, southern, and southwestern borders of the West Siberia plains, and have been cored in the central parts. A widespread Berriasian transgression submerged most of these plains. In the late Valanginian the West Siberia sea gradually retreated leaving an expanse of periodically flooded coastal plains upon which variegated clays and sands of Hauterivian to Barremian age were deposited. These contain cyrenid bivalves, dinosaur remains, and spore-pollen assemblages comprising *Cicatricosisporites*, *Classopollis*, and, in the upper horizons, *Pilosisporites* (Chlonova, 1974). Older nonmarine Cretaceous deposits possibly occur within coarse clastic wedges in the foothills of the Urals and in the Tchulymo-Jenisej basin (Papulov, 1974).

Aptian through early Albian seas were restricted to the northwestern part of the West Siberia plains and, occasionally, the seas were isolated from the Arctic Ocean

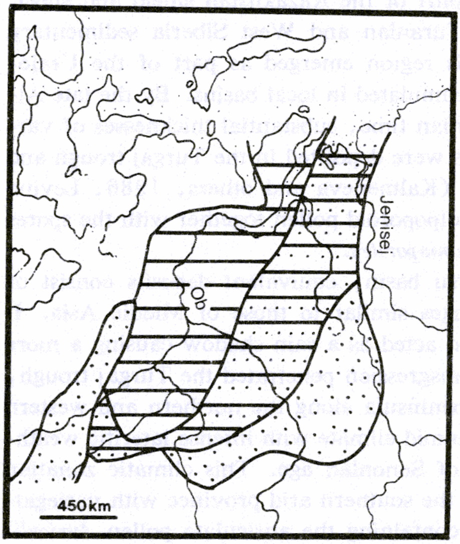

Figure 4. Palaeogeography of the West Siberian plate in Albian time. Dots-nonmarine facies; dots and hachures-paralic facies (by G. N. Papulov).

(Fig. 4). In the fringing deltaic deposits, angiosperm pollen first appeared together with characteristic Aptian morphotypes *Kuylisporites lunaris*, *Rouseisporites*, and *Cicatricosisporites pacificus*, while the Albian assemblage includes *Clavifera triplex*, *Ornamentifera* spp., and *Appendicisporites macrorhysus*.

In the southern foothills of the Ural mountains, lignitic and, in the upper horizons, bauxitic Aptian through lower Albian deposits with occasional fern macrofossils, are overlain by an alternating sandstone-siltstone sequence (Pokurskaja Formation). This formation is assigned to the late Albian to Cenomanian on the basis of infrequent foraminifera records and abundant palynomorphs. Notable among the latter are the first appearences of *Normapolles*, *Polyporites clarus* and, in the upper horizons, a characterisitc Cenomanian morphotype *Ruminatisporites*. Equivalent bauxitic beds occur to the north and in the Tchulymo-Jenisej basin (Kija Formation).

Late Cenomanian deposits are almost entirely continental with variegated kaolinitic clays predominating which contain amber and plant macrofossils consisting mostly of platanoid leaves. (Fig. 5)

During the Turonian, the West Siberia plains were again submerged by a marine transgression from the north. Areas of continental sedimentation were confined to the eastern and southeastern periphery where gravelly sandstones and kaolinitic lignitic clays of the Simonovskaja Formation contain a *Stenozonotriletes radiatus* assemblage of palynomorphs. Two successive spore-pollen assemblages are recognized in the overlying sandstones of the Symskaja Formation. The lower assemblage, of Coniacian to Campanian age, includes *Chlonovaia sibirica* and *Borealipollis bratzevae* as the principal indices, while the upper assemblage consists of the widespread Maastrichtian angiosperm pollen *Aquilapollenites*, *Wodehouseia*, *Expressipollis*, *Orbiculapollis globosus* as well as *Polypodiaceous* spores and the gymnosperm *Ephedra multipartita*.

In northeastern Siberia, between the lower reaches of the Khatanga and Anabar rivers, nonmarine cyclic coal-bearing deposits rest on a marine Berriasian to lower Hauterivian sequence for which a detailed ammonite zonation is available. To the south and southeast, the marine horizons are gradually replaced by paralic and continental facies. In the Lena basin, a Lower Cretaceous sequence (up to 4000 m thick) is mostly nonmarine with a few marine intercalations in the lower horizons (Fig. 6). Three successive floral assemblage zones are recognized spanning the Neocomian to lower Albian interval (Vachrameev, 1958; Vassilevskaja and Pavlov, 1963; Kirichkova, 1985). Lower horizons correlative with the marine Berriasian contain *Nilssoniopteris amurensis*, *Ctenis ketovae*, *C. stanovaensis*, and other cycadophytes, which suggest a comparatively warm climate. In the mid-Neocomian *Ginkgoites* ex gr. *adiantoides* first appeared, supposedly as a consequence of an upland to lowland migration caused by climatic cooling (Krassilov, 1971). In the Aptian the cycadophyte content increased again, augmented by such characteristic forms as *Neozamites verchojanensis*. The lower Albian is marked by the first appearence of angiosperm leaves *Prototrochodendroides jacutica* and more diverse conifers.

A similar succession of floral events was recognized in the nonmarine Cretaceous section in the Bureja basin to the south by Krassilov (1971, 1972), which justifies recognition of a general climatic trends.

Nonmarine Upper Cretaceous deposits are known in the Viluj basin, in local basins between the Lena and Khatanga rivers, and on adjacent Arctic islands. These are mostly sandstones and sideritic clays (occasionally coaly and tuffaceous on the islands) with plant remains indicating Cenomanian through Senonian ages (Budantsev, 1968).

TRANSBAIKALIA

Nonmarine Cretaceous deposits east of Lake Baikal fill about 300 local troughs and basins overlying, as a rule unconformably, volcanoclastic Jurassic rocks or onlaping granite basement (Scoblo and Liamina, 1986). The lower horizons are mostly coarse-grained alluvial or deltaic clastic series succeeded by fine-grained marly bituminous shales from stratified lakes; these are, in turn, overlain, or partly replaced by, coal-bearing cyclic alluvial deposits (Fig. 7). They contain one of the richest lacustrine fossil biotas in the world in which ostracods, conchostracans, insects, and fishes are the principal index fossils in regional, and beyond, correlations. Terrestrial plants and insects also provide significant stratigraphic markers.

In terms of ostracod zonation, the lower horizons belong in the *Mongolianella*

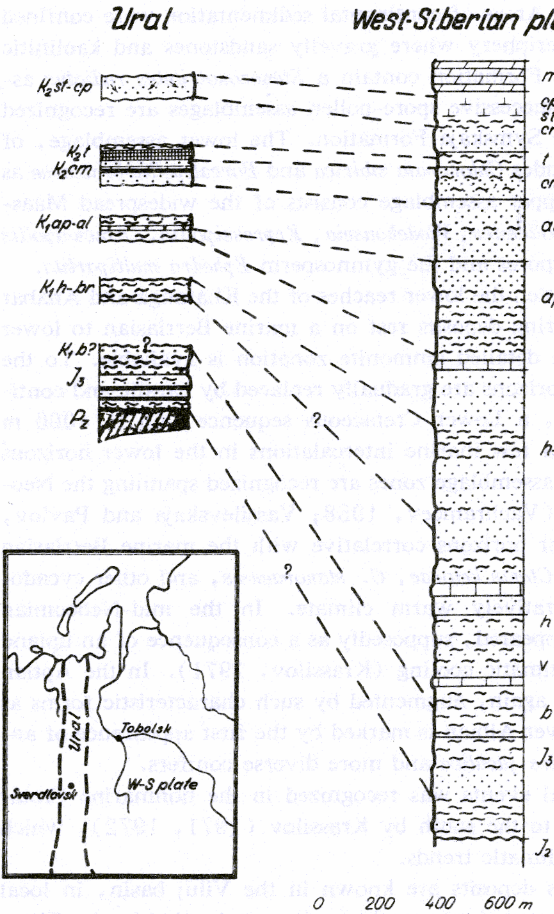

Figure 5. Correlation of nonmarine Cretaceous strata on the West Siberian plate and the Ural mountains. Vertical lines-carbonates; diagonal lines-oolitic iron ores; wavy hachures-claystones; dots-sandstones (by G. N. Papulov).

mertini-M. subexsortis assemblage zone in which the predominant Jurassic darwinulaceans and cyteraceans were replaced by *Cypridea* showing explosive speciation (Neustrueva and Scoblo, 1986). This rapid expansion of cyprideans, using the advantage of their drought-resistant eggs, appears to have been an isochronous event, not only in central Asia (Sharilin horizon in Mongolia, Carabil horizon in the Afgano-Tajik basin, and *Cypridea-Luanpingella-Eoparacypris* assemblage in China), but also in Europe (*Cypridea dunkeri* zone of the type Purbeck, *C. inversa-Mantelliana purbeckensis* assemblage in France, the Upper Malm 5 *C. inventa* zone in the north German basin, the lowermost Purbeck E in Poland, Rabekke Formation in Denmark, and Vitabak beds in Sweden).

Cyprideans dominate deltaic and tidal flat facies where they are found with unionid bivalves and occasional dinosaur bones, while mongolianellids prevailed in

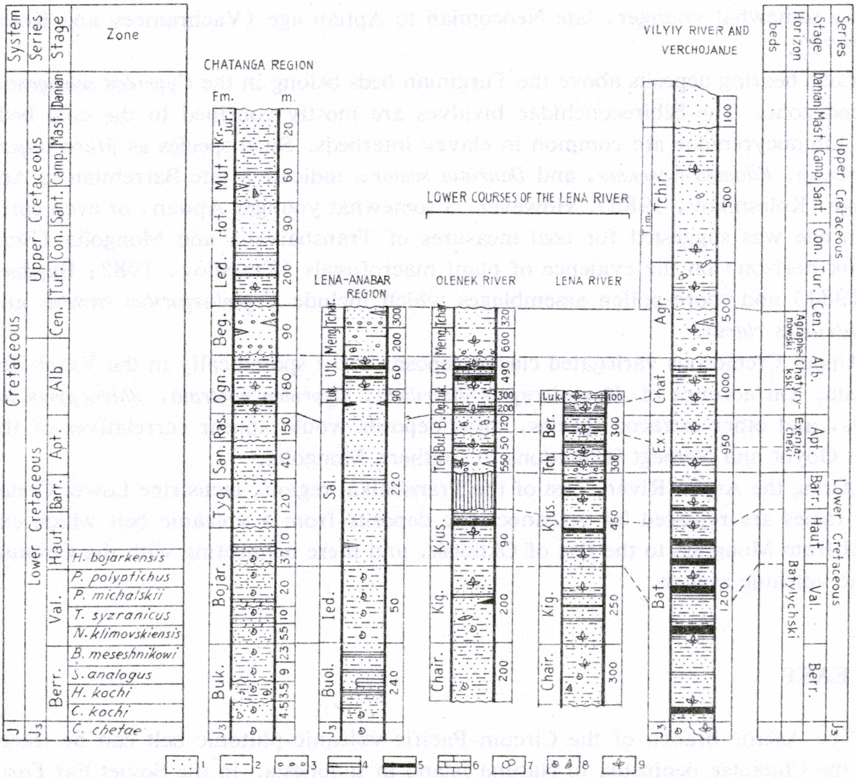

Figure 6. Sections of nonmarine Cretaceous strata in northeastern Siberia. Abbreviations of local lithostratigraphic units are listed in each column. 1——sands; 2——sandy claystones; 3——conglomerates; 4——claystones; 5——coal; 6——sandstones; 7—concretions; 8——marine invertebrate fossils; 9——plant fossils (by A. I. Kirichkova).

the less turbulent environments, preferred also by corbiculid molluscs. *Hemicorbicula recta*, *Daurinia marginata*, and *Lamproscapha murtoica* are characteristic bivalve species of this facies zone.

The limnobiota of the stratified lake facies (bituminous paper-shales with thinly laminated marl interbeds, known also as the Turginian facies) is often referred to as the *Lycoptera-Lycopterocypris-Bairdestheria* assemblage of fishes, ostracods, and conchostracans (Oleinikov, 1975), respectively. An approximate correlative with this assemblage is the *Ephemeropsis-Coptoclava* assemblage of mayfly and aquatic beetle larvae (Zherikhin, 1978). Most of the Turginian facies belong in the *Cypridea koskulensis* ostracod zone, the index species of which is known from the Barremian or Hauterivian to Barremian of Kazakhstan, northwestern China, and western Siberia. This species occurs in a red bed intercalation between two marine horizons of Hauterivian and Aptian ages in the Caspian depression. Turginian plant macrofossils belong in the *Baisia hirsuta-Otozamites lacustris-Pseudolarix erensis* assemblage (Bugdaeva, 1984), the last two index species of which are known from the Bon Tsagan locality, in Mongolia, assigned a late Neocomian age (Krassilov, 1982). At the same time a few angiospermoid pollen grains, notably *Asteropollis* and *Tricolpites*, may indicate a somewhat younger, late Neocomian to Aptian age (Vachrameev and Kotova, 1977).

Coal-bearing deposits above the Turginian beds belong in the *Cypridea selengensis* ostracod zone. The Sibireconchidae bivalves are mostly confined to the coal beds while Limnocyrenidae are common in clayey interbeds. Such species as *Musculiopsis selengiensis*, *Filosina tignensis*, and *Daurinia scalaris* indicate a late Barremian to Aptian age (Kolesnikov, 1980). However, a somewhat younger Aptian, or even early Albian age was suggested for coal-measures of Transbaikalia and Mongolia (Shin Khuduk horizon) on the evidence of plant macrofossils (Krassilov, 1982; Bugdaeva, 1984) and spore-pollen assemblages which include *Crybelosporites striatus* and *Cingulitriletes clavus*.

Upper Cretaceous variegated clastic deposits occur sporadically in the Vitim-Zaza basin. On account of *Mongolocypris distributa*, *Cypridea rostrata*, *Rhinocypris ingenicus*, and other ostracod species, these deposits would appear correlatives of the Barun Goyot and Nemegt formations in southern Mongolia.

Along the Argun River, east of the Transbaikal region, lacustrine Lower Cretaceous facies are replaced by volcanoclastic deposits from a volcanic belt which extended from Mongolia to the Sea of Okhotsk, and there connecting with the Circum-Pacific volcanic system.

FAR EAST

The Asiatic branch of the Circum-Pacific volcanic-plutonic belt can be traced from the Chukotsk peninsula to Natuna Island in Indonesia. In the Soviet Far East, the Sikhote Alin and Okhotsko-Chukotsk volcanic belts are segments of this system divided by the Uda River-Shantar Islands megashear. These segments are bounded by extensive left-lateral strike-slip faults along the continental margin and are dissected by a number of transcurrent faults which define a succession of local sedimentary basins.

The lowermost Cretaceous in the eastern Sikhote Alin ranges consist of flysch and chaotic terranes of Berriasian to Valanginian age, and occasionally contain plant-bearing beds; these include the *Alsophilites nipponensis-Nilssonia schaumburgensis* assemblage which, in some localities, occur in association with *Neocomites*, *Berriasella*, and other marine invertebrate fossils. Above the Hauterivian unconformity there are shallow marine and paralic coal-bearing molasses which grade west into an alluvial sandstone-siltstone cycle resting unconformably on mid-Jurassic and older rocks. They contain a rich fossil flora of Barremian to early Albian age of which *Cladophlebis frigida*, *Gleichenites* spp., *Nathorstia pectinata*, *Ctenis latiloba*, *Athrotaxopsis expansa*, and *Elatides asiatica* (*Elatocvladus manchurica*) are the most characteristic species (Krassilov, 1967). The age assignments are partly controlled by interbedded and homotaxial marine deposits with *Aucellina* and *Trigonia*. *Cladophlebidium dahuricum* from the middle part of the section is notable in that it provides a link with the Aptian coal-measure flora of Transbaikalia (see above). Angiosperms appear as exceedingly rare macrofossils in the Aptian below the *Trigonia* beds, but are more consistently found in the lower Albian where they are represented by several macrofossil species, such as *Cissites prodomus*, '*Aralia*' *lucifera*, *Laurophyllum* spp., *Sapindopsis* *angusta*, as well as the pollen *Clavatipollenites*, *Retitricolpites*, and *Asteropollis* (Markevich, 1982).

Volcanic activity commenced in the early Albian, and intensified greatly in late Albian to Cenomanian time resulting in volcanoclastic molasses with dacitic to an-

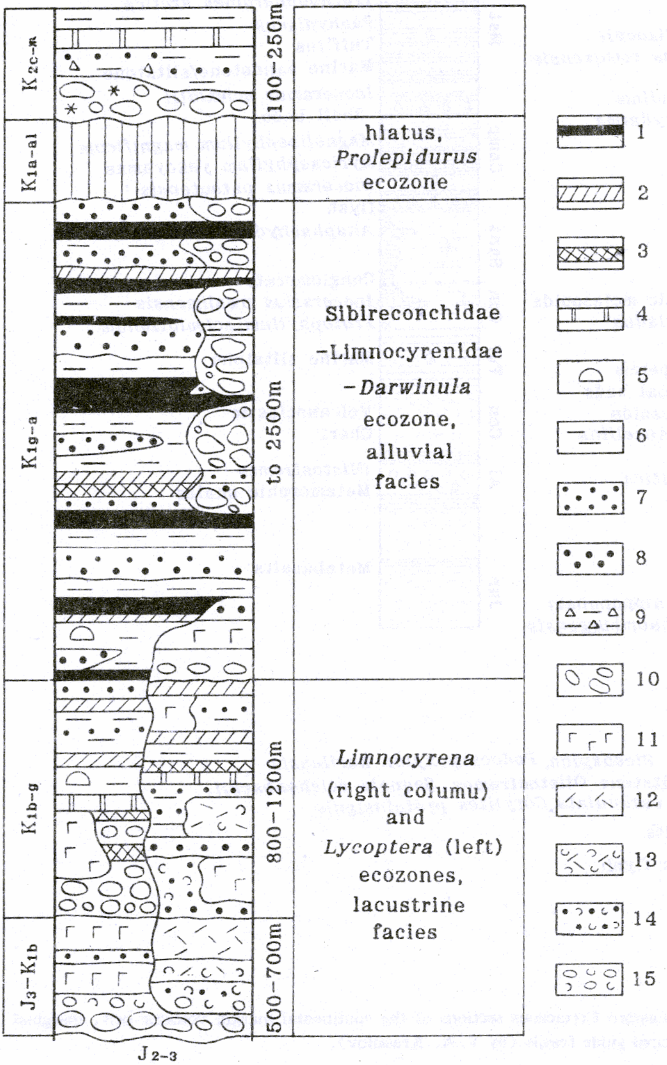

Figure 7. A generalized section of nonmarine Cretaceous strata of Transbaikalia. 1—coal; 2—claystones; 3—bituminous paper shales; 4—marls, pelitic limestones; 5—sideritic concretions; 6—siltstones; 7—fine-grained sandstones; 8—coarse-grained sandstones; 9—clayey-gravelly gritstones; 10—conglomerates; 11—latitic, trachybasaltoid and alkali andesitic-basaltoid lavas and tuffs; 12—trachyrhyolites and rhyolites; 13—other felsic tuffs and lavas; 14—tuffites and tuffaceous sandstones; 15—tuffaceous conglomerates (by V. M. Scoblo and N. A. Liamina).

desitic tuffs and lavas (Fig. 8). Their plant assemblages consist primarily of conifers and a few platanoid leaves in the upper horizons. A single locality in the

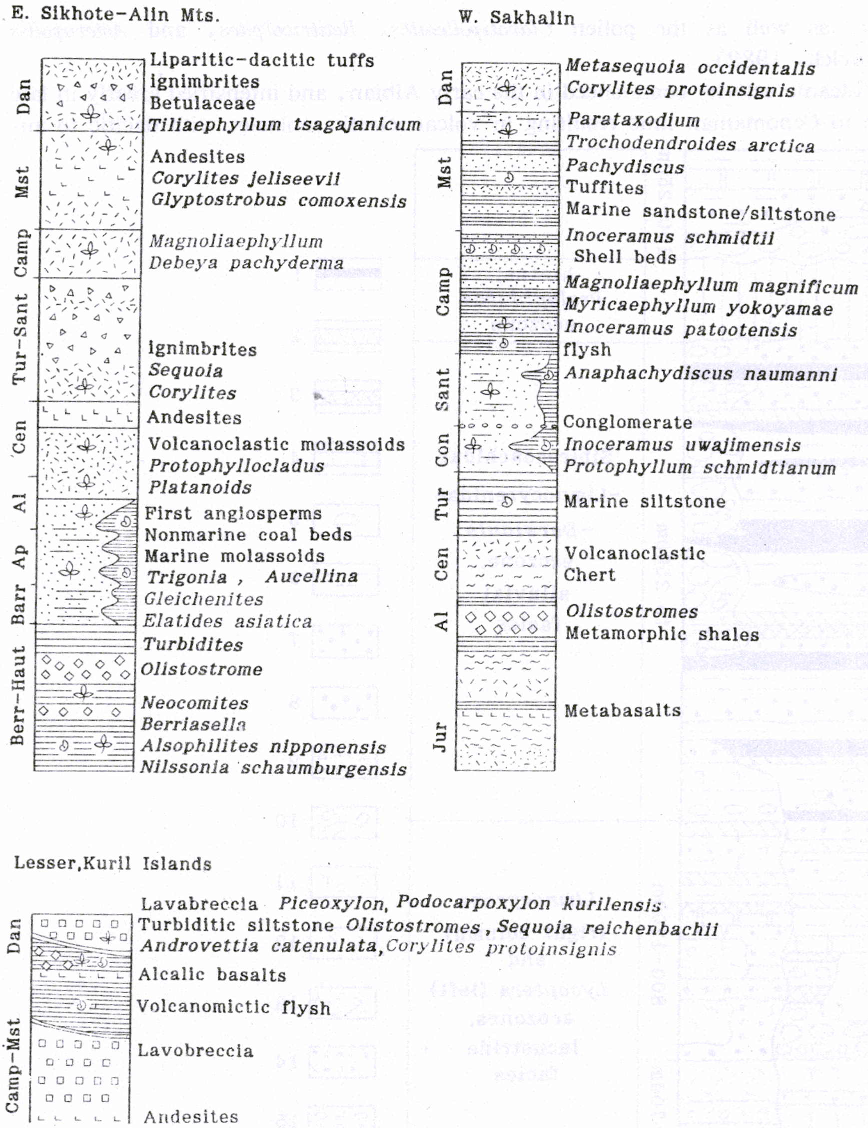

Figure 8. Three typical Far-Eastern Cretaceous sections of the continental margin volcanic belt, marginal sea, and island-arc with principal guide fossils (by V. A. Krassilov).

Bikin River basin contains abundant *in situ* remains of the bennettites *Cycadeoidea* and *Zamiophyllum*.

The next, and most impressive, stage of volcanic activity is represented by liparitic ignimbrites and tuffs up to 2000 m in thickness. Age assignments based on a few macrofossils of ferns, conifers (*Sequoia* and *Metasequoia*), and microphyllous angiosperms, are inconclusive, but do indicate a Turonian age. Large calderas formed during the Santonian to early Campanian (Mikhailov and Rybalko, 1988).

Andesitic volcanism prevailed in the Maastrichtian for which a large macrofossil and spore-pollen assemblage is available, the latter including *Wodehousia spinata* which, in the Danian ignimbritic deposits, is succeeded by *W. fimbriata* (Markevich, 1982). A similar succession of these species has been described from the Edmonton Formation in western Canada (Srivastava, 1969) and elsewhere.

In the Okhotsko-Chukotsk segment, nonmarine Neocomian molasses accumulated in the Momo-Zyrian and smaller basins along the margin of the Sea of Okhotsk. The Aptian to early Albian Kolymo-Chukotsk land was far more extensive, although it was periodically transgressed by shallow seas. In the Momo-Zyrian basin and the Omsukchan trough, the coal-bearing clastic and volcanoclastic deposits of this age contain the first angiosperm leaves (Kirichkova and Budantsev, 1967; Samylina, 1968).

Some age assignments based on macrofloras remain controversial. An Aptian age is substantiated by similarity of the lower Blairmore flora of western Canada (Bell, 1956). However, marine equivalents of lower Blairmore Group within the lowermost horizons of Fort St. John Group contain *Hastroplithes* ammonite fauna, which is no older than upper Albian.

Rising volcanic ranges of the Okhotsko-Chukotsk belt isolate the Kolyma region from shallow seas which extended in broad arcs from the Anadyr basin to the Penjin Bay in northern Kamchatka, and further south to Sakhalin where their deposits rest on Lower to mid-Cretaceous cherty volcanomictic shales and olistostromes. Volcanic activity continued from the uppermost Albian to Coniacian, and even later. Continental deposits of these ages are poorly dated withing the volcanic belt itself, but to the east, along Penjin Bay and northwestern Sakhalin, paralic deposits contain abundant plant macrofossils, the age assignments of which are substantiated by invertebrates in marine intercalations. The successive plant assemblage zones are: 1—*Cyathea sachalinensis-Protophyllum schmidtianum*, Coniacian; 2—*Araliaephyllum polevoi-Debeya tikhonovichii*, Santonian; 3—*Magnoliaephyllum magnificum-Myricaeophyllum yokoyamae*, early Campanian; 4—*Parataxodium-Trochodendroides arctica*, late Maastrichtian; 5—*Metaseguoia occidentalis-Corylites protoinsignis*, early Danian (Krassilov, 1979).

Terrestrial volcanism in western Sakhalin commenced at the Cretaceous-Tertiary boundary and the tuffaceous lower Danian deposits seem conformable upon the underlying upper Maastrichtian paralic sequence. However, an abrupt floristic turnover across the boundary suggests a concealed hiatus. In a recently discovered locality in the Lesser Kuril Islands containing marine invertebrates and terrestrial plants in turbiditic siltstones, both Late Cretaceous and early Palaeocene species, such as *Seguoia reichenbachii*, *Androvettia catenulata*, *Debeya pachyderma*, *Corylites protoinsignis*, *Viburniphyllum asperum*, occur in a single layer also containing planktonic foraminifera of the *Silicosigmolina-Haplophragmoides* assemblages indicating a lowermost Palaeocene age (Krassilov and others, 1988). Characteristic Maastrichtian spore-pollen morphotypes 'unica' and 'oculata' comprise approximately 11% of the total content, against the more abundant tricol(por)oids of Palaeogene aspect. The Cretaceous-Tertiary boundary turbidites, containing terrestrial fossils, were deposited on alkali basalts which intrude and overlie the Maastrichtian volcanomictic flysch. These basalts were associated with the emergence of a volcanic island arc, one of the minor Cretaceous-Tertiary boundary events of the western Pacific.

CORRELATION CRITERIA

In the Soviet Far East, distinctive plant macrofossil assemblages were obtained for each of the Cretaceous stages. It was then possible to construct a generalized temperature-curve based on percentages of thermophilous genera, angiosperm leaves with entire margin, and other criteria (Krassilov, 1973, 1975). Major climatic optima fall on the Berriasian, Aptian, Turonian, and Campanian stages, while comparatively less favourable conditions prevailed in the mid-Neocomian, Albian-early Cenomanian, and terminal Cretaceous (Fig. 8). This scheme was partly verified by subsequent floral studies in Transbaikalia and Crimea (Bugdaeva, 1984; Krassilov, 1984) and, with respect to Albian cooling, by Ca/Mg marine palaeotemperature analyses (Jasamanov, 1980). The climatic curve can be used as a correlation tool, especially for interfacies correlations, although its resolution remains poor.

Some apparent isochronous levels are defined by such bioevents as the cypridean expansion during the Berriasian, the advent of angiosperm pollen in the Barremian or latest Hauterivian, the mid-Turonian faunal turnover of aquatic and terrestrial vertebrate communities, and the palynological successions across the Cretaceous-Tertiary boundary. Hopefully, more such bioevent-levels might emerge during the course of future nonmarine Cretaceous studies.

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