DEPARTMENT OF THE INTERIOR
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Palynological dating of Upper Cretaceous to middle Eocene strata in the Sagavanirktok and Canning Formations, North Slope of Alaska

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CONTENTS

Page

FIGURES

Page

TABLES

ABSTRACT

This report provides palynological data and age interpretations for six outcrop areas (Ivishak River, Echooka River, Shaviovik anticline, Toolik River-White Hills, Marsh Creek anticline, and Jago River) and parts of four well sections (the Arco Ugnu SWPT-1 well, the Arco West Sak River #23 well, the Mobil West Staines State #1 well, and the Mobil et al. West Kadleroshilik Unit #1 well) on the North Slope of Alaska. The described pollen assemblages are Maastrichtian to Eocene in age. A new, latest Maastrichtian pollen subzone is proposed based on samples from the Ugnu SWPT-1 core. The Cretaceous-Tertiary (K-T) boundary in the core, and in cuttings from the Arco West Sak River #23 well, can easily be picked using the abrupt Terminal Cretaceous Extinction Event. If an unconformity is present at the K-T boundary in the Ugnu SWPT-1 well core, it is probably a minor one at least with regard to the loss of Cretaceous strata. Cretaceous samples collected near the K-T boundary along the Ivishak River, the Echooka River, and in the Shaviovik anticline area were found to be late but not necessarily latest Maastrichtian in age. At least in some places on the North Slope, it appears that lowermost Paleocene strata are present, but such a determination is difficult or impossible to make using ditch (cuttings) samples.

A range chart is compiled for pollen distributions from the middle Paleocene to the lower Eocene in the Canadian Arctic based on published sources, and, using this chart, two samples from the Toolik River-White Hills were found to be probably late Paleocene and probably middle Paleocene, respectively. Ditch samples were analyzed from the Mobil West Staines State #1 well, just west of the Arctic National Wildlife Refuge, and it is shown that upper Paleocene strata are present in the well section. Ditch samples were analyzed from the Mobil et al. West Kadleroshilik Unit #1 well, a short distance east of Franklin Bluffs on the Sagavanirktok River. The presence of middle and upper Paleocene strata could not be demonstrated in this well section; thus, it is possible but not provable that Eocene rocks rest directly on lower Paleocene rocks in this area. It has been found that the practice of consulting palynologists, studying palynomorphs in ditch samples, who pick the top of the Paleocene at the uppermost occurrence or uppermost consistent occurrence of *Paraalnipollenites alterniporus,* produces only an approximately dated correlation marker because the actual range top of the species is in the lower Eocene. Samples from the Marsh Creek anticline and the Jago River are shown to contain pollen assemblages similar to those of early to middle(?) Eocene age in the Franklin Bluffs on the Sagavanirktok River.

INTRODUCTION

Many reports have been published or cited, concerning pollen age determinations for Upper Cretaceous and Tertiary strata on the North Slope of Alaska (e.g., Wiggins, 1976; Molenaar and others, 1984; Ager and others, 1986; Frederiksen and others, 1986, 1988, 1994, 1996; Frederiksen, 1987, 1991; Frederiksen and Schindler, 1987; Fouch and others, 1993). However, at least two problems are unresolved, (1) whether a distinct unconformity exists at the Maastrichtian-Paleocene boundary, at least in some places, and (2) whether upper Paleocene strata exist on the North Slope, and if so, where. The objectives of this report are to present evidence concerning these two questions and also to provide pollen analyses from certain localities that were sampled in previous years but for which no palynological results have yet been reported.

Figure 1 is an index map showing the North Slope localities discussed in this report. Regarding the Cretaceous-Tertiary boundary, a very detailed pollen-biostratigraphic study is presented here based on closely sampled core material from the Kuparuk River Unit (the Kuparuk River oil field), and some data on the boundary are also given for samples from along the Ivishak and Echooka Rivers and the Shaviovik anticline. Information about the pollen biostratigraphy of the middle Paleocene to Eocene, and the nature

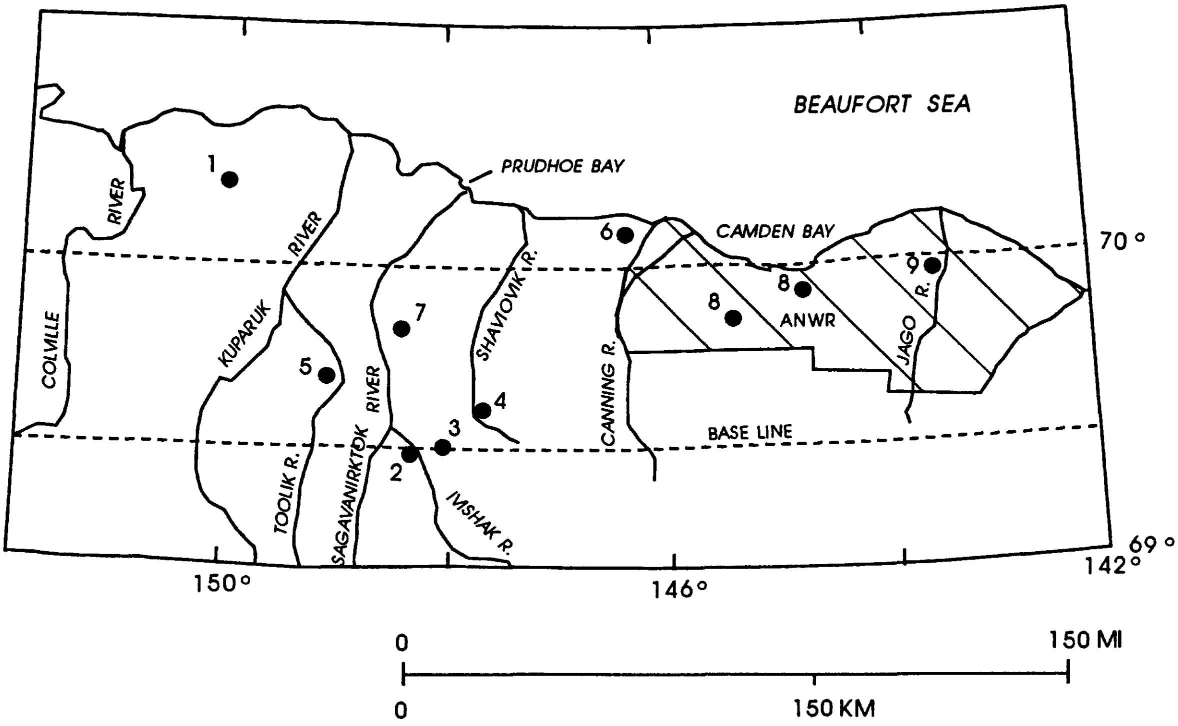

Figure 1. Index map showing locations of sections on the North Slope of Alaska that are discussed in this report: 1, two Kuparuk River Unit wells; 2, Ivishak River; 3, Echooka River; 4, Shaviovik anticline; 5, Toolik River-White Hills; 6, Mobil West Staines State #1 well; 7, Mobil et al. West Kadleroshilik Unit #1 well; 8, Marsh Creek anticline; 9, Jago River. The shaded area is the 1002 area of the Arctic National Wildlife Refuge.

of the Paleocene-Eocene boundary, is given for sections along the Toolik and Jago Rivers, from the Marsh Creek anticline, and also from two wells, the Mobil West Staines State #1 well and the Mobil et al. West Kadleroshilik Unit #1 well.

PALYNOLOGICAL METHODS

The samples discussed in this report were processed using normal palynological techniques of HCl; HF; short centrifugation with soapy water to remove fines; heavy liquid separation using a $ZnCl_2$ liquid of 1.8 to 2.2 s.g., or, in some cases, 1.45 s.g. The relatively light heavy liquid of 1.45 s.g. was effective in removing some of the abundant black woody material in the samples. The residues were stained with Bismark brown. The final step of residue preparation was screening to remove unwanted fine material, using 7 µm sieves. The residues generally contained considerable amounts of bisaccate conifer pollen, and for many of the samples some slides were made after screening the residue using a nest of 8 or 10 µm and 40 µm sieves to remove both the fine material and the larger palynomorphs, enriching the final residue in angiosperm pollen. However, counts to determine relative frequencies of palynomorph groups were only made using >7 μm residues. All residues were mounted in glycerine jelly.

PALYNOLOGY OF THE UPPER CRETACEOUS AND THE CRETACEOUS-TERTIARY BOUNDARY

Introduction

The detailed distribution of angiosperm pollen taxa across the Cretaceous-Tertiary (K-T) boundary on the North Slope of Alaska is not well known because the boundary is poorly exposed in outcrop (Frederiksen and others, 1988, 1996). All that is known is that the diversity of pollen taxa decreases in the upper part of the Maastrichtian (Frederiksen, 1989) and that, in a general way, there is a very distinct drop in pollen diversity across the boundary (Wiggins, 1976; Frederiksen and others, 1988). The palynology of the K-T boundary along the Colville River (fig. 1) was investigated by Wiggins (1976), Frederiksen and others (1986, 1988), and Frederiksen (1989, 1991). However, in this area, the stratigraphically highest Maastrichtian samples studied were approximately 23 to 69 ft below the K-T boundary (Frederiksen, 1991), and the lowest Paleocene samples examined by Frederiksen and others (1988) may have been at least that high above the boundary. Therefore, the account of the Ugnu SWPT-1 core from the Kuparuk River Unit in the present report is the first publicly available investigation from the North Slope of Alaska in which closely-spaced samples were examined from across the K-T boundary.

The K-T boundary has not been investigated in detail along the Sagavanirktok River, in the type area of the Sagavanirktok Formation (fig. 1, west of Locality 2; fig. 2). Here, the stratigraphically lowest Paleocene samples analyzed by T. A. Ager (in Carey and others, 1988, and in Spicer and Parrish, 1990) and by Frederiksen and others (1996) were perhaps 20 ft above the supposed K-T boundary, and strata thought by Detterman and others (1975) to represent the uppermost preserved Cretaceous did not contain diagnostic palynomorphs. In the Shaviovik anticline area (fig. 1, Locality 4), Wiggins (1976) provided data from one sample on either side of the boundary, Molenaar and others (1984) and Frederiksen and others (1996) reported rather generalized age determinations for a small number of samples, and in the present report, a few additional samples are dated, but the quality of the total palynological data from the Shaviovik anticline area is not very good. Some data are also presented here on the K-T boundary along the Ivishak and Echooka Rivers (fig. 1, Localities 2 and 3).

Locality 1, Kuparuk River Unit

Closely spaced core samples across the Cretaceous-Tertiary boundary were obtained from the Arco Ugnu SWPT-1[1] well in the Kuparuk River Unit (KRU) (figs. 1, 3). This well is in the Beechey Point (B-5) quadrangle; the location is sec. 7, T12N R10E, lat 70.40784° N, long 149.69038° W, kelly bushing elevation 77 ft, completed in 1983 to a total depth of 3991 ft. Pollen distributions are described here from these samples, and these distributions are compared (1) with those in a closely-sampled outcrop section across the K-T boundary on Police Island in the Brackett Basin, Northwest Territories, Arctic Canada (fig. 4), which was investigated by Sweet and others (1989, 1990), Sweet and Braman (1992), Nichols and Sweet (1993), and Sweet (1994), and (2) with distributions in ditch (cuttings) samples from the Arco West Sak River #23 well in the KRU.

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[1] SWPT = Single Well Production Test

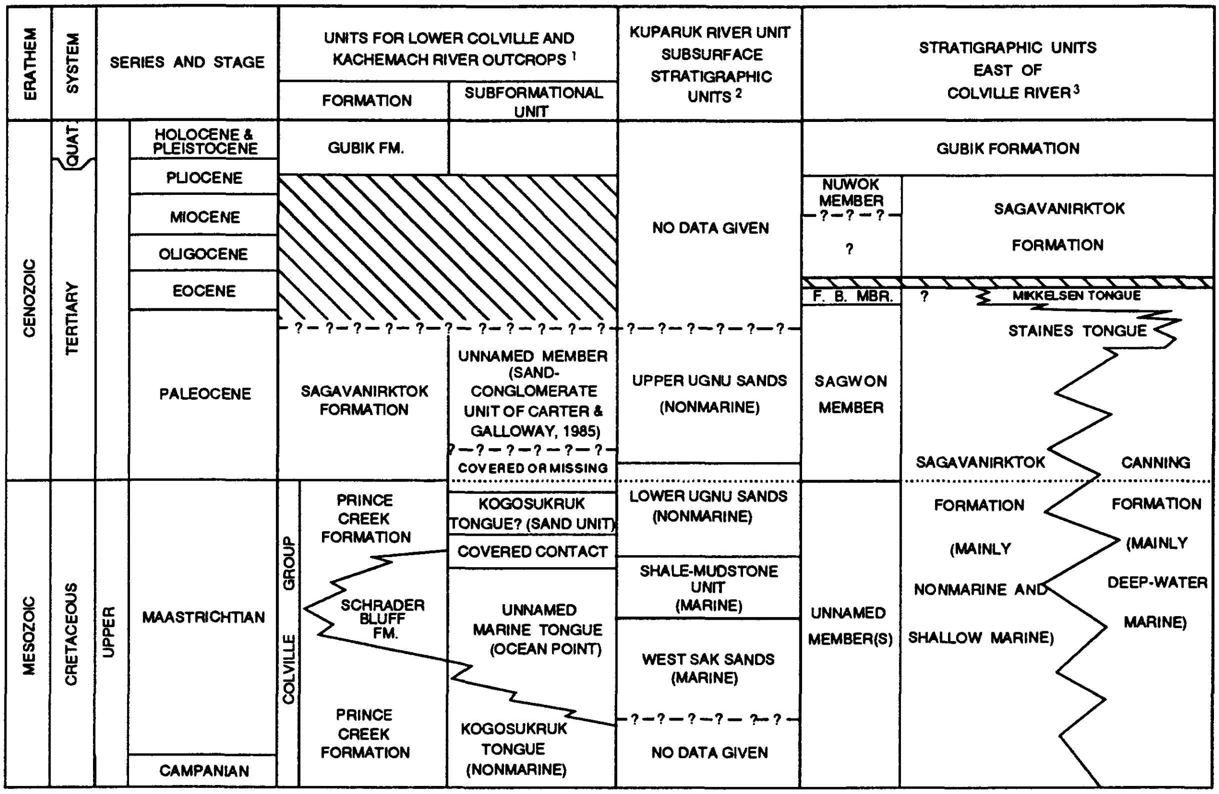

Figure 2. Stratigraphic nomenclature and ages of sedimentary rock units from the Colville River to the Canning River. Footnotes:

[1] Brosgé and Whittington (1966), Macbeth and Schmidt (1973), Carter and Galloway (1985), Frederiksen and others (1988).

[2] Werner (1987).

[3] Detterman and others (1975), Molenaar and others (1987), Ager and others (1986), Frederiksen and others (1994). The westward extension of the Mikkelsen Tongue of the Canning Formation indicates that at least marine correlatives of this member are found as far west as the Sagavanirktok River in the form of the Franklin Bluffs Member (F. B. Mbr.) of the Sagavanirktok Formation (Frederiksen and others, 1994).

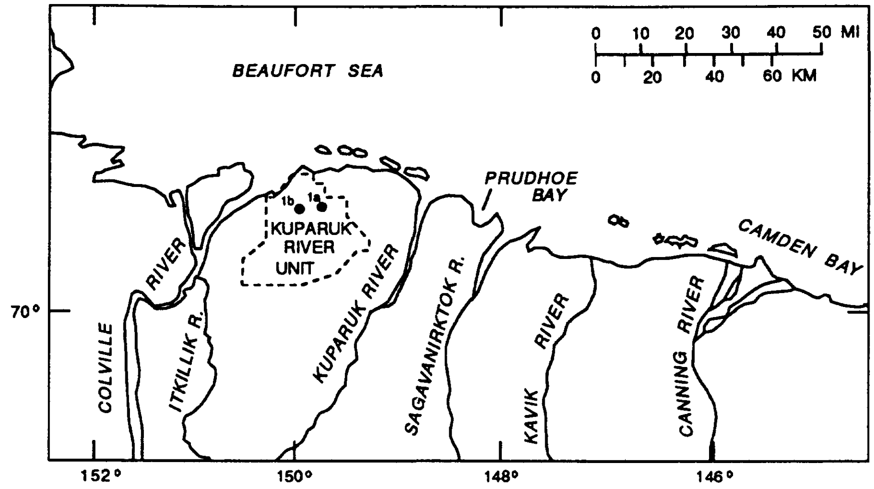

Figure 3. Location of Locality 1--the Kuparuk River Unit--and the Arco Ugnu SWPT-1 (1a) and Arco West Sak River #23 (1b) wells.

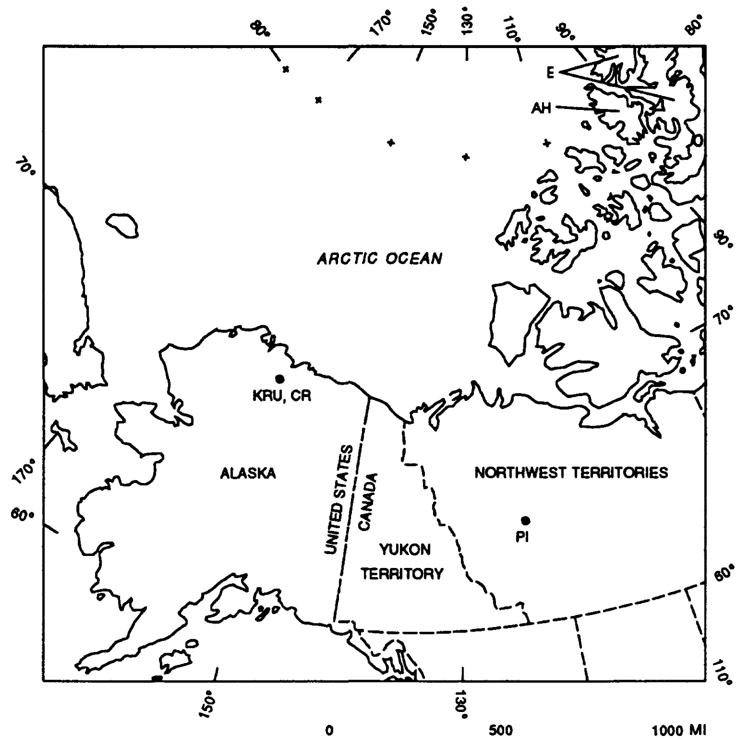

Figure 4. Location of some Cretaceous-Tertiary and Paleocene-Eocene boundary sections in Arctic North America. CR, Colville River; KRU, Kuparuk River Unit; PI, Police Island section; AH, Axel Heiberg Island; E, Ellesmere Island.

Stratigraphy and Structure

The stratigraphic nomenclature of sedimentary rock units along the Colville River and to the east is displayed in figure 2. Along the Colville River, the boundary between the Prince Creek and Sagavanirktok Formations is considered to coincide with the K-T boundary following the original definitions of these formations by Gryc and others (1951), and the strata are nonmarine on both sides of the boundary. However, to the east the term Sagavanirktok Formation is used for shallow-marine to nonmarine rocks ranging from Campanian probably to Pliocene in age following the revised definition of the formation by Molenaar and others (1987), and these strata intertongue with mainly deeper-water marine rocks of the Canning Formation (Molenaar and others, 1987). In the KRU, a separate nomenclature was developed because of the emphasis on naming the thick sandstone units of reservoir quality which contain billions of barrels of heavy oil (Werner, 1987). Werner (1987) described the stratigraphy and structure of uppermost Cretaceous and lowermost Tertiary strata in the KRU; these strata are referred to by the informal terms West Sak sands, shale-mudstone unit, lower Ugnu sands, and upper Ugnu sands, in ascending order (fig. 2), all of which are included within the Sagavanirktok Formation by Bird (1988) and Bird and Molenaar (1992). The dip of the strata in the KRU is east-northeast at 1-2°; therefore, the palynological interpretation of the Arco Ugnu SWPT-1 cored well section is not complicated by the structure.

Unpublished palynological work by Arco Exploration and Production Research, cited by Werner (1987), indicated that the K-T boundary falls within the lower Ugnu sands, an interval 250-300 ft thick. For the interpretation of the data presented in this report, it is important to know whether an unconformity exists at the K-T boundary within the lower Ugnu sands. Wiggins (1976, p. 53) stated that "a significant subsurface unconformity" is present at the boundary in the Prudhoe Bay area (fig. 1), although he did not state whether it was the uppermost part of the Cretaceous and (or) the lowermost part of the Paleocene that was missing there. Robertson (1986, p. 257) reported that "in the western portion of the Prudhoe Bay Field ... the Late Cretaceous unconformity is diachronous," presumably meaning that the age of uppermost preserved Cretaceous rocks varies from place to place in the region. However, Werner (1987, p. 540) stated that in the KRU, "stratigraphic relationships suggest that the K-T boundary is conformable." Collett and Bird (1990) noted that no unconformity could be identified at the K-T boundary in the KRU on the basis of well logs, but they did not rule out the possibility that unrecognized unconformities could exist within the Maastrichtian and Paleocene interval of that area. As discussed here under "Angiosperm Pollen Data from the Arco Ugnu SWPT-1 Well," based on the presence of certain angiosperm pollen taxa in the upper Maastrichtian samples from the well core, it is found that little if any of the uppermost Cretaceous section seems to be missing in the KRU.

The lower Ugnu sands unit "is predominantly medium-grained and ranges from fine- to coarse-grained.... Typically, there are three to five major sand beds in the lower Ugnu with interbedded siltstone and mudstone.... These sands and associated shales and coals are interpreted as delta-plain and fluvial deposits.... No invertebrate or vertebrate fossils have been found in the Ugnu sands" (Werner, 1987, p. 539-540).

The main comparison K-T boundary sections of Arctic North America (fig. 4) are also nonmarine: in the Colville River section, the highest known marine strata are approximately 650 ft below the top of the Cretaceous (Frederiksen, 1991; Brouwers and De Deckker, 1993), and in the Brackett Basin, the boundary is within the Summit Creek Formation, which appears to be entirely nonmarine (Sweet and others, 1989). Marine dinocysts are reported here from the highest sampled Cretaceous rocks along the Ivishak and Echooka Rivers, but the ages of these fossils have not been determined; therefore, it is not known whether they are autochthonous (indicating marine depositional environments) or might be reworked.

Angiosperm Pollen Data from the Arco Ugnu SWPT-1 Well

Thirty-five uppermost preserved Cretaceous and lowermost preserved Tertiary samples were processed from the lower Ugnu sands in the Ugnu SWPT-1 core, and only five of them were barren of angiosperm pollen or nearly so. However, no samples were collected by the oil-company geologist from the 14-ft thick interval between samples R4159 D and E (fig. 5), presumably because this was an interval of clean sand unlikely to contain palynomorphs. A second sand interval, this one sampled, occurs from sample R4158R to sample R4158X, inclusive. In the upper part of the sampled core, a section that includes the K-T boundary, the samples were taken at 6-inch intervals.

Discussion of palynomorph presence-absence and relative frequency data, as well as changes in pollen taxon diversities and turnover rates, is based on figures 5, 6, and 7. Figure 5 shows occurrence and stratigraphic range data for 47 angiosperm pollen taxa in the 30 productive samples from the Ugnu SWPT-1 core, but it also shows extensions of ranges based on data from the Colville River area. Figure 6 displays relative frequencies of spore-pollen groups in seven samples below and seven samples above the K-T boundary. Figure 7 compares pollen taxon diversities and turnover rates in uppermost Maastrichtian and lowermost Paleocene rocks of the Ugnu SWPT-1 core with the same kinds of data from the Police Island outcrop section in the Northwest Territories (Sweet, 1994).

The following features of the palynomorph distributions in the Ugnu SWPT-1 core may be observed:

1. Most Cretaceous taxa present within the sampled interval of the core appear to range to the top or nearly to the top of the Cretaceous.

2. Reworked Cretaceous pollen taxa are present in the lowermost Tertiary of the Ugnu SWPT-1 core (fig. 5). The question arises whether the location of the K-T boundary in the core would have been obvious if circles instead of the symbol R had been used in figure 5 to show occurrences of reworked Cretaceous taxa in Paleocene strata. Unfortunately, the K-T boundary in the core occurs within the sand interval extending from sample R4158R to sample R4158X that was referred to above. The absolute abundances and diversities of pollen are no doubt smaller within this sand interval than they would have been had the interval been composed of shale. However, nine Cretaceous taxa were still found in sample R4158X, indicating that this sample is still Cretaceous in age. On the other hand, the observed diversities of both Cretaceous taxa (presumed to be reworked) and presumed indigenous Paleocene taxa are small within the shale interval above sample R4158R, indicating that these shale samples are Paleocene in age. The exact position of the K-T boundary is picked based on two lines of evidence. First, the observed per-sample diversity of Cretaceous taxa (including specimens interpreted as being reworked) drops to a fraction of its Cretaceous values above the horizon where the line is drawn (fig. 5). Second, among the angiosperm pollen specimens, there is a distinct drop in the ratio of strictly Cretaceous specimens to mainly Paleocene specimens in the lowermost Tertiary (in fig. 6, this is the ratio of Cretaceous Angiosperms + most Other Colpates and Colporates : Porate Angiosperms).

3. In contrast to the high diversity of pollen taxa in the uppermost Cretaceous, the diversity of indigenous angiosperm pollen taxa in the lowermost Paleocene is very small, only 2-5 taxa actually observed in each sample (fig. 5), consisting of a small group of porates and two species of colpate or colporate pollen. In figure 7, using the range-through method, the diversity in the lower Paleocene samples is 13 taxa. In contrast, in the lowermost sampled Paleocene rocks along the Colville River (Frederiksen and others, 1988, localities 6-9), the range-through diversity was 18 taxa, and the observed per-sample

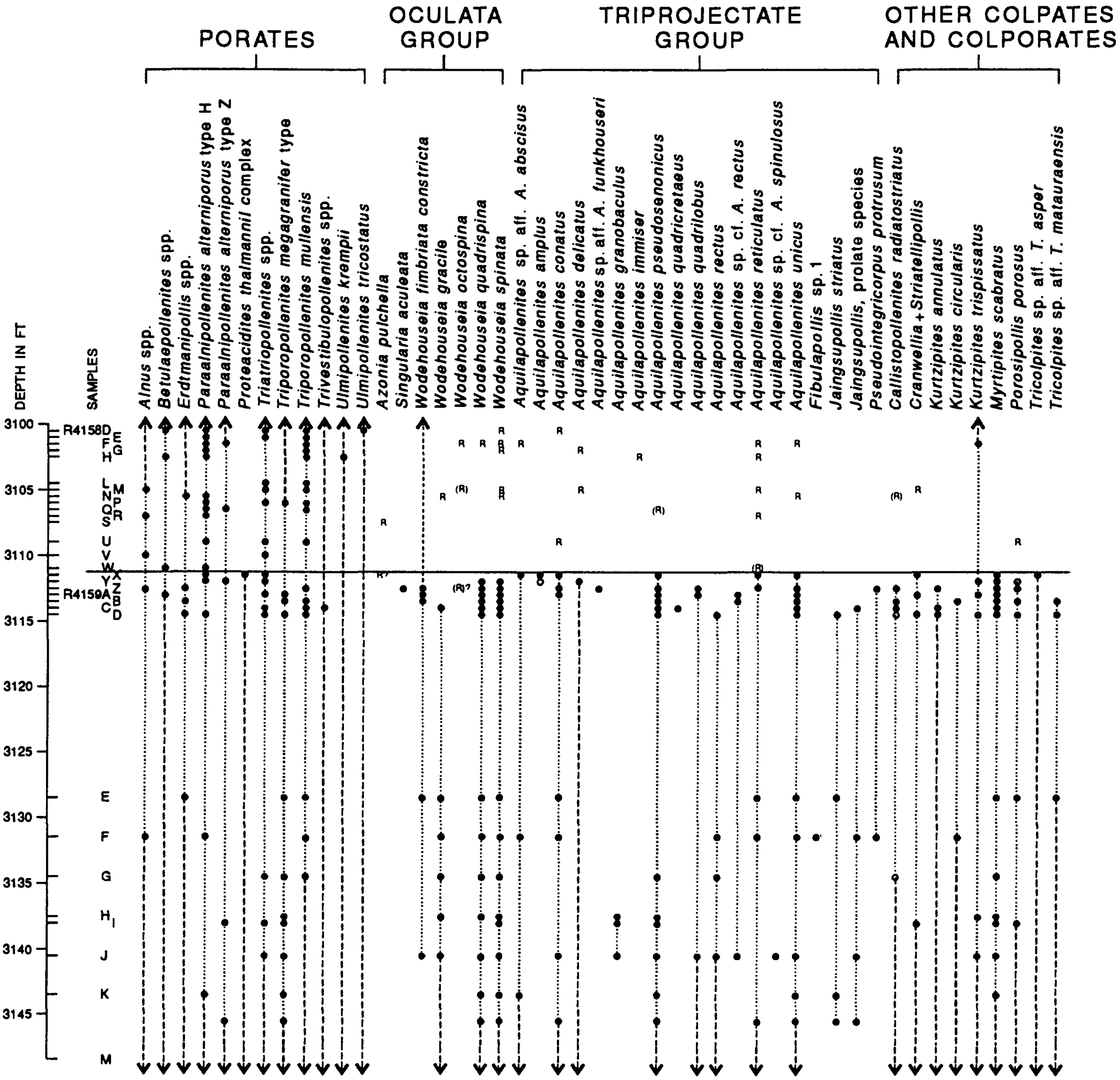

Figure 5. Occurrences of 47 angiosperm pollen taxa in 30 uppermost Cretaceous and lowermost Tertiary samples from the lower Ugnu sands in the Ugnu SWPT-1 core. Barren samples are not shown. The horizontal line is the Cretaceous-Tertiary boundary. Filled circles represent specimens considered to belong to the taxon listed; empty circles represent specimens for which the identification was not certain; R indicates specimens thought to be reworked; (R) indicates specimens thought to be reworked but for which the identification was not certain. Dotted lines connect highest and lowest observed occurrences in the Ugnu SWPT-1 core. Dashed portions of range lines are extensions of ranges based on data from the Colville River area (Frederiksen and others, 1988; Frederiksen, 1991). Therefore, the range lines are composites of data from the Colville River and the Ugnu SWPT-1 core.

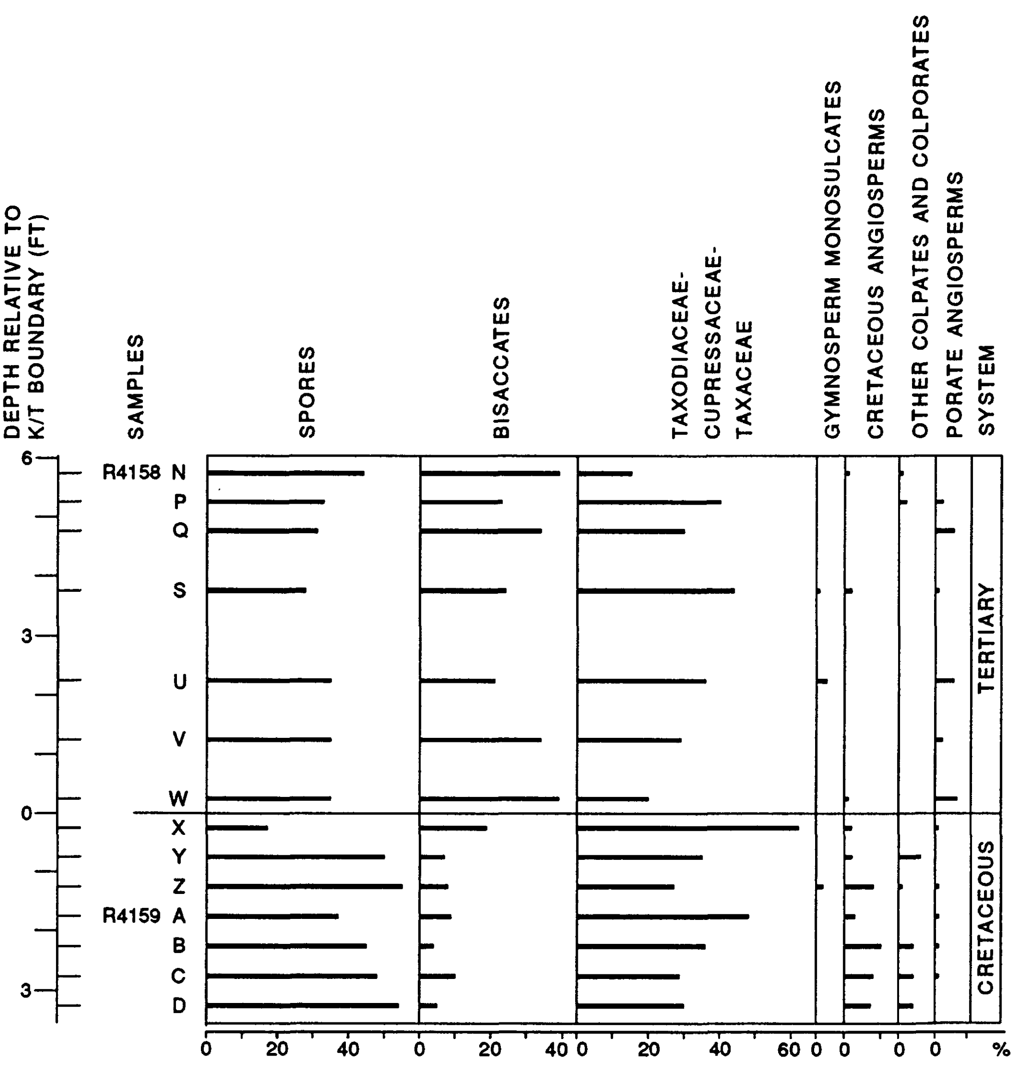

Figure 6. Relative frequencies of spore/pollen groups in 14 uppermost Cretaceous and lowermost Tertiary samples from the Ugnu SWPT-1 core.

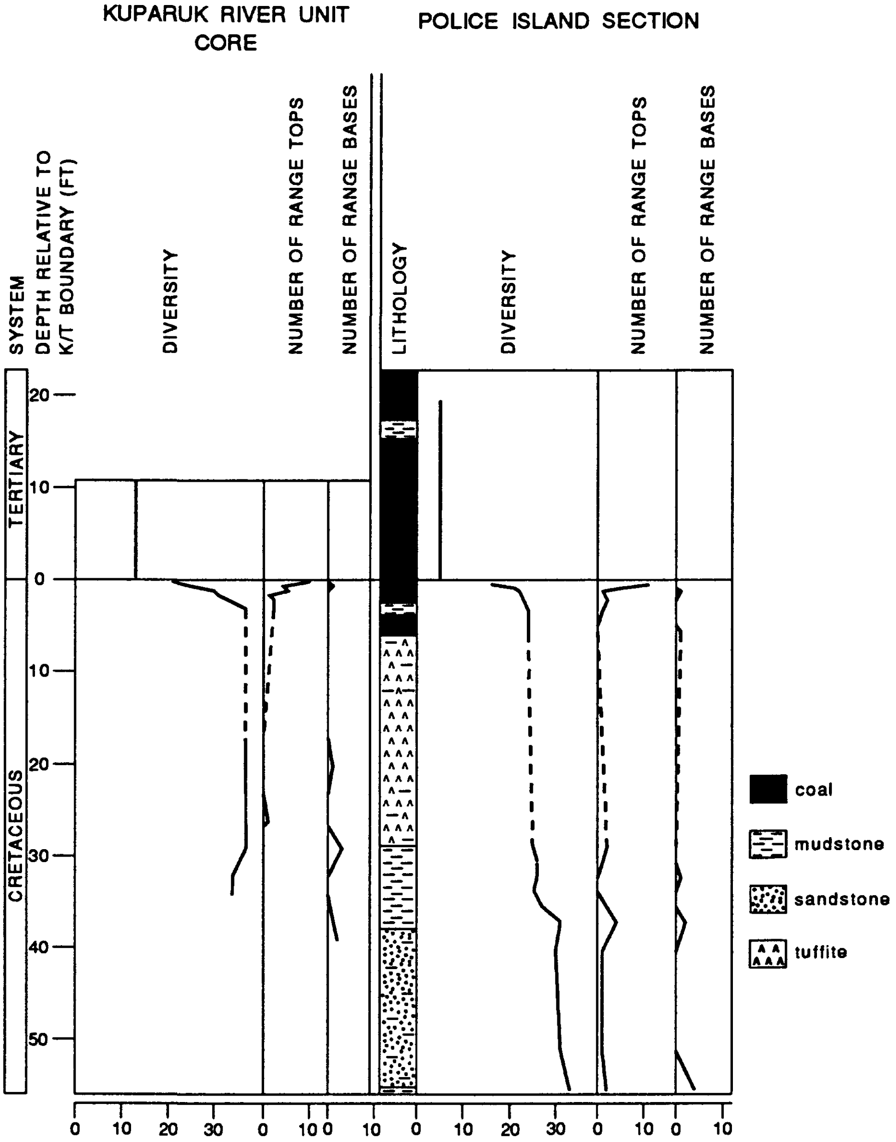

Figure 7. Pollen taxon diversities and turnover rates in uppermost Maastrichtian rocks of the Ugnu SWPT-1 core, North Slope, Alaska, and of the Police Island section, Northwest Territories (Sweet, 1994, fig. 22.12). Diversities were calculated using the range-through method of Cheetham and Deboo (1963), which assumes that each taxon occurs in every sample from its lowest to its highest occurrence; thus, the ecological bias is avoided that determines which taxa are actually observed in each sample. Turnover rates (rates of first and last appearances) are plotted as numbers of range tops and bases at each sample level. In the Ugnu SWPT-1 core section, total ranges include data from the Colville River area. The diagram shows only the upper part of the Police Island section. Dashed parts of curves indicate unsampled intervals in each section. The lithology of the Ugnu SWPT-1 core has not been published, but according to a generalized description of the "lower Ugnu sands" in the Kuparuk River Unit (Werner, 1987), the core section consists of siltstone, mudstone, unconsolidated sand, and perhaps thin coal beds.

diversity was 4-10 taxa. In a third area, in the type region of the Sagavanirktok Formation, along the Sagavanirktok River, the lowermost sampled Paleocene rocks contain extremely small pollen taxon diversities (T. A. Ager in Carey and others, 1988, and in Spicer and Parrish, 1990; Frederiksen and others, 1996), the triporate pollen species *Paraalnipollenites alterniporus* and *Triporopollenites mullensis* typically being virtually the only angiosperm pollen species found. These data are interpreted to indicate that the lowermost sampled Paleocene rocks along the Sagavanirktok River are very earliest Paleocene in age, representing a time immediately following the Terminal Cretaceous Extinction Event, whereas the lowermost sampled Paleocene rocks along the Colville River are probably slightly younger in age, representing a time when recovery from the extinction event was slightly more advanced, as plants were moving (presumably from refuges) back into the region. In the Yukon and the Northwest Territories, porate taxa also dominate the angiosperm pollen assemblages of the lowermost Paleocene (Nichols and Sweet, 1993, fig. 3; Sweet, 1994, fig. 22.12).

All Maastrichtian samples examined from the Ugnu SWPT-1 core belong to the *Wodehouseia spinata* Assemblage Zone of Nichols and others (1982), the highest palynomorph zone of the Cretaceous in the Western Interior of North America. Frederiksen (1991) defined five tentative subzones of the *W. spinata* Assemblage Zone in the Colville River area. The highest of these, Subzone 5, was characterized by the presence of *Wodehouseia octospina* and *Myrtipites scabratus* (fig. 8). On the Colville River, the species *Aquilapollenites delicatus*, *Aquilapollenites* sp. aff. *A. abscisus*, *Tricolpites* sp. aff. *T. matauraensis*, *Wodehouseia gracile*, and *Porosipollis porosus* were not found to range as high as the top of Subzone 5, but all of these species occur up to or nearly to the top of the Cretaceous in the Ugnu SWPT-1 core (fig. 5). *Jaingsupollis striatus* and *Jaingsupollis* (prolate species) were not identified in the Colville River samples but are distinctive members of the palynoflora in the Ugnu SWPT-1 core samples. Similarly, *Wodehouseia fimbriata constricta* was not observed in the Colville River samples but was found in four Maastrichtian samples from the Ugnu SWPT-1 core; Wiggins (1976, p. 66) reported that the range of this taxon on the North Slope of Alaska is "late Maastrichtian-early Paleocene.... This subspecies is never common, but is consistent in its occurrence at or near the upper Maastrichtian-Paleocene boundary." On the other hand, *Wodehouseia octospina* occurs in all samples of Subzone 5 of the Colville River area and is the most abundant species of the Oculata group (*Azonia* and *Wodehouseia*) in one of the samples from Subzone 5. However, this species is absent or nearly so in the Maastrichtian Ugnu SWPT-1 core samples (but *Wodehouseia octospina* does range to the top of the Maastrichtian in the Police Island section). In summary, it is apparent, because of the presence of *Jaingsupollis* and *Wodehouseia fimbriata constricta*, that the Ugnu SWPT-1 core samples are younger than those of Subzone 5 in the Colville River region; therefore, the Maastrichtian KRU core samples are assigned to a new tentative subzone, Subzone 6, of the *Wodehouseia spinata* Assemblage Zone.

Comparison with pollen biostratigraphy of the Arco West Sak River #23 well

Palynological data presented above from the Ugnu SWPT-1 well in the Kuparuk River Unit are very different from the palynological data from the Arco West Sak River #23 well (also known as the Kuparuk River Unit 3A-9 well) presented by Mickey and Haga (1984). The latter well was in sec. 7, T12N R9E, Beechey Point (B-5) quadrangle (fig. 3), and in contrast to the closely-spaced core samples from the Ugnu SWPT-1 well, samples from the West Sak River #23 well were composited 90- or 100-ft ditch samples. In contrast to the great diversity of Cretaceous pollen species found in the uppermost 34 ft of the Cretaceous in the Ugnu SWPT-1 well, only two species of *Aquilapollenites* (plus the generalized category

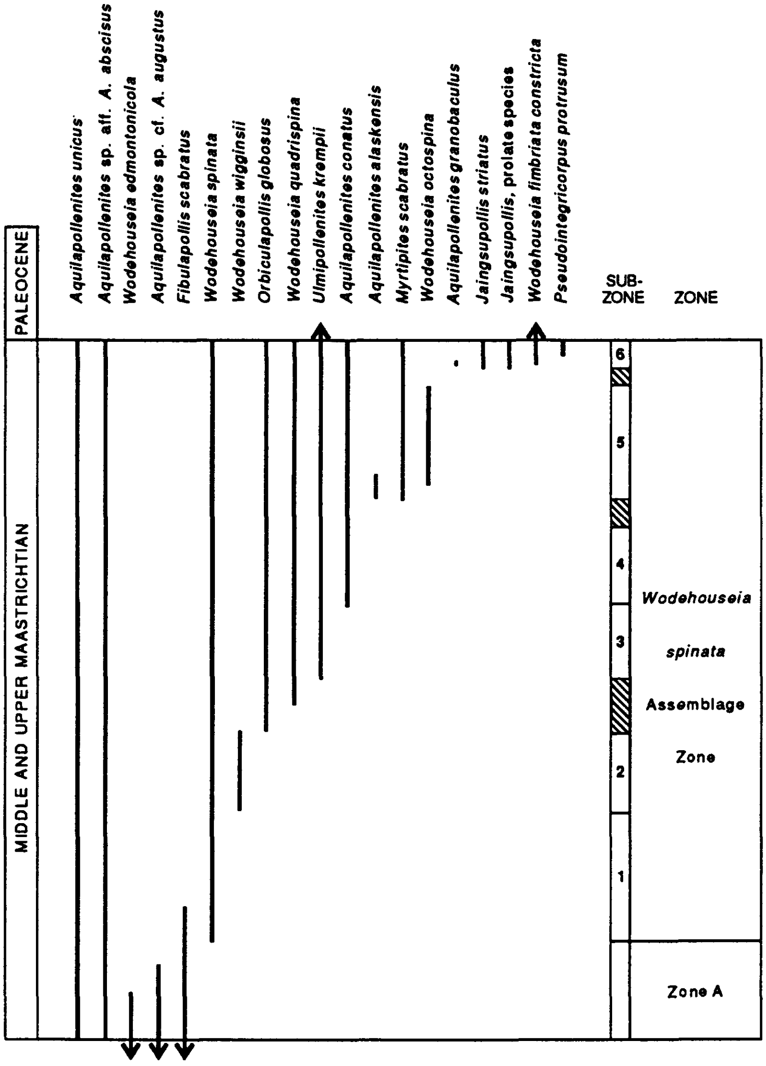

Figure 8. Revised subzonation of the *Wodehouseia spinata* Assemblage Zone on the North Slope of Alaska, based on stratigraphic ranges of pollen taxa in the Colville River area (Frederiksen, 1991, fig. 2) combined with stratigraphic ranges in the Ugnu SWPT-1 core from the Kuparuk River Unit.

Aquilapollenites spp.) and one species of *Wodehouseia* (the latter represented by only one specimen) were recorded from the uppermost 1,080 ft of the Cretaceous in the West Sak River #23 well, and only extremely small pollen diversities were recorded from the ten ditch samples assigned to the Paleocene; it appears that angiosperm pollen was uncommon to rare in the Paleocene samples and perhaps also in the Cretaceous samples from the West Sak River #23 well. It is believed that the somewhat sparse results in the consultant's report were probably due to a combination of (1) unsatisfactory sample preparation, particularly the absence of a 1.45 s.g. heavy liquid step used to drop out the abundant black woody particles, (2) small sizes of the ditch samples, (3) inclusion of sometimes abundant sand in the ditch samples as opposed to outcrop and core samples, from which shale, mudstone, and siltstone can be preferentially selected for processing, and (4) recording many specimens only to genus rather than to species level. Nevertheless, the top of the Cretaceous could be easily determined (at 2,460 ft) from the ditch samples based on the uppermost consistent occurrence of species of *Aquilapollenites*, demonstrating again that the abundance of Cretaceous specimens drops off precipitously at the boundary. The same phenomenon of very low angiosperm pollen abundance in ditch samples was observed in many Paleocene samples from the Mobil et al. West Kadleroshilik Unit #1 well (Locality 7 of the present report).

Terminal Cretaceous Pollen Taxon Extinctions

The pollen record in the upper half of the Maastrichtian along the Colville River showed a rapid rate of turnover of angiosperm pollen taxa throughout this interval, and the first and last appearances of taxa appear to have taken place in bursts, possibly due to pulses of climatic change (Frederiksen, 1989). In spite of rapid turnover, the taxon diversity remained more or less constant until about 50-100 ft below the boundary (the exact location of the boundary is uncertain). Then, within this highest 50-100 ft interval of the preserved Maastrichtian, last appearances became much more numerous than first appearances, leading to a drop in diversity (Frederiksen, 1989). In the Police Island section, this interval has a pattern of stepwise diversity decrease where the last of these extinction events before the final Cretaceous event can be seen as a peak in the range top curve at about 36-37 ft below the K-T boundary (fig. 7).

In both the Ugnu SWPT-1 and Police Island sections, the final extinctions of Maastrichtian pollen taxa take place within the uppermost 3-4 ft of the preserved Cretaceous section (figs. 5, 7). The question is whether the final floral extinction event of the Cretaceous at very high latitudes was stepwise or gradual over perhaps tens of thousands of years, or whether the final extinction event was actually catastrophic, occurring over a brief span of time, perhaps a few years to several hundreds of years. What is observed is a final gradual diversity decline, but it remains to be determined whether this observation can be taken at face value, or whether there was actually a catastrophic extinction that is masked by the Signor-Lipps effect (Raup, 1986). The Signor-Lipps effect is a statistical artifact arising from small sample sizes, discontinuous sampling, low relative abundances of some taxa, and ecological and preservational effects, which lead to the fact that some taxa are unlikely to be observed in the uppermost parts of their stratigraphic ranges, and this phenomenon tends to obscure an actual catastrophic extinction event by producing an apparent (observed) gradual or stepwise extinction event. In fact, it appears from statistical experiments that the Signor-Lipps effect must be so pervasive that observation of a true catastrophic extinction is virtually impossible (Lindberg and Lipps, 1994).

Two items of information are relevant to the evaluation of a possible Signor-Lipps effect in the Terminal Cretaceous Extinction Event in the North American Arctic. First, in both the Ugnu SWPT-1 and Police Island sections, the final observed diversity decrease coincides with a low relative abundance of late Maastrichtian pollen (fig. 6; Sweet and others, 1990), and this low relative abundance of Maastrichtian pollen suggests that some taxa are represented only by rare specimens, and therefore their true range tops may well be higher stratigraphically than their observed range tops. Second, evidence for the Signor-Lipps effect is found in the statement of Sweet and Braman (1992, p. 58-59) that, in western Canadian K-T boundary sections, "within the last tens of cm below the boundary, any single sample ... usually contains both fewer specimens and fewer species of morphologically complex pollen typical of the late Maastrichtian than in underlying [strata] ... although, if species records from several localities are summed, *most of these late Maastrichtian species are found to range into the boundary claystone*" (italics ours). On the other hand, the lower relative abundance of Maastrichtian pollen beginning several feet below the boundary also suggests that Maastrichtian angiosperms were actually beginning their final dieoff several (or many?) thousands of years before the very end of the Cretaceous. In summary, the pattern of latest Maastrichtian plant extinctions in Arctic North America is ambiguous. However, the bulk of the evidence seems to indicate that the final Cretaceous extinctions were more rapid than appears from the shape of the observed diversity curves.

One additional point is that, as stated previously, a small unconformity may exist at the K-T boundary in the detrital sequence of the Kuparuk River Unit, in which case the true nature of the final Cretaceous extinction event could not be determined at all on the basis of the present core. In contrast, in the Police Island section, the boundary occurs within a coal bed 39 ft thick (fig. 7), where there is no evidence of an unconformity at the boundary and where an iridium anomaly coincides with the boundary determined on the basis of palynological evidence. A second additional point is that, because the K-T boundary in the Ugnu SWPT-1 core occurs within a sand interval, diversities of pollen taxa are likely to be reduced within this interval because fewer taxa were preserved. Therefore, it is difficult to be sure of the exact nature of the curves across the boundary in figure 7, although, as pointed out above, even in the shale interval above the boundary, the angiosperm pollen diversities are very small.

Regardless of the exact nature of the Terminal Cretaceous Extinction Event, the flora at very high northern latitudes was profoundly affected. However, Krassilov (1981) emphasized a very important point, that floral change (a change in the list of species) must be distinguished from vegetational change (having to do with the dominants in the plant communities) across an extinction event. In the case of the K-T boundary in the Arctic, the dominants of the vegetation were conifer trees producing bisaccate and taxodiaceous pollen (fig. 6). It appears from figure 6 that gymnosperm (conifer) bisaccate pollen increased in relative frequency from the uppermost Cretaceous into the lowermost Tertiary, but such was not the case in the K-T boundary section along the Colville River (Frederiksen and others, 1988, fig. 5) nor in the Police Island section (Sweet and others, 1990), where there was no significant change in the relative frequencies of spores and gymnosperm pollen across the boundary. Therefore, the result of the K-T extinction event in the Arctic was that mainly or entirely small plants, probably herbs, became extinct, whereas the shrubs and trees were apparently virtually untouched (Frederiksen, 1989, and references therein).

Furthermore, it is very significant that the species that became extinct (most of the Oculata Group, most of the Triprojectate Group, and most of the "Other Colpates and Colporates" in fig. 5) were probably insect-pollinated, whereas the angiosperms that survived--the porates--were probably entirely wind-pollinated species, and even the sole tricolporate species shown in figure 5 as surviving the Terminal Cretaceous Extinction Event (*Kurtzipites trispissatus*) was probably also wind-pollinated (McIver and others, 1991). Therefore, it has been speculated (e.g., Sweet and Jerzykiewicz, 1987; Raine, 1988; Sweet and others, 1990) that the mass angiosperm species extinctions at the K-T boundary in the Arctic were due to the death of the pollinating insects, which in turn destroyed the means of reproduction of most of the angiosperms that had been living there. McGhee (1988) noted that the critical aspect of what is generally termed an extinction event is not what triggered the higher extinction rates, but rather, what was the inhibiting factor that caused the decrease or the actual end of the origin of new species that would replace the dying species and would maintain the diversity. The scenario of dying pollinators would answer the question of why new angiosperm species did not evolve at the end of the Cretaceous to replace the species that were becoming extinct.

Locality 2, Ivishak River

Several authors have provided measured sections of rocks along the Ivishak River; locations of these are shown in figure 9. From north to south, the localities are: locality C1 of Frederiksen and others (1996), undated; locality C2 of Frederiksen and others (1996), dated as latest Maastrichtian or early Paleocene on the basis of pollen; R91(D) = sample locality D of Roberts and others (1991), undated; M84(3) = section 3 of Molenaar and others (1984), dated as Campanian to Maastrichtian on the basis of palynomorphs and foraminifers; locality C3 of Frederiksen and others (1996), undated; and M84(5) = section 5 of Molenaar and others (1984), dated as Late Cretaceous on the basis of palynomorphs.

Section C2 is Ivishak River section 2 of the 1994 field party, collected July 25, 27, and 28 by Thomas Fouch and Norman Frederiksen, beginning immediately south of VABM Hak and extending southward through sample locality D of Roberts and others (1991) in Sagavanirktok (B-2) quadrangle. For this report, 13 additional samples from section C2 were processed, and some palynological information could be obtained from eight of these (table 1). Analyses of these eight samples and the three productive samples of Frederiksen and others (1996) are shown in table 2. Sample R4951D contains only sparse angiosperm pollen and could be either late Maastrichtian, or early Paleocene containing reworked Maastrichtian pollen. The assemblages of samples R4951 G, H, and J consist almost entirely of pollen taxa confined to the upper Maastrichtian, and R4951 J has *Wodehouseia vestivirgata*, which apparently is confined to the middle of the upper Maastrichtian (Wiggins, 1976; Frederiksen, 1991). Sample R4951K is barren of angiosperm pollen and contains only dinocysts (reworked?) and reworked Carboniferous spores. Samples R4951 P, Q, R, S, and V have very low-diversity pollen assemblages consisting mainly of porate types, typical assemblages of the lower Paleocene. Reworked Cretaceous pollen is sparse or absent in this group of five samples, except for R4951S, which has a fair number of reworked Maastrichtian *Aquilapollenites* specimens and also some pollen grains (not shown in table 2) probably from the Campanian. Sample R4951X has a rich assemblage of taxa confined to the Maastrichtian, mixed with several species of porate pollen taxa that range from the Maastrichtian to the Paleocene, and it seems probable that this sample is lower Paleocene containing abundant reworked Maastrichtian pollen grains.

In summary:

1. The Maastrichtian-Paleocene boundary can be easily picked in the Ivishak River section, between samples R4951 J and P. The Cretaceous samples are late Maastrichtian in age, but there is no evidence that they are latest Maastrichtian. However, there is a stratigraphic gap of approximately 400 m between samples R4951 J and P; therefore, it is possible that uppermost Maastrichtian rocks could be present within this unstudied interval, and the question remains unanswered whether an unconformity is present at the Cretaceous-Tertiary boundary at this locality.
2. This local section becomes younger to the south, in agreement with field observations that local folding produces southward dips.

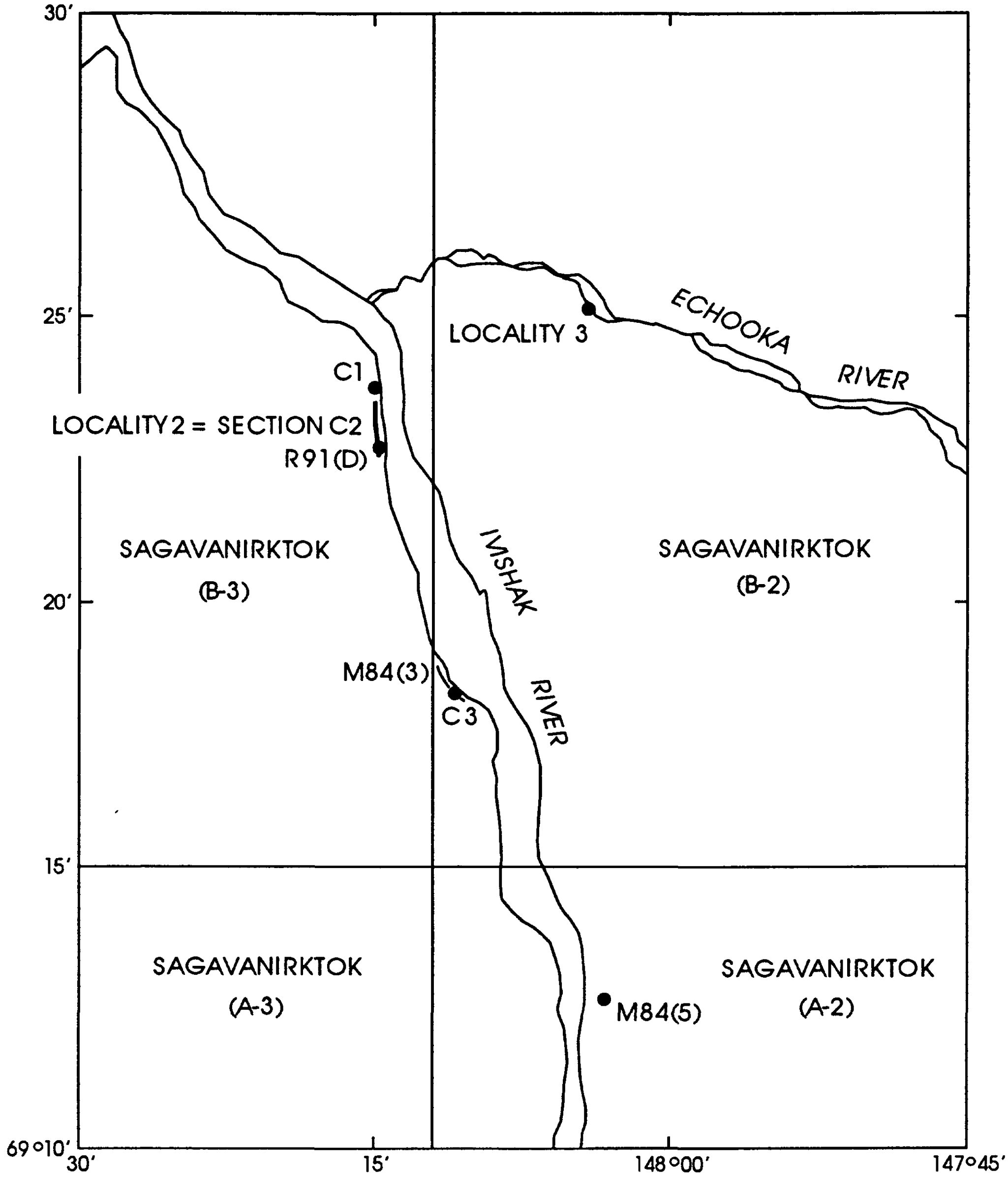

Figure 9. Location of stratigraphic sections discussed in this report, along the Ivishak River (Locality 2) and Echooka River (Locality 3) (modified from Frederiksen and others, 1996, fig. 6). Sections C1-C3 were sampled by us in 1994. M84(3) and M84(5) are sections 3 and 5, respectively, of Molenaar and others (1984); R91(D) is sample locality D of Roberts and others (1991). VABM Hak is located so close to Section C1 that no separate symbol marking the VABM could be shown.

Table 1. Samples processed for palynomorphs from Locality 2, along the Ivishak River. * indicates samples examined by Frederiksen and others (1996); ** indicates samples examined for the present report. Section measuring and sampling proceeded from north to south (upsection here) except for sample R4951A. In the Pollen Analysis column, A means an analysis was completed, B means the sample was barren of palynomorphs, and P means palynomorphs were present but either preservation was too poor for an analysis to be made, or else angiosperm pollen was rare or lacking.

Palynology number	Field number	Position	Latitude and longitude	Lithology	Pollen analysis
R4951 A*	NF94AK-28	First beds exposed south of saddle = 130 m in measured section	69°23.31'(27) 148°15.18' (base of section)	Sandstone, medium dark gray, fine-grained, muddy, carbonaceous	B
R4951 B**	NF94AK-29	North of saddle, within sandstone package		Mudrock, medium dark gray, sandy	B
R4951 C*	NF94AK-30	4.5 m south of sample 29, north of saddle	69°23.31'(27) 148°15.18'	do.	P
R4951 D*	NF94AK-31	9.6 m south of sample 30, north of saddle	69°23.31'(27) 148°15.18'	Sandstone, medium dark gray, fine-grained, carbonaceous	A
R4951 E**	NF94AK-32	Just south of sample 28	69°22.57'(27) 148°15.26'	Sandstone, medium dark gray, fine- to medium-grained, carbonaceous, probably muddy	B
R4951 F**	NF94AK-33	190 m	69°22.57'(27) 148°15.27'	Sandstone, medium dark grayish-brown, fine-grained, laminated, weathered	B
R4951 G**	NF94AK-34	250 m	69°22.62'(27) 148°15.39'	Shale, black, thin bed	A
R4951 H**	NF94AK-35	300 m, puk-puk hole	69°22.54'(27) 148°15.38'	Shale, dark gray, coaly, weathered	A

R4951 I*	NF94AK-36	432 m, float		Sandstone, medium dark gray, fine- to medium-grained	P
R4951 J**	NF94AK-38	575 m		Shale, dark gray	A
R4951 K**	NF94AK-39	?		Mudrock, medium dark gray	P
R4951 L*	NF94AK-40	660 m		do.	P
R4951 O*	NF94AK-43	873 m		Mudrock, medium dark gray, carbonaceous	P
R4951 P**	NF94AK-44	Approx. 968 m		Clay, dark gray, coaly	A
R4951 Q**	NF94AK-45	Approx. 968 m		Coal, weathered	A
R4951 R**	NF94AK-46	1000 m		do.	A
R4951 S*	NF94AK-47	1101 m, underlies coal		Clay, medium gray, coaly	A
R4951 T*	NF94AK-48	1121 m		Clay, medium gray, sandy, carbonaceous	P
R4951 U**	NF94AK-49	Approx. 1150 m		Coal	P
R4951 V**	NF94AK-50	Approx. 1150 m, underlies coal		Clay, dark gray, coaly.	A
R4951 W**	NF94AK-51	1350 m		Coal	P
R4951 X*	NF94AK-52	1348 m		Clay, medium gray, carbonaceous	A
R4951 Z*	NF94AK-54	Approx. 1526.5 m, finer material in or below coal, with some clay		Coal and clay	P

Table 2. Distribution of palynomorphs in 11 productive samples from Locality 2 along the Ivishak River. Samples are listed from north on the left to south (upsection) on the right. Underlined sample identifiers are samples examined by Frederiksen and others (1996); the remaining samples were examined for the present report. X, present; R, Late Cretaceous taxa interpreted as being reworked.

Taxon	Sample of R4951 series										
	D	G	H	J	K	P	Q	R	S	V	X
Aquilapollenites sp. aff. *A. augustus*			X								R
Aquilapollenites conatus			X								
Aquilapollenites pseudosenonicus			X								
Aquilapollenites sp. aff. *A. polaris*				X							
Aquilapollenites sp. aff. *A. rectus*			X								
Aquilapollenites reticulatus	X			X					R		R
Aquilapollenites sp. aff. *A. reticulatus*			X								R
Aquilapollenites sp. (*Mancicorpus* type)											R
Aquilapollenites unicus	X	X	X								R
Cranwellia striata											R
Erdtmanipollis sp.										X	
Expressipollis types	R								R		R
Paraalnipollenites alterniporus type H							X	X	X		X
Singularia sp.			X								
Triporopollenites mullensis	X					X	X	X	X	X	X
Ulmipollenites krempii							X				
Wodehouseia octospina											R
Wodehouseia quadrispina			X	X							
Wodehouseia spinata	X	X	X	X							R
Wodehouseia vestivirgata				X							
Dinocysts (reworked?)	X				X						
Reworked Carboniferous spores				X	X						

Locality 3, Echooka River

Four samples were collected by Franczyk and Johnsson in August, 1994, along the Echooka River (fig. 9; table 3). One was not processed because it was deeply weathered, and one (R5219B) contained only rare angiosperm pollen grains of fair to poor preservation. However, two of the samples contained useful pollen taxa, and the analyses are shown in table 4.

The samples were collected from section 7 of Molenaar and others (1984), located in NE 1/4 SE 1/4 sec. 25 T1N R16E, Sagavanirktok (B-2) quadrangle. Palynomorphs in samples collected by the

Molenaar field party were dated by consultants as undifferentiated Campanian-Maastrichtian in age. The measured section 7 of Molenaar and others was about 540 ft thick; therefore, the present productive samples (one at 150 ft and the other at 475 ft above base of section) are representative of most of section 7. Both of the productive samples contain *Wodehouseia spinata* and *Aquilapollenites unicus*, and both of these species are confined to approximately the upper half of the Maastrichtian on the North Slope (Frederiksen, 1991). All of the pollen taxa listed are confined to the Cretaceous except *Alnus* (alder), which has its range base in the upper Maastrichtian. Therefore, it seems unlikely that either of the samples is Paleocene but with reworked Maastrichtian pollen grains, and most or all of section 7 appears to be late Maastrichtian in age. On the North Slope of Alaska, *Pseudointegricorpus protrusum* is known only from Subzone 6 of the *Wodehouseia spinata* Zone, in the uppermost 20 ft of the Maastrichtian (figs. 5, 8). Therefore, it is possible that, at least as far as the Cretaceous is concerned, there is little or no unconformity at the Cretaceous-Tertiary boundary along the Echooka River. However, the samples have small observed pollen diversities; therefore, a Subzone 6 determination cannot be definitely confirmed.

In the area of the Echooka River, the K-T boundary is within the Sagavanirktok rather than the Canning Formation (Molenaar and others, 1986, section 3, east of locality 32). The two samples discussed here contain abundant dinocysts (table 4), but the ages of these have not been determined; therefore, it is not known whether they are autochthonous (indicating marine depositional environments) or might be reworked.

Table 3. Samples examined for palynomorphs from Locality 3, along the Echooka River. In the Pollen Analysis column, A means an analysis was completed, and P means palynomorphs were present but preservation was too poor for an analysis to be made.

Paly-nology number	Field number	Section	Position	Latitude and longitude	Lithology	Pollen analysis
R5219A	MJ94AK78	Echooka River	150 ft above base of section 7 of Molenaar and others (1984)	69°24'44" 148°04'29"	Siltstone, medium gray, carbonaceous	A
R5219B	MJ94AK80	do.	250 ft above base	do.	do.	P
R5219D	MJ94AK84	do.	475 ft above base	do.	do.	A

Table 4. Distribution of stratigraphically significant pollen taxa in two samples from the Echooka River locality. Sample R5219A is the older of the two samples. X, present; P = identification probable. As regards dinocysts, abund. = abundant.

Taxon	Sample	
	R5219A	R5219D
Alnus	X	
Aquilapollenites sp. aff. *A. conatus*		X
Aquilapollenites reticulatus	P	X
Aquilapollenites unicus	X	X
Proteacidites thalmannii		X
Pseudointegricorpus protrusum		X
Wodehouseia quadrispina		X
Wodehouseia spinata	X	X
Dinocysts (reworked?)	abund.	abund.

Locality 4, Shaviovik Anticline

A variety of samples from the Shaviovik anticline area have been examined by several palynologists (fig. 10), and it has long been known that the Cretaceous-Tertiary boundary occurs in the area. However, no samples analyzed by Frederiksen and others (1996) could be assigned to the Cretaceous. Therefore, it seemed worthwhile to study additional samples from the area, and here we present analyses of five samples collected by Ager on August 2, 1984 (tables 5, 6). The exact locations of the samples are not certain, but they probably came from the west end of the exposures on the north side of the anticline, probably from Sagavanirktok (C-1) quadrangle, and the traverse proceeded from west to east. Pollen was not abundant in any of the samples, but it seems clear that samples R3399 D and E are early Paleocene, whereas samples R3399 H and J are Maastrichtian. The age of sample R3399G is not obvious, but it may well be earliest Paleocene (containing a considerable amount of reworked Cretaceous palynomorphs). Potentially the most significant Cretaceous pollen species is *Pseudointegricorpus protrusum* in sample R3399J, which is known on the North Slope only from the uppermost part of the Maastrichtian (in the Ugnu SWPT-1 core , Kuparuk River Unit). However, these samples are similar to those from the Echooka River (Locality 3) in having relatively small pollen diversities; therefore, as in the case of the Echooka River samples, a latest Maastrichtian age cannot be definitely confirmed.

As in the area of the Echooka River, the K-T boundary is within the Sagavanirktok rather than the Canning Formation (Molenaar and others, 1986, section 3, east of locality 32). Uppermost(?)

Maastrichtian sample R3399J contains abundant dinocysts, but the ages of these have not been determined; therefore, it is not known whether they are autochthonous (indicating marine depositional environments) or might be reworked.

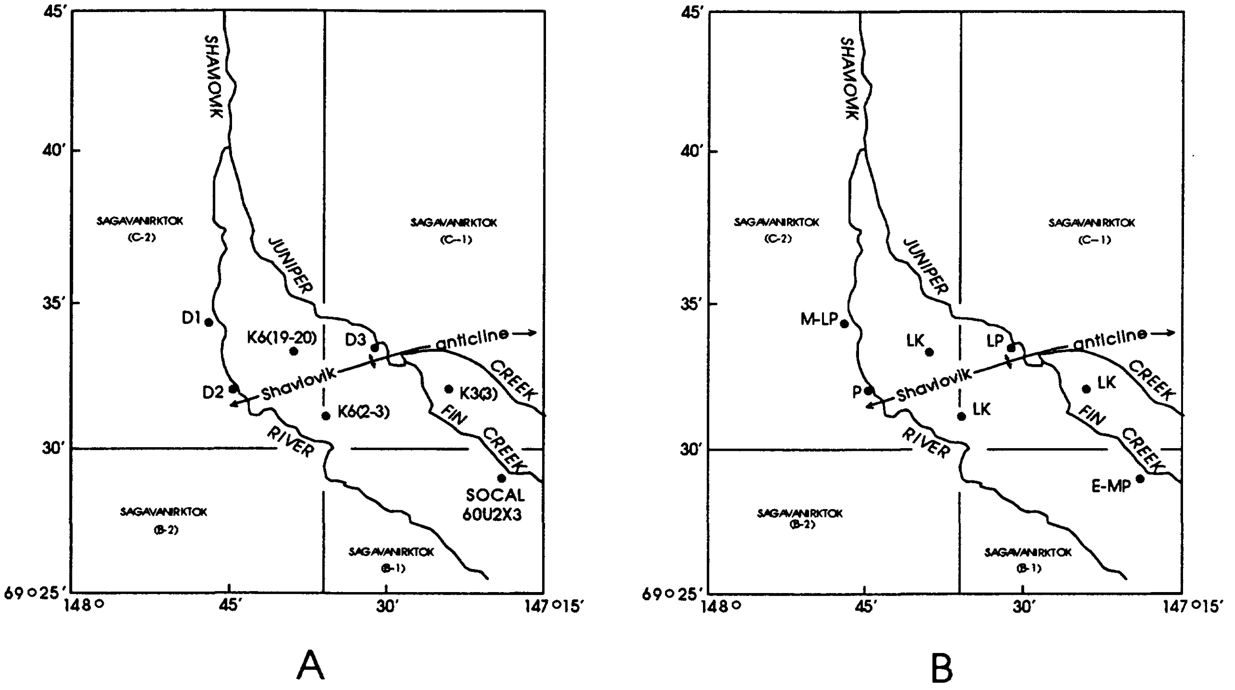

Figure 10. Location of sample localities in the Shaviovik anticline area (Locality 4; modified from Frederiksen and others, 1996, figs. 7 and 9).

A, Sample locality identifiers. Sections D1-D3 are from Frederiksen and others (1996). D1, D2, and D3 are the same as sections 9, 10, and 11, respectively, of Molenaar and others (1984). K3(3) is line 3, shotpoint 3; K6(19-20) is line 6, shotpoints 19 and 20; and K6(2-3) is line 6, shotpoints 2 and 3; all of these were dated by H. R. Bergquist in Keller and others (1961, p. 208-209, pl. 24). SOCAL 60U2X3 is a shotpoint sample dated by Wiggins (1976).

B, Ages of sample localities. E, early; M, middle, L, late. K, Cretaceous; P, Paleocene.

Table 5. Samples examined for palynomorphs from Locality 4, Shaviovik anticline area.

Palynology number	Location	Lithology
R3399D	West end of anticline	Clay
R3399E	do.(?)	Gray clayey silt
R3399G	?	Gray silty sandstone
R3399H	?	Rippled sandstone
R3399J	East end of anticline outcrop	Brownish gray clayey silt

Table 6. Distribution of pollen taxa in five samples from Section 4, in the Shaviovik anticline area. Samples apparently run from west on the left to east on the right (table 5). X, present; P = identification probable; R = interpreted as reworked from the Campanian and lower Maastrichtian. As regards dinocysts, abund. = abundant.

Taxon	Samples of R3399 series				
	D	E	G	H	J
Aquilapollenites sp. cf. *A. amplus*			X		
Aquilapollenites delicatus				X	
Aquilapollenites fusiformis					R
Aquilapollenites quadrilobus				X	
Aquilapollenites reticulatus		R	X		
Aquilapollenites sp. aff. *A. reticulatus*				X	
Aquilapollenites trialatus					R
Aquilapollenites unicus				X	
Aquilapollenites sp.			?		
Expressipollis type				R	R
Paraalnipollenites alterniporus type H	X	X	P		
Proteacidites sp.					X
Pseudointegricorpus protrusum					X
Triporopollenites mullensis	X	X	X	X	X
Total triporates	9	11	3(?)	1	5
Total specimens of taxa restricted to the Cretaceous (except those recorded by R)	0	1	4(?)	5	5
Dinocysts (reworked?)				rare	abund.

PALYNOLOGY OF THE PALEOCENE TO MIDDLE EOCENE

Introduction

The most important single reference on the Tertiary palynological biostratigraphy of the North American Arctic was published in 1997 (Norris, 1997), based on upper Paleocene to Pliocene ditch samples from the Imperial Adgo F-28 well in the Beaufort-Mackenzie Basin, northwestern mainland Canada. However, the new zonation proposed in that paper cannot be applied to the samples discussed in the present report because Norris' zonation relies to an important degree on species of fungal spores. These fossils were not used for the present study because (1) for the most part they were not previously well described or illustrated, (2) the ranges of many or most fungal spore taxa were not previously well described, and (3) there is some question (which has not been investigated by us) whether fungal spores are abundant enough to be biostratigraphically very useful in non-deltaic strata such as those of the Tertiary over much of the North Slope of Alaska.

The best information on the pollen biostratigraphy of the outcropping Paleocene-Eocene boundary in Arctic North America is in the paper by McIntyre (1991), which contains data on many samples from a thick section across the boundary on Axel Heiberg Island (fig. 4). Figure 11 is a compilation of these data. The most useful additional information on this outcropping boundary in the region is from Kalkreuth and others (1993), concerning a boundary section on Ellesmere Island (fig. 4). In that paper, the uppermost Paleocene was defined palynologically by the highest appearance of *Momipites wyomingensis*, *Momipites ventifluminis*, *Caryapollenites inelegans*, and *Caryapollenites imparalis*, together with the presence of very rare *Intratriporopollenites* (= *Tilia*); the lowermost Eocene was defined by the presence of *Carya* >28 µm (= *Carya viridifluminipites* and other Eocene forms, e.g. those of Doerenkamp and others, 1976; Choi, 1983; McIntyre, 1991).

McIntyre (1985, p. 45) reported that a distinct peak in the relative frequency of *Platycarya* pollen is found "occasionally" in rocks thought to be earliest Eocene in age in the Canadian Beaufort Sea and the Mackenzie Delta, but the only published occurrence of the peak appears to be in the Natsek E-56 well in the southwestern corner of the Canadian Beaufort Sea (McIntyre 1985; Dietrich and others, 1989). Norris (1997) reported *Platycarya* pollen in only one sample, probably from the lower Eocene, in cuttings from the Adgo F-28 well in the Beaufort-Mackenzie Basin. An abundance peak for *Platycarya* (or, indeed, more than rare specimens of this pollen type) was not seen in any lower to middle(?) Eocene samples studied by Frederiksen and others (1994, 1996) or for this report. *Platycarya* also seems to be rare to absent in the lower Eocene on Axel Heiberg and Ellesmere Islands (fig. 4; e.g., Kalgutkar and McIntyre, 1991; Kalkreuth and others, 1993). It is noteworthy that Rouse (1977) did not include *Platycarya* at all in his summary spore-pollen range chart for Arctic Canada, suggesting that pollen of this genus is so rare that, at least in many places, it is not biostratigraphically significant in that region.

Figure 11 also contains some data on pollen taxon ranges in what are rather vaguely defined lower and middle Paleocene strata in the Canadian Arctic. McIntyre (1994, p. 85) considered samples lacking *Momipites* and *Caryapollenites* to be "possibly early Paleocene," and in his spore/pollen range chart for the Canadian Arctic, Rouse (1977) showed "early(?) Paleocene" strata as containing only *Paraalnipollenites alterniporus* and *Triporopollenites mullensis*. In his papers, McIntyre relied mainly on ranges of *Momipites* and *Caryapollenites* species in Wyoming (as depicted by Nichols and Ott, 1978) for assignment of samples in the Arctic to the middle or upper Paleocene.

There are several significant aspects of figure 11. One is that it shows only one species, *Insulapollenites rugulatus*, as being confined to the upper Paleocene; unfortunately, this species seems to be rather rare at least in the Canadian Arctic (e.g., McIntyre, 1991, 1994) and it also turns out to be

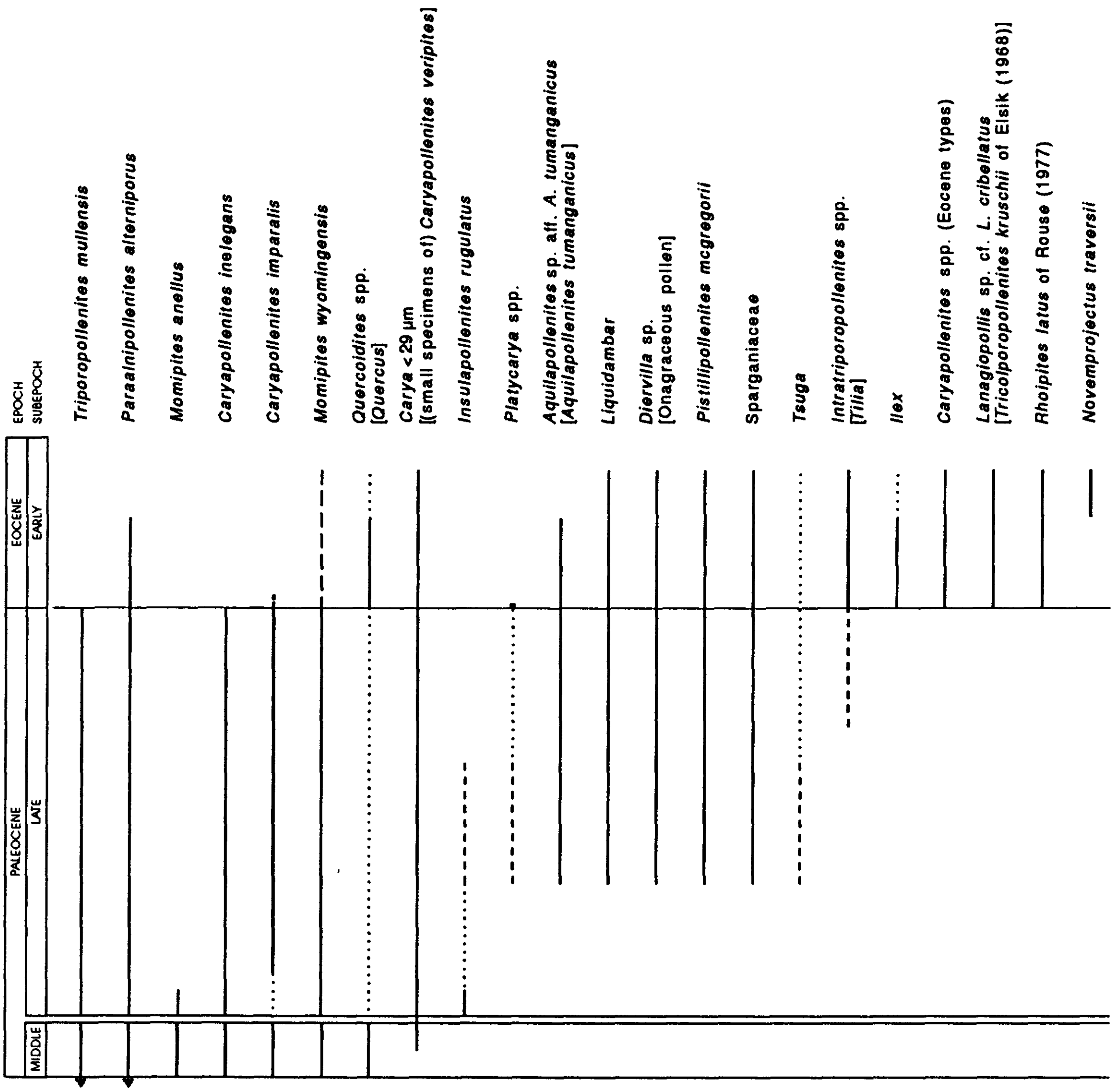

Figure 11. Ranges of some biostratigraphically important pollen taxa in middle Paleocene to lower Eocene strata of the Canadian Arctic. The upper Paleocene and lower Eocene part of the chart is from Axel Heiberg Island, with data from McIntyre (1991), except that (1) the lower Eocene portion of the range line for *Momipites wyomingensis* (shown as long dashes) signifies that this species was found in the lower to middle(?) Eocene on the North Slope of Alaska (Frederiksen and others, 1996; this report), (2) the peak occurrence of *Platycarya* pollen is from Dietrich and others (1989), and (3) the ranges of *Carya* <29µm and *Rhoipites latus* are from Rouse (1977). Middle Paleocene ranges (generalized and not to scale) are from Rouse (1977) and McIntyre (1991, 1994). Dashed portions of range lines indicate rare occurrences; dotted portions of range lines indicate that the taxon was not recorded as being present in that interval, but that it presumably was present. Names of taxa are those of the present authors; names in brackets are corresponding names used by McIntyre. "Onagraceous pollen of Ioannides and McIntyre" listed by McIntyre (1991) is the same or a very similar species as *Diervilla* sp. of Frederiksen and others (1996) and this report, as shown by a photomicrograph in Ioannides and McIntyre (1980, pl. 31-5, fig. 6).

uncommon in Alaskan North Slope samples (except in the Mobil West Staines State #1 well, Locality 6). In outcrop and core samples, it would be possible to use overlapping ranges of taxa that range below or above the upper Paleocene to define strata as being of late Paleocene age, but this is not possible with ditch samples because these contain contamination from uphole (see discussion of the Mobil West Staines State #1 well). Another significant aspect of figure 11 is that it shows no taxa as being confined to the middle Paleocene. Therefore, the middle Paleocene could be defined in outcrop and core samples by the absence of late Paleocene taxa, but this would not be possible using ditch samples. In summary, on the basis of outcrop or core samples it seems possible to subdivide the Paleocene into lower, middle, and upper portions, but on the basis of ditch samples the Paleocene is generally divided into lower and upper parts in which "upper Paleocene" includes the middle and upper Paleocene of the tripartite subdivision.

Locality 5, Toolik River-White Hills

A number of samples have been examined palynologically from the Toolik River-White Hills area (fig. 12). The youngest of these, samples R4961D and R4962A (fig. 12, localities F4 and F5, respectively, of Frederiksen and others, 1996), were considered by Frederiksen and others (1996) to be middle or late Paleocene, and probably late Paleocene, respectively. These two pollen assemblages were reexamined to see whether additional species could be found that would clarify the ages of the samples, in particular, whether either of these could truly be considered late Paleocene. Analyses are given in table 7, which includes data from the original analyses given by Frederiksen and others (1996, table 17). Newly found taxa are marked with an asterisk.

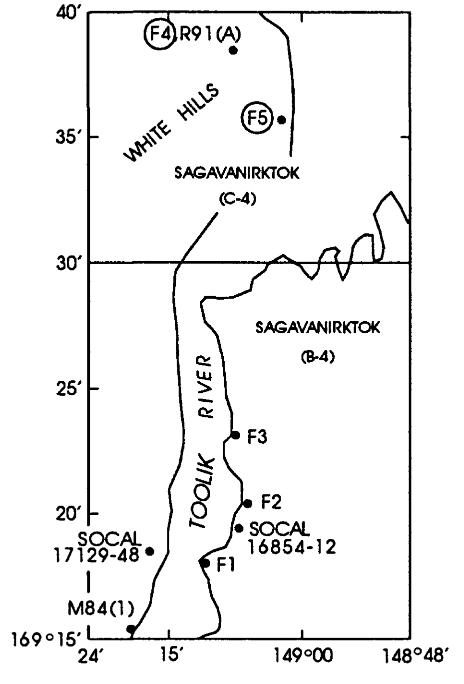

Figure 12. Location of samples examined from Locality 5, in the Toolik River-White Hills area (from Frederiksen and others, 1996); locations of samples reexamined for this report are circled.

The most significant taxa found in sample R4962A (fig. 12, Locality F5) are *Rhoipites latus* (of Rouse, 1977), *Tsuga*, *Diervilla* sp., and *Momipites wyomingensis*. Rouse (1977) showed *Rhoipites latus* as being known only from the lower and middle Eocene in the Arctic, but McIntyre did not list this species in his papers; therefore, the true range of this species in the Arctic is not very well known. McIntyre (1991) found that *Tsuga* ranges down into the upper Paleocene, though only as rare specimens; unfortunately, Rouse (1977) did not show *Tsuga* at all in his range chart for the Arctic. *Diervilla* sp. is known only from the upper Paleocene and lower Eocene (Ioannides and McIntyre, 1980; McIntyre, 1991; Kalkreuth and others, 1993). *Momipites wyomingensis* is thought to range up only to the top of the Paleocene on both Axel Heiberg and Ellesmere Islands (McIntyre, 1991; Kalkreuth and others, 1993), but it occurs in Eocene samples from the North Slope of Alaska (Frederiksen and others, 1996; this report). In summary, sample R4962A could be either upper Paleocene or lower Eocene, but (1) it lacks Eocene taxa such as *Liquidambar, Juglans, Ilex,* and especially the more or less ubiquitous Eocene genus *Intratriporopollenites*, and (2) taxa ranging from upper Paleocene to lower Eocene are so rare in the sample that most of them were not found in the first analysis (Frederiksen and others, 1996); therefore, the sample seems most likely to be upper Paleocene.

The most significant taxa found in sample R4961D (fig. 12, locality F4) are *Caryapollenites imparalis, Momipites wyomingensis,* and *Tricolpites* sp. A. The first two of these range through the middle and upper Paleocene and even up into the Eocene. *Tricolpites* sp. A is so far known only from the lower and middle(?) Eocene of Franklin Bluffs on the Sagavanirktok River (Frederiksen and others, 1996), but the range of the species is poorly known. Based mainly on the lack of taxa thought to be confined to the upper Paleocene and Eocene, this sample seems most likely to be middle Paleocene.

Table 7. Distribution of pollen taxa in two samples from Locality 5 (Toolik River-White Hills). X, present; P, probably present; R, considered to be reworked from the Cretaceous. Taxa found during a reexamination of the assemblages are marked with an asterisk.

Taxon	R4961D	R4962A
Alnus sp.	X	X
Aquilapollenites reticulatus		R
Aquilapollenites trialatus		R
Betulaepollenites spp.	X	
Caryapollenites imparalis	X	
Cercidiphyllum sp.		X*
Diervilla sp.		X
Ericaceae		X
Expressipollis types		R
Momipites wyomingensis	X*	X*
Paraalnipollenites alterniporus type H	X	X
Paraalnipollenites alterniporus type Z		X
Pterocarya sp.		X
Quercoidites sp.		X*
Retitrescolpites sp. aff. *R. anguloluminosus*	X	
Rhoipites latus type of Rouse (1977)		X*
Striate, spheroidal tricolporate with large ora		X*
Triatriopollenites spp.	X	X
Tricolpites sp. 1	P*	
Triporopollenites megagranifer	X	X
Triporopollenites mullensis	X	X
Trivestibulopollenites spp.	X	
Tsuga sp.		X*
Ulmipollenites krempii	X	X
Ulmipollenites tricostatus	X	X
Ulmipollenites undulosus	?	X

Locality 6, Mobil West Staines State #1 Well

The Mobil West Staines State #1 well (also known as the West Staines State 18-9-23 well) is near the northwest corner of the Arctic National Wildlife Refuge (fig. 1), in the Flaxman Island (A-4) quadrangle. The location is sec. 18 T9N R23E, lat 70°08'15" N, long 146°23'17" W, kelly bushing elevation 63 ft, drilled to a total depth of 13,329 ft (Bird, 1982). Casing was set at 300, 2,110, 10,080, and 13,000 ft (P. H. Nelson, oral commun., 1997).

Figure 13 shows the gamma-ray and resistivity logs, lithologic and geochronologic units, and interpreted depositional facies of strata in this well. Bujak and Davies (in press) picked the top of the Paleocene at 7,860 ft, which, in this well, coincides with the top of the Staines Tongue of the Sagavanirktok Formation. For the present report, palynology slides of ditch samples from 7,860 to 10,140 ft, and core samples from 7,749-7,763 and 10,631-10,670 ft, were studied to compile lists of taxa present at the various levels in order to compare these assemblages with those from Arctic Canada and from the North Slope of Alaska. Table 8 shows the distribution of stratigraphically significant pollen taxa in 13 ditch samples between 7,860 and 9,420 ft in the well. Ditch samples between 9,420 and 10,140 ft contained very little angiosperm pollen, and the same was true of the core samples from 7,749-7,763 and 10,631-10,670 ft.

Following common practice among palynologists, Bujak and Davies (in press) picked the top of the Paleocene in this well at the uppermost occurrence of *Paraalnipollenites alterniporus*. This species occurs throughout the sampled interval of 7,860-9,420 ft in the well; therefore, it is not listed in table 8. This interval lies stratigraphically between the casing points of 2,110 and 10,080 ft; therefore, Eocene material was free to fall down the hole thoughout the interval.

As noted previously, taxa that range from upper Paleocene to Eocene cannot be used to define the upper Paleocene in ditch samples. Therefore, only the presence of *Insulapollenites rugulatus* (fig. 11) indicates that upper Paleocene strata are present in the well section (in the sense of a tripartite subdivision of the Paleocene), but the presence of several other taxa indicates the presence of upper Paleocene in the sense that "upper Paleocene" includes middle and upper Paleocene of the tripartite subdivision. As summarized by Norris (1997), *Paraalnipollenites alterniporus* has its actual range top in the middle(?) part of the lower Eocene, so that the upper part of the *Paraalnipollenites* Zone of Norris is of early Eocene age. However, as mentioned above, the highest observed occurrence of this species in the present well is at 7,860 ft (Bujak and Davies, in press) and the highest observed occurrence of the late Paleocene species *Insulapollenites rugulatus* is at 7,890-8,100 ft (table 8). Thus, it appears that the upper part (the lower Eocene part) of the *Paraalnipollenites* Zone is very thin or missing altogether in the West Staines State #1 well.

Bujak and Davies (in press) assigned the interval of 10,620-12,450 ft to the lower Paleocene based on occurrences of several dinocyst species that are known to be restricted to, or have range tops within, the lower Paleocene. However, from the point of view of pollen data, samples below 8,820 ft, which have very low angiosperm pollen diversities, could already be assigned to the lower Paleocene.

Comments may be made about several taxa listed in table 8:

1. *Caprifoliipites* B and *Lanagiopollis* sp. cf. *L. cribellatus* have been reported only from the Eocene in the North American Arctic (Rouse, 1977; McIntyre, 1991). In the samples we studied from the well, these specimens are presumably contaminants from uphole.
2. The same may also be true of *Pseudoplicapollis* sp. aff. *P. limitatus* and *Rhoipites angustus*, which apparently have not been reported from the Canadian Arctic but which have been found in the Eocene of the North Slope (Frederiksen and others, 1996, table 6). However, it is possible that these species do range down into the upper Paleocene.

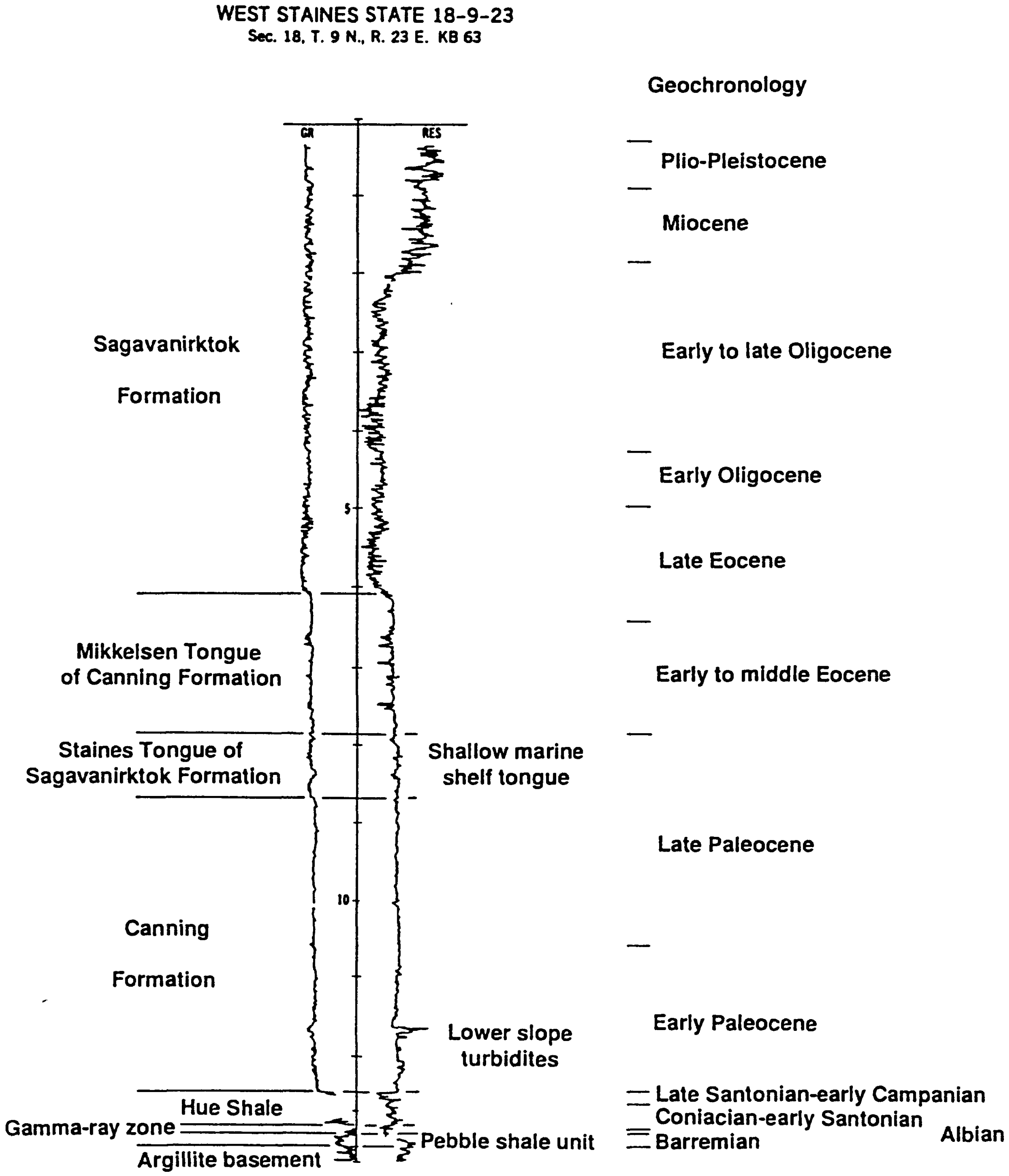

Figure 13. Gamma-ray and resistivity logs, lithologic and geochronologic units, and interpreted depositional facies of strata in the Mobil West Staines State #1 well (also known as the West Staines State 18-9-23 well; Locality 6), taken from Bird and Molenaar (1987, pl. 1). Geochronology is from Bujak and Davies (in press) and was based on palynomorphs from cuttings. GR = gamma-ray log; RES = resistivity log; KB = elevation of kelly bushing. 5 and 10 are thousands of feet depth.

3. As noted in the Introduction to "Palynology of the Paleocene to Middle Eocene," the range top of *Momipites ventifluminis* was taken by Kalkreuth and others (1993) to define, in part, the top of the Paleocene on Ellesmere Island (fig. 4). This species ranges from the middle to the upper part of the Paleocene in the Western Interior (Nichols and Ott, 1978).
4. *Momipites anellus* was reported only from the middle Paleocene and lowermost part of the upper Paleocene in the Canadian Arctic (fig. 11) but ranges to the top of the Paleocene in the Western Interior (Nichols and Ott, 1978).

Table 8. Distribution of stratigraphically significant pollen taxa in 13 ditch samples from the Mobil West Staines State #1 well. P = probable.

	7,860-7,980'	7,980-8,100'	8,100-8,220'	8,220-8,340'	8,340-8,460'	8,460-8,580'	8,580-8,700'	8,700-8,820'	8,820-8,940'	8,940-9,060'	9,060-9,180'	9,180-9,300'	9,300-9,420'
Rhoipites angustus	X	X											
Momipites wyomingensis	X	X	X					X	X			X	
Caryapollenites imparalis	X	X	X	X	X			X					X
Momipites ventifluminis	X												
Lanagiopollis sp. cf. *L. cribellatus*		P				X		P					
Carya <29µm		X											
Insulapollenites rugulatus		X	X				X	X					
Momipites anellus		X	X										
Pseudoplicapollis sp. aff. *P. limitatus*			X		X	X	X						
Caprifoliipites B			X				X	X					
Tsuga								X					
Caryapollenites inelegans								X					

Locality 7, Mobil et al. West Kadleroshilik Unit #1 Well

This well is located in Sagavanirktok (D-3) quadrangle, about 2 km east-northeast of locality A5 of Frederiksen and others (1996) (fig. 14). The location is sec. 14 T5N R14E, lat 69°46'59" N, long 148°35'12" W, kelly bushing elevation 909 ft, drilled to a total depth of 4,566 ft; casing was set at 65, 308, 1,228, and 2,294 ft; and strata at a depth of about 700 ft in the well should be at about the level of the Sagavanirktok River, that is, equivalent to the base of the Eocene sections measured by Fouch, Collett, and Carter (Fouch and others, 1993; Frederiksen and others, 1996) in the Franklin Bluffs to the west of the well (Bird, 1982 and written commun., 1997). In the area of the Sagavanirktok River (Molenaar and others, 1986, locality 32), Maastrichtian and Paleocene strata were assigned to the Sagavanirktok Formation, but Eocene strata did not crop out as far south as locality 32 (Arco Nora Federal #1 well).

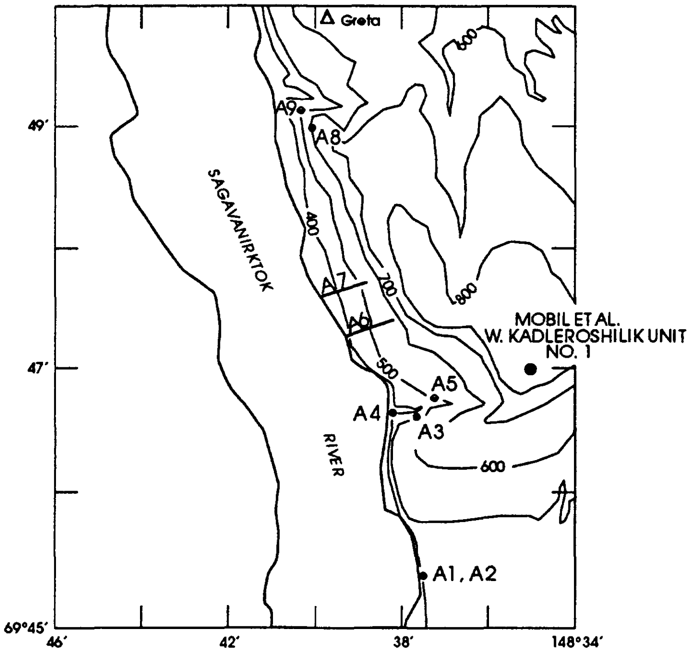

Figure 14. Location of Locality 7, the Mobil et al. West Kadleroshilik Unit #1 well (modified from Frederiksen and others, 1996, fig. 4). A1 to A9 are localities of Frederiksen and others (1996).

For this report, 20 samples of washed cuttings from the West Kadleroshilik Unit #1 well were examined for pollen, from the interval between 480 and 4,566 ft. Some of these had been processed by Ager in 1985, but most were processed by Frederiksen in 1997. Six samples were barren of angiosperm pollen or nearly so, from 1,290-1,320, 1,350-1,410, 2,610-2,640, 3,270-3,300, 3,830-3,860, and 4,490-4,520 ft.

Table 9 shows the distribution of stratigraphically significant pollen taxa in the West Kadleroshilik well. The uppermost occurrence, and uppermost consistent occurrence, of *Paraalnipollenites alterniporus* are found in the sample from 990-1,050 ft; therefore, it may be that this is the top of the Paleocene in the well. However, this species also occurs with some consistency throughout the outcropping lower and middle(?) Eocene strata at Franklin Bluffs. Therefore, it is difficult to pick the exact top of the Paleocene in the West Kadleroshilik well. A distinct dropoff of strictly Eocene and middle or upper Paleocene to Eocene pollen taxa (*Intratriporopollenites* sp. 1, *Momipites wyomingensis*, *Caryapollenites imparalis*, *C. inelegans*, *Nyssapollenites* sp. 2) occurs below the casing point at 1,228 ft. Because of the very low pollen diversities below 1,228 ft, the entire section at least from that depth to total depth at 4,566 ft may be lower Paleocene, except that *Pistillipollenites mcgregorii* at 1,530-1,590 ft is not known to range below the upper Paleocene. Therefore, there are several possible interpretations of these pollen distribution data: (1) part of the section below 1,228 ft may be upper Paleocene and simply has an anomalously low species diversity, or (2) the specimen of *Pistillipollenites mcgregorii* at 1,530-1,590 ft may represent a contaminant from uphole even though it occurs below the casing point at 1,228 ft. If this specimen is a contaminant, then there is no good evidence that any middle or upper Paleocene strata actually exist in the well section, because all occurrences of middle or upper Paleocene to Eocene taxa in the samples above casing could represent Eocene pollen either as indigenous specimens or as contaminants from uphole. If no middle or upper Paleocene strata exist in the well section, then Eocene strata rest directly on lower Paleocene strata in this area. There are few data from the Sagavanirktok River that can be used to evaluate the possibility of the presence or absence of middle and upper Paleocene strata in this area. In the Sagwon Bluffs area, two sections examined were no younger than early Paleocene (sections B1 and B2 of Frederiksen and others, 1996) and a third section, B3 of these authors, was found to be questionably late Paleocene in age.

Table 9. Distribution of stratigraphically significant pollen taxa in 14 ditch samples from Locality 7, the Mobil et al. West Kadleroshilik Unit #1 well. P = probable; Q = possible.

	480-510'	960-990'	990-1,050'	1,050-1,110'	1,110-1,200'	1,200-1,290'	1,410-1,470'	1,470-1,530'	1,530-1,590'	1,890-1,950'	2,340-2,430'	3,000-3,090'	4,010-4,070'	4,520-4,566'
Sample R3587	A	D	BA	BB	BC	BD	BF	BG	BH	AB	AC	AD	AE	AF
Tsuga	X													
Momipites wyomingensis	X				X	X								
Caryapollenites imparalis	X		X		X	X								
Caryapollenites inelegans	X		X		X									
Triatriopollenites spp.	X	X	X	X	X	X	X	X						
Trivestibulopollenites spp.	X													
Casuarinidites/Subtriporopollenites sp.	X	X												
Triporopollenites mullensis	X	X	X	X	X	X	X	X	X	X	X	X	X	X

Ulmipollenites undulosus	X		X	X	X	X			X	X	X		X	X
Pterocarya	X		X			X								
Alnus	X	X	X	X	X	X	X							
Liquidambar type 1	X													
Tricolporopollenites A of Rouse (1977)	X													
Intratriporopollenites sp. 1	X		X	X	X	X								
Intratriporopollenites sp. 3	X													
Bombacacidites nacimientoensis	X													
Bombacacidites sp. 1 of Frederiksen (1983)	X													
Basopollis obscurocostatus	P													
Novemprojectus? sp.	X													
Reworked Late Cretaceous pollen	X		X	X	X	X	X		X	X	X	X		
Rhoipites angustus		X		X										
Nyssapollenites sp. 2		X				X								
Ulmipollenites tricostatus			X	X	X	X			X					
Paraalnipollenites alterniporus type H			X	Q	X		Q	X	X	X	X	X		X
Cercidiphyllum			Q	P							Q			
Aquilapollenites tumanganicus			X											
Caryapollenites veripites <29µm				P										
Pistillipollenites mcgregorii					X	X			X					
Betulaepollenites sp.					X									
Ulmipollenites krempii							X							

Locality 8, Marsh Creek Anticline

Five Eocene or questionably Eocene samples collected from the Marsh Creek anticline area (fig. 15) by C. M. Molenaar in 1983 were processed for palynomorphs by Ager, and four of these samples produced good assemblages (tables 10, 11).

Sample R3621 is from Carter Creek and is near locality 2 of Palmer and others (1979) and Lyle and others (1980); sample R3621 and locality 2 are so close to each other that no separate data point is shown for locality 2 in figure 15. Sample R3621 and locality 2 are within the Sagavanirktok Formation

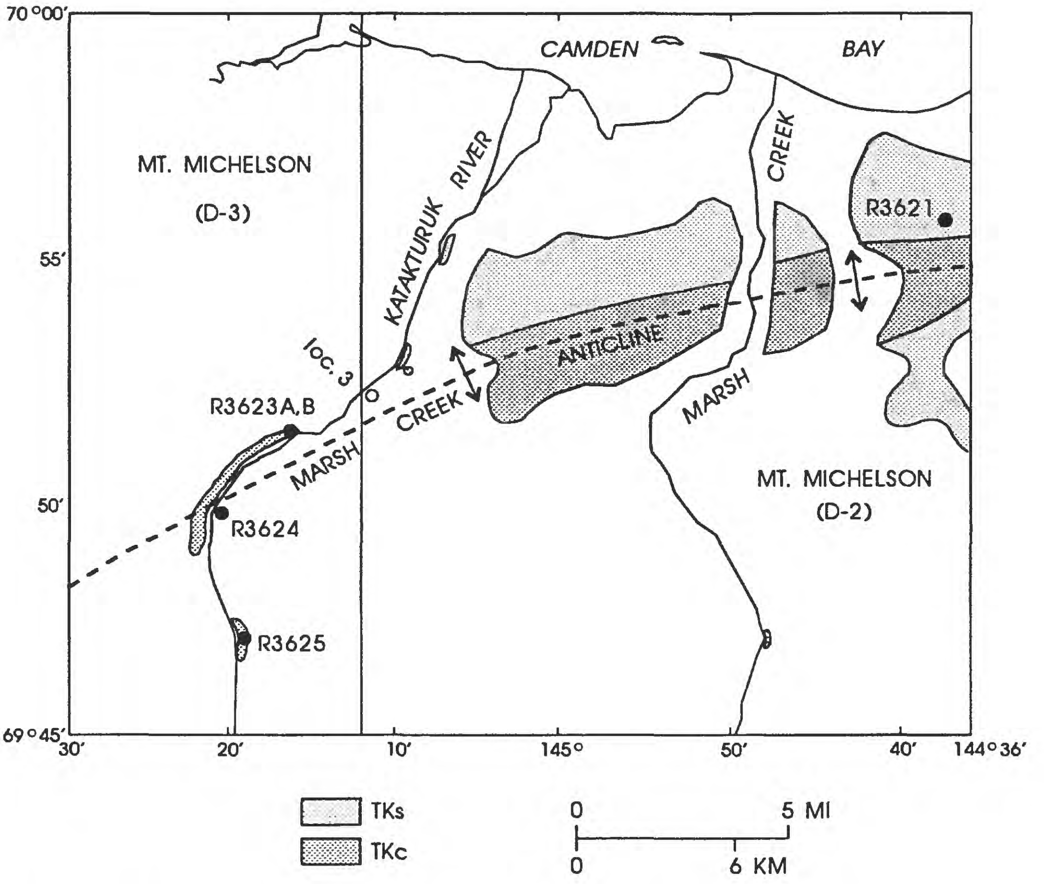

Figure 15. Location of samples examined from Locality 8, the Marsh Creek anticline. Outcrops from Bader and Bird (1986): TKs = "Sagavanirktok Formation (Tertiary and Cretaceous)--Poorly consolidated gray siltstone, mudstone, sandstone, and lesser amounts of conglomerate.... Nonmarine and shallow-marine deposits." TKc = "Canning Formation.... Gray shale and siltstone containing interbeds of mostly thin-bedded, very fine to fine-grained lithic sandstone (turbidites).... Deep-water marine deposits.... Age is Cretaceous and early Tertiary." Samples with R-numbers were analyzed for this report. Localities 2 and 3 of Lyle and others (1980) are discussed in the text; locality 2 essentially coincides with R3621 and therefore is not shown as a separate data point.

outcrop area in the map of Bader and Bird (1986). Locality 2 was found by palynological analysis to have an Eocene age and a marine environment of deposition. Locality 2 was assigned by Palmer and others (1979) and Lyle and others (1980) to the Sagwon Member of the Sagavanirktok Formation, but considering the age and depositional environment of the sample, it presumably should be assigned to the Franklin Bluffs Member of the Sagavanirktok Formation (fig. 2).

Samples R3623A, R3623B, R3624, and R3625 were from southwest of locality 3 of Palmer and others (1979) and Lyle and others (1980). Locality 3 was not paleontologically dated but was assigned by Lyle and others (1980) to the Sagavanirktok Formation. Samples R3623A, R3623B, R3624, and R3625 are within the Canning Formation outcrop area in the map of Bader and Bird (1986).

All four analyzed assemblages in table 10 are Eocene in age. They are similar to assemblages from Franklin Bluffs (fig. 14, Localities A1-A9) that were dated by Ager and others (1986) and Frederiksen and others (1994, 1996) as being early and middle(?) Eocene. All four samples contain dinocysts, but the ages of these have not been determined; therefore, it is not known whether they are autochthonous (indicating marine depositional environments) or might be reworked.

Table 10. Samples processed for palynomorphs from Locality 8, Marsh Creek anticline area. Latitude and longitude were calculated from locations plotted by Molenaar on quadrangle maps. In the Pollen Analysis column, A means an analysis was completed, and P means palynomorphs were present but preservation was too poor for an analysis to be made.

Palynology number	Field number	Latitude and longitude	Location and stratigraphic unit	Pollen analysis
R3621	83-AMK-25	69°55.66' 144°37.35'	Mt. Michelson (D-2) quadrangle, east end of Marsh Creek anticline, sec. 27 T7N R30E, marine Eocene shale	A
R3623A	83-AMK-33A	69°51.68' 145°16.36'	Mt. Michelson (D-3) quadrangle, north side of Katakturuk River, sec. 24 T6N R27E, marine Eocene shale	P
R3623B	83-AMK-33B	do.	do.	A
R3624	83-AMK-34	69°50.14' 145°21.00'	Mt. Michelson (D-3) quadrangle, Katakturuk River, Marsh Creek anticline axis, sec. 34 T6N R27E, marine Eocene shale	A
R3625	83-AMK-35	69°47.47' 145°18.92'	Mt. Michelson (D-3) quadrangle, east side of Katakturuk River south of Marsh Creek anticline, sec. 14 T5N R27E, marine Eocene(?) shale	A

Table 11. Distribution of pollen taxa in four samples from Locality 8, in the Marsh Creek anticline area. Samples run from south on the left to north and northeast on the right (fig. 15). X, present; A = aff., specimen is similar to but probably is not the same species as the species listed; C = cf., specimen is similar to and may belong to the species listed; P = identification probable; ?, identification uncertain.

Taxon	Sample			
	R3625	R3624	R3623b	R3621
Tsuga		X		X
Triatriopollenites spp.				X
Trivestibulopollenites spp.				P
Triporopollenites mullensis	X	X	X	X
Momipites wyomingensis	X	X	X	X
Momipites strictus			?	?
Carya <29 µm	X			X
Carya >28 µm		X	X	
Ulmipollenites krempii				X
Ulmipollenites undulosus		X	X	X
Pterocarya	X	?	P	X
Juglans		X		X
Alnus	X	X	X	X
Liquidambar type 1		X		
Quercoidites spp.		X		C
Cercidiphyllum			X	
Tricolpites sp. 1			P	
Prolate quercoid tricolporates		X		X
Rhoipites angustus type		X		
Aff. *Rhoipites angustus* (apparently psilate)	X			
Nyssapollenites sp. 1			X	
Nyssapollenites sp. 2				X
Intratriporopollenites sp. 1	X	X	X	X
Intratriporopollenites sp. 2	X			X
Intratriporopollenites sp. 3		X	X	
Bombacacidites paulus	X			
Bombacacidites fereparilis	X			
Nudopollis terminalis				A
Dinocysts (reworked?)	common	sparse	sparse	abundant
Reworked Cretaceous pollen		X	X	X

Locality 9, Jago River

Seven Eocene samples, collected from the west bank of the Jago River by C. M. Molenaar in 1980 and 1983, were processed for palynomorphs by Ager. All the samples were within several kilometers of one another in Demarcation Point (D-4) quadrangle (fig. 16). Figure 16 shows that all of the samples came from outcrops mapped as Cretaceous and Tertiary Canning Formation. Sample R3609 is close to locality 20 of Palmer and others (1979) (= locality 22 of Lyle and others, 1980), which in these reports was dated palynologically as Eocene with sparse reworked Cretaceous palynomorphs. Six of the seven samples of figure 16 had at least a small to moderate recovery of pollen taxa, but the preservation was not particularly good (tables 12, 13). Samples R3607A, R3607B, R3609, R3619A, and R3619B are all Eocene in age. Although the observed diversities are rather small, and most of the taxa in the upper half of table 13 are more typically Paleocene than Eocene, taxa such as *Tsuga*, *Juglans*, *Quercoidites*, *Verrutricolporites*, *Ilexpollenites*, *Rhoipites angustus* type, *Intratriporopollenites* sp. 3, and *Novemprojectus* are good markers for the lower and middle(?) Eocene. Sample R3620A contained practically no angiosperm pollen at all, and R3620B does not contain any pollen taxa definitive for the Eocene, although *Intratriporopollenites* sp. 1 is mainly confined to Eocene and younger rocks. All seven samples contain dinocysts, but these fossils have not been studied to determine their ages and whether they are autochthonous or might be reworked.

The outcrop south of the inferred fault in figure 16, mapped as Hue Shale in Bader and Bird (1986), was found on the basis of palynomorphs to be marine Late Cretaceous (locality 21 of Palmer and others, 1979 = locality 23 of Lyle and others, 1980).

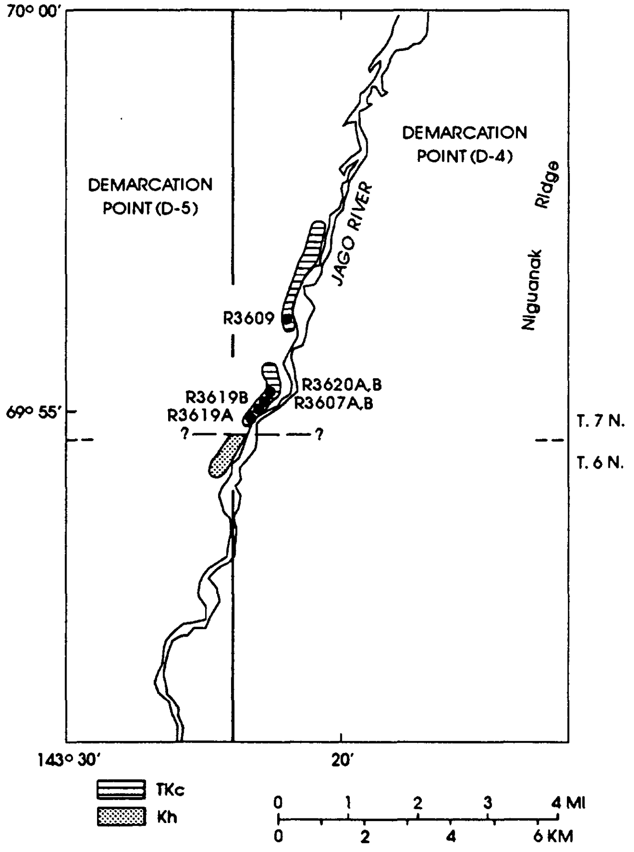

Figure 16. Location of samples examined from Locality 9, along the Jago River. Map of outcrops and fault is from Bader and Bird (1986). TKc = "Canning Formation (Tertiary and Cretaceous)"; Kh = "Hue Shale (Cretaceous)."

Table 12. Samples processed for palynomorphs from Locality 9, along the Jago River. Latitude and longitude were calculated from locations plotted by Molenaar on a quadrangle map. In the Pollen Analysis column, A means an analysis was completed.

Paly-nology number	Field number	Latitude and longitude	Location and stratigraphic unit	Pollen analysis
R3607A	80-AMK-71A	69°55.13' 143°22.46'	Demarcation Point (D-4) quadrangle, Jago River, sec. 34 T7N R35E, petroliferous shale	A
R3607B	80-MK-71B	do.	do.	A
R3609	80-AMK-87	69°56.14' 143°21.75'	Demarcation Point (D-4) quadrangle, lower Jago River, sec. 27 T7N R35E, Eocene shale (Canning Formation)	A
R3619A	83-AMK-21B	69°54.97' 143°23.01'	Demarcation Point (D-4) quadrangle, Jago River, sec. 34 T7N R35E, Eocene shale	A
R3619B	83-AMK-21C	69°55.05' 143°22.61'	do.	A
R3620A	83-AMK-22A	69°55.09' 143°22.53'	do.	A
R3620B	83-AMK-22B	69°55.13' 143°22.46'	do.	A

Table 13. Distribution of palynomorphs in seven samples from Locality 9, along the Jago River. X = present; P = identification probable; ? = identification uncertain. As regards preservation, F = fair; G = good; P = poor. As regards dinocysts, R = rare; S = sparse.

Taxon	Sample (R36---)						
	O7A	07B	09	19A	19B	20A	20B
Preservation	F	F-G	F-G	F-G	F	F-P	F-P
Tsuga	X			X	X		
Trivestibulopollenites spp.	X						
Triatriopollenites spp.	X	?	X	X			?
Triporopollenites mullensis	X	X	X	X	X		P
Paraalnipollenites alterniporus type H	?	X			X		X
Carya <29 µm	X		X		X		
Caryapollenites imparalis				X	X		
Ulmipollenites krempii	P						
Ulmipollenites undulosus	X	X					
Pistillipollenites mcgregorii				X			
Alnus	X	X	X	X	X	X	X
Pterocarya	X	X	X	X	X		X
Juglans				X			
Cercidiphyllum					P		
Quercoidites spp. (including verrucate forms)	X	X	X	X			
Verrutricolporites	X						
Ilexpollenites					X		
Tricolpites sp. 1		P					
Rhoipites angustus type		X					
Intratriporopollenites sp. 1	X	X	X	X			X
Intratriporopollenites sp. 3				X			
Novemprojectus sp.			X				
Dinocysts (reworked?)	R	S	S	S	S	S	S
Reworked Cretaceous pollen	X			X			X

SUMMARY AND CONCLUSIONS

This report provides palynological data and age interpretations for six outcrop areas (Ivishak River, Echooka River, Shaviovik anticline, Toolik River-White hills, Marsh Creek anticline, and Jago River) and parts of four well sections (the Arco Ugnu SWPT-1 well, the Arco West Sak River #23 well, the Mobil West Staines State #1 well, and the Mobil et al. West Kadleroshilik Unit #1 well) on the North Slope of Alaska. The described pollen assemblages are Maastrichtian to Eocene in age. Emphasis has been placed on the questions of (1) whether a distinct unconformity exists at the Cretaceous-Tertiary boundary, at least in some places, and (2) whether upper Paleocene strata exist on the North Slope, and if so, where. Following is a summary of results and conclusions:

1. The Arco Ugnu SWPT-1 well section, in the Kuparuk River Unit, is of great importance because it is the only section (now) publicly known from the North Slope of Alaska that crosses the Cretaceous-Tertiary (K-T) boundary and has been studied on the basis of closely-spaced core samples. In this section, a new, latest Maastrichtian subzone of the *Wodehouseia spinata* Assemblage Zone is proposed. The K-T boundary in the core could be picked very precisely using the abrupt Terminal Cretaceous Extinction Event, which compares well with the event in a well-described outcrop section in the Northwest Territories that has an iridium anomaly at the boundary. If an unconformity is present at the K-T boundary in the Kuparuk River Unit core, it is probably a minor one at least with regard to the loss of Cretaceous strata. Composited ditch samples from the Arco West Sak River #23 well, also in the Kuparuk River Unit, allow the stratigraphic position of the K-T boundary to be easily picked, but pollen taxon diversities, especially in the Upper Cretaceous, are only a small fraction of the diversities present in the core and outcrop samples that cross the boundary.

2. Some samples collected in 1994 near the K-T boundary along the Ivishak River had previously been examined for pollen (Frederiksen and others, 1996), but those samples had yielded ambiguous age determinations. Additional samples from the 1994 field season have now been examined, and some of these have provided reasonably good late Maastrichtian and early Paleocene dates. However, given the large stratigraphic distances between the samples, it cannot be determined whether the uppermost Maastrichtian is missing by unconformity. This local section along the Ivishak River becomes younger to the south, in agreement with field observations that local folding produces southward dips.

3. Samples collected in 1994 along the Echooka River were found to be late but not necessarily latest Maastrichtian in age.

4. Samples collected in 1994 from the Shaviovik anticline area, and examined by Frederiksen and others (1996), had yielded only Paleocene ages. Here we present pollen analyses of samples collected by Ager in 1984, and these are late but not necessarily latest Maastrichtian in age, and early Paleocene.

5. The lower Paleocene has an extremely low angiosperm pollen diversity. Although the diversity slowly increases upward, the lower Paleocene cannot at present be subdivided into pollen zones. As a result, it is impossible to determine whether any of the lowermost Paleocene is missing at the K-T boundary at any particular locality.

6. A range chart is compiled for pollen distributions from the middle Paleocene to the lower Eocene in the Canadian Arctic based on published sources. Two samples from the Toolik River-White Hills that had been examined by Frederiksen and others (1996) were re-analyzed and, using this chart, could be dated as probably late Paleocene and probably middle Paleocene, respectively.

7. Ditch samples between 7,860 and 9,420 ft were analyzed from the Mobil West Staines State #1 well, just west of ANWAR, and it is demonstrated that upper Paleocene strata (in the sense of a tripartite subdivision of the Paleocene) are present in the well section.

8. Ditch samples between 480 and 4,566 ft were analyzed from the Mobil et al. West Kadleroshilik Unit #1 well, a short distance east of Franklin Bluffs on the Sagavanirktok River. The presence of upper Paleocene strata (in the sense of including middle and upper Paleocene strata of a tripartite subdivision of the Paleocene) could not be demonstrated in this well section; thus, it is possible but not demonstrable that Eocene rocks rest directly on lower Paleocene rocks in this area. Analysis of this well section demonstrates the importance of taking into account the casing points, because below these points there is an abrupt decrease in uphole contamination.

9. The middle and upper Paleocene interval is not easy to recognize unless pollen species rather than genera are tabulated, and unless considerable effort is expended in scanning slides. The apparent rarity of known middle and upper Paleocene strata in outcrops on the North Slope could be explained in part if this interval were shaley and therefore not well exposed. This interval is difficult to recognize in ditch samples that have Eocene contamination from uphole. Finally, the middle and upper Paleocene may be thin or may be missing altogether by unconformity in some areas.

10. In working with ditch samples, consulting palynologists pick the top of the Paleocene at the uppermost occurrence or uppermost consistent occurrence of *Paraalnipollenites alterniporus* (= *P. confusus* of some authors). Abundant evidence now exists that this species actually ranges up into the lower Eocene, but it is sparse in the Eocene, moderately abundant in the upper Paleocene (of the Toolik River-White Hills area) and increasingly more abundant in stratigraphically lower samples within the Paleocene. Therefore, the practice of palynologists in basing their pick of the top of the Paleocene on occurrences of *Paraalnipollenites alterniporus* produces only an approximately dated correlation marker.

11. Samples collected by C. M. Molenaar in the 1980s from the Marsh Creek anticline and the Jago River are shown to contain pollen assemblages similar to those of early to middle(?) Eocene age in the Franklin Bluffs of the Sagavanirktok River.

Table 14. Annotated list of taxa cited in this report.

Alnus spp.
Aquilapollenites sp. aff. *A. abscisus* Chlonova 1961 of Frederiksen et al. (1988)
Aquilapollenites alaskensis Frederiksen 1991
Aquilapollenites amplus Stanley 1961
Aquilapollenites sp. cf. *A. augustus* Srivastava 1969 of Frederiksen (1991)
Aquilapollenites conatus Norton 1965
Aquilapollenites delicatus Stanley 1961
Aquilapollenites sp. aff. *A. funkhouseri* Srivastava 1966
Aquilapollenites fusiliformis B. D. Tschudy 1969
Aquilapollenites granobaculus Song in Song et al. 1981[1]
Aquilapollenites immiser Sweet 1986
Aquilapollenites sp. aff. *A. polaris* Funkhouser 1961
Aquilapollenites quadricretaeus Chlonova 1961
Aquilapollenites quadrilobus Rouse 1957 *sensu* B. D. Tschudy and Leopold (1971)
Aquilapollenites rectus B. D. Tschudy 1969
Aquilapollenites reticulatus (Mchedlishvili in Samoilovich & Mchedlishvili 1961) B. D. Tschudy & Leopold 1971
Aquilapollenites sp. cf. *A. spinulosus* Funkhouser 1961
Aquilapollenites tumanganicus Bolotnikova (1973)
Aquilapollenites sp. aff. *A. tumanganicus*[2]
Aquilapollenites unicus (Chlonova 1957) Chlonova 1961
Aquilapollenites pseudosenonicus (Frederiksen 1991) new comb.
Aquilapollenites trialatus Rouse 1957
Aquilapollenites sp. (*Mancicorpus* type)
Aquilapollenites spp.
Azonia pulchella Felix & Burbridge 1973
Basopollis obscurocostatus Tschudy 1975
Betulaepollenites spp.
Bombacacidites fereparilis Frederiksen 1983
Bombacacidites nacimientoensis (Anderson 1960) Elsik 1968
Bombacacidites paulus Frederiksen 1989
Bombacacidites sp. 1 of Frederiksen (1983)
Callistopollenites radiatostriatus (Mchedlishvili in Samoilovich & Mchedlishvili 1961) Srivastava 1969
Caprifoliipites B of Rouse (1977)
Carya viridifluminipites Wodehouse 1933
Carya <29 µm of Frederiksen and Christopher (1978)[3]
Caryapollenites imparalis Nichols & Ott 1978
Caryapollenites inelegans Nichols & Ott 1978
Caryapollenites veripites (Wilson & Webster 1946) Nichols & Ott 1978[3]
Caryapollenites spp. (Eocene types) [including *Carya* >28 µm of Frederiksen and Christopher (1978)]
Casuarinidites/Subtriporopollenites sp.
Cercidiphyllum spp.
Cranwellia striata (Couper 1953) Srivastava 1966
Cranwellia + *Striatellipollis*
Diervilla sp. of Frederiksen and others (1996)

Erdtmanipollis spp.
Ericaceae
Expressipollis types
Fibulapollis scabratus B. D. Tschudy 1969
Fibulapollis sp. 1
Ilex
Insulapollenites rugulatus Leffingwell 1970
Intratriporopollenites sp. 1 of Frederiksen and others (1994)
Intratriporopollenites sp. 2 of Frederiksen and others (1994)
Intratriporopollenites sp. 3 of Frederiksen and others (1994)
Intratriporopollenites spp.[4]
Jaingsupollis striatus Song in Song et al. 1980
Jaingsupollis, prolate species
Juglans
Kurtzipites annulatus Norton in Norton & Hall 1969
Kurtzipites circularis (Norton in Norton & Hall 1969) Srivastava 1981
Kurtzipites trispissatus Anderson 1960
Lanagiopollis sp. cf. *L. cribellatus* (Srivastava 1972) Frederiksen 1988
Liquidambar
Liquidambar type 1 of Frederiksen and others (1994)
Momipites anellus Nichols & Ott 1978
Momipites strictus Frederiksen & Christopher 1978
Momipites ventifluminis Nichols & Ott 1978
Momipites wyomingensis Nichols & Ott 1978
Myrtipites scabratus Norton in Norton & Hall 1969
Novemprojectus traversii Choi 1984
Novemprojectus sp.
Novemprojectus? sp.
Nudopollis terminalis (Pflug & Thomson in Thomson & Pflug 1953) Elsik 1968
Nyssapollenites sp. 1 of Frederiksen and others (1994)
Nyssapollenites sp. 2 of Frederiksen and others (1994)
Onagraceous pollen of Ioannides and McIntyre (1980)
Orbiculapollis globosus (Chlonova 1957) Chlonova 1961
Paraalnipollenites alterniporus (Simpson 1961) Srivastava 1975, type H of Frederiksen and others (1988)[5]
Paraalnipollenites alterniporus type Z of Frederiksen and others (1988)
Pistillipollenites mcgregorii Rouse 1962
Platycarya spp.
Porosipollis porosus (Mchedlishvili in Samoilovich & Mchedlishvili 1961) Krutzsch 1969
Proteacidites thalmannii Anderson 1960 and *P. thalmannii* complex
Proteacidites spp.
Pseudointegricorpus protrusum Takahashi & Shimono 1982
Pseudoplicapollis sp. aff. *P. limitatus* Frederiksen 1978
Pterocarya
Quercoidites spp.
Retitrescolpites sp. aff *R. anguloluminosus* (Anderson 1960) Frederiksen 1979
Rhoipites angustus Frederiksen 1980

Rhoipites angustus type
Rhoipites latus Frederiksen 1980 type of Rouse (1977)
Singularia aculeata Samoilovich in Samoilovich & Mchedlishvili 1961
Singularia sp.
Sparganiaceae
Tilia
Triatriopollenites spp.
Tricolpites sp. aff. *T. asper* Frederiksen 1978 of Frederiksen and others (1988)
Tricolpites sp. aff. *T. matauraensis* Couper 1953 of Frederiksen (1991)
Tricolpites sp. A
Tricolpites sp. 1 of Frederiksen and others (1996)
Tricolporopollenites kruschii (Potonié 1934) Thomson & Pflug 1953 of Elsik (1968)
Tricolporopollenites A of Rouse (1977)
Triporopollenites megagranifer (Potonié 1934) Thomson & Pflug 1953 type of Frederiksen and others (1988)
Triporopollenites mullensis (Simpson 1961) Rouse & Srivastava 1972
Trivestibulopollenites spp.
Tsuga
Ulmipollenites krempii (Anderson 1960) Frederiksen 1979
Ulmipollenites tricostatus (Anderson 1960) Frederiksen 1980
Ulmipollenites undulosus Wolff 1934
Verrutricolporites sp.
Wodehouseia edmontonicola Wiggins 1976
Wodehouseia fimbriata Stanley 1961 subsp. *constricta* Wiggins 1976
Wodehouseia gracile (Samoilovich in Samoilovich & Mchedlishvili 1961) Pokrovskaya 1966
Wodehouseia octospina Wiggins 1976
Wodehouseia quadrispina Wiggins 1976
Wodehouseia spinata Stanley 1961 (includes *Wodehouseia stanleyi* Srivastava 1966)
Wodehouseia vestivirgata Wiggins 1976
Wodehouseia wigginsii Frederiksen 1991

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[1] Zhou and Wang (1983) pointed out that in their new species *Aquilapollenites bibacillus*, the grana have blunt tips rather than being conate, and they are concentrated over the body and equatorial projections and less prominent at the poles, which is also true of the Alaskan specimens. They noted that *A. granobaculus* Song in Song et al. 1981 is very similar but has equatorial projections that are distinctly slimmer than the body. In the Alaskan specimens, the equatorial projections may be slimmer than the body or equal in width to that of the body; therefore, we have assigned the Alaskan specimens to *A. granobaculus*.

[2] In figure 11, the name *Aquilapollenites* sp. aff. *A. tumanganicus* refers to specimens termed *Aquilapollenites tumanganicus* Bolotnikova 1973 by McIntyre in various papers. As explained by Frederiksen and others (1996), these Canadian specimens do not belong to true *A. tumanganicus* but to a similar though different species that is here termed *Aquilapollenites* sp. aff. *A. tumanganicus*. In a recent paper, Norris (1997) illustrated three specimens that he referred to *Aquilapollenites tumanganicus* from the Beaufort-Mackenzie Basin. Two of the specimens belong to what we would term *Aquilapollenites* sp. aff. *A. tumanganicus*, but the third specimen may belong to what we would term *A.*

tumanganicus or may be transitional between what we consider to be true *A. tumanganicus* and what we would term *Aquilapollenites* sp. aff. *A. tumanganicus,* indicating the close morphological and apparently the close temporal relationship between these two species.

[3] *Caryapollenites veripites* (Wilson & Webster 1946) Nichols and Ott (1978), as described by Nichols and Ott, has a size range of 23-32µm, with a modal size of 29µm. However, in the Atlantic and Gulf Coastal Plains, it seems biostratigraphically worthwhile to separate specimens <29µm from those >28µm (e.g., Tschudy, 1973; Frederiksen, 1980), and that practice is continued in this report.

[4] Latest Paleocene and Eocene species of *Intratriporopollenites* are described by Frederiksen and others (1994, p. 28-29).

[5] The name *Paraalnipollenites alterniporus* (Simpson) Srivastava 1975 is a replacement for *P. confusus* (Zaklinskaya) Hills & Wallace 1969, the name used by Frederiksen and others (1994).

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