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Coal-bearing deposits of the Soviet Far East

V. A. Krassilov
Institute of Biology and Pedology, Vladivostok 22, U.S.S.R.

ABSTRACT

Coal basins in the Soviet Far East were controlled by tectonic events and to a lesser degree by climate and vegetation. Most of the Early Cretaceous basins developed on the margins of cratonic massifs or on their fold-belt borders. Mid-Neocomian tectonism either reduced coal accumulation inherited from the Jurassic or formed new basins by downfaulting. This tectonism caused an eastward shift in coal deposition and the sites of coal accumulation were pushed farther eastward in the Late Cretaceous when a new tectonic pattern with a coastal volcanic belt–miogeosynclinal trough–island-arc system had emerged. Coal basins extended across the major phytoclimatic boundary at about 50°N while the plant material was supplied by different types of plant communities. However, the rain shadow from volcanic ranges restricted coal accumulation to the miogeosyncline trough where it was further reduced by the rise of the continental margin at the Cretaceous/Tertiary boundary.

INTRODUCTION

The Soviet Far East is the territory west of the Siberian platform, the eastern margin of which is marked by the Verkhojansk Ranges and the Aldan Uplands. Coal deposition in the Far East ranged from Devonian to Neogene, but all the minable coals are Mesozoic and Tertiary. There are about 1,000 coal sites; about one-third of them in the Cretaceous.

Coal basins (i.e., sedimentary basins that contain economically important coal deposits, sometimes separable into several coalfields) are scattered along the Pacific coast. They occur from Chukotka in the north to southern Primorye (Vladivostok area) in the south and spread inland as far as the fringe belts of the Siberian platform. This platform divides the Soviet Far East area from the extensive coal-producing areas of the Lena River basin, southern Yakutia, and Transbaikalia.

The following overview is based on my stratigraphical and paleofloristic studies in the Partisanskian, Rasdolninskian, Burejan, Zeja-Burejan, and western Sakhalinian basins (Krassilov, 1967, 1972, 1976, 1979) and on data borrowed from the literature. Structural setting of the coal basins has been considered in a number of papers, notably by Cherepovsky (1983, 1984), Matveev and others (1982), Pogrebnov (1976), Popov (1979), Sharudo and Timofeev (1976), Varnavsky and others (1982), and Vlasov and others (1979). Because the structural patterns of the Early and Late Cretaceous are entirely different, coal basins of these ages are described separately below.

EARLY CRETACEOUS BASINS

Long before a collage concept of Pacific margins was introduced into western geological thinking, Soviet Far Eastern geologists had considered their territory as a mosaic of cratonic "massifs" (see Krassilov, 1985, for references). The commonly recognized massifs from north to south are Chukotian (or Beringian), Kolymian, Omolonian, Okhotian, Burejan, and Khankian (Fig. 1). They were never conceived of as long-distance drifters but some degree of independent movement for them was envisioned before their final welding into what is now northeastern Asia. The suture zones are marked by extensive volcanism, ophiolitic rock, and nappe formation. In Late Jurassic and Early Cretaceous time, residual troughs in the suture zones were filled with the coal-bearing molassoid deposits and formed major coal basins. However, some coal basins are confined to the fault-bounded sag areas within the massifs or on their margins.

The Zyrianskian basin is located around the Zyrianka River, a left tributary of the Kolmya River. It extends 500 km northwest-southeast along the southwestern margin of the Kolymian massif. In early Neocomian time it was connected to geosynclinal seas in the lower reaches of the Kolyma, but after the

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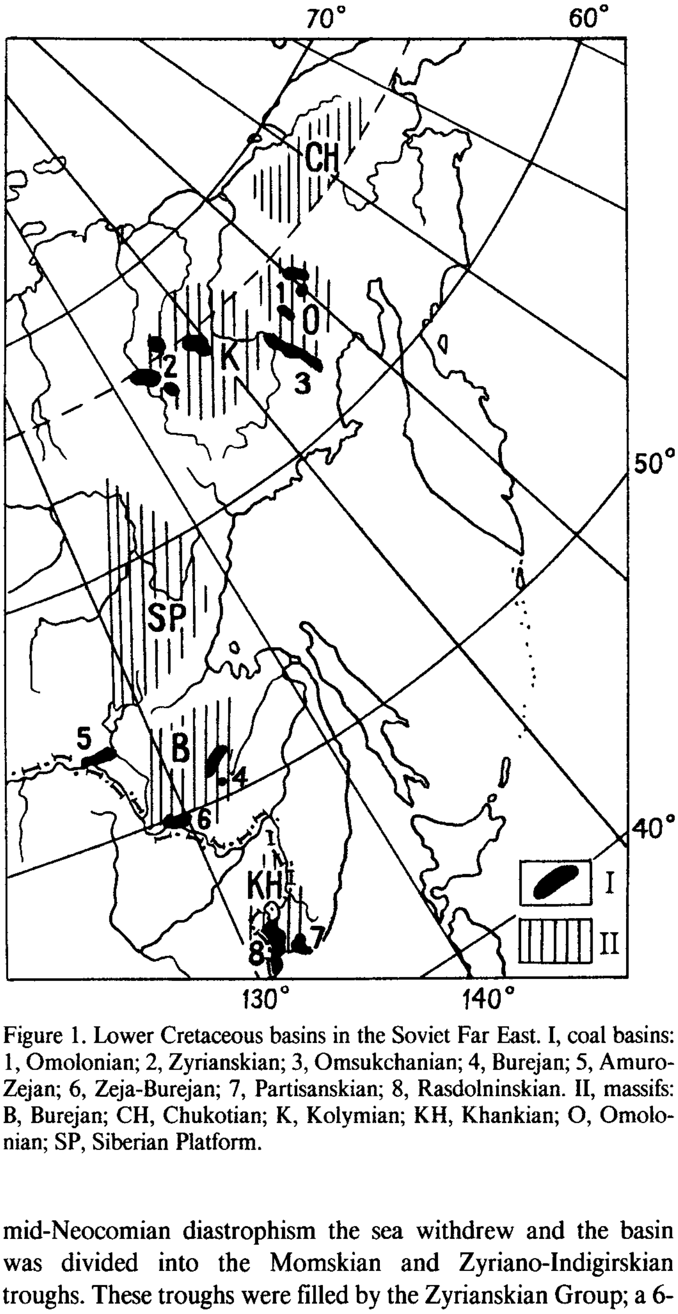

Figure 1. Lower Cretaceous basins in the Soviet Far East. I, coal basins: 1, Omolonian; 2, Zyrianskian; 3, Omsukchanian; 4, Burejan; 5, Amuro-Zejan; 6, Zeja-Burejan; 7, Partisanskian; 8, Rasdolninskian. II, massifs: B, Burejan; CH, Chukotian; K, Kolymian; KH, Khankian; O, Omolonian; SP, Siberian Platform.

mid-Neocomian diastrophism the sea withdrew and the basin was divided into the Momskian and Zyriano-Indigirskian troughs. These troughs were filled by the Zyrianskian Group; a 6- to 8-km-thick sequence of continental clastic sedimentary rocks containing about 108 coal seams that are mostly 2 to 5 m thick and have a maximum thickness of 6 m. Most minable coals are confined to the upper Buor-Kemussian Formation of early Albian age (Koporulin, 1979).

The Omsukchanian basin lies farther to the east and is a narrow trough about 15 km long, aligned almost north-south. It is sometimes considered a pericratonic downwarp of the Omolonian massif similar to the Zyrianskian basin (Popov, 1962), but differs from the latter in that it was cut across the lower Mesozoic basement folds in mid-Neocomian time and was filled with entirely nonmarine Aptian to lower Albian clastics and upper Albian to Upper Cretaceous volcanoclastics. The coal-bearing Omsukchanian Group, about 3,000 m thick, rests unconformably on marine Upper Jurassic and older rocks. It contains about 18 coal seams in the upper half of the section, correlative with the Buor-Kemussian Formation of the Zyrianskian basin.

The Omolonian basin consists of several intracratonic taphrogenic troughs that are supposedly of the same nature as the Omsukchanian trough but much shallower. The Lower Cretaceous clastic infilling is about 1 km thick and contains five coal seams.

In the southern Far East several discrete coal basins are confined to the pericratonic depressions of the Burejan and Khankian massifs. The Amuro-Zejan (or Upper Amurian) basin consists of two parallel troughs extending southwest-northeast between the Amur and Dep Rivers. The troughs were downfaulted and filled with coal-bearing sedimentary rocks in Late Jurassic time. The Neocomian part of the sequence, which accumulated after the troughs had merged into one broad depression, is about 1,000 m thick and contains comparatively thin coal seams.

The Zeja-Burejan basin is present in the lower reaches of the toponymal rivers that are tributaries of the Amur. This basin also consists of several graben-like depressions all striking northeast. However, the coal measures are mostly post-Hauterivian. The Hauterivian to lower Albian Poiarkovskian Formation, 500 to 800 m thick, is confined within the grabens and contains about 20 coal seams of brown and transitional coals. The Upper Cretaceous deposits are of wider areal extent and also contain a few brown coal seams.

The Burejan (or Bureyan) basin consists of one large and two lesser subbasins situated in the upper reaches of the Bureja River and along the Tyrma and Gerbikian Rivers. The main Upper Burejan subbasin is a symmetrical graben-like depression about 250 to 300 km long and 60 to 80 km wide, striking northeast. Nonmarine deposition commenced in early Late Jurassic time. The lowermost coal-bearing Talynjan Formation rests on marine Callovian deposits, which contain an ammonite fauna. In the basal Talynjan beds, I found limulids attesting to a gradual transition from marine to nonmarine environments (Krassilov, 1972). My stratigraphic and paleofloristic work suggests a hiatus between the Jurassic Talynjanian Formation and the overlying lowermost Cretaceous Urgalian Formation, though other authors have interpreted continuous sedimentation across the Jurassic/Cretaceous boundary (Vakhrameev and Doludenko, 1981). The Urgalian Formation contains 45 coal seams, of which 19 are minable. Seams are up to 10 m thick. Another hiatus is suspected between the Urgalian coarse clastics and the upper Neocomian to Albian that consists predominantly of fine-grained basinal facies with little coal.

The Partisanskian basin is in the South Primorye area east of Vladivostok. It is a fault-bounded depression covering an area of 14,500 km^2 northeast from the Sea of Japan along the Partisankaja River. It is sometimes considered an intrageosynclinal trough (Pogrebnov, 1976), but the geosynclinal phase actually ended with deposition of flysch and olistostromes in the

Berriasian and Valanginian. The main body of coal-bearing paralic and nonmarine clastics accumulated after the Hauterivian restructuring. It was extensively faulted and intruded by magmatic rocks during formation of the overlying Late Cretaceous volcanic belt as described later in the paper. Two sedimentary cycles up to 600 m thick are recognized in the coal-bearing sequence. Each cycle contains about 20 coal seams, which range from 0.1 to 12 m in thickness (average of 2 m). All of the peat accumulated on a coastal plain with marine influence from the north. Sparse shells of brackish-water bivalves are present throughout the coal-bearing section. Overlying the section are *Trigonia* beds deposited during a brief incursion of the sea that transgressed coastal bogs in the early Albian. The succeeding lagoonal and lacustrine facies that filled the residual basin contain only a few thin coal lenses. They are overlain by tuffaceous sandstones and reddish shales deposited in association with the initial volcanic activity over the Sikhote-Alin Ranges.

Though less than 100 km to the west, and defined by the same system of southwest-northeast striking faults, the Rasdolnenskian basin differs from the Partisanskian basin in both structural setting and depositional environments. The basin extends from Amur Bay along the Rasdolnaja River to the Khanka Lake and over the national border into China. The pattern of coalfields conform to the horst and graben structure superimposed on the Khankian massif. Cretaceous sedimentation commenced after Hauterivian tectonism, and the late Neocomian to Aptian nonmarine coal-bearing deposits rest unconformably on mid-Jurassic and older strata. Albian sandstones and shales are tuffaceous and are similar to those of the Partisanskian basin and the two basins may have been part of the same depositional system. In the central graben the Cretaceous sedimentary rocks attain a maximum thickness of 1,300 m but contain little coal, whereas in the thinner sequences at the margins there are up to 30 coal seams. Seams are up to 17 m thick and nine of them are minable.

In conclusion, mid-Neocomian tectonism affected all the Far Eastern sedimentary basins, either reducing coal accumulation, which commenced in the Late Jurassic, or defining new downfaulted depressions that were superimposed on cratonic massifs or their fold-belt borders. The resultant eastward shift of the coal-depositing environments continued in the Late Cretaceous.

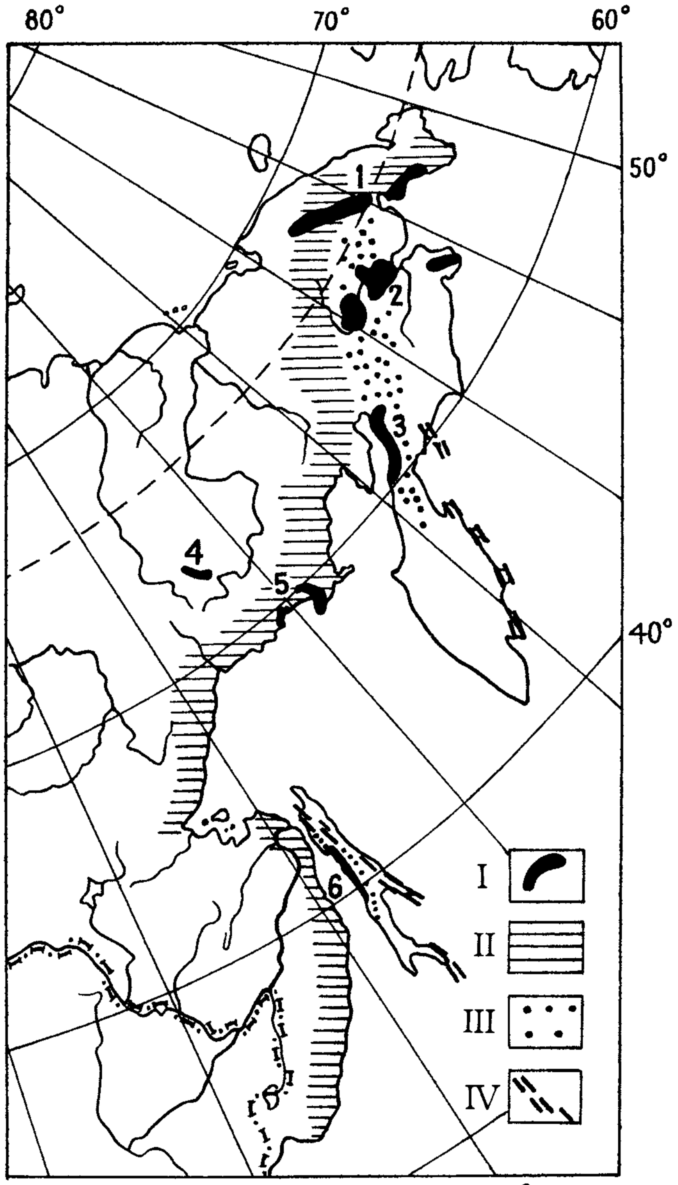

Figure 2. Upper Cretaceous basins in the Soviet Far East. I, Coal basins: 1, Chaun-Chukotskian; 2, Anadyrian; 3, Penjinskian; 4, Arkagalian; 5, Okhotskian; 6, western Sakhalinian. II, volcanic belt; III, miogeosynclinal belt; IV, island-arc complex.

LATE CRETACEOUS BASINS

After the final consolidation of the mosaic structure of cratonic massifs, the Pacific Plate encountered a huge mass of continental crust. A buffer structure, of corresponding dimensions, was formed. Beginning in the Albian, a new pattern of depositional belts emerged along the newly formed continental margin (Fig. 2). A terrestrial volcanic belt extended along the coast from Chukotka to Primorye and farther south to Korea and China. To the east it bordered on a miogeosynclinal trough filled with marine, paralic, and nonmarine clastic and subordinate volcanoclastic deposits. It is traceable from the Anadyr River in the north to Penjin Ray to western Sakhalin. Still farther east, the obducted fragments of the island arc volcano-sedimentary complex form marginal belts of eastern Kamchatka, eastern Sakhalin, and the Lesser Kuril Islands.

Within the volcanic belt there are several minor coal basins, such as the Chaun-Chukotskian basin, extending from the Bering Sea to the Chaun Bay of the Chukchee Sea or the Okhotskian basin near Magadan. The coal measures of late Albian to Turonian age alternate with volcanic and volcanoclastic rocks. They contain a maximum of 15 coal seams, a few of which are minable.

Seams are up to 5 m thick but most are much thinner. The Arkagalian basin is exceptional in that it is situated landward of the volcanic belt, in the outer perivolcanic zone. It consists of two depressions extending southeast-northwest between the upper reaches of Kolyma and Indigirka. The basin is superimposed on the early Mesozoic Yano-Kolymian fold belt and is filled with about 1,000 m of Upper Cretaceous conglomerates, finer clastics, and tuffs (Koporulin and Eremeev, 1983). There are 10 to 12 coal seams up to 20 m thick. The age of the coal measures was a matter of long dispute but such pollen forms as *Aquilapollenites* and *Trudopollis* suggest an age no older than late Turonian.

In contrast, coals of the miogeosynclinal trough east of the volcanic belt can be dated more precisely because there are several marine intercalations and because the strata pass laterally into marine facies rich in ammonites and inoceramoids. The Anadyrian basin, along the Anadyr River, provides a long record of coal accumulation from the Cenomanian to the Neogene. The Upper Cretaceous part of the section is no less than 2,000 m thick. In the Beringian, Pekulnejan, and Ugolnaja coalfields, most coals are confined in the Koriakian and Rarytkian Formations of Maastrichtian age. In the Penjinskian basin, along the eastern coast of Penjin Bay in northern Kamchatka, the coal-bearing sequence is bracketed between the precisely dated Cenomanian and Maastrichtian but the major part of it, containing 26 coal seams, is equivalent to late Turonian to early Coniacian shallow-marine deposits (German, 1984).

In western Sakhalin, nonmarine Upper Cretaceous deposits crop out along the Tatar Strait in the northern part of the island. Marine intercalations increase in thickness southward and the entire section is marine south of 48°N. Most coal seams are confined to the Coniacian to Santonian Arkovskian Formation, which is 2,000 m thick. There are about 20 seams that are between 1 and 2 m thick; 15 of them are minable. A few thin coal seams are present in the overlying Campanian and Maastrichtian paralic deposits. Coals of this age are also known on the eastern coast in what might have been an interarc basin, but the depositional environments of these coals are still to be studied.

CLIMATES, VEGETATION, AND COALS

In the Soviet Far East, two rather well-defined Cretaceous phytoclimatic zones are recognized and are separated at about 50°N latitude. Much research has been done on several hundred fossil plant localities in order to understand the vegetation and climate of this area during the Cretaceous. Deciduous trees with *Phoenicopsis*-type dwarf shoots dominated mesic forests of the northern "temperate" zone while the locally abundant species of *Czekanowskia, Pseudotorellia,* and *Pityophyllum* might have prevailed in some pioneer, seral, or edaphic communities. A few cutinites in the Burejan basin consist of the cuticles of either *Czekanowskia* or *Pseudotorellia* and *Pityophyllum.* These genera of the czekanowskialeans, ginkgoaleans, and pinaceous conifers, respectively, might have contributed most of the peat material in the northern zone.

In the southern "subtropical" zone, shrubby cycadophyte and brachyphyllous conifer-gnetophyte communities seem to have been the most widespread vegetation types. Prominent among this flora is the barrel-like *Cycadeoidea,* which is completely absent in the north. No cutinites with recognizable cuticles are known. In the coaly shales of coal seam splits, a taxodiaceous conifer *Elatides* is most abundant in the Partisanskian basin. In the epicratonic Rasdolninskian basin, similar splits contain either the single bennettite species *Nilssoniopteris rhitidorachis* or a multispecies assemblage dominated by the cycadophyte genus *Ctenis* in association with various conifers. In the northern part of the basin there are peculiar resinitic coals consisting of the rodlike resin bodies, presumably of some cycadophytalean or gnetalean plants. This coal type is thought to indicate stable peat-accumulating environments (Krapiventseva and others, 1979). The pollen genera *Classopollis* and *Eucommiidites* are particularly abundant in some Rasdolinskian coals. Their taxonomic position is uncertain, but in the author's opinion they may belong to gnetophytes.

Most of the Late Cretaceous coals formed in the temperate zone or warm-temperate ecotone in paralic environments. The coal-producing vegetation consisted mostly of fern marshes, with *Nilssonia* bordering on *Sequoia* or *Parataxodium* forests that had various angiosperms in the understory. A few angiosperms penetrated the fern-*Nilssonia* marshes, which maintained their Mesozoic aspect up to the end of the Cretaceous.

Despite the obvious differences in the peat-bog plant communities, the humic coals of all the Far Eastern basins are petrographically similar. They are mostly clarains with collinite or, less commonly, telinite macerals (Krapiventseva and others, 1979; see McCabe, 1984, for updated maceral classification). Durains are prominent in the Rasdolninskian basin only, whereas an appreciable amount of fusinite is present in the Partisanskian and Sakhalinian coals, suggesting, therefore, paralic conditions rather than climatic conditions of periodic dryness as conventionally assumed. Detailed facies analysis is beyond the scope of this paper, but in most cases the coals seem to rest on rooted siltstones of alluvial fans, whereas the overlying sediments are either similar siltstones with leaf fossils or channel sandstones with coarse plant debris. The coals usually have a high ash content.

In most taphrogenic basins the center of the graben was predominantly filled with lacustrine or lagoonal facies while coal-producing swamps developed at the margins on alluvial fans. Fine-grained facies contain numerous thin coals but minable coals are mostly associated with coarse-grained, poorly sorted clastic supposedly deposited by rapid but intermittent sedimentation. In both the Partisanskian and Rasdolnenskian basins, coal-bearing molassoid facies occur along the faulted margins in piedmont areas (Fig. 3). Downfaulting of these marginal areas may have been spasmodic with periodically associated sedimentation. Such coal-producing environments were created by mid-Neocomian tectonism in several but not all basins. Where subsidence was more uniform, as in the Alchanskian basin to the north (Fig. 3), the extent of coal accumulation was limited. Differences between the Partisanskian and Rasdolnenskian basins

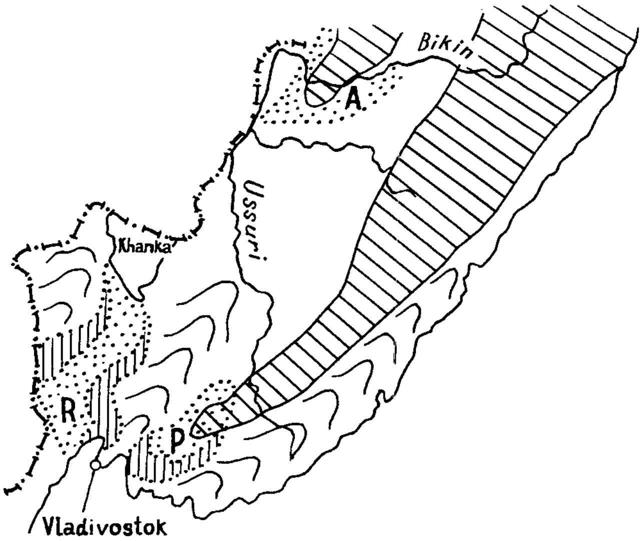

Figure 3. Coal basins north of Vladivostok. A, Alchanskian basin; P, Partisanskian basin; R, Rasdolnenskian basin; inclined shading, Sikhote Alin Range; vertical shading, molassoid facies, stipples, lacustrine/lagoonal facies.

(less numerous coal seams, more durainitic coals with resinite interlayers in the latter) may be due to climatic and vegetational factors, particularly more open vegetation and more prominent cycadophyte "chaparral" in the west. Generally this type of vegetation was widespread in the warmer Cretaceous climates characterized by short periods of summer droughts. Coals occur in this zone even in the Angola basin, but on a somewhat reduced scale.

Climatic differences across 50°N latitude may have been comparable to those encountered at the present across 36°N latitude in Japan. This gives some idea as to how much warmer the Cretaceous was compared to the present. As for humidity, one can only deduce that in the Far East it was sufficient to sustain extensive swamps in both phytoclimatic zones. However, from the late Albian to the end of the Cretaceous peat accumulation was drastically reduced, especially in the south where red-bed facies appeared for the first time. These sedimentary events might have been caused by climatic changes associated with a rain-shadow effect of the rising volcanic ranges and, on a reduced scale, in the intermontane depressions within the volcanic belt itself. These coals are often underlain by reworked and rooted tuffaceous sediments and are overlain by tuffs. Peat growth was usually terminated by heavy ash falls that buried the swamps, preventing accumulation of thick coal seams.

There were only two short intervals when coal accumulation ceased almost everywhere: first in the late Albian–early Cenomanian, and then at the Cretaceous/Tertiary boundary. The causes for this could be regressions, shifts of climatic zones (for which there is a lot of independent evidence), and, above all, vegetational changes. It is well known that major vegetational changes took place within these particular intervals. Accordingly, coal accumulation might have resumed in Paleogene time in response to the steadily ameliorating climatic conditions and increased vegetational productivity. However, in the Far East this might have happened somewhat later than in western North America, where coals are sometimes used as the Cretaceous/Paleogene boundary markers. Alternatively, the American sections may be more condensed. In any event, coal accumulations seem sensitive to major environmental crises.

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