

# Maastrichtian–Paleocene Floras of Northeastern Russia and North Alaska and Floral Changes at the Cretaceous–Paleogene Boundary

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**Abstract**—Taphofloras of the Koryak Upland and the Sagwon Locality of North Alaska are described in terms of their taxonomic composition, stratigraphic ranges, and comparison with coeval floras of Northeastern Russia and Alaska. Causes and amplitude of changes in Arctic floras across the Cretaceous–Paleogene boundary are considered. In its aspect and taxonomic composition, the Late Maastrichtian flora of the Amaam Lagoon (the Koryak Upland) is very close to the early Paleocene Sagwon flora of North Alaska. This is inconsistent with a hypothesis of the global ecological crisis at the Cretaceous–Paleogene boundary. Development of floras was controlled by long-term climatic fluctuations and by evolution and migration of plants.

**Key words:** Cretaceous–Paleogene boundary, paleobotany, Northeastern Russia, North America.

## INTRODUCTION

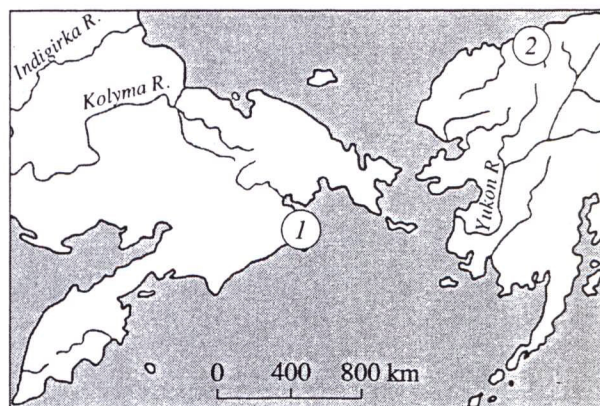
The Cretaceous–Paleogene boundary rightfully attracts attention of geologists and paleontologists, as it marks very dramatic events in history of the Earth's biota. Subjects of vivid discussions and debates are synchronism, stages, and magnitude of extinctions in various biotic groups in different regions of the globe and causes of this ecological crisis. For several decades the crisis was thought to have been caused predominantly by impact events (Alvarez *et al.*, 1980). The impact theory does not elucidate however a number of problems concerning the biota transit across this boundary. Meteoritic impacts were likely one of the factors that distorted ecological balance. It should be noted that principal evidences of catastrophic flora extinction in the terminal Cretaceous are known from mid-latitude North America (Spicer, 1989; Spicer *et al.*, 1994).

In this work, changes in Arctic floras at the Late Cretaceous–early Paleogene boundary time are considered based on floras known from below and above the boundary, i.e., on the late Maastrichtian flora of the Koryak Upland, Northeastern Russia, and on the early Paleocene Sagwon flora of North Alaska (Fig. 1).

## THE KORYAK FLORA OF NORTHEASTERN RUSSIA

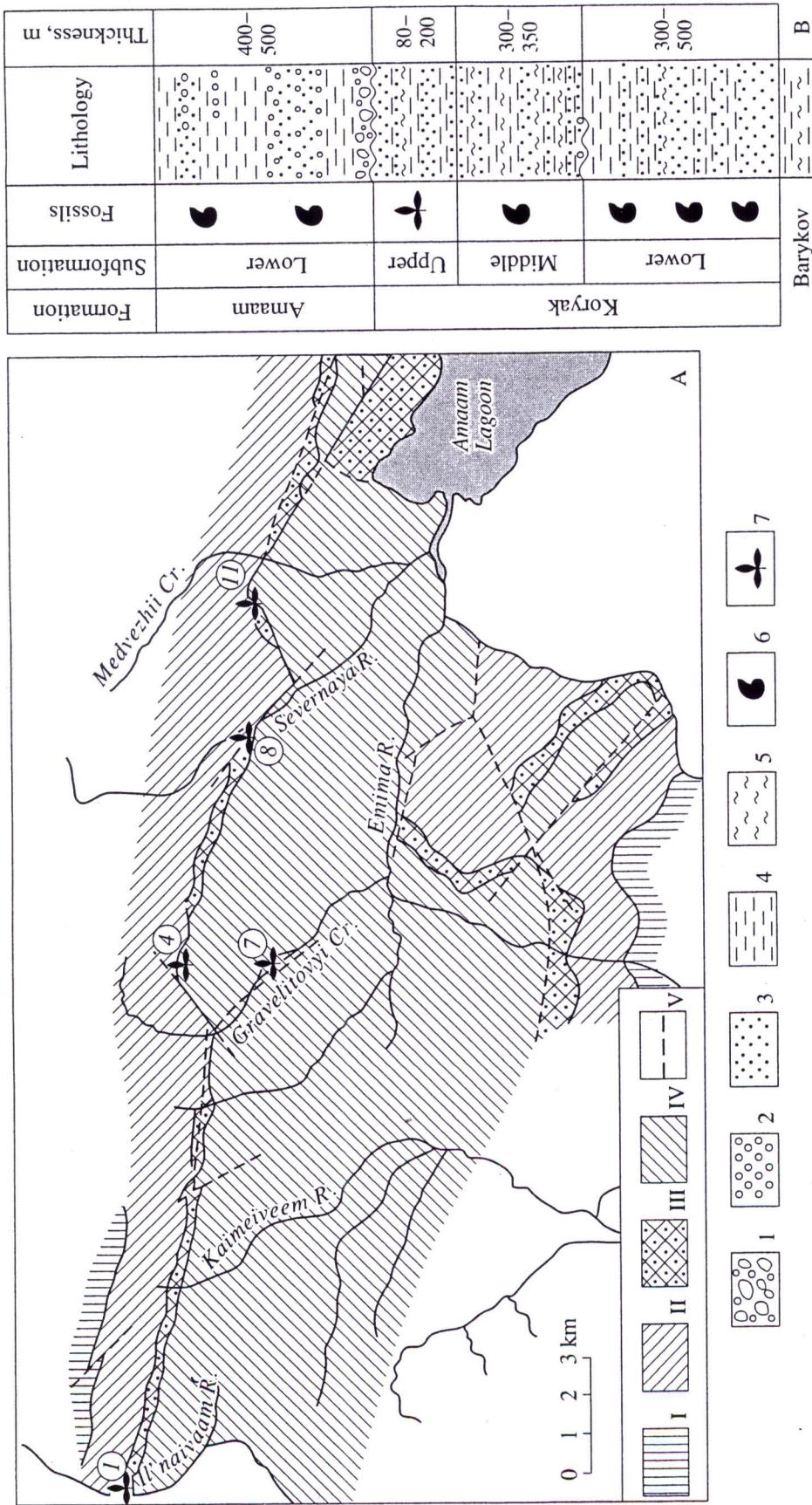
Continental and marine Upper Cretaceous–Lower Paleogene deposits are widespread in the Koryak Upland and further northward in the Anadyr' River

basin and the Pekul'nei Ridge. Sequences in the Amaam Lagoon area, which are composed of alternating marine beds with mollusks and continental flora-bearing deposits, are of particular stratigraphic significance. The Koryak taphoflora is known from the upper Koryak Formation in the Amaam Lagoon area and the Emima–Il'naivaam interfluve (Fig. 2). Plant fossils first collected here by Volobueva and Terekhova (1974) were studied by Vasilevskaya and Abramova (1974) and later on by Golovneva (1994). The collection of fossils is stored under no. 1199 at the Botanical Institute of Russian Academy of Sciences (St. Petersburg). Plant remains collected by Golovneva and myself in the



**Fig. 1.** Localities of the late Maastrichtian Koryak (1) and the early Paleocene Sagwon floras (2).





**Fig. 2.** Schematic geological map (A) of the Emima-II' naivaam Interfluve, the Aamaam Lagoon area (after Volobueva and Terekhova with additions), and lithostratigraphic column (B): (I) Barykov Formation, (II) lower and middle subformations of the Koryak Formation, (III) upper subformation of the Koryak Formation, (IV) Amaam Formation, (V) fault, encircled figures denote fossil flora localities; (1) conglomerate, (2) gritstone, (3) sandstone, (4) clay siltstone, (5) tuff, (6) fossil fauna, (7) fossil flora.

Taxonomic composition of the Koryak (Northeastern Russia) and Sagwon (North Alaska) taphofloras

Species	Koryak taphoflora	Sagwon taphoflora	Species	Koryak taphoflora	Sagwon taphoflora
<i>Equisetum arcticum</i> Heer	+	+	<i>Trochodendroides</i> ex gr. <i>vassilenkoi</i> Iljinskaya et Romanova		+
<i>Onoclea hesperia</i> R.W. Brown	+	+	<i>Trochodendroides</i> sp.	+	
<i>Coniopteris tschuktschorum</i> (Krysht.) Samylina	+		<i>Nyssidium arcticum</i> (Heer) Iljinskaja	+	+
<i>Ginkgo</i> ex gr. <i>adiantoides</i> (Ung.) Heer	+		" <i>Cocculus</i> " sp.		+
<i>Pseudolarix arctica</i> Krysht.	+		<i>Platimelis platanoides</i> Golovn.	+	
<i>Pityophyllum</i> sp.	+		<i>Rarytkinia terechovae</i> Vassilevsk. et Golovn.	+	+
<i>Sequoia</i> sp.	+		" <i>Platanus</i> " <i>raynoldsii</i> Newberry	+	
<i>Metasequoia occidentalis</i> (Newb.) Chaney	+	+	" <i>Platanus</i> " sp.		+
<i>Metasequoia</i> sp. (cones)	+	+	<i>Menispermites</i> (?) sp.		+
<i>Glyptostrobus nordenskioldii</i> (Heer) R.W. Brown	+		<i>Corylites beringianus</i> (Krysht.) Herman	+	+
<i>Mesocyparis beringiana</i> (Golovn.) McIver et Aulenback	+		" <i>Rubus</i> " sp.	+	+
<i>Mesocyparis</i> (?) sp.		+	<i>Celastrinites septentrionalis</i> (Krysht.) Golovn.	+	
<i>Elatocladus talensis</i> Golovn.	+		<i>Castaliites inordinatus</i> Hollick		+
<i>Haemanthophyllum cordatum</i> Golovn.	+		<i>Quereuxia angulata</i> (Newberry) Kryshtofovich		+
<i>Haemanthophyllum</i> ex gr. <i>kamtschaticum</i> Budantsev		+	<i>Zizyphus</i> sp.	+	
<i>Phragmites alaskana</i> Heer		+	<i>Viburnum rarytkense</i> Budantsev		+
<i>Phragmites</i> sp.		+	<i>Cissites pekulneense</i> (Philipp.) Moiseeva	+	
<i>Sparganiophyllum</i> sp.	+		<i>Cissites hermanii</i> Moiseeva	+	
<i>Trochodendroides arctica</i> (Heer) Berry		+	<i>Liriophyllum</i> cf. <i>aeternum</i> Golovn.	+	
<i>Trochodendroides bidentata</i> Vassilevsk. et Golovn.	+		<i>Carpolithes biloculatus</i> Golovn.	+	
<i>Trochodendroides emimensis</i> Golovn.	+		<i>Dicotylophyllum</i> sp. 1	+	
<i>Trochodendroides lamutensis</i> Golovn.	+	+	<i>Dicotylophyllum</i> sp. 2		+

Emima basin during summer of 1987 and by myself in the Il'naivaam basin in 1990 are stored at the Geological Institute of Russian Academy of Sciences (Moscow), collection no. 4843.

In the Emima basin, the Koryak Formation above the Barykov Formation is divided into three subformations (Herman, 1999). The lower and middle subformations are composed of terrigenous–volcanogenic deposits enclosing a diverse molluscan fauna of Campanian–early Maastrichtian age (Fig. 2). The upper subformation of continental deposits bearing abundant plant remains.

In the lower Koryak Subformation, prevailing volcanomictic to polymictic sandstones are intercalated with subordinate beds of siltstones, tuffs, and tuffstones of acidic composition. Based on abundant ammonites and inocerams found in the unit, it attributed to the lower half of the upper Campanian (Volobueva and Terekhova, 1974). The subformation is 300–500 m thick.

The middle Koryak Subformation (300–350 m) is mainly composed of acidic tuffs, tuffites, tuffstones, and tuffaceous siltstones. Rare *Inoceramus* ex gr. *balticus* Boehm., *Acila* sp. indet., "*Parallelodon*" *sachalin-*



*ensis* Schmidt, *Thracia* sp., *Gonomys* sp. indet., *Hypophylloceras* sp. indet., *Gaudryceras* sp., *Canadoceras newberryanum* (Meck), *C. kossmati* Mat., and *C. aff. multicosatum* Mat. indicate that this subformation corresponds in range to the terminal upper Campanian–lowermost Maastrichtian (Volobueva and Terekhova, 1974; Volobueva and Krasnyi, 1979). In addition, the early Maastrichtian *Patagiosites alaskensis* Jones and *Inoceramus pilvoensis* Sok. (identified by V.P. Pokhialainen in 1990) were found in the unit (Herman, 1993).

The upper Koryak Subformation bearing plant remains conformably overlies the middle unit. It is composed mainly of sandstones and tuffstones alternating with siltstones, carbonaceous siltstones, rare conglomerate interbeds, and coal lenses. The rocks are 80 to 200 m in total.

The Amaam Formation of conglomerates, gritstones, sandstones, and siltstones rests on a slightly eroded surface of the Koryak Formation. The lower part of the Amaam Formation yields endemic mollusks *Glycymeris amaamensis* Volobueva, *Crassatella* cf. *unioidea* (Stanton), *Herella* sp., *Turitella* aff. *pachecoensis* Stanton, the Maastrichtian–Paleocene foraminifers (identified by M.Ya. Serova, see in Volobueva and Terekhova, 1974), and some malacostracans and columnals of the Late Cretaceous crinoid *Wielsenicrinus* (Dundo *et al.*, 1974). “*Parallelodon*” sp. and remains of inoceramid prismatic layers were detected in the lower part of the Chukotka Formation (an equivalent of the Amaam Formation) in the Al’katvaam River valley. These fossils indicate the Maastrichtian age of lowermost beds in the Amaam Formation. Thus, the flora-bearing part of the Koryak Formation is within the early–late Maastrichtian interval (basal portion excluded) or in the late Maastrichtian only (Herman, 1999).

We studied both collections of fossil plants sampled from five localities of the upper Koryak Subformation along the northern edge of the Amaam depression (Fig. 2). Plant remains occur in lower and upper parts of the subformation, and sampled exposures are spaced apart for about 25 km at maximum. Because of persistent taxonomic composition throughout the subformation section, plant remains are considered as representing a single taphoflora. The Koryak taphoflora includes 31 species (table) of Equisetites, ferns, ginkgophytes, conifers, and angiosperms.

Rare *Equisetum arcticum* found in the localities is the only taxon of Equisetites. Innumerable ferns are represented by sparse *Onoclea hesperia*, a characteristic component of the Koryak flora, and by fragments of *Coniopteris tschuktschorum*. Sporadic species *Ginkgo* ex gr. *adiantoides* represent ginkgophytes.

Conifers and angiosperms are dominants of a very diverse composition. Prevailing among conifers are species *Metasequoia occidentalis* and *Glyptostrobus nordenskioldii* of Taxodiaceae and *Mesocyparis beringiana* cupressaceous. They occur in association with

*Metasequoia* cones and sparse impressions of morphologically peculiar shoots (lacking cuticle) and broad flattened *Sequoia* leaves. Pinaceae are represented by rare impressions of long *Pityophyllum* needles and fruit scales of *Pseudolarix arctica*. *Elatocladus talensis* having shoots with dense linear large leaves arranged spirally was identified among conifers of unclear systematic position.

Angiosperms, primarily arboreal dicotyledons are also quite abundant and diverse, being dominated by *Corylites beringianus*, “*Platanus*” *raynoldsii*, and *Trochodendroides*. The last genus is represented by four species: *Trochodendroides bidentata* with large crenate and bicrenate leaves, less frequent *T. lamutensis* and *T. emimemsis*, and by leaves with pinnate venation of *Trochodendroides* sp., which may correspond to first leaves of shoots. Fruits and leaves of *Nyssidium arcticum* occur associated.

Characteristic but infrequently dominant species of the Koryak flora are *Cissites pekulneense*, *C. hermanii*, *Liriophyllum* cf. *aeternum*, *Platimelis platanoides*, *Celastrinites septentrionalis*, and *Rarytkinia terekhova*. They are typical the Koryak flora and the Rarytkin plant assemblage from the Anadyr’ River basin but have no affinity to other floras of the Northern Hemisphere. The flora under consideration also includes single leaf imprints of “*Rubus*” sp., *Zizyphus* sp., *Dicotyllophyllum* sp. 1, and small fruits of *Carpolithes biloculatus*. Monocots are represented by semiaquatic *Haemanthophyllum cordatum* and by oblong linear leaves of presumably aquatic herb *Sparganiophyllum* sp.

The Koryak flora has a little in common with younger Cretaceous floras of the Ugol’naya Bay and Rarytkin Range. The Campanian Barykov flora of the Ugol’naya Bay (Herman, 1999) is dominated by “*Quercus*” *tchucotica*, *Macclintockia ochotica*, *Macclintockia beringiana*, and by cycadophytes. *Paraprotophyllum ignatianum* is most abundant among Platanaceae. These taxa are absent in the Koryak flora. Taxa of a wide stratigraphic range, such as *Equisetum arcticum*, *Ginkgo* ex gr. *adiantoides*, *Metasequoia occidentalis*, *Glyptostrobus nordenskioldii*, and *Nyssidium arcticum*, represent species in common for the Koryak flora and early Maastrichtian Gornaya Rechka assemblage of the Anadyr’ basin (Golovneva, 1994). *Mesocyparis beringiana*, *Corylites beringianus*, and *Celastrinites septentrionalis* are scarce in the above assemblage, being abundant in the Koryak flora.

In its general aspect, the Koryak flora is similar to the Danian–early Paleocene floras of Northeastern Russia, especially to the Rarytkin flora of the Anadyr’ basin (Golovneva, 1994). In these floras, Equisetales, ferns, and ginkgophytes are relatively scarce and conifers are less abundant than angiosperms plants and include dominant *Metasequoia occidentalis*, *Mesocyparis beringiana*, and *Glyptostrobus nordenskioldii*. The Koryak and comparable floras of northeastern Russia contain *Elatocladus talensis*. Taxa prevailing among



angiosperms are *Corylites beringianus*, several *Trochodendroides* species (first of all, *T. bidentata*), and "*Platanus*" *raynoldsii*. *Cissites pekulneense*, *Platimelis platanooides*, *Celastrinites septentrionalis*, *Rarytkinia terechovae*, *Liriophyllum aeternum*, and *Haemanthophyllum cordatum* are species in common.

The Koryak flora also shows a close similarity with other Early Paleogene floras of the Russian Far East. Like the Danian Boshnyakovo assemblage of Sakhalin (Krassilov, 1979), it is dominated by leaves of *Corylites* and by genera *Metasequoia* and *Glyptostrobus* of *Taxodiaceae*, all associated with *Trochodendroides*, *Celastrinites*, and *Liriophyllum*. Abundant *Trochodendroides* leaves, *Onoclea*, *Ginkgo*, *Metasequoia*, *Mesocyparis*, and "*Platanus*" *raynoldsii* remains represent taxa in common for the Koryak flora and Danian Tsagayan assemblage from the Amur area (Krassilov, 1976; Akhmet'ev *et al.*, 2002). Predominance of *Metasequoia*, *Corylites*, and *Trochodendroides*, as well as presence of *Onoclea*, *Coniopteris*, *Equisetum*, *Ginkgo*, and Cupressaceae are characteristic of both the Malaya Mikhailovka flora from lower courses of Amur River (Akhmet'ev and Golovneva, 1998) and the Koryak flora.

#### THE SAGWON FLORA OF NORTH ALASKA

Compact coarse-grained sandstones and conglomerates of the Upper Cretaceous–lower Paleocene Prince Creek Formation and of the Paleogene Sagavanirktok Formation constitute the topmost beds of hills from mile 352 to mile 354 of the Dalton highway. The rocks are best exposed in the Sagavanirktok River scarp near the Sagwon Locality, and their outcrops are traceable downstream for a distance of 8 to 10 km (Fig. 3). The younger, upper Paleocene–Eocene non-marine deposits of the Sagavanirktok Formation are well exposed in the Franklin Bluff area, the eastern bank of the Sagavanirktok River, from mile 381 to mile 395 of the Dalton highway (Mull and Harris, 1989).

Abundant plant fossils were collected from the upper part of the Prince Creek Formation (the left bank of the Sagavanirktok River near the Sagwon Locality, Fig. 3) by J.A. Wolfe in 1951 (the unnumbered collection of USGS is stored in the Smithsonian Institute, Washington, USA). Spicer collected here plant remains in 1987 and Spicer, Ahlberg, and myself in 2001 (collections of USGS 11481, 87RAS, and 01RAS are in the Open University, Milton Keynes, Great Britain). In river scarps confined to axial zone and to northern and southern wings of the Ivishak anticline, there are exposed terrigenous and coal-bearing deposits of the upper Prince Creek Formation of the Late Cretaceous–early Paleocene age, as well as sandstones and conglomerates of the basal Sagwon Member of the Sagavanirktok Formation of the late Paleocene–Miocene age (Mull and Harris, 1989; Mull *et al.*, 2003).

In above areas, the upper part of the Prince Creek Formation is composed of alternating conglomerates, poorly cemented sandstones, siltstones, carbonaceous shales, and coals, the latter of autochthonous (carbonized wood) and, probably, of allochthonous types. Three coal layers reaching 7 m thickness (the upper layer) are well traceable in all exposures being the marker horizons. Plant fossils were found mainly in the siltstones, carbonaceous and clayey shales, and in siderite concretions, hosting the best-preserved remains. The flora-bearing beds of the Sagwon Locality are 100 to 115 m thick in general.

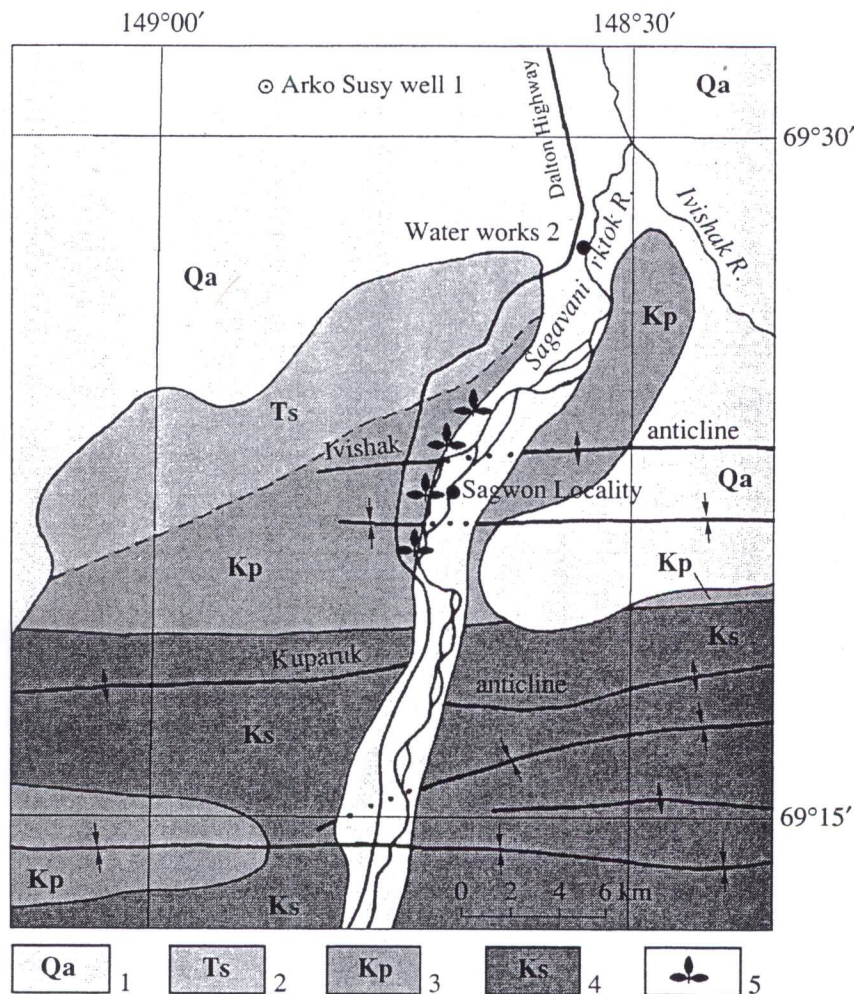
Basal 25- to 30-m-thick beds of the Sagavanirktok Formation are represented by light colored and whitish, poorly cemented quartz sandstones white at the weathered surface, and by sands, conglomerates, and gritstones. The rocks are exposed in river scarps downstream from the Sagwon Locality (Mull and Harris, 1989; Mull *et al.*, 2003). Their lower unexposed contact appears to be sharp, corresponding to a certain stratigraphic unconformity (Mull *et al.*, 2003). The upper, poorly exposed part of the Sagwon Member is composed of poorly lithified clayey and coaly deposits. The overall thickness of the Sagwon Member of the Sagavanirktok Formation is up to 900 m.

Flora-bearing coaliferous deposits of the Sagwon Locality were previously attributed to the lower Sagavanirktok Formation (the Sagwon Member), and the Cretaceous–Paleogene boundary was positioned within them (Spicer *et al.*, 1994). Later on it was proposed to distinguish this boundary between the Prince Creek and Sagavanirktok formations above the coal-bearing unit and at the base of well traceable whitish sandstones, conglomerates, and gritstones, because that unit is similar in lithology to underlying rocks rather than to overlying strata (Mull *et al.*, 2003).

Flora-bearing deposits of the upper Prince Creek Formation were dated back to the early Paleocene based on palynological data (Frederiksen *et al.*, 1996; Mull *et al.*, 2003). The oldest, coal-bearing deposits of the Sagwon Locality (sections B1 and B2), contain several pollen taxa typical of the Paleocene along with characteristic Late Cretaceous–Early Paleogene forms (Frederiksen *et al.*, 1996). As stated in the mentioned work, prevalence of *Triporopollenites mullensis* indicates the Paleocene or, more likely, the early Paleocene age of host deposits. Stratigraphically higher, the upper, coaly part of the Sagwon Member (section B3 downstream the Sagavanirktok River, at the Ivishak River mouth) yielded a palynomorph assemblage presumably of the late Paleocene age (Frederiksen *et al.*, 1996). Accordingly, the Sagwon Member (and, subsequently, the basal part of the Sagavanirktok Formation) is the late Paleocene in age (Mull *et al.*, 2003).

We studied all four collections of plant fossils from the upper Prince Creek Formation of the Sagwon locality, the eponymous site used to name the flora. Plant remains have been collected from several outcrops on





**Fig. 3.** Schematic geological map of the Sagavanirktok River basin in the Sagwon Locality (after Mull and Harris, 1989, with modifications): (1) undifferentiated alluvial deposits, Quaternary; (2) Sagavanirktok Formation, Upper Paleocene; (3–4) Colville Group: (3) Prince Creek Formation, Upper Cretaceous-lower Paleocene; (4) Schrader Bluff and Seabee formations, Upper Cretaceous, (5) fossil locality.

the left bank of the Sagavanirktok River (Fig. 3) and united into a single assemblage owing to a great taxonomic similarity. The Sagwon taphoflora includes 22 species (table), fructifications of two types (most likely of angiosperms), an imprint of a long shoot with short attached branches, and an imprint of presumably aquatic plant stem.

In general, the Sagwon flora is of a relatively low taxonomic diversity. It is interesting that the early Paleocene palynological assemblages from the same deposits are also of low diversity, which gradually increased in North Alaska throughout the Paleocene and Eocene (Frederiksen *et al.*, 1996, 1998).

Equisetites are represented by *Equisetum arcticum* and ferns by *Onoclea Hesperia*. Both species are rare. Conifers of low abundance and diversity dominate in few localities. Their most frequent components are *Metasequoia occidentalis* shoots with leaves, whereas fragmented specimens of *Mesocyparis* are rare. Mono-

cots are represented by probably semiaquatic taxon *Haemanthophyllum* ex gr. *kamtschaticum*. Oblong leaves with parallel venation, which are traditionally referred to the genus *Phragmites*, may belong to aquatic monocots. These plants together with *Quereuxia angulata* constitute "an aquatic community" of the Sagwon taphoflora, which grew in swampy oxbow lakes.

The greater part of angiosperm leaves belonged to arboreal and bushy dicots. Polymorphous and frequently large-sized leaves of *Corylites beringianus* prevail among them. It is to be noted that palynomorph assemblages from flora-bearing deposits are dominated by anemophilous (wind-pollinated) triporate species *Paraalnipollenites alterniporus* and *Triporopollenites mullensis*, which, according to Frederiksen *et al.* (1996), might be produced by plants with the *Corylites beringianus* leaves. Some localities contain abundant *Trochodendroides* leaves (three species) in addition to



*Nyssidium* and *Quereuxia* leaves associated with fruits. Remains of other angiosperms are infrequent or single.

The Sagwon taphoflora shows the closest similarity to the late Maastrichtian Koryak flora of the Amaam Lagoon of Northeastern Russia. These floras are compared in detail below. Another taxonomically similar fossil flora is probably the late Maastrichtian flora from the upper half of the Rarytkin Formation of the eponymous ridge (Golovneva, 1994). It includes almost all plant species found in the Sagwon taphoflora.

The Sagwon flora is also similar to some Early Paleogene floras of the Russian Far East. The early Danian Boshnyakovo flora of Sakhalin is also dominated by *Metasequoia*, *Corylites*, *Platanus*, and *Trochodendroides*, although it includes cycadophyte *Nils-sonia* in distinction (Krassilov, 1979). The late Maastrichtian–early Danian flora of the Yurii Island in the Lesser Kurile group includes abundant Taxodiaceae and Cupressaceae along with angiosperm genus *Corylites* (Krassilov *et al.*, 1988). Abundant remains of *Metasequoia*, *Trochodendroides* ex gr. *artica*, *Corylites*, and *Equisetum arcticum*, *Onoclea*, *Woodwardia*, *Glyptostrobus*, and others are known in the Danian Malaya Mikhailovka flora from lower courses of the Amur River (Vakhrameev and Akhmet'ev, 1977). *Metasequoia*, *Thuja*, *Trochodendroides arctica*, "*Corylus*," and other representatives of Betulaceae dominate in the early Paleocene Takhobe flora of Sikhote-Alin' (Vakhrameev and Akhmet'ev, 1977).

Thus, most characteristic taxa of the Sagwon flora (*Equisetum arcticum*, *Onoclea*, *Metasequoia*, *Mesocyparis* (?) cf. *Rubus*, *Trochodendroides*, *Corylites*, and probably "*Platanus*" *raynoldsii*) are also typical of the Danian–early Paleocene floras of the Far East and Northeastern Asia. The Sagwon flora characterizes typical vegetation of deciduous broad-leaved and mixed coniferous–broad-leaved forests, which grew in wide river valleys with swampy oxbow lakes of subarctic zone under temperate (probably warm–temperate) and humid climate conditions.

#### FLORAL CHANGES ACROSS THE CRETACEOUS–PALEOGENE- BOUNDARY IN THE NORTH PACIFIC

The described Koryak taphoflora of Northeastern Russia and the Sagwon taphoflora of North Alaska are suitable for investigation of taxonomic changes in floras of the North Pacific across the Cretaceous–Paleogene boundary that marks one of most significant ecological crises of the Earth history (Fig. 4). The late Maastrichtian age of the Koryak flora is reliably established based on correlation of flora-bearing continental and marine deposits, because the latter yield the age-diagnostic faunal remains. The Sagwon taphoflora is dated as the early Paleocene in age, and this assessment based on palynological data but not on marine fossils appears to be sufficiently reliable as well. The Rarytkin

flora from the eponymous ridge (Golovneva, 1994) is also of interest, because the Cretaceous–Paleogene boundary is suggested to be within its stratigraphic range that is established, though less reliably, based on plant macrofossils (Fig. 4).

The Koryak taphoflora has much in common with the Sagwon taphoflora. Dominant components in both floras are angiosperm dicots, whereas content of Equisetites forms and ferns is lower. Conifers rather diverse and abundant in the Koryak flora were important components of vegetation cover. The Sagwon flora of a lower taxonomic diversity includes nevertheless almost all the components established in the Koryak flora (table). *Corylites beringianus*, several *Trochodendroides* species, *Nyssidium* leaves with associated fruits, and *Metasequoia occidentalis* are dominants of both floras. The other taxa in common are *Equisetum arcticum*, *Onoclea hesperia*, *Rarytkinia terechovae*, *Hae-manthophyllum*, and "*Rubus*".

At the same time, the Sagwon flora contains fewer conifers than the Koryak flora. It is devoid of *Glyptostrobus*, *Elatocladus*, *Pityophyllum*, and *Pseudolarix*, while remains of *Mesocyparis* are scarcer and fragmentary. The Sagwon flora is also lacking the characteristic Koryak dicots *Cissites*, *Celastrinites*, *Platimelis*, and *Liriophyllum*, whereas "*Platanus*" is represented by single specimens. Absence of characteristic Cretaceous taxa indicates a younger age of the Sagwon taphoflora that is consistent with palynological data implying the early Paleocene age of this flora (Frederiksen *et al.*, 1996). *Castaliites inordinatus*, *Quereuxia angulata*, and *Viburnum rarytkense* are the unique taxa of the Sagwon flora.

The fact that the late Maastrichtian Koryak flora of the Amaam Lagoon site is very similar in taxonomic composition and general aspect to the early Paleocene Sagwon flora of northeastern Alaska (Fig. 4) evidences against a hypothesis of a global ecological crisis at the Cretaceous–Paleogene boundary (Spicer, 1989; Spicer *et al.*, 1994). In any case, the crisis did not result in a considerable extinction of plants and had no significant effect on evolution of the North Pacific floras.

Golovneva (1990, 1994) who studied the Rarytkin flora arrived at the same conclusion. In her opinion, the Cretaceous–Paleogene boundary is within the flora-bearing beds of the Rarytkin Formation at the level separating the early and late subassemblages of the flora (Fig. 4). If this is correct, then it is very significant that floral changes across the boundary are unimportant, allowing the floras of each side of the boundary to be regarded as subassemblages of the single Rarytkin taphoflora. "The subassemblages of the Rarytkin Formation flora are not sharply different from each other" (Golovneva, 1994, p. 41). More essential taxonomic changes in plant assemblages are recorded in the Maastrichtian part of the Rarytkin Formation (approximately in the middle or upper Maastrichtian), where the Rarytkin assemblage replaces the Gornaya Rechka flora



System	Northeastern Russia				North Alaska	
	Rarytkin Range		Amaam Lagoon and Ugol'naya Bay		Sagavanirktok R., Sagwon Locality	
Paleogene	Rarytkin Fm.	Upper Subfm.	Late Rarytkin subassemblage ● ∞	Amaam Fm.	Chukchi Fm.	Sagavanirktok Fm. ∞
		Middle Subfm.	Early Rarytkin subassemblage ●			Prince Creek Fm. ∞ ●
Cretaceous	Rarytkin Fm.	Lower Subfm.	Gornaya Rechka assemblage ●	Koryak Fm.	Upper Subfm., Koryak taphoflora ●	Schrader Bluff Fm.  <div style="border: 1px solid black; padding: 5px; display: inline-block;">           ● 1            ● 2            ∞ 3            ● 4         </div>
					Lower and middle subfms. ●	

**Fig. 4.** Floral changes in North Alaska and northeastern Russia at the Cretaceous–Paleogene boundary: (1) taphofloras of the Koryak and Sagwon evolutionary stages, (2) taphofloras of the Gornaya Rechka stage; (3) age-controlling palynological assemblages; (4) age-controlling marine mollusks.

(Fig. 4). Golovneva (1994) noted that the Rarytkin taphoflora was distinguished from the Gornaya Rechka assemblage based on several features. These were "...a noticeable change in species composition of ferns, gymnosperms, and angiosperms, an alteration of dominant species, the replacement of older conifer taxa (*Sequoia minuta*, *Crypromerites*, *Parataxodium*) by younger ones (*Metasequoia*, *Glyptostrobus*, *Taxodium*), and diminishing proportion of extinct form genera versus growing abundance of recent genera" (Golovneva, 1994, p. 41). As is concluded in her work, floras of Danian affinity substituted the Maastrichtian type flora in the Koryak Upland at the middle–late Maastrichtian boundary time and radiated then southward during the progressing cooling.

Paleobotanic evidence for catastrophic events recorded at the Cretaceous–Paleogene boundary are known mostly from middle-latitude North America (Spicer, 1989; Spicer *et al.*, 1994). Data considered above imply however that the most significant (but not catastrophic!) change in the North Pacific floras took place in the Maastrichtian time rather than at the Cretaceous–Paleogene boundary (Fig. 4). Changes across the latter are no larger in scale than those known in the "crises-free" Late Cretaceous (Golovneva, 1990, 1994; Golovneva and Herman, 1998; Spicer *et al.*, 1994; Herman and Spicer, 1995, 1997). Thus, the high-latitude floras of Asia and North America (Johnson, 1988; Johnson *et al.*, 1989) do not evidence in favor of catastrophic event at the Cretaceous–Paleogene boundary time. On the contrary, development of floras was likely controlled here by long-term climatic fluctuations and by evolution and migration of plants. As the essential

changes in composition of Late Cretaceous floras are untypical of the North Pacific region, it is possible to conclude that presumable consequences of meteoritic impacts (mass extinction of plants as a result of cooling and sharply depressed photosynthesis in response to reduced transparency of the atmosphere) are recorded in the middle-latitude North America only and have not been global in scale.

A similar development of floral changes across the Cretaceous–Paleogene boundary are recognized in the southeastern part of the Zeya–Bureya basin (Akhmet'ev *et al.*, 2002). Flora from the upper part of the middle Tsagayan Subformation is of the Late Maastrichtian age, as is established based on palynomorph assemblages, plant macrofossils (data of Markevich and Bugdaeva in *Flora...*, 2001), and some other geological records. The Danian (early Danian?) flora of the upper Tsagayan Formation includes many plant remains characteristic of the middle subformation and associated with some typical Paleogene taxa. "Taxonomic analysis of floral assemblages from the middle and upper subformations shows that they differ from each other mainly due to appearance of new species" (Akhmet'ev *et al.*, 2002, p. 313). In other words, evidence in favor of catastrophic events at the Cretaceous–Paleogene boundary, i.e., any noticeable extinction of plants, has not been discovered here as well.

The Maastrichtian–Eocene palynological assemblages of North Alaska demonstrate a gradual increase in palynomorph diversity from low in the early Paleocene to very high in the early and middle Eocene, and this is thought to be an indication of floral restoration after mass extinction in the terminal Cretaceous (Fred-



eriksen *et al.*, 1996, 1998). However, another interpretation is also possible. The gradual increase of taxonomic diversity in the North Alaskan floras could be a consequence of progressing warming from the pessimum phase in the second half of the Maastrichtian, which is inferred from a low diversity of the Kogosukruk flora (Spicer and Parrish, 1990), to the global temperature optimum in the late Paleocene–early Eocene.

As noted above, the Koryak flora is similar in taxonomic composition and general aspect to the Early Paleogene floras of northeastern Asia and North America rather than to the Late Cretaceous floras. The Late Maastrichtian flora of the Koryak Upland might be a source community for many Sagwon plants, species of which migrated to North Alaska from northeastern Asia during the Paleocene warming. Probably, it was the late Maastrichtian Koryak flora that gave rise to the Early Tertiary deciduous floras of the Arctic and adjacent regions (Herman and Spicer, 1995, 1997).

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