Stratigraphy and Palynology of the Tullock Formation
of the Fort Union Group (Paleocene)
McConie County, Montana

by

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A thesis submitted to the faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science (Geology).

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This thesis establishes a range zonation of selected palynomorphs from the Cretaceous-Tertiary boundary through early Paleocene strata in the Bug Creek Quadrangle of McCone County, Montana. The rock units included in this zonation are the upper portion of the Hell Creek Formation, the entire local Tullock Formation, and the lower portion of the Lebo Formation. This zonation is applied to currently interpreted boundaries of provincial vertebrate ages and to an established magnetic reversal datum.

Five sections were measured, described and correlated lithologically. Twenty-six coal and shale samples were selected for processing. Thirteen samples proved to have sufficient number and diversity of pollen to be useful for this investigation.

Results of this investigation suggest that the early Paleocene strata in Bug Creek Quadrangle can be divided into three pollen zones. The first extends from the Cretaceous-Tertiary boundary to the X coal. This zone is typified by \textit{Wodehouseia spinata} and a large number of fern spores. The second zone begins at the X coal and terminates at 175 ft (53.34 m) above the Cretaceous-Tertiary Boundary. \textit{Brevicolporites sp.} and \textit{Wodehouseia fimbriata}
are confined to this zone, and Momipites sp. makes its appearance at the bottom of this zone and continues throughout the rest of the sections. The third pollen zone begins at 175 ft (53.34 m) and ends near the base of the Lebo Formation at 251 ft (76.50 m). The pollen assemblages are sparse and are characterized by a genus of unknown affinity. A lower Lebo Formation sample yielded micro-foraminifers that might be indicative of a marine or brackish water origin.
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I am especially appreciative to Dr. Karl R. Newman who provided me with the guidance and insights needed to complete the work required for this thesis. Drs. J. Keith Rigby, Jr., and J. Keith Rigby Sr., were instumental in providing guidance and logistical support during my stay in the thesis field area. Gratitude is also expressed to the other members of my thesis committee, Dr. Harry Kent and Dr. Graham Closs, for providing me with additional insights used in the composition of this paper. Were it not for the assiduous support from my family, however, no part of my master's program would have been possible.
INTRODUCTION

Purpose and Objectives

This thesis establishes a range zonation for selected palynomorphs from the Paleocene upper Hell Creek Formation and the Tullock Formation. This zonation may assist in the biostratigraphic correlation of early Paleocene strata in northeast Montana as well as in western North America. Interpretive stratigraphy was used in establishing a vertical succession of depositional events upon which this zonation is based.

The succession of pollen zones will also serve as an additional basis for stratigraphic control of vertebrate assemblages, orogenic events, and paleomagnetic reversal data for current and future studies.

The major objective of this thesis is the establishment of the range zonation for selected palynomorphs. The means by which this was accomplished is threefold. First, the Paleocene strata of the Bug Creek Quadrangle, Montana, were measured and described. Samples were collected in the field, and rock units were correlated as shown on the columnar section chart (Plate 4). Secondly, the samples from the field were processed to extract the pollen. Thirdly, the pollen specimens were
examined and identified. The occurrences of the individual species are shown on the range zonation chart (Plate 5).

Geographic Location

The area of study is located in McCone County, northeast Montana, within Bug Creek Quadrangle (Figure 1), T. 23-24 N. and R. 43-44 E.. Outcrops were measured and described along an 8 1/4 mi (13.28 km) traverse of badlands east (1-3 mi; 1.60-4.80 km) of the Dry Arm Branch of the Fort Peck Reservoir (Plate 4).

The study area is 20 mi (32.19 km) south of the town of Fort Peck and 21 mi (33.80 km) north of State Route 200 on either side of State Route 24 (S.R. 24, Figure 2). The nearest major town is Glasgow, Montana, which is approximately 60 mi (96.56 km) to the northwest. Rock Creek State Park is approximately 3 mi (4.83 km) northwest of the study area.

The semi-arid, temperate climate allows for the growth of grasses and small shrubs on the terraces and flats. Small trees are able to grow in the gullies of the badlands and along the stream and lake margins. Rattlesnakes, bull snakes, rodents, and small birds are the principal inhabitants of these grasslands. The small
Figure 1 - The study area is Bug Creek (after Smit, et al., 1987).
(after Collier and Knechtel, 1939)

Figure 2 - Locations of the major sections within the study area.
amount of rainfall, coupled with seasonal thunderstorms and soft bedrock, are determining factors in the formation of the badland-type topography which is common in this locality. The exposures for all of the sections measured are the badland slopes and gullies that are characteristic of eastern Montana. The exposures are, for the most part, excellent.
PREVIOUS WORK

Stratigraphic Studies

The earliest work in northeast Montana and North Dakota was done by Hayden (1861) who described and named the Fort Union Formation. The name Fort Union was taken from an army post whose name was changed to Fort Buford near present-day Buford, North Dakota. Originally this formation was interpreted to be early Tertiary, but later the age was further refined to be Paleocene.

J.B. Hatcher (1903) first used the term "Lance Creek beds" in Wyoming. From his discussion, the term "Lance" came to apply to sediments in Montana that now belong to the Hell Creek and Tullock Formations. The term "Lance" was adopted for a short time by the U.S. Geological Survey.

Stone and Calvert (1910) named the Lebo Formation in the Livingston area of south-central Montana to define a sequence of strata between the underlying Lance Formation and overlying Fort Union Formation. The Fort Union during this time was believed to consist of strata younger than the Lebo Formation.

Calvert (1912) created the alphabetized naming of coals in northeast Montana. The A coal was defined to
be the stratigraphically lowest coal of the area, and the following letters of the alphabet were assigned to subsequent coals in ascending stratigraphic order. It was Calvert (1912) who introduced the concept of "a lowest persistent lignite," (i.e. the A coal) as separating the Lance Formation beds from the Fort Union Formation.

The Tullock Formation was first described by Rogers and Lee (1923) in the vicinity of present-day Hardin, east of where the Bighorn River meets the Yellowstone River. The Tullock was initially assigned to the Lance Formation.

The most important work relevent to this study was done by Collier and Knechtel (1939). These authors mapped the study area and brought into use the system of naming coals in reverse stratigraphic order. The lowest group of coals in the former Lance Formation was named the Z coal. These coals were known to separate the Hell Creek Formation from the overlying Tullock Formation. Major coals overlying the Z coal in ascending sequence were labelled "Y, X, W, V, and U." The base of the U coal separates the Tullock Formation from the overlying Lebo Formation. The system of naming the coals created by Collier and Knechtel (1939) has been the convention for subsequent studies in Garfield and McConne Counties including this thesis.
Collier and Knechtel (1939) also placed the contact between the Hell Creek and Tullock Formations at the base of a single Z coal or the base of the uppermost Z coal (if there are several). This illustrates that both authors realized that the "Z coal" can be one or more coals.

Dorf (1940) through flora studies recognized the dissimilarity between the Paleocene upper Lance Formation (present Tullock/Lebo Formations) and the Cretaceous lower Lance Formation (present Hell Creek Formation). He also recognized and proved a similarity between the Fort Union and upper Lance Formations. So the Fort Union Formation was elevated to group status and came to include the Tullock, Lebo, Ludlow and Cannonball Formations. The term "Lance," has henceforth been suppressed in Montana and North Dakota usage.

The U.S. Geological Survey has since stratigraphically lowered the base of the Fort Union to include all the Paleocene units (Tullock, Lebo, Ludlow, and Cannonball). But the U.S. Geological Survey retained the Fort Union as a formation, and all the units within it were kept as members. On the other hand, the North Dakota Geological Survey uses the Fort Union as a group name and the inclusive units as formations. This thesis will apply group status to the Fort Union in accordance with the practice of
the North Dakota Geological Survey (Figure 3).

Later discussions of the Paleocene in northeast Montana by Brown (1952, 1962) confirmed the position of the A coal to be the lowest sequence of coal above the stratigraphically highest in-place dinosaur remains. This "formula" of selecting the lowest persistent coal (hence the Tullock/Hell Creek contact) along with the position of dinosaur remains became formalized and thereupon accepted into widespread use in northeast Montana, although the term "A" coal has not been used since.

Archibald (1982) perpetuated the use of Collier and Knechtel's (1939) naming of the coals in Garfield County. In his study, Archibald (1982) recognized that the Z coal was not merely a single coal, but rather a series or complex of coals with as much as 45 ft (13.70 m) separating the uppermost from lowermost Z coal. To distinguish between the upper Z coal and the lower Z coal, he instituted the use of "Z" to represent the upper Z coal and "Z" to represent the lower Z coal. No special designation was allotted for the coals in between. For simplicity's sake, no abbreviations will be used when discussing the Z coals in this study. Archibald (1982) erred, however, in stating that the lower Z coal was the contact between the Tullock Formation and the Hell
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Figure 3 - This diagram shows the different formations of eastern Montana and western North Dakota with respect to time.
Creek Formation. The distinctly yellow beds of the Tullock Formation do not begin until above the upper Z coal. Therefore, the base of the upper Z coal has come to be the contact between the Tullock and Hell Creek Formations (Rigby, Jr., pers. comm.).

Moore (1976) and Cherven and Jacob (1985) interpreted the paleogeography of the Williston Basin from late Cretaceous through Paleocene time. From these investigations, the study area was interpreted to be fluvial settings inland from the Cannonball Sea to the east in present-day North Dakota. Sediments were said to be brought from uplifted areas of the Blackhills, Elkhorn, and Bighorn Mountains.

Fastovsky (1987) completed a stratigraphic analysis of the Tullock Formation within the study area and determined that the sediments of the study area were deposited by fluvial systems in floodplain-type settings. Part of the strata he studied encompass units included in this thesis.

Retallack, et al., (1987a, 1987b) and Leahy, et al., (1985) conducted investigations of the rock units and paleosols on either side of the Cretaceous-Paleocene boundary at Russell Basin. These studies interpreted the environmental conditions of the late Cretaceous through early Paleocene time, which are discussed later in this thesis.
Paleomagnetic Studies

Archibald, et al. (1982) defined the rock intervals of reversed polarity and normal polarity at four locations in and around the study area. Three periods of the earth's polarity were recorded. Two of the locations they studied are in Garfield County, one at Billy Creek and the other at Snow Creek. The other two localities are in McCone County at Bug Creek Antihills and at Purgatory Hill. The intervals that were defined at Purgatory Hill are included in a measured section within this thesis. Archibald, et al. (1982) found that a change from reversed polarity to normal polarity is recorded approximately eleven meters below the Purgatory Hill channel sequence.

The Terminal Cretaceous Event

In 1980, Alvarez, et al., through studies at numerous localities, proposed the terminal Cretaceous event theory to explain anomalously high values of iridium in marine sediments at the Cretaceous-Paleocene boundary. This theory also intended to explain the mass extinctions at the end of the Cretaceous. These scientists reasoned that the most likely source of the iridium was extra-
terrestrial. The occurrence of the iridium, in association with the Cretaceous extinctions, led Alvarez, et al. (1980) to conclude that the extinctions were caused by the same mechanism that created the iridium anomaly. The mechanism they proposed was the impact of a meteor at the earth's surface. Inclusive to this theory is the possibility that sunlight may have been blocked for several months (Alvarez, et al., 1982) and in the process, vast amounts of vegetation would have been destroyed. Animals unable to live without sunlight, or on the dead and decaying debris at the earth's surface, would have died.

The recovery of the flora may have started with large numbers of mosses and ferns on a denuded landscape, thus causing a "fern spore spike," to be formed and left in the sediments. This "spike," implies that large numbers of mosses and ferns (spore bearing plants) of limited diversity created a statistical overabundance of spores in the rock record immediately above the iridium anomaly (Orth, et al., 1981: Tschudy, et al., 1984).

The impact theory is outside the direct scope of this thesis. But it is mentioned because the studies which are discussed at greater length in the following two sections have a bearing on this theory.
Recent controversy over the impact event proposed by Alvarez, et al. (1980) created the need for paleontological studies where there is an exposed transition from Cretaceous through Paleocene in the rock record. Some of the paleontological work on early Paleocene mammals predating this theory was done by Sloan and Van Valen (1965). This study defined the stratigraphic position of late Puercan age mammal fossils to be at the base of the Purgatory Hill channel sequence. Further mammal studies by Sloan (1987) and Smit, et al. (1987) have refined the position of vertebrate ages in Bug Creek to be as follows: Lancian age fossils occur well below the lower Z coal; Bugcreekian age fossils occur on either side of the lower Z coal, but below the upper Z coal; and the late Puercan age fossils occur at Purgatory Hill (which is mid-Tullock). The exact limits of the Mantuan and Torrejonian mammal ages are not known (Figure 4).

Rigby, et al. (1987) question dinosaur extinctions by an impact event because of evidence gathered from channel sequences in the Bug Creek area. Dinosaur teeth and bones suggest that several species of dinosaurs were extant during the earliest Paleocene.
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<td>Lancian</td>
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Figure 4 - The positions of the provincial vertebrate ages relative to the lithologic units of this thesis in addition to the standard marine ages and time.
Palynologic Studies

Norton and Hall (1969) completed palynologic studies of late Cretaceous and early Paleocene strata in the type locality of the Hell Creek Formation north of Jordan in Garfield County, Montana. The palynologic studies of the earliest Paleocene in North Dakota by Robertson (1975), and a similar study of the upper Cretaceous and lower Tertiary of northwestern South Dakota by Stanley (1960), were used for comparative purposes during the identification of the pollen for this thesis.

Tschudy (1970) completed pollen studies of the upper Hell Creek Formation and lower portion of the Tullock Formation (40-50 ft; 12.20-15.20 m above the Z coal) in various localities south of the Missouri River and north of Miles City, Montana. His study outlined some of the flora extinctions that took place from Cretaceous through earliest Paleocene.

Numerous pollen studies have been initiated in the U.S. and Canada in order to test the impact theory. Most of these studies took place in areas where the rock record representing the Cretaceous through Paleocene is exposed at the surface.

Orth, et al. (1981) defined some of the palynologic changes that took place from latest Cretaceous through
earliest Tertiary time in the Raton Basin of New Mexico. Further studies of the same basin by Tschudy, et al. (1984) confirmed the existence of a boundary fern spore spike at Trinidad, Colorado, and the ecologic conditions that the proposed meteorite impact had on the Cretaceous flora were discussed.

Near Morgan Creek in south-central Saskatchewan, Nichols, et al. (1986) discovered both the iridium anomaly and fern spore spike. In the Alberta foothills, Sweet (1986) and Jerzykiewicz and Sweet (1986) conducted taxonomic analysis of the palynomorphs across the Cretaceous-Paleocene boundary. Lerbekmo, et al. (1986) also analyzed the pollen assemblages across the Cretaceous-Paleocene boundary in Alberta, Canada. The latter study was also a geochemical study that found iridium and fern spore spikes in Deer Valley, Frenchman Valley, and Coal Valley. All the results from the Canadian studies served as a basis for comparing pollen species for this thesis.

Smit, et al. (1987) found a fern spore spike at Russell Basin, McCone County, immediately above the base of the lower Z coal, thus confirming the stipulation that the lower Z coal is the stratigraphic boundary between the Cretaceous and Paleocene. Orth (cited in Fastovsky and Dott, 1986, and Rigby, et al., 1986) found the iridium
anomaly at the base of the lowermost Z coal at Russell Basin, which shows that evidence for the impact does exist in the study area.
GEOLOGIC SETTING

General Stratigraphy

The strata of the study area are part of the western limb of the Williston Basin. The axis of this basin lies in western North Dakota. The Cretaceous Fox Hills Formation is exposed west of the study area in McCone County. On top of the Fox Hills is the predominately Cretaceous Hell Creek Formation. Overlying the Hell Creek Formation are the formations of the Fort Union Group: Tullock, Lebo, Tongue River, and Sentinel Butte. The Cannonball and Ludlow Formations are also formations of the Fort Union Group in North Dakota. They were deposited contemporaneously with the Tullock/Lebo Formations (Figure 5). The Tullock Formation is overlain by the sediments of the Lebo Formation. Both formations grade eastward into the Ludlow Formation of North Dakota. The Ludlow Formation is known to intertongue with the marine Cannonball Formation in western North Dakota.

In central Montana, the Tullock and Lebo Formations have been eroded due to tectonic uplifting. That is, at the surface, the Tullock and Lebo Formation are bound to the west by the older Hell Creek Formation because the strata of the Hell Creek Formation and Fort Union
Figure 5 - A paleogeographic map of eastern Montana and North Dakota showing the relative positions of the study area (within the box) and the Cannonball Sea (according to present outcrop limits) during the deposition of the Tullock and Ludlow Formations. The direction of drainage in the study area is to the southeast.
Group of northeast Montana gently dip eastward, and away from the uplifts.

Paleoenvironments

The Fox Hills Formation was deposited as the Cretaceous sea retreated to the east at the end of the Cretaceous. As the sea regressed toward present-day North Dakota, the terrestrial Hell Creek Formation formed on top of the transitional Fox Hills Formation. The Hell Creek Formation is believed to have been deposited in lowland subtropical environments (Leahy, et al., 1985). The soils are believed to have been well drained and able to support abundant closed canopy forests (Leahy, et al., 1985). Due to these conditions, the formation of coal was inhibited.

The latest Cretaceous and Paleocene appear to have brought on topographic as well as climatic changes. According to Leahy et al. (1985), the paleosols of uppermost Hell Creek and the Tullock Formations reflect cooler temperatures, more humid climates, consistently high water tables, and abundant vegetation. The formation of coals was more likely to take place under such conditions. During the deposition of the Tullock Formation,
the Ludlow Formation was deposited contemporaneously to the east in present-day North Dakota. This formation reflects the conditions of the Tullock Formation, although the Cannonball sea no doubt had a greater influence on the Ludlow Formation than on the Tullock Formation. The presence of this marine body of water to the east determined the base level for drainage and the possible sources of brackish water. The height of the water table may have been affected if this sea was proximal to the study area. These factors may have determined whether or not coals could form in the Fort Union Group.

The Tullock Formation in the study area has been divided into two facies (Rigby, pers. comm.). One is the mudstone facies (the lower half), and the other is the sandstone facies (the upper half). Both have been interpreted to reflect sedimentation in a fluvial plain. Both facies comprise a clastic wedge of sediments that were shed from uplifted areas such as the Elkhorn Mountains, Bighorn Mountain, and the Black Hills (Cherven and Jacob, 1985) to the west and south of the study area.

The Z Coal

The datum for the sections studied in this thesis will be the Z coal. In this discussion the Z coal and
the Z coal complex are regarded as the same lithologic and time unit. The possibility does exist, however, that they may not be the same coal seam over wide areas. It is believed that the environment of deposition of the Z coal and the Z coal complex were the same. The Z coal complex resulted from splitting of the single Z coal.

There are two basic assumptions that this thesis will be based upon. The first assumption is that the uppermost Z coal at Russell Basin corresponds approximately to the Z coal at the other sections in the study area. The second assumption is that the Z coal and the Z coal complex are associated with the lowest persistent coal of other study areas (e.g. Brown, 1952). The impact of the latter assumption is lessened by the local scope of this thesis. The use and application of the term "Z coal" in this thesis corresponds to the usage of the "Z coal" by Rigby et al. (pers. comm.). However, the first assumption is a critical one, and it cannot, as yet, be confirmed. This is due to the fact that the Z coal complex encountered at Russell Basin is within a topographic basin. It cannot be traced to any area outside the basin since it is the lowest exposed coal of that vicinity.
METHODS OF INVESTIGATION

The Sections

Four partial sections and one complete section of the Tullock Formation (Plate 4) were measured and described in the study area. The four partial sections are: Bonin Pass (B.P.), Purgatory Hill (P.H.), Russell Basin (R.B.), and McGuire Points (MC.P.). The complete section is South Fork Rock Creek. The Bug Creek Quadrangle map was used in locating the sections in addition to assistance provided to the author by J.K. Rigby, Jr., in the field.

The Bonin Pass section is within SE 1/4 sec. 14, T. 23 N., R.43 E.. The section starts approximately 2000 ft (609.6 m) west of B.M. 2367, east of S.R. 24, in a small ravine south of a dirt road, and ends at the top of a hill overlooking S.R. 24. Stratigraphically, the section begins at the single Z coal (within the ravine) and ends at a muddy sandstone unit at the top of the hill.

The Purgatory Hill section is in SW 1/4 sec. 36, T.23 N., R.43 E.. The section begins at the single Z coal approximately 500 ft (152.4 m) east of S.R. 24 and ends approximately 1,000 ft (304.8 m) east of S.R. 24 at the lower sandstone facies. The Purgatory Hill "A" section (P.H. A) is a section skirting the Purgatory Hill channel...
sequence 800 ft (243.8 m) to the south on surrounding topographic bluffs.

The South Fork Rock Creek section, the control section, begins in the NW 1/4 sec. 2, T.22 N., R.43 E., and ends in the NW 1/4 sec. 12, T.22 N., R.43 E.. The single Z coal is encountered in a ravine 500 ft (152.4 m) west of S.R. 24. The Lebo Formation shale occurs as outliers of rock visible to the east from S.R. 24 approximately 3000 ft (914.4 m) away. This section contains the entire local thickness of the Tullock Formation.

The section at Russell Basin is located within the NW 1/4 sec. 15, T.22 N., R.44 E.. The Z coal is believed to split in this locality, so the starting point is the lower Z coal and the ending point is the upper part of the mudstone facies.

The final section is the McGuire Points section. This section begins at the X coal in an erosional valley at the top center of sec. 36, T.22 N., R.43 E., and ends at the Lebo Formation shale outliers at the NW 1/4 sec. 31, T.22 N., R.44 E.. The starting point is 2500 ft (762.0 m) east of S.R. 24, and the ending point can be reached via dirt roads approximately 1 mi (1.6 km) east of S.R. 24. The McGuire Points "A" section (MC.P. A.) is an alternate mudstone section that flanks an interpreted channel sequence (Plate 4).
Field Methods

The sections were measured with the level on a Brunton compass. The starting point was the contact between the Hell Creek Formation and the Tullock Formation at all sections other than Russell Basin. At Russell Basin, the starting point was slightly above the Cretaceous-Paleocene boundary at the lower Z coal. The finishing point was the lower portion of the Lebo Formation. At two sections, South Fork Rock Creek and McGuire Points, the Lebo Formation was reached. The other sections did not extend into the Lebo Formation and were completed once the highest possible thickness was reached as determined by the topography.

The section at Russell Basin contains the Cretaceous-Paleocene boundary at the base of the lower Z coal. This investigation encompasses those strata above the Cretaceous-Tertiary boundary and, therefore, includes the Paleocene strata of the Hell Creek Formation above the lower Z coal (K-P boundary) as well. Throughout the rest of the study area, the Z coal complex is believed to be a single coal, thus making it both a formation contact between the Tullock Formation and the Hell Creek Formation, and also a time boundary between the Cretaceous and Paleocene.

Samples for pollen were collected at approximately 10 foot intervals, and a total of 26 were selected for
processing. Because the section at South Frok Rock Creek contains the greatest and most complete local thickness of the Tullock Formation, this section was made the control section. It was for this reason that 19 of the 26 samples were collected from South Fork Rock Creek. Other sections were correlated lithologically to this section where possible. 7 samples were processed from sections other than South Fork Rock Creek. 4 samples were taken from Russell Basin, and 3 were taken from Purgatory Hill.

Laboratory Preparations

Samples were first split into two groups, those containing a high percentage of humic material, and those of siliceous composition. The lignites were included in the former category and the carbonaceous shales were included in the latter.

The lignites were treated with a bleach solution (6% sodium hypochlorite) to break down the humic material and to separate the pollen from the rest of the organic material. These samples were then diluted with tap water. They were then size-separated with respect for fine material, and then to coarse material, to isolate the particle sizes of pollen (5-40 microns). If the resulting residue contained a high percentage of mineral debris, then HF (49%) or HCL (30%)
was added to dissolve such constituents.

The carbonaceous shales were first treated with HF (49%) and washed in a manner similar to the coals. The finest material was decanted after the pollen-size particles were allowed to settle. The heavy particles were washed out of the beakers when the pollen was decanted from a stirred solution. If the resulting solution contained a large percentage of organic material, a 6% sodium hypochlorite solution was added. If a high percentage of mineral debris still remained in the solution, HCL or HF was added once again. These steps were repeated as necessary until the samples were clean of all debris except the pollen-sized particles in a water solution.

Permanent slides were made by placing a drop of the sample suspension onto a cover slip containing a drop of Clearco (setting medium) and mixed. The cover slip was mounted on a labelled microscope slide using Permount, and then the slide plus cover slip was placed on a hot plate and allowed to dry. The labels on the slides indicate the section, the footage, and the slide number (in sequence) which was made from each sample residue.

An American Optical Series 10 microscope was used in identifying the pollen grains. Pollen that could not be assigned to a published genus were coded according to the classification system proposed by Tschudy (1957). Photo-
graphs were taken with a Leitz Orthomat microscope camera on an Ortholux Microscope.
DESCRIPTIVE STRATIGRAPHY

Of the five sections measured, only one, the South Fork Rock Creek Section (SFRC), contains the entire local thickness of the Tullock Formation. Three other sections, Russell Basin (R.B.), Purgatory Hill (P.H.), and Bonin Pass (B.P.), begin at the Cretaceous-Paleocene boundary and end at the beginning of the sandstone facies (Plate 4). The McGuire Points section begins at the local X coal and ends at the outliers of the brown Lebo Shale.

The Tullock Formation consists of two distinct lithologic facies: the underlying mudstone facies, and the overlying sandstone facies. Unless otherwise stated, the section at South Fork Rock Creek will be the principal basis for the descriptions.

Mudstone Facies

This facies lies between the lower Z coal and the overlying sandstone facies. Interbedded mudstones and siltstones occur between the lower Z and the upper Z coals. The mudstones are generally orange to tan and the siltstones are light grey in color. Generally the grain size increases with lightness in color. Two coals
that range in thickness from .5 to 1.5 ft (.15-.45 m) thick occur between the lower Z and upper Z coals.

The single Z coal for the sections other than Russell Basin varies from 1.0-2.0 ft (.30-.61 m) thick. At Russell Basin, however, the distance separating the upper Z from the lower Z coal is approximately 14.0 ft (4.27 m), with the Z coals ranging in thickness from .5 to 1.0 ft (.15-.30 m) thick.

Interbedded mudstones and siltstones immediately overly the upper Z coal are interbedded mudstones and siltstones. These are tan to grey in color, very fine grained, and possess organic layers that create partings. The laminations appear varve-like. There may be as many as twenty laminations within an inch (2.5 cm) of rock. The organic laminations contain pulverized plant material. Root structures are also present throughout.

Above the Z coal and below the Y coal are the so-called pajama-striped beds (Rigby and Smit, pers. comm., 1985). These are referred to as such because of the tan to orange and grey colored mudstones and siltstones. These sediments are interbedded in a repeated and regular fashion.

A lignite generally appears 6-15 ft (1.83-4.57 m) above the Z coal. Above this lignite, the sequence of interbedded mudstones and siltstones continues up to
the vicinity of the Y coal, which at South Fork Rock
Creek, occurs at 15 ft (4.52 m). At this level, lenses
of fine-grained sandstone, possibly representing splay
channel sequences, are more evident than below. Crevasse
splays and crevasses channels also become more evident
above the Y coal. In the vicinity of the Y coal, the
varve-like appearance of the interbedded mudstones and
siltstones fades, and lateral accretion deposits begin
to appear. The basic lithology in this vicinity continues
to be interbedded mudstones and siltstones. The grey
siltstones vary in thickness from 1.0-3.0 in (2.54-
7.62 cm); the corresponding tan to orange mudstones
have the same thickness. Root structures and laminations
of pulverized organic material are also present. In
areas of channel sequences, organic laminations within
a mud matrix compose the drapes that lime the conspicuous
channel bottoms and sides. Figures 6A & B illustrate
the nature of the bedding in this interval at Purgatory
Hill. The bases of these channelled areas are medium
to fine grained sandstones. Upward toward the top of
the channel (approximately 15.0 ft or 4.57 m), the lithology
becomes finer-grained and more organic rich until the
entire sequence culminates at the X coal capping the
unit.
Figures 6A & B - Examples of lateral accretion and planar bedding are evident at Purgatory Hill. Both photographs show the interbedded mudstones and siltstones between the marker coals of the lower Tullock Formation.
Above the X coal, the channel sequences change slightly. The bulk of the rock remains as interbedded mudstones and siltstones, with some light grey, fine grained sandstone lenses. Lateral accretion deposits can easily be seen. But the steepness of the channel banks is less, and the channel sequences generally are wider in lateral extent. Root structures are still quite abundant. Laminations of organic material are present in those beds that are basically horizontal and also within the channel margins.

Above the X coal is the W coal, which generally occurs at 70 ft (21.34 m) in the section. Volcanic ash beds are also present within this coal. The repetition of interbedded siltstones and mudstones continues with occasional lenses of fine-grained sandstones. It is here that there seems to be a return to the horizontally bedded mudstones and siltstones. Channels are still quite evident, but they appear to occur on a much smaller scale than in the section below. Interbedded mudstones and siltstones continue from the 90 ft (27.43 m) coal, and above, up to the contact with the sandstone facies. Channel sequences seem to be much less numerous.

The mudstone facies terminates at a coal or carbonaceous shale directly below the first portion of the sandstone facies.
The Sandstone Facies

This facies of the Tullock Formation is characterized by sandstone units of the upper portion of the formation. The dominant lithologies are: 1) buff-colored, fine-to-medium grained, poorly indurated sandstones, and 2) brown, fine-to-medium grained, poorly indurated sandstones. The latter contain a high percentage of organic matter, shales, and a lack of cemented sandstone lenses.

The second lithology will be referred to here as the muddy sandstone as shown on Plate 4. It is bounded on the top and bottom by the buff-colored sandstones where it occurs at McGuire Points and South Fork Rock Creek.

The sandstone facies begins at 118 ft (35.97 m) in the South Fork Rock Creek section. The facies is composed of relatively clean, fine-to-medium grained sandstones of poor induration. The color varies little from pale yellow to buff (Figure 7A). Some orange streaks may be present. The only structures visible are those structures found within segments of lithified sandstone lenses, where ripple cross-laminations and trough cross-bedding are evident. The sets of cross-bedding at Purgatory Hill (where they are most evident) are approximately 4.0 ft (1.23 m) in scale. The stratigraphic
Figures 7A & B - Two photographs of the Purgatory Hill sandstone sequence. A - is a southward view of the sequence. B - is a close up of the conglomerate that forms a wedge adjacent to the sandstone.
positions of these lithified sandstones are not consistent through the study area.

Within the sandstone facies at Purgatory Hill is a wedge of lithified claystone conglomerate. The individual clasts are .5 to 4.0 in (1.27-10.16 cm) in diameter, are well rounded and are completely without sorting (Figure 7B). The wedge is approximately 10.0 ft (3.05 m) thick.

Coals separate the sandstone bodies that appear to be stacked throughout the sandstone facies. These coals do not appear to be as wide in lateral extent as those coals of the mudstone facies. In one instance, at 150 ft (45.72 m), there are several feet (less than 10.0 ft or 3.05 m) of carbonaceous shales.

The muddy sandstone appears at 176 ft (53.64 m) at South Fork Rock Creek (and slightly lower at McGuire Points). This lithology is composed of mostly fine-to-medium grained sands with a large percentage of intermixed organic rich clays. These organic particles impart a dark color to this unit that is recognizable from quite some distance. The muddy sandstone, like the buff-colored sandstones below and above, has little, if any, induration.

An upper sequence of buff-colored sandstones begins at 194 ft (59.13 m). They resemble the lower sequence of buff-colored sandstones below the muddy sandstone.
Lithified sandstone sequences are intermittent in this sandstone, and these are identical to the lithified sandstones within the lower portions of the sandstone facies.

The local U coal near the top of the South Fork Rock Creek section (at 231-235 ft or 70.41-71.63 m) is the thickest U coal seen in the study area. The coal seam at this locality is approximately 4.0 ft (1.23 m) thick and was at one time used by ranchers as a source of fuel. This coal contains abundant lenses of volcanic ash.

At 236.0 ft (71.93 m) within the Lebo Formation is a sandstone unit that is very much like the uppermost Tullock Formation sandstones except that the Lebo Formation sandstone is white in color. It possesses slightly better induration than those sandstones of the Tullock Formation. The sandstone is approximately 14 ft (4.26 m) thick.

Above the Lebo Formation sandstone are outliers of shale that occur at 251 ft (106.98 m) in the section. These outliers are brown to grey shales that weather to rounded knobs that look like layers of chocolate cake from a distance.
INTERPRETIVE STRATIGRAPHY

Mudstone Facies

The mode of sediment deposition from slightly below the lower Z coal, up though the upper Z coal and into the lowermost positions of the Tullock Formation was probably fluvial. The tan to orange and grey color of the Tullock Formation, in addition to the organic laminations that occur above the Z, or upper Z coal, seem to indicate that sediment deposition did change, however, with respect to the sediments of the Hell Creek Formation. This is because the sediments of the Hell Creek Formation are known for their drab colors. This color change supports the assumption that the single Z coal at the sections of this thesis is the same lithologic boundary between the Hell Creek and Tullock Formations as at the upper Z coal at Russell Basin. This color change, and the increase in the number of carbonaceous shales and coals in the Tullock Formation, suggest that the environment of deposition was probably wetter than that of the Hell Creek Formation.

The interbedded mudstones and siltstones between the upper and lower Z coals are believed to be sediments deposited in a fluvial setting. These sediments possess
the characteristic drab colors of the Hell Creek Formation. Above the Z coal are distinctly orange markings of the pajama-striped beds of the Tullock Formation. These beds begin above the upper Z coal at Russell Basin, and above the single Z coal in the other sections. Climatic conditions apparently changed from Cretaceous to early Paleocene (Retallack, et al., 1987), but whether or not these changes caused the sedimentological changes from Hell Creek time through Tullock time cannot yet be ascertained.

It is interpreted that the mudstones and siltstones of the pajama-striped beds were deposited in areas where fluvial channels avulsed. The muds collected, along with the organic debris, in quiet water conditions. The avulsion occurred as the rivers flooded on a seasonal or more regular basis. Carbonized root fragments attest to the fact that the water could not have been deep where such waters settled. Also, the pulverized organic laminations must have been in a position where they could not have been exposed to prolonged oxidation. Such a position most likely could have been in areas where the water table met the surface, or where the sediments were constantly wet (as in a floodplain).

Stratigraphically, these mudstones and siltstones can be considered to be a repetitious sequence of seat
earths, but the exact conditions required for coal formation were not quite met. The rate of sediment supply was probably too great, or the water table was too low. For whatever reason, coal was unable to form. But the essential environmental elements were at least present on a repetitive basis. These elements were: abundant vegetation and a high water table (Retallack, 1987a). This environmental interpretation is supported, in part, by the presence of crevasse splays and crevasse channels in these sequences of interbedded mudstones and siltstones.

Once the swampy conditions forming the Y coal ended, the environmental conditions that created the pajama-striped beds were resumed. Laminated sediments were deposited in low-lying areas as stream systems avulsed. In some areas where the channel sequences were wide in lateral extent, a definite upward-fining sequence can be encountered.

Widespread swampy conditions created the X coal. Rather that the coal being allowed to accumulate to any great thickness, there may have been a change in the water or sediment supply (probably an increase in the latter) and the interbedded mudstones and siltstones accumulated once again.

The nature of the channel sequences above the X coal changed to some extent. Lateral accretion deposits became larger, and the banks of the channel became less
steep. Also, the channels overlapped one another so that fining-upward sequences were repeated.

Environmental conditions once again created a wet, marshy, sediment-free setting of the study area long enough for the W coal (at 70.0 ft of 21.34 m) to form. Above this coal, generally, (although at Purgatory Hill it happens slightly below this coal) environmental conditions returned to those reminiscent of the conditions that created the pajama-striped beds. Above the W coal, the floodplain conditions recurred.

From the W coal to where the sandstone facies cuts into the section, the sediments making up the floodplain facies are mostly interbedded siltstones and mudstones. Some crevasse splays and channel are also well developed.

The Sandstone Facies

The sandstone facies was deposited as channel-fill sediments. The causal stream systems were of the meandering type because: 1) the coals within this facies are of limited lateral extent, 2) trough cross-bedding is evident where the sandstones are indurated, 3) some channel margins can be seen, and 4) the sandstones occur at different levels in the sections (which may be the result of channel
meandering, and hence incising, into the mudstone facies to different depths).

The wedge of claystone conglomerate at Purgatory Hill may have been the result of bank failure as a main channel meandered. Sediment from the channel bank may have fallen into the channel and occupied its deepest portion (i.e. thalweg). These clasts appear to be derived from the Tullock Formation itself.

Some portions of the sandstone facies are better indurated than other. That is, cementation was not uniform throughout the sandstones. It is through the lithified lenses that one can interpret the depositional environment from which these sediments were deposited.

The author interprets the muddy sandstones of South Fork Rock Creek and McGuire Points (Plate 4) to be the result of conditions in which the rate at which sediment was being deposited decreased slightly or altogether. It is interpreted that this muddy sequence is a series of sediments deposited in abandoned channels. In general, this unit is thick in some areas (in excess of 40.0 ft or 12.19 m at McGuire Points) but most of it may have been eroded by the incision of the upper portion of the sandstone facies as a result of channel meandering.

Sandstone sequences reappear above this muddy sandstone which are similar to those directly above the mudstone
facies. It is interpreted that channels once again meandered through the study area.

Coals mark the boundaries between the individual sandstone units. The fact that the coals are of limited extent seems to indicate that many coals were incised by channel meandering. These coals were deposited in areas where the sediment supply ceased momentarily during the lateral shifting of channels. As the channels resumed their positions, the supply of sediment was renewed, and another sandstone unit was deposited.

Finally, the base of the U coal represents the boundary between the Tullock and Lebo Formation (Collier and Knechtel, 1939). It was during this time that the study area was a swamp setting.

The white Lebo Formation sandstone atop the U coal represents the continuation of conditions that deposited the sandstone facies. The major change in lithologies from the Tullock Formation to the Lebo Formation occurs at the brown shales on top of these white sandstones. It was at this level that the previous rate of sand supply decreased, and swampy conditions once again prevailed. These shales within the Lebo Formation are quite organic rich. At the base of these shales is a lignite. The lignite grades upward into the shales. The shales contain abundant leaves and stems. The environmental conditions
creating such lithologies must have been similar to that of present-day marshes or bogs. The shales may have formed by conditions in which the topography was immersed in water.

From palynologic evidence reported in this thesis, these shales and coals may have been deposited in brackish waters. It is possible that the Cannonball Sea to the east may have been the source of such waters.

Volcanic Activity

Volcanic activity was frequent and sporadic throughout the time that the Tullock Formation was deposited. Ash beds could not be correlated because the lateral extent of these ashes often could not be traced farther than a few hundred feet, and the ashes are most often less than 1 in (2.5 cm) thick. Even so, some ashes were encountered at the same level throughout the different sections. The difficulty in correlating ashes here is that, if the ashes settled in anything by a ponded environment, the volcanic debris would be dispersed amongst the sediments. The popcorn texture (Fastovsky, 1987) of the weathered sediments of the Tullock Formation is common, and it seems to be the result of volcanically-derived expandable
clays. This illustrates the high degree to which volcanism took place in northeast Montana during early Paleocene time.
PALYNOCOLOGICAL RESULTS

In order for the range zonation of this thesis to be constructed, samples had to have been collected from the sections at levels that are measureable from the established datum of the Cretaceous-Tertiary boundary. Twenty-six samples were taken from selected rocks in three sections of this thesis to process for palynomorphs. Four were taken from Russell Basin (the upper Z coal, the lower Z coal, and two coals inbetween), three were taken from Purgatory Hill (one of, and on either side of, the W coal: which is the level at which the change from 29R to 29N in the earth's polarity is recorded), and 19 were taken from the section at South Fork Rock Creek.

Of the twenty-six samples taken, 13 proved to have useable numbers of selected pollen to construct the zonation for this thesis. The samples from Purgatory Hill were not productive; neither were any of the coals from Russell Basin except for the lowermost Z coal. In total, 12 samples from South Fork Rock Creek provided pollen in sufficient numbers and diversity to construct the following pollen zones. The positions of the productive samples are shown on Plate 5 under "sample footages."
It is not the intention of this thesis to provide a taxonomic analysis of all pollen and spores that were found. But rather is it to determine the stratigraphic positions of key pollen and spores.

Emphasis has been placed upon the position of angiosperm triporate and polyporate pollen. Tricolpate and tricolporate pollen were noted where it was thought that their positions would be useful for defining pollen intervals. Monolete, trilete, saccate, and inaperturate pollen and spores were thought not to be useful for this thesis because of their longer range zones.

Plates 1, 2, and 3 are photomicrographs of the palynomorphs of this study. Plates 1 and 2 are photomicrographs of the angiosperm pollen, Plate 3 is composed of the photomicrographs of the spores, microforaminifers, and actitarchs of this study. On the page facing these plates are the numbers, names, and microscope magnification for each corresponding palynomorph.
POLLEN ZONATION

The early Paleocene strata in the vicinity of Bug Creek, McCone County, Montana can be divided into three pollen zones. They are: P1, P2, P3, with P1 at the base and P3 at the top.

There are characteristic pollen belonging to each zone, although some overlap does occur. In some instances a species may be known to exist during the Cretaceous and continue into the Paleocene. But in this investigation, such species did not appear until the Paleocene was well underway. Such is the case with Kurtzipites simplex and Tricolpites anguloluminosus. Sampling or preservational variables may have prevented such pollen from being found in lower samples. Despite these problems, the zonation of this thesis represents the assemblages of fossil pollen throughout the measured sections of the study area. Future pollen studies of the sections of this thesis may add more detail to the following results.

Pollen Zone One (P1)

This zone begins at the lower Z coal at Russell Basin (slightly above the established Cretaceous-Tertiary
boundary) and terminates at 40.5 ft (12.34 m) at South
Fork Rock Creek (slightly above the local X coal).

Between the lower Z coal at Russell Basin to 6.5
ft (1.98 m) at South Fork Rock Creek, the palynologic
assemblages are characterized by mostly trilete, monoletle,
inaperturate, and saccate pollen and spores. At the
lower Z coal the following pollen are encountered:
Erdtmannpolis sp., Triporopollenites rugatus, Ulmoidei-
pites sp., and Wodehouseia spinata. The spore
Lycopodiumsporites sp. was also found in this coal.
A form of Aquilapollenites sp. makes a single appearance
at the lower Z coal. This Aquilapollenites species has
smooth walls. Because it could not be positively identi-
fied in the literature, it was labelled Aquilapollenites
sp. #1. Kurtzipites simplex and Paraalnipollenites sp.
were questionably identified in the lower Z coal. At
6.5 ft (1.98 m), at South Fork Rock Creek, there are
occurrences of three pollen species; Syncolporites sp.,
Kurtzipites trispissatus, and Cupanieidites inequalis.

The top of zone Pl is marked by the last appearance
of Wodehouseia spinata. This zone ends at 40.5 ft
(12.34 m) in the section at South Fork Rock Creek directly
above the local X coal.
Pollen Zone Two (P2)

The second pollen zone is found between 40.5 and 175.5 ft (12.34-53.49 m) at South Fork Rock Creek. This zone begins with the first positive appearance of Paraalnipollenites sp. and Momipites sp.. Tiliaepollenites reticulatus makes a single appearance at this level. At 78.5 ft (23.92 m), Brevicolporites sp., Pandaniidites sp., Alnus trina, and the first positively identified Kurtzipites simplex appear.

At 115 ft (35.05 m) there is a change from the mudstone facies to the sandstone facies. This level is marked by a single appearance of a reticulate form of Aquilapollenites sp. (temporarily labelled Aquila-pollenites sp. #2), the first appearance of Wodehouseia fimbriata, and the last positive appearance of Alnus trina and Syncolporites sp..

Two pollen found at 115 ft (35.05 m) were not documented in previous literature. They have smooth and extremely thick exines, and they were labelled P3sm-1 and P4sm-1. They may represent the same species with P3sm-1 being a three pored variant of P4sm-1. Another species, P4st-1, is a rugulate tetraporeate pollen. In no other samples were these pollen encountered.

From 158 ft (48.16 m) to the top of pollen zone 2
at 175 ft (53.34 m), some gradual changes in the flora took place. At 158 ft (48.16 m), *Wodehouseia fimbriata* makes its last appearance. *Erdtmanipollis* sp. was not seen above 165 ft (50.29 m).

The sample at 175 ft (53.34 m) yielded some interesting results. This sample was taken from the top of the muddy sandstone unit from within the middle of the sandstone facies. The dominant constituent pollen is *Brevicolporites* sp.. It was the highest point at which this pollen was found. *Pandaniidites* sp. and *Lycopodiumsporites* sp. also were found at this level and no higher.

Pollen Zone Three (P3)

This zone begins at 175 ft (53.34 m) and ends at 251 ft (76.50 m) at South Fork Rock Creek. It extends from the muddy sandstone unit up through the U coal (Tullock/Lebo Formation contact), and concludes at the base of the outliers of the brown Lebo Formation shale.

This zone did not yield a great variety of specimens. From 175 ft to 251 ft (53.34-76.50 m), the following pollen were seen consistently: *Kurtzipites simplex*, *Paraalnipollenites* sp., *Triporopollenites rugatus*, and *Ulmoideipites* sp.. The spore *Zlivisporis* sp. also occurs from bottom to top within this zone. *Tricolpites angulo-
luminosus was encountered at the U coal locality at 231 ft (76.50 m) and was not seen in subsequent slides. A single specimen of Momipites sp. was found in the sample from 251 ft (76.50 m).

A smooth triporate pollen of unknown affinity, P3sm-2, is abundant at 251 ft (76.50 m), although its first appearance is in the sample from 175 ft (53.34 m). The most notable feature of this particular pollen are the very large pores.

At 251 ft (76.50 m), 15 specimens of microforaminifers were found. These are unidentified in the literature, so, like the pollen, they are classified temporarily as M1, M2 and M3. M1 and M2 represent a coiled biserial form (although the two differ slightly in appearance), and M3 represents a trochospiral form. Also in the sample at 251 ft (76.50 m) were two palynomorphs considered to be acritarchs. These are of unknown affinity, and they are temporarily labelled "acritarchs," on the range zonation chart (Plate 5).

The microforaminifers and the acritarchs are at the uppermost limit of the third and final zone of this thesis. Their anomalous presence suggests that brackish water may have been present at this location during the deposition of the shales of the lower Lebo Formation.
CONCLUSIONS

The Tullock Formation can be divided into two basic lithologies: interbedded mudstones and siltstones comprise the lower portions of the Tullock, and poorly indurated fine-to-medium grained sandstones comprise the upper portions of the Tullock Formation.

The interbedded mudstones and siltstones of the lower Tullock Formation are interpreted to be sediments deposited in a floodplain environment. The evidence used to support this interpretation includes: 1) abundant root structures, 2) sandstones and siltstones with laminations of organic material, 3) paleosols as discussed by Retallack, et al. (1987a, 1987b), and 4) crevasse splays and channels.

The poorly indurated sandstones of the top of the Tullock Formation are sediments deposited as channel fill. The evidence used to support this interpretation includes: 1) trough cross bedding where the sandstones are indurated, 2) uneven thicknesses across the study area where the sandstones appear or disappear, 3) thalweg deposits, such as those found at Purgatory Hill, 4) visible channel margins, and 5) coal of limited lateral extent.

The change from mudstone to sandstone facies may have been the result of a shift in a major stream system
to the Bug Creek area, or it may have been due to the uplift of certain areas as described by Cherven and Jacob (1985).

This thesis largely supports the work by Smit et al. (1987) by showing that the very earliest Paleocene, represented by the Z coals at Russell Basin (within Pl), is dominated by fern spores. Their work also showed that the range of *Aquilapollenites sp.* did not extend into the Paleocene. However, their work is contradicted here by showing that at least two forms of *Aquilapollenites sp.*, if not recycled, did survive into the Paleocene in the vicinity of Bug Creek. The dominance of fern spores from the Cretaceous-Paleocene boundary to 6.5 ft (1.83 m) at South Fork Rock Creek may have been due to two factors: 1) the fact that the coals from which the samples were taken formed from fern dominated swamps or, 2) the environmental conditions of the Paleocene were completely different than that of the Cretaceous. Whether the inferred meteorite impact was the cause of the second factor cannot be proved here.

The dominant group of palynomorphs found in this investigation consists of monolete and trilete spores. The studies of Retallack, et al. (1987a, 1987b) and Leahy, et al. (1985) have shown that the environmental conditions were much wetter and cooler during the early Paleocene
when compared to the late Cretaceous. This might be a possible explanation for the relative abundance of fern spores. Spore bearing plants may have found such conditions favorable for growth and proliferation.

Pollen zone 2 is marked by the first appearance datum of *Momipites sp.* at 40.5 ft (12.34 m) and by an overall decrease in the relative abundance of fern spores. This datum for *Momipites sp.* can now be used for regional biostratigraphic correlations in western North America. Within pollen zone 2 is the change from reversed polarity (29R) to normal polarity (29N) approximately at the local W coal. Unfortunately, the coal at this level contained few recoverable numbers of pollen. No significant change in the pollen assemblages is evident from below the W coal to above the W coal. Thus the W coal, or magnetic datum, cannot be used in regional correlations as a position or time at which a significant change in pollen assemblages took place. The Purgatory Hill channel sequence, which contains a late Puercan age mammal fauna, is within pollen zone 2.

At 115 ft (35.05 m) several new species appear. Overall, the sample from this level is very productive of pollen. The author proposes that this sample level be used as a local marker because: 1) there is a relatively
large abundance of pollen, 2) there is the presence of relatively abundant, and unknown types of pollen (P3sm-1, P4sm-1, P3st-1), and 3) this level is roughly coincident with the facies change in the Tullock Formation from mudstone to channel-fill deposits at the South Fork Rock Creek section.

The sample at 175 ft (53.34 m) is unusually rich in *Brevicolporites sp.*. This sample is also the last appearance datum for *Brevicolporites sp.*. From 115 ft to 175 ft (35.05-53.34 m) there is a gradual reduction in the number of pollen genera that range through all three zones. An unnamed species of pollen (P3sm-2), makes its appearance at the bottom of this zone, and it can readily be found in sediments overlying the 175 ft (53.34 m) thickness and into the Lebo Formation.

15 microforaminifers were found at 251 ft (76.40 m) in the section in South Fork Rock Creek within the basal Lebo Formation shales. Most foraminifers are recovered from marine sediments. It would therefore seem that microforaminifers should not be expected in sediments formed in fresh water environments. If they are not recycled from Cretaceous marine strata, storm conditions may have brought water from the east into the study area to introduce such fossils. A more regional
investigation of these shales is needed to determine the significance of the microforaminifers.

When compared to the previously established provincial ages by Sloan (1987) in the Bug Creek Quadrangle, the pollen zones are positioned as shown in Figure 8. Bugcreekian age mammal fossils occur within pollen zone 1, late Puercan age fossils occur within pollen zone 2, and Torrejonian mammal fossils are suspected to be within pollen zone 3. The exact extent of the Mantuan mammal age is not known locally, nor can it be positively assigned to a pollen zone of this thesis.
<table>
<thead>
<tr>
<th>Period / Epoch</th>
<th>Provincial Vertebrate Ages</th>
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<th>pollen zones</th>
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<tr>
<td>Cretaceous</td>
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</table>

Figure 8 – Positions of the pollen zones with respect to lithologic units, provincial vertebrate ages, and time.
REFERENCES CITED


Robertson, E.B., 1975, Pollen and spores as stratigraphic indices to the North Dakota Paleocene, Ph.D. Diss., U. of Minn.


Plate 1:

<table>
<thead>
<tr>
<th>ANGIOSPERM POLLEN</th>
<th>microscope magnification</th>
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<tr>
<td>1. Aquilapollenites sp. #1</td>
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<tr>
<td>2. Aquilapollenites sp. #2</td>
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<tr>
<td>3. Alnus trina (Stanley, 1965)</td>
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<tr>
<td>4. Brevicolporites sp.</td>
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<tr>
<td>5. Cupanieidites inequalis (Leffingwell, 1966)</td>
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<tr>
<td>6. Erdtmanipollis sp.</td>
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<tr>
<td>7. Kurtzipites simplex (Leffingwell, 1966)</td>
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<td>9. Momipites sp.</td>
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<td>12. Syncolporites sp.</td>
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<td>Tiliaepollenites reticulatus (Groot and Groot, 1962)</td>
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<td>18</td>
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<td>P4sm-1</td>
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