DEPARTMENT OF THE INTERIOR

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Palynomorph biostratigraphy of mid(?)-Campanian to upper Maastrichtian strata along the Colville River, North Slope of Alaska

By

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ABSTRACT

This study concerns a sequence about 3800 ft thick consisting of the mainly marine Sentinel Hill Member of the Schrader Bluff Formation and the mainly nonmarine Kogosukruk Tongue of the Prince Creek Formation, which intertongue with each other in the Colville River area and form the mid(?)-Campanian to upper Maastrichtian part of the Colville Group. The pollen biostratigraphy and chronostratigraphy presented here are based on the observed distribution of 103 angiosperm pollen taxa in 148 samples arranged to form 21 sample groups. Dinoflagellate cyst (dinocyst) chronostratigraphy is based on distributions of 20 species in 10 samples from the lower and middle parts of the Sentinel Hill Member and on dinocyst species found in 12 samples from strata below the Sentinel Hill. Because of the large number of pollen range tops and range bases, a reasonably fine-scaled biostratigraphic subdivision of the entire sequence is now possible, as demonstrated by a detailed pollen correlation of the lower part of the Kogosukruk Tongue between two stratigraphic sections, the outcropping section and the Sentinel Hill core test 1 section, about 8.0-12.5 mi apart. Chronostratigraphy is based here on pollen and dinocyst data integrated with published information from a large variety of other fossil types and from radiometric data. It is concluded that (1) the Campanian-Maastrichtian boundary is near the top of the middle part of the Sentinel Hill Member, slightly below the level where Smiley (1969) placed this boundary, and (2) the (informal) substage boundary between the lower and upper Maastrichtian is near the top of the middle part of the Kogosukruk Tongue, not far below the "Ocean Point marine beds," which represent the upper part of the Sentinel Hill Member. Thus, the "Ocean Point marine beds" are early late Maastrichtian in age. Dinocysts from below the Sentinel Hill Member demonstrate that the base of this member is mid(?)-Campanian in age. Given the chronostratigraphic conclusions, the 3800-ft thick section studied here consists of about 1315 ft of upper Maastrichtian strata, about 1525 ft of lower Maastrichtian strata, and about 960 ft of "middle" to upper Campanian strata.

INTRODUCTION

Mapping of sedimentary rocks on the North Slope of Alaska often requires paleontological data in order for the various stratigraphic units to be identified and correlated. The purposes of this report are to display the observed stratigraphic ranges of 103 mid(?)-Campanian to late Maastrichtian pollen taxa and 20 dinoflagellate cyst (here termed "dinocyst") taxa based on samples from along and near the Colville River; to use the pollen taxon range tops and bases to correlate between two sections of the sequence; and to integrate known pollen and dinocyst age information with published fossil and radiometric data from the area in order to place the boundaries between the Campanian and Maastrichtian Stages, and between the lower and upper Maastrichtian (informal) substages, in this area. The economic importance of these strata derives from the fact that correlative rocks in the West Sak Field, about 30 mi east of the Colville River, contain a multibillion-barrel accumulation of heavy oil.

Table 1 is a list of dinocyst taxa and their occurrences, table 2 is an annotated list of the samples and sample groups upon which the pollen and dinocyst occurrence presentations are based, and table 3 is a list of the pollen taxa mentioned in this report.

PREVIOUS WORK

Several reports have been published or open-filed on the pollen biostratigraphy of Upper Cretaceous strata on the North Slope outside of the areas of the Colville River and the National Petroleum Reserve in Alaska (NPRA; fig. 1) (e.g., Tschudy, 1969; Wiggins, 1976, 1981; Frederiksen and others, 1996, 1998). Upper Cretaceous rocks along the Colville River and in the NPRA have been intensively studied for decades by oil company and university as well as State and Federal geologists and paleontologists, but much of the biostratigraphic work has not been made available to the public. Pollen-stratigraphic articles dealing with this area that have been published or open-filed include those by Witmer and others (1981a, 1981b), Wiggins (1976, 1982), Mickey and Haga (1988), and Kimyai (1992). The present report summarizes the pollen-stratigraphic work along the Colville River that was begun by the writer and other U.S. Geological Survey (USGS) palynologists more than ten years ago. Most of our work published or open-filed thus far has concerned the upper Maastrichtian and the Paleocene (Frederiksen and others, 1986, 1988; Frederiksen, 1991), although an abstract (Frederiksen and Schindler, 1987) contained some biostratigraphic information about the Campanian. An additional article, by Frederiksen (1989), concerning Campanian and Maastrichtian palynology along the Colville River, was based on the biostratigraphic data contained in the present report but did not present these background data, being oriented primarily toward biological rather than biostratigraphic conclusions.

The paper by Frederiksen (1991), mentioned above, presented a detailed pollen biostratigraphy for the upper half of the Maastrichtian along the Colville River. These data are summarized in the present report.

Published articles on Late Cretaceous dinocysts from Arctic North America are mainly concerned with Arctic Canada, for example papers by Norford and others (1972), Felix and Burbridge (1973), McIntyre (1974, 1975, 1985), Doerenkamp and others (1976), and Ioannides and McIntyre (1980). Apparently the only published report on Late Cretaceous dinocysts from the North Slope of Alaska was by Kimyai (1992).

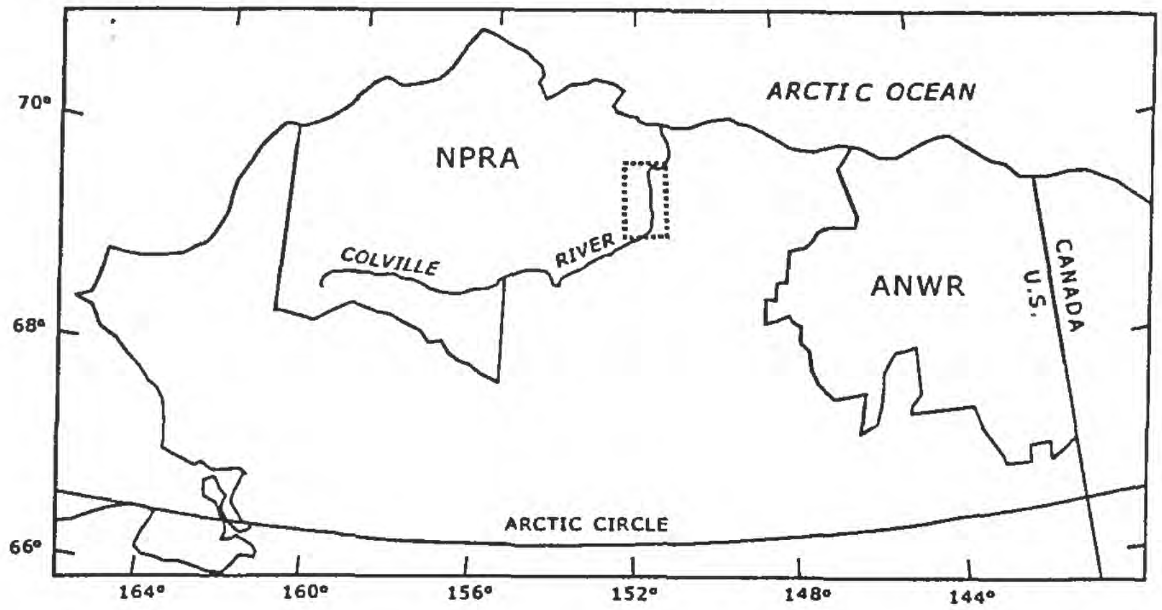


Figure 1. Index map showing locations of the Colville River, the National Petroleum Reserve in Alaska (NPRA), and the Arctic National Wildlife Refuge (ANWR). The box shows the area of figure 2.

Figure 2 (following page). Map showing locations of sample localities on the North Slope of Alaska that are discussed in this report. Geologic features from Brosgé and Whittington (1966). Numbers from 1 to 21 are locations of sample groups. X symbols mark locations of samples that are not included in the sample groups but are discussed in the text. Numbers accompanied by arrows identify locations of stations (individual measured sections) used by Brosgé and Whittington (1966) in compiling their composite measured section 14 along the Colville River below Umiat; the stations are on the west side of the river. Straight lines at north end of map are the three USGS seismic shothole lines that were sampled in the area. ARCO shothole samples 98, 97, and 266 (table 2) are east of the map area.

Stratigraphic units (disregarding Quaternary deposits; stratigraphic nomenclature is that of this report):

Kpk Kogosukruk Tongue of the Prince Creek Formation and the middle and upper parts of the Sentinel Hill Member of the Schrader Bluff Formation undifferentiated. Sample groups 18 and 19 include the uppermost portion of the lower part of the Sentinel Hill Member, the lower part of the Kogosukruk Tongue, and the lowermost portion of the middle part of the Sentinel Hill Member; the upper part of the Sentinel Hill Member makes up most of sample group 4.

Kss Lower part of the Sentinel Hill Member of the Schrader Bluff Formation.

Ksb Barrow Trail Member of the Schrader Bluff Formation.

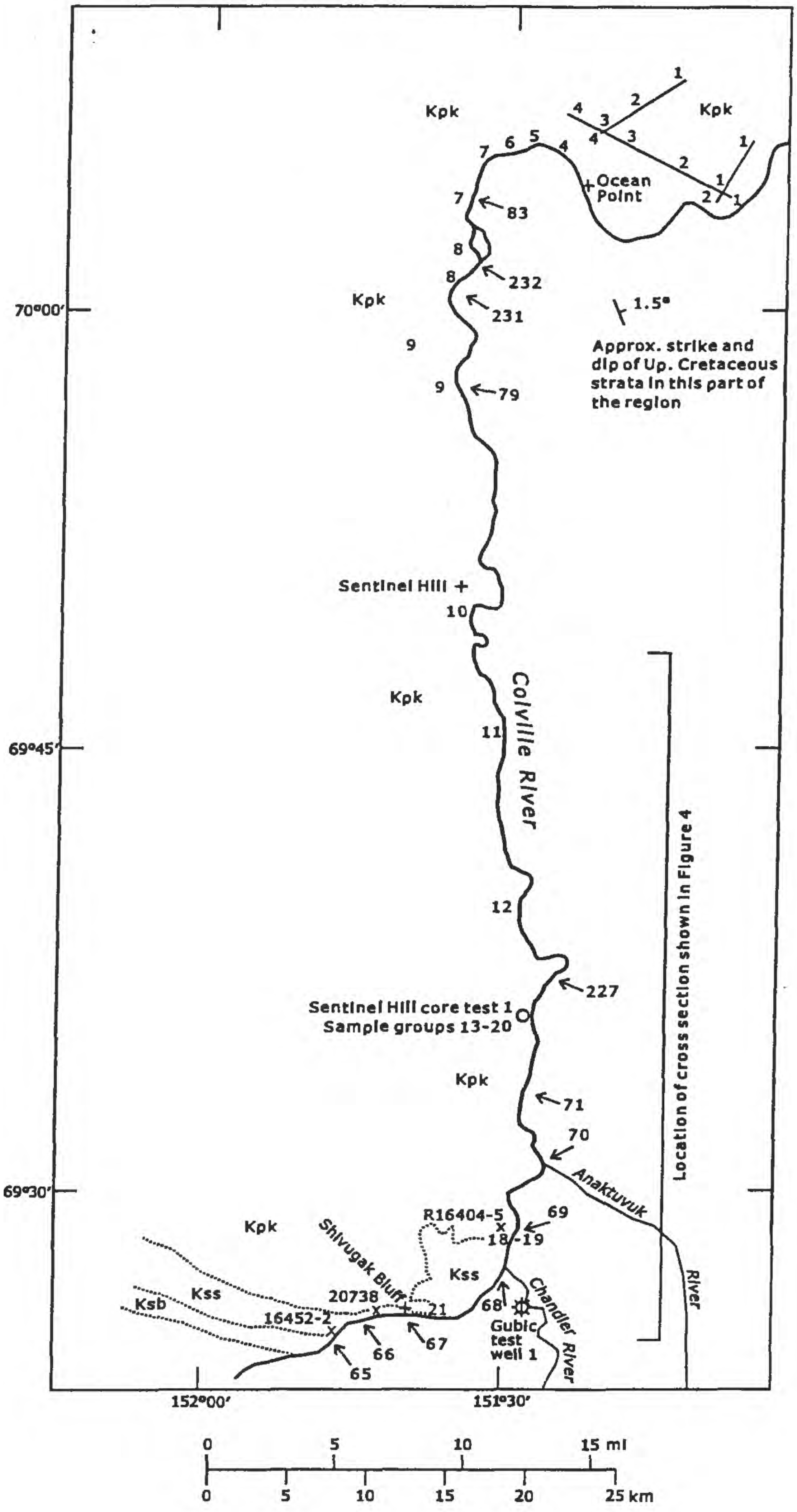

Kpk
Kpk
Ocean Point
83
232
231
70°00′
Kpk
1.5°
Approx. strike and dip of Up. Cretaceous strata in this part of the region
79
Sentinel Hill
Colville River
69°45′
Kpk
Location of cross section shown in Figure 4
227
Sentinel Hill core test 1
Sample groups 13-20
Kpk
71
70
69°30′
Anaktuvuk River
69
R16404-5
18-19
Kpk
Shivugak Bluff
Kss
Kss
Ksb
20738
16452-2
21
68
Gubic test well 1
Chandler River
65
66
67
152°00′
151°30′
0 5 10 15 mi
0 5 10 15 20 25 km

Figure 2

PALYNOLOGICAL METHODS

With the possible exception of samples from Sentinel Hill core test 1, the samples discussed in this report were processed using normal palynological techniques of HCl; HF; HNO_3; short centrifugation with soapy water to remove fines; and heavy liquid separation using a $ZnCl_2$ solution of 1.45 or 1.8 s.g. The relatively light heavy liquid of 1.45 s.g. was used in order to remove 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 10 μm sieves. The residues were mounted in glycerine jelly.

Samples from Sentinel Hill core test 1 were processed by the USGS laboratories in Denver in 1969, and the exact details of this processing are not available.

STRATIGRAPHY

Strata sampled for this study belong to the Upper Cretaceous Colville Group, which includes the Seabee, Schrader Bluff, and Prince Creek Formations (Brosgé and Whittington, 1966). The Colville Group is about 5480 ft thick south of the area in figure 2, according to well data (Brosgé and Whittington, 1966), and thins to about 3770 ft thick near Ocean Point according to seismic reflection data (Tetra Tech, Inc., 1982). The Seabee Formation is at least partly of Turonian age; it has not been studied for this report. The Schrader Bluff and Prince Creek Formations (fig. 3) overlie the Seabee. The mainly marine Schrader Bluff and the mainly nonmarine Prince Creek intertongue with each other in the study area and consist of shale, sandstone, and bentonitic and tuffaceous strata; the Prince Creek also includes coal beds. Prince Creek strata referred to in this report are assigned to the Kogosukruk Tongue, and Schrader Bluff strata referred to in this report are assigned to the Sentinel Hill Member (fig. 3). The stratigraphic nomenclature of this report differs from that of Brosgé and Whittington (1966) because those authors apparently were not aware of the presence of shallow marine shelf and interdistributary bay strata (Phillips, 1988, 1990) near Ocean Point which are now considered to form the uppermost tongue of the Sentinel Hill Member of the Schrader Bluff Formation (Phillips, 1990, and references therein). Underlying the Sentinel Hill Member are, in descending order, the Barrow Trail and Rogers Creek Members of the Schrader Bluff Formation and the Tuluvak Tongue of the Prince Creek Formation (fig. 3), but these units are not discussed in detail in this report. Overlying the Schrader Bluff and Prince Creek Formations are sandy, gravelly, lignitic strata of the Tertiary Sagavanirktok Formation (Carter and Galloway, 1985). The great advantage of studying and sampling Upper Cretaceous strata along the Colville River derives from the very extensive exposures along the river that make it possible to trace packets of strata and even individual beds for significant distances (fig. 4).

The composite section along and near the Colville River that was sampled for this report, from the base of the Sentinel Hill Member, mid(?)-Campanian in age, to the top of the Maastrichtian, is estimated to be 3800 ft thick. This thickness is based on the following:

1. The measured section of Phillips (1988), from its base (base of sample group 7 of this report, fig. 2) to its top (lower part of sample group 4 of this report, northwest of Ocean Point on the bluff of the Colville River) is 584 ft thick.
2. The downdip (east-northeast) map distance from the top of Phillips' section to the top of the Maastrichtian section sampled for this report (sample group 1) is about 1.67 times the

<table>
<tr><th colspan="2">THIS REPORT</th><th colspan="3">BROSGÉ AND WHITTINGTON (1966)</th></tr>
<tr><th>FORMATION</th><th>SUBUNIT</th><th>FORMATION</th><th>SUBUNIT</th><th>MAP SYMBOL</th></tr>
<tr><td>PRINCE CREEK</td><td>KOGOSUKRUK TONGUE, UPPER PART</td><td rowspan="3">PRINCE CREEK</td><td rowspan="3">KOGOSUKRUK TONGUE, UPPER PART</td><td rowspan="5">Kpk</td></tr>
<tr><td>SCHRADER BLUFF</td><td>SENTINEL HILL MEMBER, UPPER PART</td></tr>
<tr><td>PRINCE CREEK</td><td>KOGOSUKRUK TONGUE, MIDDLE PART</td></tr>
<tr><td>SCHRADER BLUFF</td><td>SENTINEL HILL MEMBER, MIDDLE PART</td><td>SCHRADER BLUFF</td><td>SENTINEL HILL MEMBER, UPPER PART</td></tr>
<tr><td>PRINCE CREEK</td><td>KOGOSUKRUK TONGUE, LOWER PART</td><td>PRINCE CREEK</td><td>KOGOSUKRUK TONGUE, LOWER PART</td></tr>
<tr><td>SCHRADER BLUFF</td><td>SENTINEL HILL MEMBER, LOWER PART</td><td rowspan="3">SCHRADER BLUFF</td><td>SENTINEL HILL MEMBER, LOWER PART</td><td>Kss</td></tr>
<tr><td colspan="2" rowspan="3"></td><td>BARROW TRAIL MEMBER</td><td>Ksb</td></tr>
<tr><td>ROGERS CREEK MEMBER</td><td>Ksr</td></tr>
<tr><td>PRINCE CREEK</td><td>TULUVAK TONGUE</td><td>Kpt</td></tr>
</table>

Figure 3. Stratigraphic nomenclature used for mid(?)-Campanian to upper Maastrichtian units in this report compared with the nomenclature of Brosgé & Whittington (1966). Thicknesses of units not to scale. Units below the Sentinel Hill Member of the Schrader Bluff Formation are not discussed in detail in this report, but the Tuluvak Tongue of the Prince Creek Formation is thought to be older than Campanian (Jones and Gryc, 1960).

east-northeast map distance from the base to the top of Phillips' section; therefore, the Maastrichtian strata sampled for this report that lie above Phillips' section apparently are about 975 ft thick.

3. The portion of the measured section of Brosgé and Whittington (1966, plate 54, section 14) from the base of the Kogosukruk Tongue (fig. 2, Kpk/Kss contact) to the top of their measured section, at the approximate site of the lower part of sample group 7, is 1811 ft thick. However, if the uppermost part of Brosgé and Whittington's measured section (their station 83, fig. 2) in fact coincides with the lowermost measured section of Phillips (1988; his section 1, at the base of sample group 7), then there are perhaps 60 ft of overlap between the composite sections of Brosgé and Whittington and of Phillips, in which case the total thickness calculated here, from the base of the Sentinel Hill Member to the top of the Maastrichtian, would be approximately 60 ft too great.

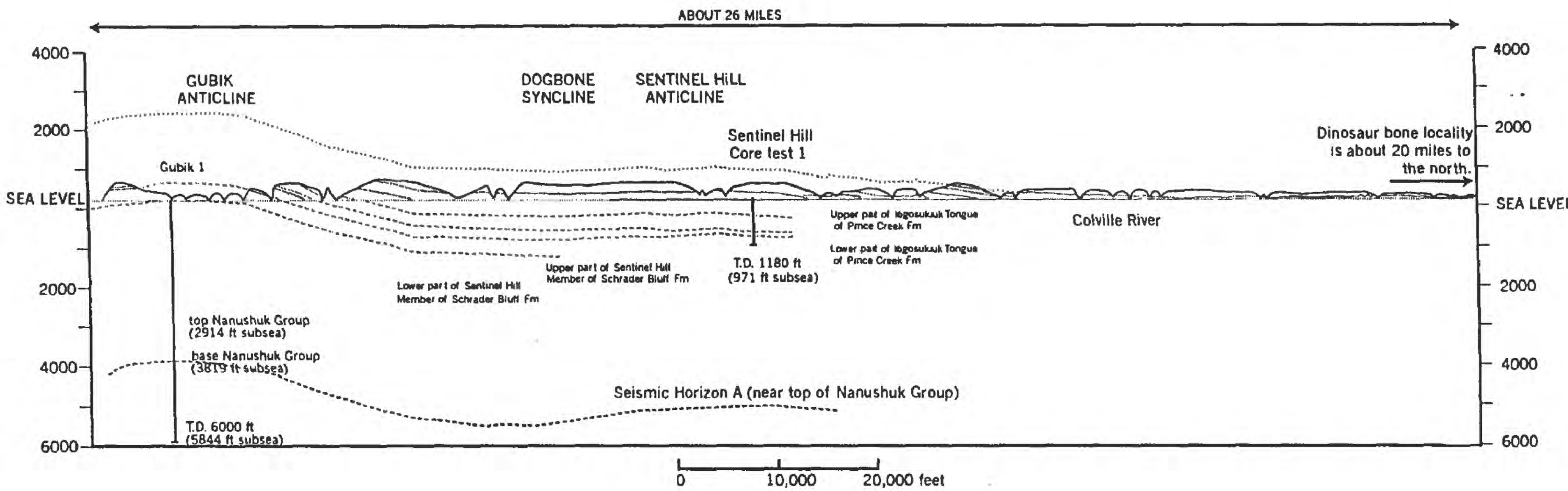


Figure 4. Cross section along the Colville River. Adapted from Brosgé and Whittington (1966, fig. 120) by K. J. Bird, 1999. The diagram shows the great length of virtually continuous exposures along the river that allow one to trace beds for significant distances. Note that the stratigraphic nomenclature of this diagram is that of Brosgé and Whittington; see figure 3 of the present report.

4. The lowermost part of the section sampled for this report is at the east end of Shivugak Bluff and is taken to be 389 ft thick. This is the site of the R3694 samples (sample group 21, fig. 2). The entire bluff section at the east end of Shivugak Bluff consists of the lower part of the Sentinel Hill Member, the top of this unit coinciding with the tops of the bluffs in that area (Brosgé and Whittington, 1966). The total thickness of the lower part of the Sentinel Hill is 389 ft in this, its type area (Brosgé and Whittington, 1966). The east end of Shivugak Bluff is about 400 ft high according to the topographic map (Umiat (B-3) quadrangle); thus, the base of the bluff at this locality must more or less coincide with the base of the Sentinel Hill Member. Therefore, the section from the base of the Kogosukruk Tongue down to the lowest sample of this report, R3694N, which was collected at or near the base of Shivugak Bluff, must be close to 389 ft thick.
5. It has been estimated that the top of the Maastrichtian strata along and near the Colville River from which shothole samples were obtained (fig. 2, north end of map) "is probably within 7-21 m [23-69 ft] of the Cretaceous-Tertiary boundary in the area" (Frederiksen, 1991, p. E8). If a thickness of 41 ft is estimated for the interval from the topmost sample of this study to the top of the Maastrichtian, then the entire interval from the base of the Sentinel Hill Member to the top of the Maastrichtian would be approximately 3800 ft. This is similar to the thickness of 4,000 ft estimated by Wiggins (1976) for the interval from at or near the base of the Sentinel Hill Member to the top of the Maastrichtian in this same area.

Except for several anticlines and synclines in the southern part of the study area, dips of strata in the study section are less than 3° north-northeast in the southern part of the area and about 1.5° east-northeast in the northern part of the area (Brosgé and Whittington, 1966; Tetra Tech, Inc., 1982; Werner, 1987; T. A. Ager, written commun., 1988; K. J. Bird, oral commun., 1989; Brouwers and De Deckker, 1993).

SAMPLE LOCALITIES AND BIOSTRATIGRAPHIC RESOLUTION

The pollen biostratigraphy in this study is based on 148 samples arranged to form 21 sample groups (listed in table 2; figs. 2, 5), and 103 angiosperm pollen taxa (almost entirely pollen species, listed in table 3). Most upper Maastrichtian samples are from U.S. Geological Survey and ARCO seismic line shotholes (Frederiksen, 1991); many samples (41 of them) in the lower part of the study section are core samples from U.S. Navy Sentinel Hill core test 1 (fig. 2). Remaining samples were collected from outcrops by a variety of geologists and palynologists (table 2).

Ten samples from the lower and middle parts of the Sentinel Hill Member were examined for dinocysts; three of these samples had also been examined for pollen (tables 1, 2). Twenty dinocyst species were observed (table 1), and the known age ranges of these species were used in this study for chronostratigraphic purposes. An additional 12 samples were examined for dinocysts from strata underlying the Sentinel Hill Member, and the presence of Campanian dinocysts in some of the latter samples was noted (details on these samples will be presented in a later report).

Figure 5 (following two pages). Range chart of 103 pollen taxa from the mid(?)-Campanian to the upper Maastrichtian along the Colville River. The fraction following each taxon name represents the number of samples in which the taxon was found, followed by the total number of samples from the lowest to the highest observed occurrence of the taxon. The fraction thus indicates the relative sample presence for each taxon and therefore indicates the probable reliability of the observed sample range. KT, Kogosukruk Tongue; PC, Prince Creek Formation; SB, Schrader Bluff Formation; SH, Sentinel Hill Member. Subunit assignments are from Robinson and Collins (1959), Brosgé and Whittington (1966), and papers summarized by Frederiksen (1991). Strata above sample group 1 were not sampled for this study. Tops and bases of ranges are placed at the midpoint of each sample group, except for the uppermost and lowermost sample groups, where the event point is at the level of the highest or lowest sample, respectively.

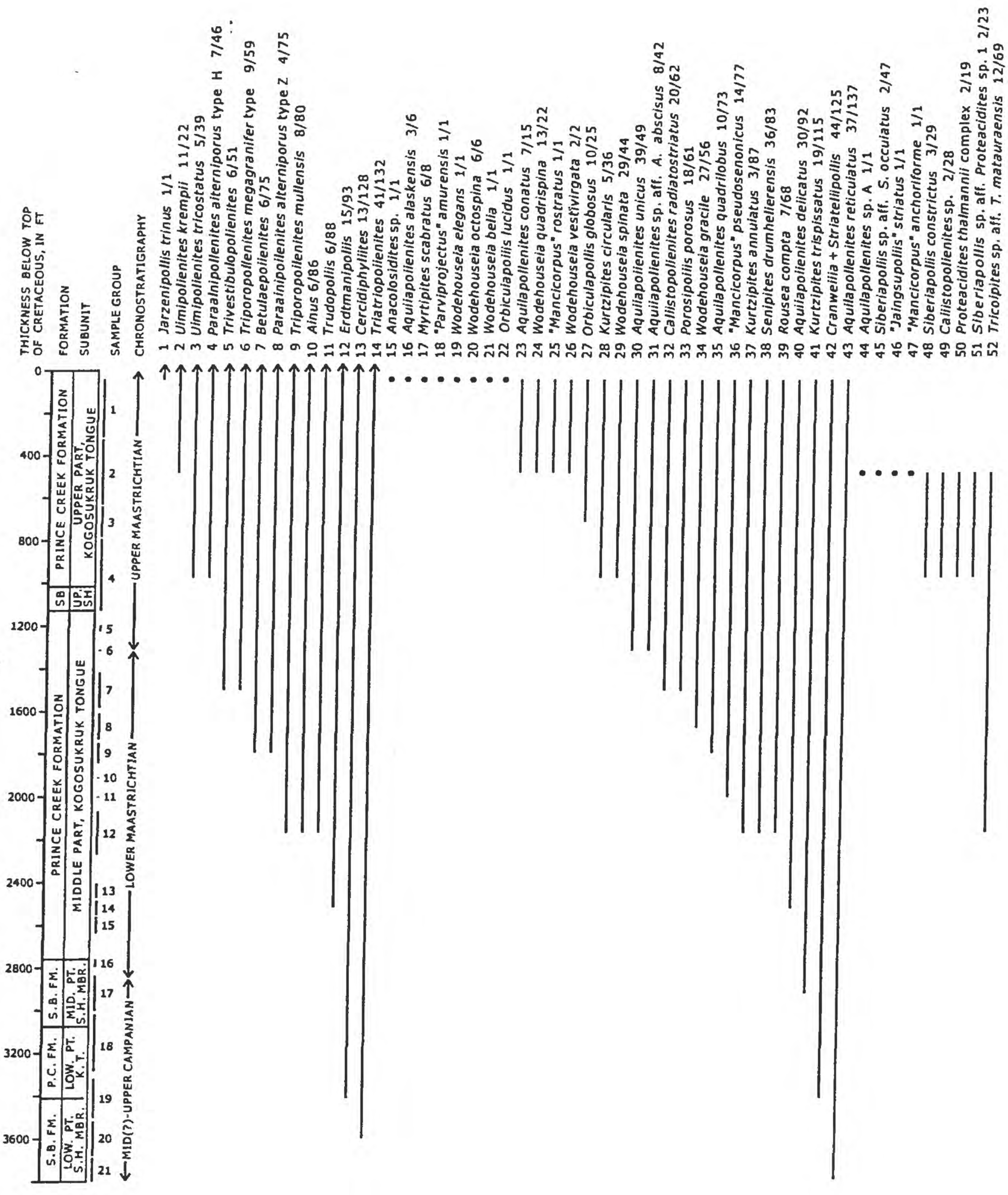


Figure 5, part 1

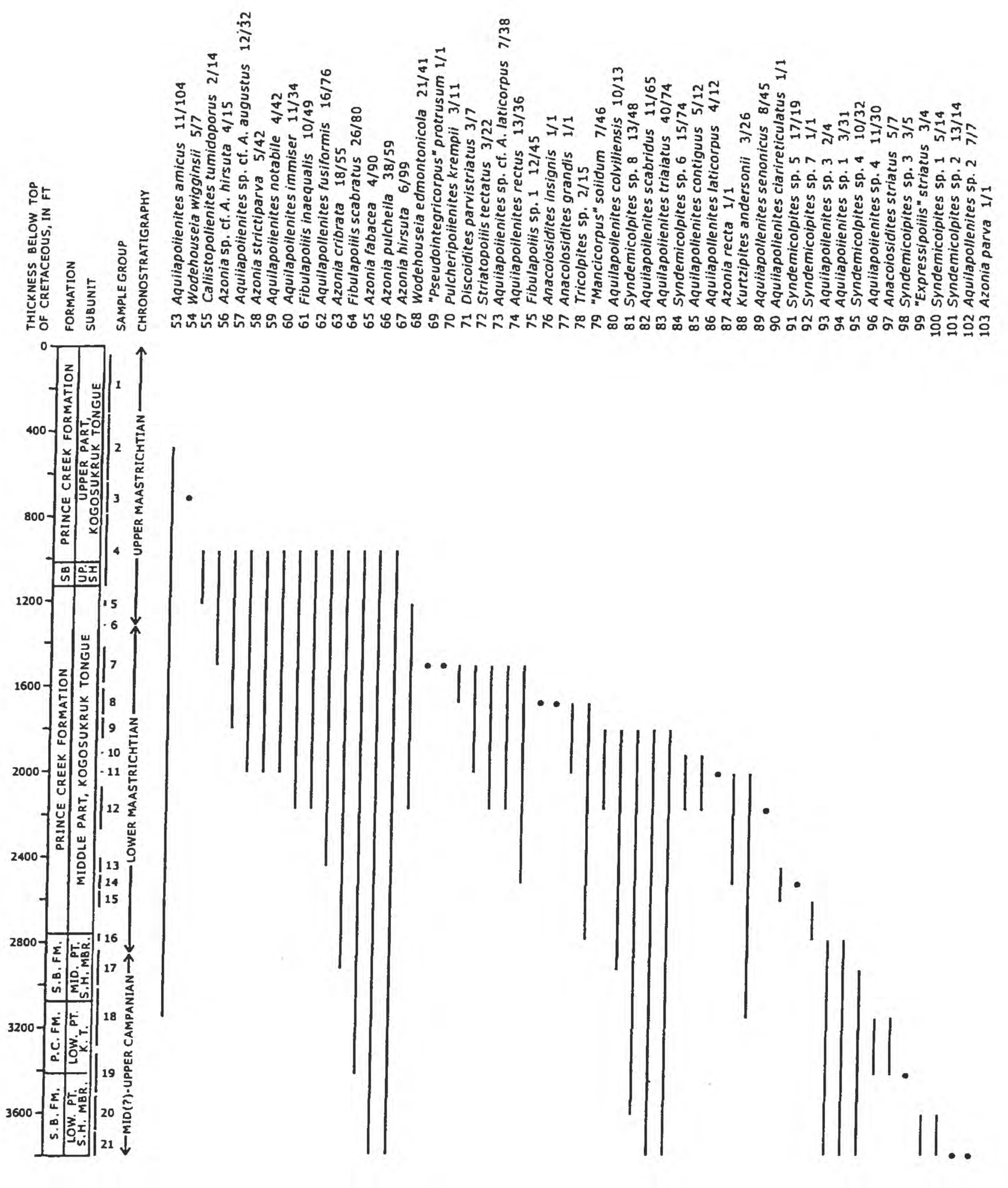


Figure 5, part 2

POLLEN BIOSTRATIGRAPHY AND CORRELATIONS

Because much of the mid(?)-Campanian to Maastrichtian section along the Colville River lacks useful marine fossils, pollen grains are the most useful fossil group for detailed correlations in this section. In the range charts (fig. 5), the pollen taxa are arranged in order of range tops because these are the datums needed for correlations using ditch samples, but the division of the section into 21 sample groups (informal pollen zones) utilizes both range tops and range bases, and these extremities of the range lines are termed pollen-stratigraphic events. Two-thirds of the taxa either range up into the Paleocene or else they have range tops within the upper Maastrichtian. Pollen taxa in the middle part of the lower Maastrichtian are well known from the paper by Tschudy (1969) on the D3124// samples from sample group 12. Most taxa having range tops in the lowermost part of the Maastrichtian and in the Campanian have not previously been described although a few of them have been illustrated by various authors.

In summary, pollen range-top data allow a reasonably fine-scaled subdivision of the entire sequence, and additional resolution can be obtained using range bases if outcrop or core samples are available.

The utility of the pollen-stratigraphic events for correlation is considered in figure 6. In this diagram, observed events in the lower part of the outcropping section along the Colville River are compared with the same events in Sentinel Hill core test 1 (fig. 2). The two sections are about 8.0-12.5 mi apart. The interval that is compared includes the lower part of the Sentinel Hill Member, the lower part of the Kogosukruk Tongue, and the middle part of the Sentinel Hill Member. No outcrop samples definitely known to have come from the middle part of the Sentinel Hill Member were available, but this interval in the core is shown in figure 6 because sample 16404-5 might come from this unit (this possibility is discussed later in this section of the report). In addition, no outcrop samples were available from the lower strata of the middle part of the Kogosukruk Tongue (sample groups 13-15); therefore, pollen data from this interval are known only from the core.

The lower part of the Kogosukruk Tongue is separated from underlying and overlying strata of the Sentinel Hill Member by the absence of calcareous marine fossils. This part of the Kogosukruk Tongue thickens markedly southward, apparently indicating that strata to the south were less influenced by the marine transgressions of the time, or that deposition was more rapid in the south. However, the middle part of the Sentinel Hill Member thickens much less to the north.

Correlations are of course difficult or impossible for parts of the sequence in which samples are not available from both sections being compared; in the present case (fig. 6), samples are lacking from two rather thick intervals within the Colville River outcrop section. However, the relative abundance of correlation lines within the lower part of the Kogosukruk Tongue suggests that many range bases and tops shown in the diagram would be useful for correlation if more outcrop samples were available from the lower and middle parts of the Sentinel Hill Member. It cannot be determined whether the boundary between the lower part of the Kogosukruk Tongue and the middle part of the Sentinel Hill Member is isochronous between the two sections, although the correlation lines for the range top of species 5 ("*Expressipollis*" *striatus*) and the occurrences of species 8 (*Syndemicolpites* sp. 3) do provide

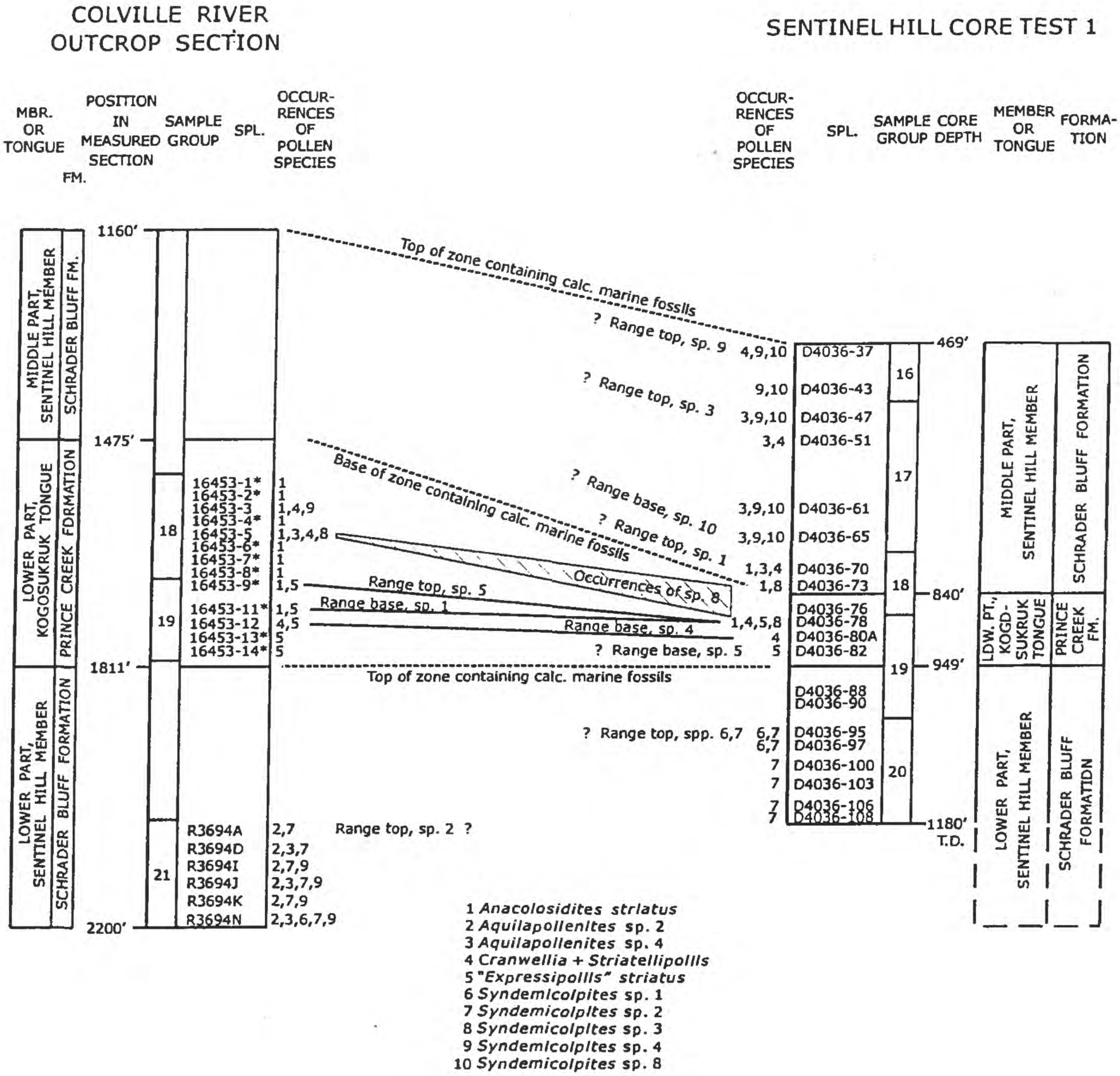


Figure 6. Correlations between the lower part of the Sentinel Hill core test 1 section and the Colville River outcrop section of Brosgé and Whittington (1966), based on observed range bases and range tops of pollen taxa. The datum is arbitrarily picked as the contact between the lower part of the Sentinel Hill Member of the Schrader Bluff Formation and the lower part of the Kogosukruk Tongue of the Prince Creek Formation. In section 16453, samples marked with an asterisk indicate those for which the only available pollen occurrence data are for the important species *Anacolosidites striatus* and "*Expressipollis*" *striatus* (from Wiggins, 1982). Dashed lines indicate the projected basal portion of the lower part, Sentinel Hill Member, in Sentinel Hill core test 1, on the assumption that this unit is the same thickness at the drillsite as in the composite outcrop section to the south along the Colville River, an assumption for which there is little evidence one way or the other.

a small amount of evidence for isochroneity of this boundary. Similarly, the correlation lines for the range bases of species 1 and 4 (*Anacolosidites striatus* and *Cranwellia* + *Striatellipollis*) suggest that the boundary between the lower part of the Sentinel Hill Member and the lower part of the Kogosukruk Tongue may be isochronous between the two sections. Unfortunately, the range base of the important species 5 ("*Expressipollis*" *striatus*) could not be determined in the outcrop section.

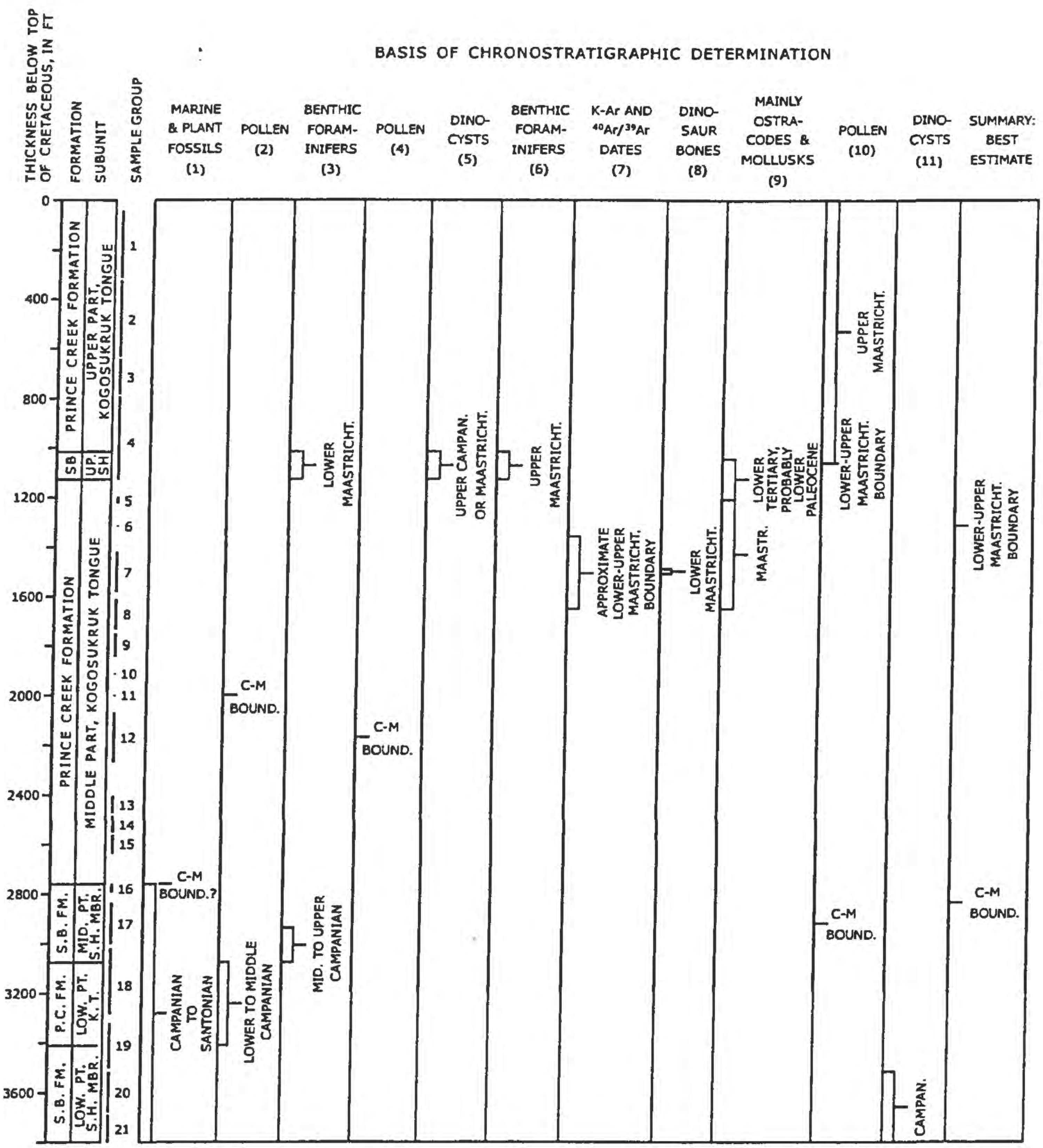
The presence of species 2 (*Aquilapollenites* sp. 2) in every sample from sample group 21 and the complete lack of this species in any sample from Sentinel Hill core test 1 appears to be good evidence that the core did not extend down into the basal 140 ft of the lower part of the Sentinel Hill Member.

Three samples—16404-5, 16452-2, and 20738—were not assigned to sample groups in table 1 because their stratigraphic positions are uncertain.

- As stated in table 2, sample 16404-5 (fig. 2) must come from relatively near the boundary between the lower part of the Kogosukruk Tongue and the overlying middle part of the Sentinel Hill Member. This sample contains few significant pollen taxa; among the taxa listed in figure 6, only species 3 and 4 (*Aquilapollenites* sp. 4 and *Cranwellia* + *Striatellipollis*) were found. The lack of species 1 (*Anacolosidites striatus*) and 10 (*Syndemicolpites* sp. 8) is significant if it is assumed that the boundary between the lower part of the Kogosukruk Tongue and the middle part of the Sentinel Hill Member is isochronous between the two sections compared in figure 6; in that case, sample 16404-5 must come from low within the the middle part of the Sentinel Hill Member, near the boundary between sample groups 17 and 18.
- Sample 16452-2 is from the lowest strata of the Sentinel Hill Member (fig. 2; table 2), and therefore it belongs to sample group 21. Information is available about only one species in this sample, whose presence is shown in figure 5 (taxon 103).
- Sample 20738 was stated by its collector to be from the lower part of the Kogosukruk Tongue (table 2). This sample contains, among other taxa, species 2, 6, and 7 (*Aquilapollenites* sp. 2 and *Syndemicolpites* spp. 1 and 2, respectively, in fig. 6). It seems from the stated location of the sample (fig. 2) that it should come from near the boundary between the lower part of the Sentinel Hill Member and the lower part of the Kogosukruk Tongue (Kpk/Kss boundary in fig. 2). However, species 2, 6, and 7 are known only from the lower part of the Sentinel Hill Member; furthermore, species 2 is known only from sample group 21 near the base of the Sentinel Hill Member. Apparently sample 20738 is older than any samples from Sentinel Hill core test 1 (fig. 6) but might be slightly younger than the R3694 series. In any case, it seems unlikely to be any younger than the middle strata within the lower part of the Sentinel Hill Member. It is, of course, possible that the sample was mislabeled during laboratory processing; this would explain why the sample has a different age than would be thought based on its supposed collecting site.

CHRONOSTRATIGRAPHY

Strata discussed in this report can be assigned to geologic stages and substages based on a variety of sources, and these data are summarized in figure 7. Marine mollusks are generally sparse within the Sentinel Hill Member (Robinson and Collins, 1959; Detterman and



SOURCES:
1. SMILEY (1969)
2. WIGGINS (1976, 1982)
3. MC DOUGALL (1987)
4. FREDERIKSEN & SCHINDLER (1987)
5. FREDERIKSEN AND OTHERS (1988)
6. W. V. SLITER IN FREDERIKSEN (1991)
7. CONRAD AND OTHERS (1990)
8. CLEMENS (1992)
9. BROUWERS & DE DECKKER (1993)
10. THIS REPORT AND FREDERIKSEN (1991)
11. THIS REPORT

Figure 7. Chronostratigraphic assignments for mid(?)-Campanian to Maastrichtian strata along the Colville River, based on a variety of data. C-M, Campanian-Maastrichtian; K.T., Kogosukruk Tongue; P.C., Prince Creek Formation; S.B., Schrader Bluff Formation; S.H., Sentinel Hill Member.

others, 1963; Brosgé and Whittington, 1966; Smiley, 1969). However, benthic foraminifers and dinocysts occur in some strata of the Sentinel Hill Member (fig. 7, columns 1, 3, 6, and 5, 11, respectively). Ostracodes and mollusks in the middle part of the Kogosukruk Tongue and the upper part of the Sentinel Hill Member (column 9) include nonmarine, brackish-water, and marine forms. Other nonmarine fossils from the studied section include plant megafossils (column 1), pollen grains (columns 2, 4, and 10), and dinosaur bones (column 8).

Geochronologic data are available from radiometric measurements of the sediments, and from these data chronostratigraphic assignments can also be made. Conrad and others (1990) determined K-Ar and $^{40}Ar/^{39}Ar$ dates for five tephra samples from the sites of sample groups 7 and 8 of this report (fig. 7, column 7). Estimated ages of the samples ranged from 66.0 to 70.5 Ma, and the best combined age estimate for the five samples was 69.1 ± 0.3 Ma, close to the age of the (informal) substage boundary between the lower and upper Maastrichtian, which is currently considered to be 69.5 Ma (Gradstein and others, 1995).

Dinocyst Age Determinations

The only dinocyst data previously available from the stratigraphic section studied here were from the upper part of the Sentinel Hill Member (fig. 7, column 5), and these were not definitive as to a Campanian or Maastrichtian age. Here (table 1), we present McIntyre's data on dinocyst assemblages from 10 samples from the lower and middle parts of the Sentinel Hill Member. In summary:

1. Samples containing *Laciniadinium biconiculum*, from R3694D (sample group 21) to D4036-100 (sample group 20), are no older than Campanian.
2. Samples containing *Laciniadinium biconiculum*, *Heterosphaeridium difficile*, *Scriniodinium obscurum*, and(or) *Trithyrodinium suspectum*, from R3694N (sample group 21) to D4036-100 (sample group 20), are no younger than Campanian.
3. Samples from D4036-66 to D4036-41 (sample groups 17 and 16), which contain none of the above four species, could be either Campanian or Maastrichtian.

As noted previously, Campanian dinocysts have now been found in strata below the Sentinel Hill Member, in the Barrow Trail and Rogers Creek Members of the Schrader Bluff Formation (fig. 3); therefore, the base of the Sentinel Hill Member is considered to be mid(?)-Campanian in age.

Age of the "Ocean Point Marine Beds"

Of all strata in the Colville River succession, the most controversial in terms of age are those making up the 111 ft-thick upper part of the Sentinel Hill Member (the "Ocean Point marine beds" of Frederiksen, 1991, and other authors). Using mollusk and ostracode evidence, Marincovich and others (1985, 1986), Brouwers (1988), and Brouwers and De Deckker (1993) suggested that these marine to brackish-water strata are early Tertiary, probably early Paleocene, in age (fig. 7, column 9). However, most species of mollusks and ostracodes in these beds are endemic to the North Slope; thus, the ages of these fossils apparently must be uncertain. Pollen taxa found from the upper part of the Sentinel Hill Member to the top of the studied section appear to be late Maastrichtian (fig. 7, refs. 2, 4,

Sample	D4036-41	D4036-49	D4036-64	D4036-66	D4036-100	D4036-101	D4036-105	D4036-107	R3694-D	R3694-N
Sample Group	16	17	17	17	20	20	20	20	21	21
Species										
Alterbidinium minus (Alberti) Lentin & Williams					X		X		X	
Chatangiella ditissima (McIntyre) Lentin & Williams	X	X			X	X	A	X	C	X
Chatangiella granulifera (Manum) Lentin & Williams		X			X	X	X			X
Chatangiella verrucosa (Manum) Lentin & Williams							X		X	
Circulodinium distinctum (Deflande & Cookson) Jansonius	X		X	X	X		X	X		
Fromea chytra (Drugg) Stover & Evitt			X	X						
Fromea laevigata (Drugg) Stover & Evitt							X			
Heterosphaeridium difficile (Manum & Cookson) Ioannides[2]							X			
Isabelidinium cooksoniae (Alberti) Lentin & Williams				X			X	X		
Isabelidinium sp. A	X		X	A	X				C	C
Isabelidinium sp. B	X			X	X	X	X	X	X	C
Laciniadinium arcticum (Manum & Cookson) Lentin & Williams							X			
Laciniadinium biconiculum McIntyre[1]					X		X		X	
Oligosphaeridium complex (White) Davey & Williams		X	X			X	X	X		
Oligosphaeridium pulcherrimum (Deflandre & Cookson) Davey & Williams			X							
Phelodinium sp.					X					
Scriniodinium obscurum Manum & Cookson[2]						X	X	X		
Spinidinium ?uncinatum May			X							
Trithyrodinium suspectum (Manum & Cookson) Davey[2]					X	X				X
Wallodinium anglicum (Cookson & Hughes) Lentin & Williams									X	

Table 1. Occurrences of dinocyst species in 10 samples from the lower and middle parts of the Sentinel Hill Member of the Schrader Bluff Formation along the Colville River. Samples are arranged youngest to oldest from left to right. Occurrences are as follows: X, present; A, abundant; C, common. The biostratigraphically important species are footnoted as follows:

[1]Known only from the Campanian

[2]Range top is within or at the top of the Campanian

10). Dinocysts suggest a late Campanian or Maastrichtian age for the upper part of the Sentinel Hill Member (column 5), whereas benthic foraminifers are considered to be early Maastrichtian (column 3) or late Maastrichtian (column 6).

Boundary between the Lower and Upper Maastrichtian

The exact position of the (informal) substage boundary between the lower and upper Maastrichtian along the Colville River is difficult to establish, particularly because it probably occurs within the middle part of the nonmarine Kogosukruk Tongue. Nichols and Sweet (1993) demonstrated that the range base of the pollen species *Wodehouseia spinata* approximately coincides with the substage boundary from Colorado to Montana and in the Yukon and Northwest Territories. Along the Colville River, the observed range base of *Wodehouseia spinata* occurs within sample group 4, in the middle of the upper part of the Sentinel Hill Member (fig. 8B; fig. 7, column 10). Dinosaur bones approximately 370 ft below the base of that unit, in the middle part of the Kogosukruk Tongue, are considered to be early Maastrichtian in age (column 8), and radiometric dates from about the same level are not far from the age of the substage boundary (column 7). In summary, the boundary between the lower and upper Maastrichtian is most probably within the upper strata of the middle part of the Kogosukruk Tongue, and as a compromise mainly between the radiometric, dinosaur, and pollen data, the boundary is here arbitrarily placed at the level of sample group 6.

Campanian-Maastrichtian Boundary

Campanian-Maastrichtian Boundary According to Pollen Data

The most authoritative paper on the ages of pollen assemblages in the Upper Cretaceous of the Western Interior Basin of North America is that of Nichols and Sweet (1993), who correlated pollen assemblages between New Mexico and the Yukon Territory and also correlated the pollen assemblages with marine fossil occurrences that are the basis for determining European Stage boundaries in the region. They stated (1993, p. 543) that "the placement of the Campanian-Maastrichtian (C-M) boundary in the Western Interior is an unresolved problem" because the position of the boundary has variously been placed at the base of the *Baculites baculus*, *B. reesidei*, and *B. compressus* Zones. "These three boundary positions ... span an interval of about 2.5 million years.... For purposes of palynostratigraphy of non-marine rocks of the Western Interior Basin ... we designate the lowest stratigraphic occurrence of either *Wodehouseia* or *Kurtzipites* as a practical, regional datum to mark the C-M boundary. The lower first occurrence of these two pollen genera is used where their ranges are not coincident. ...we consider this datum to approximate a medial position for the C-M boundary relative to those cited above for marine rocks." Since then, the worldwide C-M boundary has been placed in a middle position between the *Baculites baculus* and *B. reesidei* Zones (Gradstein and others, 1995); thus, the rationale behind Nichols' and Sweet's (1993) choice of palynological C-M boundary for the Western Interior Basin remains valid.

Figure 8A summarizes pollen data from the present report (fig. 5) that are pertinent to the placement of the Campanian-Maastrichtian boundary along the Colville River. In his

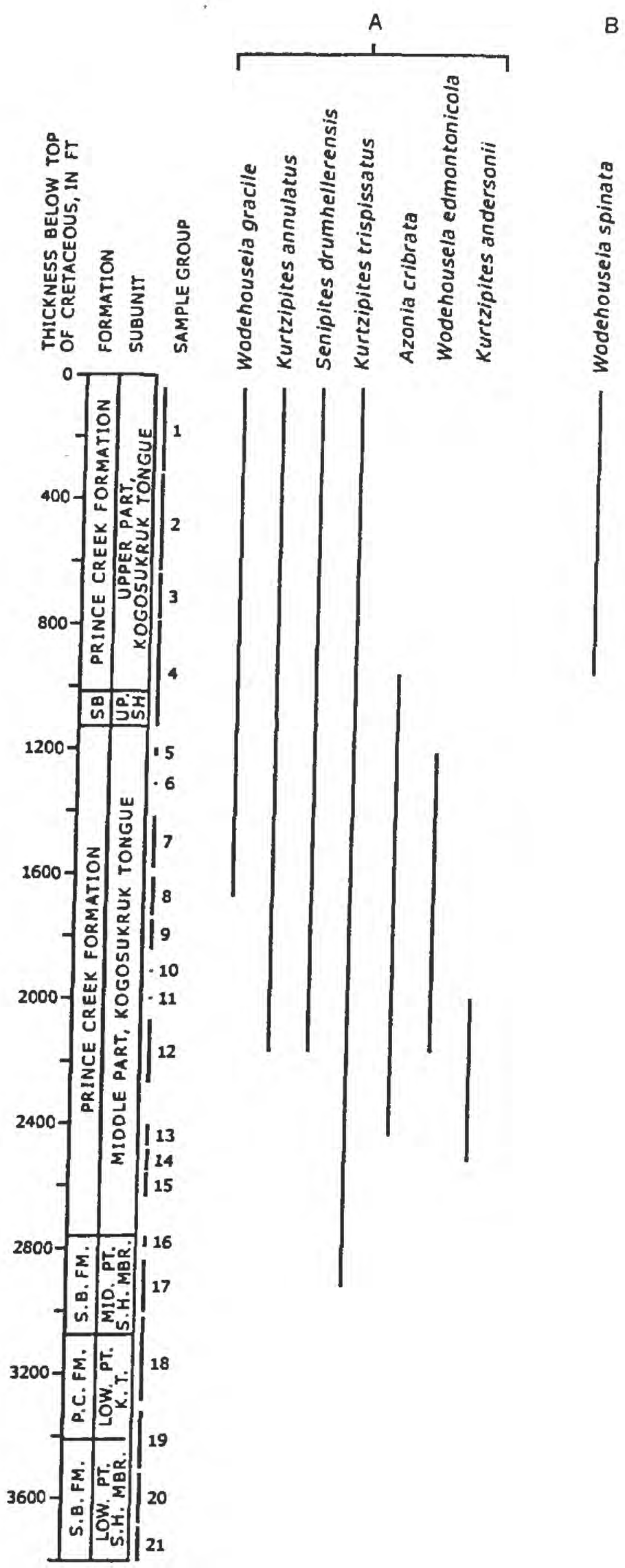


Figure 8. Range chart summarizing pollen taxon range tops and range bases pertinent to the placement of (A) the Campanian-Maastrichtian boundary, and (B) the boundary between the lower and upper Maastrichtian, along the Colville River.
KT, Kogosukruk Tongue; PC, Prince Creek Formation; SB, Schrader Bluff Formation; SH, Sentinel Hill Member.

outstanding paper on the oculata group of pollen grains in the Upper Cretaceous and Paleocene of Alaska, Wiggins (1976) provisionally accepted the Campanian-Maastrichtian boundary tentatively placed by Smiley (1969) near sample group 16 (fig. 7, column 1). Wiggins found that this boundary approximately coincided with the range top of *Azonia cribrata,* with the range bases of *Wodehouseia gracile* and *W. edmontonicola,* and with the range base of the genus *Kurtzipites*. It appears from figure 8A that there is a considerable discrepency between Wiggins' range top of *Azonia cribrata* and range bases of *Wodehouseia gracile* and *W. edmontonicola,* and these three events in the present report, evidently due at least in part to somewhat differing interpretations of these species.

In a brief preliminary report on the Upper Cretaceous pollen biostratigraphy along the Colville River, Frederiksen and Schindler (1987) stated that "the Campanian-Maastrichtian boundary is approximately marked by the range bases of *Wodehouseia edmontonicola* and *Senipites drumhellerensis* and is nearly as far south (downsection) as [the site of] Sentinel Hill core test 1."

We agree with Nichols and Sweet (1993) that the Campanian-Maastrichtian boundary should be picked, if only pollen data are available, at the lowest stratigraphic occurrence of either *Wodehouseia* or *Kurtzipites,* whichever is lower. Figures 8A and 7 (column 10) show that, following this principle, the boundary determined on the basis of pollen would be placed at the range base of *Kurtzipites trispissatus,* within the middle part of the Sentinel Hill Member, at sample group 17, not far below the boundary proposed by Smiley (1969) and accepted by Wiggins (1976). The position of the Campanian-Maastrichtian boundary proposed by Frederiksen and Schindler (1987), based on the range bases of *Wodehouseia edmontonicola* and *Senipites drumhellerensis,* within the middle part of the Kogosukruk tongue, is considerably higher stratigraphically (fig. 7, column 4).

Placement of the Campanian-Maastrichtian Boundary Based on Integrated Data

On the basis of marine fossils (mainly benthic foraminifers and mollusks) from the lower and middle parts of the Sentinel Hill Member, Smiley (1969) dated these units as Santonian to Campanian (fig. 7, column 1), and based on these fossils in addition to plant megafossils from the Kogosukruk Tongue, he tentatively equated the Campanian-Maastrichtian boundary with the boundary between the middle part of the Sentinel Hill Member and the overlying middle part of the Kogosukruk Tongue (column 1). Strata from the lower part to the middle part of the Sentinel Hill Member have since been assigned to the Campanian Stage based on pollen, benthic foraminifers, and dinocysts (columns 2, 3, 10, 11). The exact position of the Campanian-Maastrichtian boundary in the Colville River section, however, is somewhat uncertain. Here (fig. 7, summary column), we compromise between the data of marine and plant fossils (column 1), benthic foraminifers (column 3) and pollen (column 10) and somewhat arbitrarily place the Campanian-Maastrichtian boundary at the top of pollen sample group 17, within the upper strata of the middle part of the Sentinel Hill Member, slightly below the boundary proposed by Smiley (1969).

CONCLUSIONS

1. This study concerns a sequence about 3800 ft thick consisting of the mainly marine Sentinel Hill Member of the Schrader Bluff Formation and the mainly nonmarine Kogosukruk Tongue of the Prince Creek Formation, which intertongue with each other in the Colville River area and form the mid(?)-Campanian to upper Maastrichtian part of the Colville Group. The nomenclature of these tongues is revised from that of Brosgé and Whittington (1966), so that the Sentinel Hill and Kogosukruk are now each considered to have lower, middle, and upper parts.
2. Biostratigraphic conclusions in this report are derived from the observed distribution of 103 angiosperm pollen taxa in 148 samples arranged to form 21 sample groups. Two-thirds of the taxa either range up into the Paleocene or else they have range tops within the upper Maastrichtian. However, enough pollen events (range tops and range bases) are now available to allow a reasonably fine-scaled subdivision of the entire sequence. The biostratigraphic usefulness of these events is demonstrated by a diagram that correlates the lower part of the Kogosukruk Tongue in some detail between outcrops along the river and strata in the Sentinel Hill core test 1 section about 8.0-12.5 mi north of the outcrops. From a botanical viewpoint, the pollen taxon range chart shows a rapid growth of diversity of angiosperm plants from 11 taxa in the mid(?)-Campanian to 43 taxa just before the terminal Cretaceous extinction event.
3. Chronostratigraphic conclusions are derived from the stratigraphic ranges of selected pollen species, from the distributions of 20 dinocyst species in 10 samples from the lower and middle parts of the Sentinel Hill Member, and from dinocyst species found in 12 samples from strata below the Sentinel Hill Member. Based on these data, integrated with published information from a large variety of fossil types and from radiometric data, it is concluded that (1) the Campanian-Maastrichtian boundary is near the top of the middle part of the Sentinel Hill Member, slightly below the level where Smiley (1969) placed this boundary, and (2) the (informal) substage boundary between the lower and upper Maastrichtian is near the top of the middle part of the Kogosukruk Tongue, not far below the "Ocean Point marine beds," which represent the upper part of the Sentinel Hill Member. Thus, the "Ocean Point marine beds" are early late Maastrichtian in age. Campanian dinocysts have now been found in strata below the Sentinel Hill Member; therefore, the base of this member is considered to be mid(?)-Campanian in age.
4. Given the chronostratigraphic conclusions, the 3800-ft thick section studied here consists of about 1315 ft of upper Maastrichtian strata, about 1525 ft of lower Maastrichtian strata, and about 960 ft of "middle" to upper Campanian strata.

SYSTEMATIC PALEONTOLOGY

Generic classifications of triprojectate taxa and oblate pollen types with very long colpi have been proposed by various authors. The whole complex of these pollen types has several features in common, so that most of them could all be grouped together forming one morphological continuum. Here, this complex is somewhat arbitrarily divided into two groups, one in which the grains are mainly observed lying in equatorial view (the triprojectate taxa *sensu stricto*) and one in which the grains are mainly observed lying in polar view, comprising the "*Expressipollis*" group and *Kurtzipites*.

The most complex classifications of triprojectate taxa have been those of Takahashi (1981) and Farabee (1990). However, because biostratigraphic applications depend on species level rather than genus level identifications, there seems to be little biostratigraphic purpose in using a complicated genus classification. Therefore, we have used the simplified classification of Tschudy (1969) and Tschudy and Leopold (1971), according to which all triprojectates are placed in *Aquilapollenites* and *Fibulapollis*. Krutzsch's (1969) generic classification of oblate pollen types with very long colpi—which include syncolp(or)ate, syndemicolpate, demicolpate, and deeply colpate forms—is based mainly on the nature of the apertures and appeared at first glance to be relatively easy to apply to Late Cretaceous pollen species. However, it was found to be difficult to differentiate consistently between *Syndemicolpites* and *Sindorapollis*. Both genera are demicolpate, meaning that the colpi do not cross the equator of the grain, "the furrows being divided in two by equatorial 'bridges'" (van Hoeken-Klinkenberg, 1964, p. 221). In *Syndemicolpites* van Hoeken-Klinkenberg 1964, the colpi meet at the poles. In *Sindorapollis* Krutzsch 1969, on each hemisphere, each of the three colpi is isolated from the others because they do not extend to the poles. However, in the Campanian and lower Maastrichtian material from the North Slope of Alaska, it is commonly difficult to determine whether the colpi of individual specimens and species actually extend completely to the poles. For example, in "*Expressipollis*" *striatus*, some grains are clearly syndemicolpate, whereas in other specimens the colpi are so faint in the polar region that the specimens might better be classified as demicolpate (Wiggins, 1982, fig. 3). Therefore, it seems practical to combine *Syndemicolpites* and *Sindorapollis*. *Syndemicolpites* van Hoeken-Klinkenberg 1964 has priority over *Sindorapollis* Krutzsch 1969.

ACKNOWLEDGMENTS

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Table 2. Sample locations and sample groups. Details on the locations of samples from the upper half of the Maästrichtian are given by Frederiksen (1991) and are not repeated here. Field numbers including the identifier EB are samples collected by E. M. Brouwers of the U.S. Geological Survey; field numbers including the identifier RAS are samples collected by R. A. Spicer of The Open University; field numbers including the identifier 84SHIII and 84PC-I are samples collected by H. S. Sonneman of Exxon Company, U.S.A.; sample numbers lacking a prefix of D or R and beginning with 164 are samples of V. D. Wiggins of Chevron USA Inc. Unless otherwise stated, samples were examined only for pollen.

Sample locations:

16404-5 NE 1/4 Sec. 36, T. 2 N., R. 2 E., Umiat (B-3) quadrangle. No direct data are available as to the stratigraphic unit from which this sample was taken. However, it is geographically near station 69 of Brosgé and Whittington (1966) (fig. 2 of the present report) and therefore must come from relatively near the boundary between the lower part of the Kogosukruk Tongue of the Prince Creek Formation and the overlying middle part of the Sentinel Hill Member of the Schrader Bluff Formation. The sample has not been assigned with certainty to a sample group, as discussed in the section on "Pollen Biostratigraphy and Correlations."

16408-4 Sec. 25, T. 5 N., R. 2 E., Umiat (D-3) quadrangle; sample of Wiggins (1976). Sample group 11.

16409 Approximately the same locality as R3317; samples 4 and 5. Sample group 7.

16410-3 Sec. 22 or 23, T. 8 N., R. 2 E., Harrison Bay (A-3) quadrangle. Sample group 8.

16452-2 Sec. 24, T. 1 N., R. 1 E., Umiat (B-3) quadrangle; sample of Wiggins (1976), who stated that it was from the Schrader Bluff Formation and showed it as coming from at or near the base of the Sentinel Hill Member. The locality is at or a little east of station 65 of Brosgé and Whittington (1966) and evidently comes from not far above river level. The only pollen occurrence available for this sample is a listing of *Azonia hirsuta* by Wiggins (1976). The stratigraphic and biostratigraphic positions of this sample are discussed in the section on "Biostratigraphy and Pollen Correlations."

16453 Sec. 1, T. 1 N., R. 2 E., Umiat (B-3) quadrangle. Wiggins (1982, p. 39) described the section as representing "an interfingering marine and nonmarine, deltaic sequence; and arenaceous foraminifera ... were recovered from the claystones interbedded with the coals (samples 1-3, 5-8, 11-13). Possible *Inoceramus* prisms were recovered from samples 11-13 along with *Spumellaria* radiolaria and echinoid spines." This locality lies between stations 68 and 69 of Brosgé and Whittington (1966) and therefore must come from the lower part of the Kogosukruk Tongue of the Prince Creek Formation. Sample number, stratigraphic distance below top of local section, (sample group): 1, about 6 ft, (18); 2, about 38 ft, (18); 3, about 55 ft, (18); 4, about 70 ft, (18); 5, about 92 ft, (18); 6, about 110 ft, (18); 7, about 129 ft, (18); 8, about 147 ft, (18); 9, about 172 ft, (19); 11, about 210 ft, (19); 12, about 232 ft, (19); 13, about 248 ft, (19); 14, about 265 ft, (19).

20738 "Shivugak Bluff. Lower part of Kogosukruk Tongue, Prince Creek Formation, about 50 ft above base of tongue" (Smiley, 1969, table 2, his locality 52); Umiat (B-3) quadrangle. According to Smiley's small-scale map (his fig. 2), this locality appears to be in sec. 19, T. 1 N., R. 2 E., a mile or less east of station 66 of Brosgé and Whittington (1966). The 20738 sample number is that of the Mobil R&D Corp. palynology laboratory. The sample has not been assigned to a sample group, as discussed in the section on "Biostratigraphy and Pollen Correlations."

D3124 Sec. 29, T. 4 N., R. 2 E.(?),[1] Umiat (C-3) quadrangle; samples of Tschudy (1969). Samples A, B, C, G, H. Sample group 17.

D4036 U.S. Geological Survey Sentinel Hill core test 1, lat 69° 36' 57" N., long 151° 27' 11" W., Umiat (C-3) quadrangle. Robinson and Collins (1959) described the lithology of the core and placed the intertonguing formation boundaries as follows: base of Prince Creek Formation at 469 ft; base of Schrader Bluff Formation at 840 ft; base of Prince Creek Formation at 949 ft; below that level is the Schrader Bluff Formation. Samples, depths, lithologies (these are mainly shale unless otherwise noted), and sample groups:

Prince Creek Formation:

1, 109-119 ft; 2, 119-129 ft; 3, 129-139 ft; 5, 149-159 ft; 6, 159-169 ft; 7, 169-179 ft; 8, 179-189 ft. Sample group 13.

9, 189-199 ft; 10, 199-209 ft; 12A, 219-229 ft; 12B, 219-229 ft, lignite; 13, 229-239 ft; 14, 239-249 ft; 15, 249-259 ft. Sample group 14.

19, 289-299 ft; 20, 299-309 ft; 21, 309-319 ft; 22, 319-329 ft; 26, 359-369 ft; 27A, 369-379 ft; 30, 399-409 ft. Sample group 15.

Schrader Bluff Formation:

37, 469-479 ft; 41[2], 509-519 ft; 43, 529-539 ft. Sample group 16.

47, 569-579 ft; 49[2], 589-599 ft; 51, 609-619 ft; 61, 709-719 ft; 64[2], 739-749 ft; 65, 749-759 ft.; 66[2], 759-769 ft. Sample group 17.

70, 799-809 ft; 73, 829-839 ft. Sample group 18.

Prince Creek Formation:

76, 859-869 ft. Sample group 18.

78, 879-889 ft; 80A, 899-909 ft, lignite; 82, 919-929 ft. Sample group 19.

Schrader Bluff Formation:

88, 979-989 ft; 90, 999-1005 ft. Sample group 19.

95, 1045-1052 ft; 97, 1060-1070 ft; 100[3], 1090-1100 ft; 101[2], 1100-1110 ft; 103, 1120-1130 ft; 105[2], 1140-1150 ft; 106, 1150-1160 ft; 107[2], 1160-1170 ft; 108, 1170-1180 ft. Sample group 20.

R3317 Sec. 3 of Phillips (1988), NE 1/4 NW 1/4 sec. 11, T. 8 N., R. 2 E., Harrison Bay (A-3) quadrangle; collected by T. A. Ager. Sample A, 4 ft below bone bed; sample B, 6 inches below bone bed. Sample group 7.

R3694 Field no. 84SHIII, C sec. 22, T. 1 N., R 2 E., east end of Shivugak Bluff, lower part of bluff, Umiat (B-3) quadrangle. Samples and distances below top of sampled section: A, 0 ft; D[3], 30 ft; I, 90 ft; J, 100 ft; K, 110 ft; N[3], 140 ft. Sample group 21. Measured section of H. S. Sonneman consists entirely of bentonitic silty shale and subordinate silt.

R3695 Field no. 84-PC-I, sec. 31(?), T. 4 N.(?), R 3 E.,[4] Umiat (C-3) quadrangle. Samples and distances below top of section: B, 10 ft; C, 20 ft; F, 50 ft; H, 70 ft; M, 120 ft. Sample group 12.

R3945 Kikiakrorak River near its confluence with the Colville River, NW 1/4 sec. 9, T. 7 N., R. 2 E., Umiat (D-3) quadrangle. Samples and field numbers: A, 86EB23; D, 86EB26; H, 86EB30; N, 86EB36. Sample group 9.

R3946 Same locality as R3317. Sample P, field no. 86EB16; sample Q, field no. 86EB17. Sample group 7.

R3947 Strata near tephra bed in sec. 1 of Phillips (1988), SE 1/4 NW 1/4 sec. 11, T. 8 N., R. 2 E., Harrison Bay (A-3) quadrangle. Samples and field numbers: B, 86EB165; D, 86EB167; J, 86EB173; K, 86EB174. Sample group 7.

R4073 Field no. 86RAS 144-145, SE 1/4 SW 1/4 sec. 35, T. 6 N., R. 2 E., Umiat (D-3) quadrangle. Sample group 10.

R4074 Field no. 86RAS 149-150, NW 1/4 NE 1/4 sec. 22, T. 7 N., R. 2 E., Umiat (D-3) quadrangle. Sample group 9.

R4075 Field no. 86RAS 153-154, SW 1/4 SE 1/4 sec. 5, T. 7 N., R. 2 E., Umiat (D-3) quadrangle. Sample group 9.

R4076 Same locality as R4075, field no. 86RAS 163. Sample group 9.

R4077 Field no. 86RAS 170-175, NE 1/4 SW 1/4 sec. 5, T. 7 N., R. 2 E., Umiat (D-3) quadrangle. Sample group 9.

R4079 Field no. 86RAS 200-202, N 1/2 sec. 34, T. 8 N., R. 2 E., Harrison Bay (A-3) quadrangle. Sample group 8.

R4080 Field no. 86RAS 214-217, SE 1/4 sec. 27, T. 8 N., R. 2 E., Harrison Bay (A-3) quadrangle. Sample group 8.

R4081 Field no. 86RAS 221-225, E 1/2 sec. 27, T. 8 N., R. 2 E., Harrison Bay (A-3) quadrangle. Sample group 8.

R4082 Same locality as R4081, field no. 86RAS 233-237. Sample group 8.

R4295 Sample, field number, section of Phillips (1988) in the Harrison Bay (A-3) quadrangle, and sample group: A, 86EB45, section 7; B, 86EB65, section 10; C, 86EB82, section 11; sample group 7. E, 86EB93, section 15, sample group 6. F, 86EB103, section 17; G, 86EB99, section 17; sample group 5. H, 86EB114, section 20, sample group 4.

[1] Tschudy (1969, p. A2) gave the location of sample locality D3124 as "lat 69°40' N., long 51°25' W., in T. 4 N., R. 2 E., Umiat quadrangle." However, the 1985 edition of the Umiat (C-3) quadrangle shows lat 69°40' N., long 151°25' W. as being in a marsh in T. 4 N., R. 3 E. The most likely location of the samples is in the cliffs on the west side of the Colville River in sec. 30 or 31, T. 4 N., R. 3 E. Therefore, as a result of the problem discussed in footnote 4, locality D3124 is (1) just to the north of, or is the same locality as, R3695, or is (2) a mile or more north of locality R3695. In figures 2 and 5, locality R3695 is assumed to be slightly south, downsection, from locality D3124.

[2] Samples analyzed for dinocysts but not for pollen.

[3] Samples analyzed for both dinocysts and pollen.

[4] Above the drawing of H. S. Sonneman's measured section 84-PC-I (locality R3695 of the present report), the location is stated as "sec. 31, T4N, R3E." However, the location map

for section 84-PC-I shows it as being located in NW 1/4 sec. 8, T. 3 N., R. 3 E., about 1.5-2 mi south of the location stated on the measured section.

Sample groups, samples listed in descending stratigraphic order (locations of samples from sample groups 1-6 were given by Frederiksen, 1991):

1 ARCO 98; ARCO 97; R3768; R3924; ARCO 266; R3818; R3819; R3820; R3769; R3821; R3786
2 R3770; R3787; R3772; R3823; R3789; R3824; R3885; R3889; R3828; R3825; R3826; R3827; R3828
3 R3791; R3890; R3834; R3835; R3792; R3837
4 R3838; R3891; R3892; R3152 C, B, A; R4140 A, B, C, D, F, G; R3413 Q, O; R4295 H; R3413 G, E
5 R4295 G, F
6 R4295 E
7 R4295 C, B, A; R3946 Q, P; 16409-4, -5; R3317 B, A; R3947 B, D, J, K
8 16410-3; R4082, R4081, R4080, R4079
9 R3945 N, H, D, A; R4077, R4076, R4075, R4074
10 R4073
11 16408-4
12 D3124 A, B, C, G, H; R3695 B, C, F, H, M
13 D4036-1, -2, -3, -5, -6, -7, -8
14 D4036-9, -10, -12A, -12B, -13, -14, -15
15 D4036-19, -20, -21, -22, -26, -27A, -30
16 D4036-37, -43
17 D4036--47, -51, -61, -65
18 D4036-70, -73, -76; 16453-1 to -8
19 D4036-78, -80A, -82, -88, -90; 16453-9 to –14
20 D4036-95, -97, -100, -103, -106, -108
21 R3694 A, D, I, J, K, N

Table 3. Annotated list of pollen taxa mentioned in this report. Numbers preceding names are the order of the taxa in figure 5.

Porate pollen

10 *Alnus*
77 *Anacolosidites grandis* Bondarenko 1966
76 *Anacolosidites insignis* Samoilovich in Samoilovich & Mchedlishvili 1961
97 *Anacolosidites striatus* Wiggins 1982
15 *Anacolosidites* sp. of Frederiksen (1991)
7 *Betulaepollenites*
12 *Erdtmanipollis*
1 *Jarzenipollis trinus* (Stanley 1965) Kedves 1980
4 *Paraalnipollenites alterniporus* (Simpson 1961) Srivastava 1975 type H = *P. confusus* (Zaklinskaya 1963) Hills & Wallace 1969, type H of Frederiksen and others (1988)
8 *Paraalnipollenites alterniporus* type Z = *P. confusus*, type Z of Frederiksen and others (1988)
50 *Proteacidites thalmannii* Anderson 1960 complex
14 *Triatriopollenites*
6 *Triporopollenites megagranifer* (Potonié 1934) Thomson & Pflug 1953 type of Frederiksen and others (1988)
9 *Triporopollenites mullensis* (Simpson 1961) Rouse & Srivastava 1972
5 *Trivestibulopollenites*
2 *Ulmipollenites krempii* (Anderson 1960) Frederiksen 1979
3 *Ulmipollenites tricostatus* (Anderson 1960) Frederiksen 1980

Tricolpate and tricolporate pollen

32 *Callistopollenites radiatostriatus* (Mchedlishvili in Samoilovich & Mchedlishvili 1961) Srivastava 1969
55 *Callistopollenites tumidoporus* Srivastava 1969
49 *Callistopollenites* sp. of Frederiksen and others (1988)
13 *Cercidiphyllites*
42 *Cranwellia* + *Striatellipollis*
17 *Myrtipites scabratus* Norton in Norton & Hall 1969
27 *Orbiculapollis globosus* (Chlonova 1957) Chlonova 1961
22 *Orbiculapollis lucidus* Chlonova 1961
33 *Porosipollis porosus* (Mchedlishvili in Samoilovich & Mchedlishvili 1961) Krutzsch 1969
70 *Pulcheripollenites krempii* Srivastava 1969
39 *Rousea compta* Frederiksen 1991
38 *Senipites drumhellerensis* Srivastava 1969
48 *Siberiapollis constrictus* (Samoilovich in Samoilovich & Mchedlishvili 1961) Frederiksen 1991

45 *Siberiapollis* sp. aff. *S. occulatus* (Samoilovich in Samoilovich & Mchedlishvili 1961) Tschudy 1971 = *Proteacidites* sp. of Frederiksen and others (1988, pl. 1, fig. 17)
51 *Siberiapollis* sp. aff. *Proteacidites* sp. 1 of McIntyre (1974) = *Proteacidites* sp. 1 of McIntyre (1974) of Frederiksen and others (1988, pl. 1, fig. 18)
72 *Striatopollis tectatus* Leffingwell 1971
52 *Tricolpites* sp. aff. *T. matauraensis* Couper 1953 of Frederiksen (1991)
71 *Discoidites parvistriatus* (Norton in Norton & Hall 1967) Nichols & Brown 1992
78 *Tricolpites* sp. of Bratzeva (1969, pl. 17, figs. 1-6)
11 *Trudopollis*

<u>Oculata pollen</u>

63 *Azonia cribrata* Wiggins 1976
65 *Azonia fabacea* Samoilovich in Samoilovich & Mchedlishvili 1961
67 *Azonia hirsuta* (Samoilovich 1965) Wiggins 1976
56 *Azonia* sp. cf. *A. hirsuta* of Frederiksen (1991)
103 *Azonia parva* Wiggins 1976
66 *Azonia pulchella* Felix & Burbridge 1973
87 *Azonia recta* (Bolkhovitina 1959) Samoilovich in Samoilovich & Mchedlishvili 1961
58 *Azonia strictiparva* Frederiksen 1991
21 *Wodehouseia bella* Wiggins 1976
68 *Wodehouseia edmontonicola* Wiggins 1976
19 *Wodehouseia elegans* (Samoilovich in Samoilovich & Mchedlishvili 1961) Wiggins 1976
34 *Wodehouseia gracile* (Samoilovich in Samoilovich & Mchedlishvili 1961) Pokrovskaya 1966
20 *Wodehouseia octospina* Wiggins 1976
24 *Wodehouseia quadrispina* Wiggins 1976
29 *Wodehouseia spinata* Stanley 1961 (includes *Wodehouseia stanleyi* Srivastava 1966)
26 *Wodehouseia vestivirgata* Wiggins 1976
54 *Wodehouseia wigginsii* Frederiksen 1991

<u>Triprojectate taxa *sensu stricto*: Grains are mainly observed lying in equatorial view</u>

31 *Aquilapollenites* sp. aff. *A. abscisus* Chlonova 1961 of Frederiksen and others (1988)
16 *Aquilapollenites alaskensis* Frederiksen 1991
53 *Aquilapollenites amicus* Srivastava 1968
57 *Aquilapollenites* sp. cf. *A. augustus* Srivastava 1969 of Frederiksen (1991)
90 *Aquilapollenites clarireticulatus* (Samoilovich 1965) Tschudy 1969
80 *Aquilapollenites colvillensis* Tschudy 1969
23 *Aquilapollenites conatus* Norton 1965
85 *Aquilapollenites contiguus* Tschudy 1969
40 *Aquilapollenites delicatus* Stanley 1961
62 *Aquilapollenites fusiformis* Tschudy 1969
60 *Aquilapollenites immiser* Sweet 1986

86 *Aquilapollenites laticorpus* Tschudy 1969
73 *Aquilapollenites* sp. cf. *A. laticorpus* of Tschudy (1969)
59 *Aquilapollenites notabile* (Mchedlishvili in Samoilovich & Mchedlishvili 1961) Farabee 1990
35 *Aquilapollenites quadrilobus* Rouse 1957
74 *Aquilapollenites rectus* Tschudy 1969
43 *Aquilapollenites reticulatus* (Mchedlishvili in Samoilovich & Mchedlishvili 1961) Tschudy & Leopold 1971
82 *Aquilapollenites scabridus* Tschudy 1969
89 *Aquilapollenites senonicus* (Mchedlishvili in Samoilovich & Mchedlishvili 1961) Tschudy & Leopold 1971
83 *Aquilapollenites trialatus* Rouse 1957
30 *Aquilapollenites unicus* (Chlonova 1957) Chlonova 1961
44 *Aquilapollenites* sp. A of Frederiksen (1991). *Pentapollenites paradolium* Zhou in Song et al. 1981 is very similar but seems to have a thicker exine at the poles.
94 *Aquilapollenites* sp. 1. Somewhat similar to *Aquilapollenites reticulatus* (Mchedlishvili in Samoilovich & Mchedlishvili 1961) Tschudy & Leopold 1971 but smaller, the polar axis about 22-26 μm; the body of the grain is rather rectangular in shape, the poles flattened; the equatorial projections are short, rather narrow, pointed. Exine only about 1 μm thick. Very finely reticulate.
102 *Aquilapollenites* sp. 2. Somewhat similar to *Aquilapollenites reticulatus* but the body of the grain is rather rectangular in shape, the poles flattened. The equatorial projections are rather long and are broadly rounded at the ends. Exine about 2.5 μm thick; nexine very thin. Columellae tend to be less distinct at the poles than over the remainder of the body. Lalongate ora, as in *Parviprojectus dolium* Samoilovich 1965, are distinct to obscure. The polar axis is about 30-39 μm. Very finely reticulate.
93 *Aquilapollenites* sp. 3. Similar to *Aquilapollenites trialatus* Rouse 1957, but the fine reticulum of the body disappears at the poles, which are psilate. The poles are flat. Polar axis about 65 μm.
96 *Aquilapollenites* sp. 4. Straight-sided body; broadly rounded poles; finely retistriate. Specimens range from a polar axis of 26 μm with a length:width ratio of 1.6 to a polar axis of 53 μm with a length:width ratio of 2.0; therefore, at least two species may be present within this category. *Aquilapollenites parallelus* Tschudy 1969 is coarsely striate and has larger equatorial projections. Zhou and Wang (1983) described a number of finely retistriate species of *Aquilapollenites*, but all of them have much higher length:width ratios, and the equatorial projections are larger.
61 *Fibulapollis inaequalis* Frederiksen 1991
64 *Fibulapollis scabratus* Tschudy 1969
75 *Fibulapollis* sp. 1. Similar to *Fibulapollis scabratus*, but the major polar projection is more highly developed, and the tip of the major polar projection is punctate to nearly psilate as in "*Mancicorpus*" *pseudosenonicus* Frederiksen 1991.
46 "*Jaingsupollis*" *striatus* Song in Song et al. 1981
47 "*Mancicorpus*" *anchoriforme* Mchedlishvili in Samoilovich & Mchedlishvili 1961
36 "*Mancicorpus*" *pseudosenonicus* Frederiksen 1991

25 *"Mancicorpus" rostratus* Srivastava 1968
79 *"Mancicorpus" solidum* Mchedlishvili in Samoilovich & Mchedlishvili 1961
18 *"Parviprojectus" amurensis* Bratzeva 1965
69 *"Pseudointegricorpus" protrusum* Takahashi & Shimono 1982

"Expressipollis" group and *Kurtzipites*: Grains are mainly observed lying in polar view

99 *"Expressipollis" striatus* Wiggins 1982
100 *Syndemicolpites* sp. 1. Synonym: *"Expressipollis"* sp. A of Kimyai (1992, pl. 5, fig. 8). Similar to *"Expressipollis" accuratus* Chlonova 1961, but distinctly demicolpate rather than syndemicolpate; size about 27-44 μm. The exine is about 1.5 μm thick, thinner than in *"E." accuratus*, and in contrast to *"E." accuratus* and to *"E." striatus* Wiggins 1982, the exine commonly thins slightly at the equator where the exine forms "bridges" separating the colpi of each hemisphere. The sides of the grain are gently concave, less concave than in *"E." striatus*. The exine is punctate-striate as in *"E." striatus*. The corners of the grain are more narrowly rounded than in *"E." accuratus* but slightly more broadly rounded than in *"E." striatus*. There seems to be no tendency for the colpi traces to be thickened between the slightly gaping ends of the colpi and the polar areas where the colpi traces are lacking.
101 *Syndemicolpites* sp. 2. Synonym: *Expressipollis* type of Frederiksen and others (1988, pl. 3, fig. 16). The most similar species is *Syndemicolpites* sp. 1. By comparison, *Syndemicolpites* sp. 2 is larger (about 43-46 μm in polar view), and the colpi traces are thickened (about 2-5 μm wide) between the slightly gaping ends of the colpi and the poles where the colpi traces would probably be invisible were the thickenings not present. The colpi trace thickenings are wider than in *"E." striatus* but about the same width as in *Cupanieidites borealis* Chlonova 1961 (see Bondarenko, 1969, pl. 3, figs. 5, 7; 1983, pl. 11, fig. 1a). Distinct thickenings of the exine are present midway between the corners of the grain. In contrast to *Syndemicolpites* sp. 1, the exine is punctate rather than punctate-striate. In equatorial view, the equatorial axis is about 45 μm, the polar axis about 31 μm; the two polar projections seem to be about equally developed and are rounded at their ends.
98 *Syndemicolpites* sp. 3. Similar to *"Expressipollis" striatus*, but in polar view, the tips of the equatorial projections are more broadly rounded, the design is reticulate (brochi about 1 μm) rather than punctate-striate, and the size is a little smaller, about 48-58 μm. In equatorial view, only one polar projection is present, so that the grain is a straight-sided isosceles triangle; the equatorial axis is about 64 μm, the polar axis about 35 μm.
95 *Syndemicolpites* sp. 4. Very similar to *"Accuratipollis" enodatus* Chlonova 1961 except that the apertures are distinctly demicolpate rather than crossing the equator as in *"A." enodatus* (Chlonova, 1961, pl. 16, fig. 126; 1962, pl. 3, fig. 17). In polar view, the sides are slightly less concave than in *"A." enodatus*; size about 51-53 μm. In equatorial view, the equatorial axis is about 65 μm, the polar axis about 43 μm; one polar projection is higher than the other; the tips of both polar projections are pointed.
91 *Syndemicolpites* sp. 5. Outline triangular, sides moderately concave; corners very broadly rounded to flat. Size about 39-43 μm. Exine slightly thinner at the corners of

the grain than elsewhere. The demicolpi may or may not extend to the poles; some specimens are parasyndemicolpate. The edges of the colpi are generally but not always bordered by narrow thickenings; in some specimens, the ends of the colpi gape irregularly near the equator. The exine is finely reticulate-striate.

84 *Syndemicolpites* sp. 6. This species is intermediate between "*Accuratipollis*" *enodatus* and *Syndemicolpites* sp. 5. The important differences from "*A.*" *enodatus* are that (1) the exine distinctly thickens from the corners to midway along the sides, (2) in polar view, the polar projections can be seen to be quite small and may be barely noticeable, and (3) the exine is punctate-striate. In contrast to *Syndemicolpites* sp. 5, the corners of the grain are narrowly rounded, almost pointed.

92 *Syndemicolpites* sp. 7. Outline in polar view triangular, sides only very slightly concave. Size about 31-34 μm. Exine only about 1 μm thick except at the corners of the grain, where it is about 1.5-2.5 μm thick. The demicolpi extend to the poles; the ends of the colpi do not gape near the equator. The exine is finely retistriate.

81 *Syndemicolpites* sp. 8. Shape in polar view triangular, sides nearly straight, corners narrowly rounded to pointed. Size about 28-40 μm. Demicolpi do not extend to the poles. Colpi very narrow, usually lacking gaping distal ends, edges of colpi not thickened. The exine is rugulate to striate, with patches of fine reticulum mixed in. "*Loranthacites*" *pilatus* Mchedlishvili in Samoilovich & Mchedlishvili 1961 is very similar but has slightly more rounded corners, and the exine is finely clavate. "*Loranthacites*" *macrosolenoides* Mchedlishvili in Samoilovich & Mchedlishvili 1961 is colpate, not demicolpate, and the exine is finely reticulate. In equatorial view, the equatorial axis is about 42 μm, the polar axis about 33 μm; the two polar projections seem to be about equally developed and are broadly rounded at their ends. "*Loranthacites*" *macrosolenoides* Mchedlishvili of Jarzen (1977, fig. 5, 8-9) seems to be similar to this species.

88 *Kurtzipites andersonii* Srivastava 1981

37 *Kurtzipites annulatus* Norton in Norton & Hall 1969

28 *Kurtzipites circularis* (Norton in Norton & Hall 1969) Srivastava 1981

41 *Kurtzipites trispissatus* Anderson 1960

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