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The Hell Creek Formation in North Dakota

Charles I. Frye

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THE HELL CREEK FORMATION IN NORTH DAKOTA

by

Charles L. Frye

B. A., University of New Hampshire 1958
M. S., University of Massachusetts 1960

A Dissertation
Submitted to the Faculty
of the
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This dissertation submitted by Charles I. Frye in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in the University of North Dakota is hereby approved by the Committee under whose work has been done.

Willa Wood
Chairman

Dean of the Graduate School
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ABSTRACT

This paper is a discussion of the surface stratigraphy and petrology of the Bell Creek Formation in North Dakota and eastern Montana. Principal areas of study included the Missouri Valley south of Bismarck, North Dakota; the Little Missouri Valley in Slope and Bowman Counties, southwestern North Dakota; the Yellowstone Valley, near Glendive, Dawson County, Montana; and the type area of the Bell Creek Formation on Bell Creek and East Bell Creek, Garfield County, Montana on the south shore of the Fort Peck Reservoir.

Two and one-half summers were spent in the field measuring 72 stratigraphic sections, correlating between the measured sections, collecting petrographic samples and fossils from the Bell Creek Formation and associated formations. Laboratory studies included heavy mineral analyses, preparation and study of petrographic thin sections, and the identification of the fossils collected.

The Bell Creek Formation was found to be divisible into 8 members, 7 of which are new. In central North Dakota (from oldest to youngest) the Croughest Member, the Breien Member (named prior to this paper), the Fort Rice Member, the Huff Member, and the Pretty Butts Member were recognized. In southwestern North Dakota (from oldest to youngest) the Little Beaver Creek Member, the Harmerth Member, the Bacon Creek Member, the Huff Member and the Pretty Butts Member were defined. In eastern Montana a set of sandstones at the base of the formation was recognized.
as a possible ninth member but was not named. The Pretty Suite and
Buff Members appear to be present over all of western and central North
Dakota as well as eastern Montana. The other members have only local
importance.

The top of the Hell Creek Formation is considered a time line as
a result of the studies of the fossils (particularly dinosaurs) and
bentonites. The base of the Hell Creek Formation was found to become
progressively younger in an eastward direction. No unconformity was
found at the top of the formation. The base of the formation was found
to be vertically and horizontally gradational with the Fox Hilla Sand-
stone in the east and to lie unconformably upon the Fox Hilla Sandstone
in the west.

The Hell Creek Formation may be visualized as the subaerial top-
set beds of a giant delta stretching eastward from the Rocky Mountain
Front into the Fox Hilla-Camoumball Sea at the close of Cretaceous
time. Laterally equivalent marine top-set beds of this delta are the
Fox Hilla Formation. Fore-set and bottom-set beds are represented by
the Pierre Shale.

The climate during Hell Creek times in North Dakota was warm,
temperate, summer-moist with probably no frosts as indicated by such
plants as Narcespous, Ceroidiphylus, Ficus, and Magnolia, and by such
animals as dinosaurs, crocodiles, and alligators. The early Paleocene
climate appears to have changed little if any from the preceding Hell
Creek climate since there is a continuation of such plant genera as
Ceroidiphylus and Narcespous and such animals as crocodiles, into the
Cenozoic Era.
Figure 1. Location map.
Figure 2. County map of western North Dakota.
sections were measured to facilitate locating stratigraphically zoned
which did not correspond to the physical position of the measured sec-
tion. Persistent beds were traced from one set of exposures to the next
to compare measured sections.

LABORATORY PROCEDURES

Lithologic specimens were studied under the binocular microscope
and color, sediment size, mineralogy, and internal structures were
recorded. Sand from selected measured sections was studied for heavy
mineral content. Specimens of various lithologies were thin-sectioned
and observed under the petrographic microscope with the standard and
universal stage. The composition of plagioclase sand grains was deter-
mined by use of a five-axis universal stage. Compositions of volcanic
glass shards in the sediments were determined by oil immersion methods.

A REVIEW OF THE LITERATURE CONCERNING THE HELL CREEK
FORMATION IN NORTH DAKOTA

Introduction

The history of the nomenclature of the upper Cretaceous and lower
Paleocene Series found in the Northern Great Plains of the United States
is extremely complex. An attempt will be made here to give, as com-
pletely as possible the use of the name Hell Creek Formation in the
state of North Dakota. The literature of related formations is only
discussed when it is pertinent. The literature of the Hell Creek For-
mation in regions exclusive of North Dakota is only discussed when it
relates to this formation in North Dakota. A detailed summary of the
literature of the Cretaceous-Tertiary boundary problem in the Great
Plains and the Rocky Mountain States may be found in Brown (1962).
Early Literature of the "Great Lignite Group"

The development of ideas related to the "Great Lignite Group" evolved slowly because these beds contain complex facies which seriously hindered understanding of the stratigraphic relationships by the first workers. These early misinterpretations impeded later workers. Summaries of the early development of the nomenclature of the "Great Lignite Group" may be found in several publications (Basson, 1875, p. 182-202; Ward, 1886, p. 406-436; Merrill, 1906, p. 647-658; Knowlton, 1922, p. 3-51; Russell, 1932, p. 121-136; Nance, 1936, p. 56-87; Specker, 1946, p. 142-160; Russell, 1953, p. 106-113).

In 1854 and subsequent years, Hayden and his associates explored the coal bearing region of the Rocky Mountains and the Great Plains, particularly in the Missouri and Yellowstone Valleys. He called the lignite bearing strata the "Great Lignite Group" (Hayden, 1862, p. 433; Reynolds, 1865). Data were collected concerning the general stratigraphy of the group and collections were made of the fossil vertebrates, invertebrates and plants. Hayden's chief co-worker, Meek, substituted the geographical name Fort Union for the name "Great Lignite" (Meek and Hayden, 1862, p. 433). The name Fort Union was more specifically applied to strata along the north side of the Missouri River between Snowden, Montana, and Buford, North Dakota. These sediments are now known to comprise only a part of what was then called the "Great Lignite Group." The name Fort Union was taken from an United States Army Fort located on the banks of the Missouri River in Montana near the North Dakota-Montana border.

In 1854, Hayden collected dinosaur remains from the Judith River region of Montana, and in 1872 Meek found part of a dinosaur Ankylosaur.
sylvestris Cope in the same region. Plant fossils collected by Beck and Hayden from the upper part of the "Great Lignite Group" were identified by Newberry in 1869 as Tertiary in age. Thus it was established early in the studies of the "Great Lignite Group" that the Mesozoic-Cenozoic boundary lay within this lignitic sequence.

Clarence King, in 1876, complicated the Cretaceous-Tertiary boundary discussion when he introduced the name Laramie for lignitic beds on the Laramie Plains of Wyoming without designating a specific type locality. Shortly thereafter, the "Great Lignite Group" of Hayden, including the Fort Union Group, was loosely referred to as the Laramie Group. This problem was not resolved until 1910, when the U. S. Geological Survey restricted the name Laramie to the region of the Denver Basin, where it is considered Cretaceous in age.

Leopold Lesquereux, a paleobotanist, added confusion with the publication of his paper "The Tertiary Flora" (1878), which included many plants now known to have come from the Cretaceous. A year later Newberry stated that the Fort Union Group was the basal unit of the Tertiary and indicated the lower portion of the lignite strata belonged to the Cretaceous (Newberry, 1888, p. 329), the view held today.

White, on evidence of nematine invertebrates, regarded the "Great Lignite Group" as transitional between the Cretaceous and Tertiary (White, 1883). This concept was accepted by Lester Ward, who after reviewing the opinions of Newberry, Lesquereux, Cope, White, and others, said,

It is, therefore, futile and indeed puerile, longer to discuss this question, and we can well afford to dismiss it altogether and settle down to more serious study of the real problems which still lie before us. (Ward, 1886, p. 435).
Because of his viewpoint, Ward failed to recognize the differences between the older "Wyoming and Colorado Laramie" and the younger "Fort Union Laramie." His "Laramie" flora is now known to contain plants from as old as the Mesaverde (Upper Cretaceous) to those as young as the Wasatch (Lower Eocene) (Brown, 1962, p. 4). Commenting upon Ward's "Types of the Laramie Flora," Newberry (1868, p. 329) showed that he (Newberry) had succeeded in distinguishing between plants of the Fort Union and plants of the true Laramie. He repeated this opinion in 1890 (p. 325). Much later, in 1940 and 1942, Dorf published a preliminary comparison of the Lance and Fort Union floras and confirmed Newberry's contentions.

The confusion concerning the age of the "Great Lignite Group" did not lie with the facts but with interpretations of poorly located collections (Brown, 1962, p. 4, 5). The poor stratigraphic location of collections was partially contingent upon the lack of a systematic field guide with which to determine the Mesozoic-Cenozoic boundary. A lithologic guide was first given by Calvert (1912, p. 196, 197) when he observed that in the Glendive, Montana region, a "persistent bed of lignite" coincided with the stratigraphic position of a color change between the dark "Lance" (Bell Creek) and the yellowish basal Fort Union formation. However, he reported dinosaur remains above the stratigraphic position (Calvert, 1912, p. 197, 198). R. W. Brown (1962, p. 10), who studied the area in detail came to the conclusion "Some mixup in locality citation or in fossil collections probably accounts for this erroneous record." One other report of dinosaur remains above the lowest persistent coal comes from Rodgers and Lee (1923, p. 34); however, R. W. Brown searching the notes of these gentlemen found that the bone
had been collected not 50 feet above this coal as stated in the report but 50 feet below it (notebook 2745, p. 1026, Rodgers and Lee) (Gowan, 1962, p. 10).

Subdivision of the "Great Lignite Group"

The subdivision of the "Great Lignite Group" began about 1890, prior to this date such names as Fort Union and Laramie had been introduced, but not adequately defined.

The subdivision of the "Great Lignite Group" was accomplished by many workers. Today it is divided into the Upper Cretaceous Lance and Hell Creek Formations, and the Paleocene Tullock, Lebo, Tongue River, Ludlow, and Cannonball Formations. Long before the subdivision of this unit, it was known that this unit was overlain by the Wasatch Group of Hayden (1869) in Montana and by the White River Formation of Meek and Hayden (1858) in North Dakota, and underlain in its extent by the Fox Hills Formation. The Fox Hills Formation was considered to be of Upper Cretaceous age on the basis of its marine invertebrate fauna. The Wasatch and White River beds were considered Eocene in age on the basis of plant fossils for the former and on fish remains for the latter (White, 1883, p. 411-416).

Stanton and Knowlton (1897, p. 155, 156), after studying the geology and fossils along Lance Creek in eastern Wyoming, differentiated the lower portion of the "Great Lignite Group" with its primitive mammals, dinosaurs, non-marine invertebrates, and plants (therein called Laramie) from the overlying Fort Union Formation with its invertebrates and plants, but no dinosaurs. Had this example been followed in subsequent work, there might have been much less confusion as to the location of the Cretaceous-Tertiary boundary in the Northern Great Plains.
At about this same time, Harsh (1889, p. 301) proposed the name "Ceratops beds" for the dinosaur-bearing strata of the "Great Lignite Group," also called Laramie. He claimed these beds had been traced 600 miles along the Rocky Mountain Front. His rather sweeping statements, plus he had spent very little time in the field, caused some geologists to attack violently the concept of the "Ceratops beds" (Hatcher, 1896, p. 116, 117). However the name was found useful, although it was not always applied to the same stratigraphic position (Judith River to Hell Creek) (Hatcher, 1896, p. 116), it became firmly entrenched in the literature of the time.

In 1903, Hatcher proposed the name Lance Creek to replace the name "Ceratops beds" for strata along Lance Creek, Converse County, Wyoming, stating that the Lance Creek beds conformably overlie the Fox Hills Formation and are conformably overlain by the Fort Union Group. This was the first time a subdivision of the "Great Lignite Group" had been adequately defined. Four years later Barnum Brown proposed the name Hell Creek for a sequence of beds exposed along Hell Creek and East Hell Creek, Garfield County, Montana (Brown, 1907, p. 829-835). This sequence of strata had also been referred to as the "Ceratops beds." The Hell Creek beds were described in detail and were shown (Brown, 1907, p. 829, 834) to overlie unconformably the Fox Hills Sandstone, and to be conformably overlain by Fort Union strata. Shortly thereafter, Barnum Brown demonstrated that the Hell Creek and Lance Creek beds were unequivocally correlative (Brown, 1914, p. 356).

In the meantime, in North Dakota, South Dakota, and Montana, geologists were beginning to notice color difference in the upper lignite strata, the Fort Union Group.
Leonard (1908) defined and named the darker more shaly upper portion of the Fort Union Formation the Sentinel Butte Shale for exposures at Sentinel Butte in southwestern North Dakota (Leonard, 1908, p. 57, 108-111).

Taff, in 1909, named the Tongue River Member of the Fort Union Formation for the lower, light colored, coal-bearing sediments exposed along the Tongue River Valley, Sheridan County, Wyoming (Taff, 1909, p. 129-131).

The same Lebo "Andesitic" Member of the Fort Union Formation was proposed, in 1910, by Stone and Calvert, for exposures along Lebo Creek on the northeast side of the Crazy Mountains. These beds are gray sandstones with interbedded shales and are found near the base of the Fort Union Formation (Stone and Calvert, 1910, p. 746). Eastward the Lebo Member becomes more shaly and is often referred to as the Lebo "Shale" Member.

In 1914, Lloyd recognized marine strata in the lower part of the Fort Union Formation in central North Dakota which he named the Cannonball "Marine" Member of the Fort Union Formation for exposures along the Cannonball River in Grant County, North Dakota (then a part of Morton County) (Lloyd, 1914, p. 246-249).

Lloyd and Haras, in 1915, named the Ludlow "Lignitic" Member of the Fort Union Formation for exposures of lignitic nonmarine strata lying stratigraphically below, but interfingered with, the Cannonball "Marine" Member and designated the type area as Ludlow, Harding County in northwestern South Dakota (Lloyd and Haras, 1915, p. 523-547).

This left one other major stratigraphic unit to be subdivided from the Fort Union Formation: the Tullock Member. This was done much later.
by Rodgers and Wallace in 1923. The Tullock Member was named for Tullock Creek, Treasure County, Montana, for exposures of yellowish sandstones, shales, and lenticular coals (Rodgers and Wallace, 1923, p. 29).

Since these units are manifestations of rather complex lithologic facies of the "Great Lignite Group," in many cases the relationships between units were not understood, or only partly understood. The nomenclature proposed was found useful for local mapping, but problems arose when the units were found to migrate vertically in the section (Rodgers, 1913, p. 719-721; Pierce, 1936, p. 60; Brown, 1943, p. 1270-1271; 1962, p. 5, 6).

Knowlton complicated the nomenclature and literature with opinions concerning the stratigraphic relationships of beds in the lignite strata of eastern Montana (Knowlton, 1909, p. 180-193, 237). He divided the sequence of beds above the Fox Hills Sandstone into an "Upper" and "Lower Fort Union Formation." His upper and more lightly colored unit corresponded primarily to what now is referred to as Tongue River Formation. His lower and more darkly colored unit corresponded to what is now referred to as Hell Creek Formation, Tullock Formation, and Lebo Shale. He combined the Cretaceous, dinosaur-bearing beds of the Hell Creek Formation with the overlying dark colored, non-dinosaur-bearing, Paleocene beds of the Tullock Formation and Lebo Shale. He then applied the name "Upper Lance" to the Tullock and Lebo beds. This nomenclature in turn led to the error of combining the flora and fauna of the Cretaceous Hell Creek and Lance Formations with those of the Tertiary Tullock and Lebo beds (Knowlton, 1911, p. 258; 1914, p. 323; 1933, p. 31).

The result of these errors was first to consider all of the beds
Tertiary and then to consider all of the beds Cretaceous before realizing the systemic boundary lay between the Hell Creek Formation and Tullock Formation.

Stanton working upon the flora of the same beds in 1909 recognized that it should be divided differently for he suggested that the dinosaur beds ought to be considered separately (Stanton, 1909, p. 286). Knowlton ignored the suggestion.

**History of the Nomenclature of the Hell Creek Formation in North Dakota**

The formal history of the Hell Creek Formation in North Dakota began with the studies of Leonard, although earlier surveys previously discussed were concerned with these beds. In 1908, Leonard divided the Fort Union Formation into three members. He used the name Fort Union synonymously with Hayden's "Great Lignite Group," that is, he included all lignitic strata above the Fox Hills Sandstone. The three members consisted of a lower unit composed of dark colored sand and shales containing dinosaur remains, a middle unit of light ash-gray and buff sandstones and shales containing abundant plant fossils, and an upper unit composed of dark gray sandstones and shales. He considered them all to be of "Soocene" Age (basal Tertiary, as then defined). He also noted that the lower unit occupied the same stratigraphic position as the Hell Creek beds in Montana (Leonard, 1908, p. 45), but failed to call the unit in North Dakota the Hell Creek Formation (Leonard, 1908, p. 45, 46, 50, and 84).

May, in 1910, commented upon the age of the dinosaur-bearing strata and referred them to the Cretaceous (May, 1910, p. 295). He
also noted that one should not expect to find a world-wide unconformity at the top of the Cretaceous (Gay, 1910, p. 286).

Stanton, in 1910, studied the geology of the Standing Rock Indian Reservation in North Dakota and South Dakota. He mapped the Bull Creek Formation under the name "Lance" Formation and recognized its freshwater origin. He said this formation had been called the "Caratops beds," "Laramie," "Lower Fort Union," and the "somber beds" (Stanton, 1910, p. 173). Knowlton reported the flora collected was of Tertiary Age. Stanton reported dinosaur remains were abundant in the lower 100 feet of the formation. He found no unconformity between the Fox Hills Formation which is Cretaceous in age and the "Lance" which he considered Tertiary (Stanton, 1910, p. 181). He correlated the "Lance" on the Standing Rock Indian Reservation with similar beds in the Little Missouri Valley near Marmarth, North Dakota (Stanton, 1910, p. 182, 183), a correlation which has been substantiated by later work.

In 1911, Leonard described the Tertiary and Cretaceous formations of western North Dakota and eastern Montana. He placed (1911, p. 514) the Mesozoic-Cenozoic contact between the Fox Hills and "Lance" Formations. This was actually between what is now called the Timber Lake Member of the Fox Hills Formation and the Bull Head Member of the Fox Hills Formation. He divided (1911, p. 523) the "Lance" into three members in south-central North Dakota: a lower unit consisting of alternating thin shales and sands "which may be 350 feet thick," a middle unit composed of dark shales with scattered thin sandstones about 200 to 250 feet thick, and an upper sandstone about 100 feet thick. The upper two members correspond to what is now mapped as
Hill Creek Formation and the lower member of the Bull Head Member of the Fox Hills Formation. Leonard (1911, p. 525) noted that in the Little Missouri Valley there was an occasional contact between the Fox Hills and "Lance" Formations and considered it to be "contemporaneous in nature." In the Little Missouri Valley he mapped the "Lance" in two members, an upper and a lower (Leonard, 1911, p. 526). His "Lower Lance," the dinosaur-bearing strata, corresponds to what is now mapped as Hell Creek Formation. The upper member of his "Lance" Formation contains both Tullock and Ludlow beds. This information is gained from the following excerpt:

Only thin beds of coal, not over eighteen inches thick or less, occur in the lower 300 feet or more of the Lance formation. . . . But in the upper portion of the formation, thick beds of lignite are found in many places. In the vicinity of Yule, five or six beds are present in the upper part of the member, and the coal of Bacon and Coyote creeks occurs at about the same horizon. . . . (Leonard, 1911, p. 525).

The Hell Creek Formation in this region contains only traces of coal, but coal is abundant in the Tullock and Ludlow Formations. Leonard also states that oysters are found in the Lance Formation near Yule. We now know these oyster-bearing beds belong to the very upper part of the Ludlow Formation.

Leonard (1912, Folio 181) working in the Bismarck Quadrangle, North Dakota restated his views concerning the Fox Hills, "Lance," and Fort Union Formations which he formulated in 1911 but in addition assigned ages to the formations. He considered the Fox Hills to be Cretaceous age, the Lance transitional between the Cretaceous and Eocene, though tending toward Knowlton's views that the formation was Tertiary in age, and the Fort Union Formation to be Tertiary in age.
In 1914, Calvert and others published their work on the Standing Rock Indian Reservation in North Dakota and South Dakota. They described (p. 13) the Fox Hills Formation as containing 100 feet of variegated shales in the upper part which would indicate that they included the Bull Head Member of the Fox Hills Formation within the Fox Hills and not in the "Lance" Formation as Leonard had done in 1911. They considered the Fox Hills Formation to be the uppermost Cretaceous marine beds in the region (Calvert and others, 1914, p. 13). Their "Lance" Formation contains the Ludlow beds, for they stated in the description of the Lance, "During the progress of field work one exceptional bed of lignite was traversed for about 7 miles along the south side of Cedar Creek in T. 129 S., R. 88 W., North Dakota." (Calvert and others, 1914, p. 17). The lignite described is now mapped in the base of the Ludlow Formation. They (p. 16) noted the interfingering relationship of the "Lance" and Fox Hills Formations in this region. The reasons were reviewed (p. 18-22) for assigning the "Lance" either to the Cretaceous or to the Tertiary systems but they took no stand. Knowlton on the basis of plant fossils (p. 21) referred these beds to the Tertiary.

Lloyd tentatively assigned the "Lance" Formation to the "Eocene (?)" (lowermost Tertiary) (Lloyd, 1914, p. 246). He divided the "Lance" into upper and lower parts. His "lower Lance" consisted of Hell Creek and Ludlow Formations. The "upper Lance" he named the Cannonball "Marine" Member (Lloyd, 1914, p. 249). Thus, he extended the use of the name Lance to include beds which had been previously
mapped as Fort Union, a mistake extending from Knowlton's decision in 1909 to map Tullock and Labo in the "lower Fort Union" in eastern Montana.

Stanton, in 1914 (p. 343), restricted his use of the name Lance to the "dinosaur beds." He said (p. 349), that the invertebrate fauna is more closely allied to the Cretaceous but followed Knowlton for the age who stated, the plants are the same as the Fort Union plants and gave them a Tertiary age (Stanton, 1914, p. 349).

In 1915, Lloyd and Hare named the Ludlow "Lignitic" Member of the "Lance" Formation for exposures near the town of Ludlow, Harding County, northwest South Dakota (Lloyd and Hare, 1915, p. 328-333). These beds are located stratigraphically above the dinosaur-bearing strata and below the Cannonball Member. The Ludlow "Lignitic" Member and the Cannonball "Marine" Member of the "Upper Lance" were found to interfinger. The Hell Creek Formation was mapped as the "Lower Lance" Formation (Lloyd and Hare, 1915, p. 527). The thickness of the "Lower Lance" (Hell Creek) Formation near the town of Selon, Sioux County, North Dakota, appears to have been given erroneously as 400 feet. The writer has measured only 250 feet of strata at this locality. It is possible perhaps that the Bull Head Member of the Fox Hills Formation was included the "Lower Lance" Formation of these authors as it was by Leonard in 1911. The "Lance" Formation was questionably assigned to the Tertiary but they also gave a prepared statement by Stanton who said:

The fauna of the Cannonball marine member of the Lance may now be characterized as a modified Fox Hills fauna. It contains a considerable portion of undescribed species of Cretaceous
affinities, and it is noteworthy that a number of the most common Fox Hills species have not been discovered in this fauna. (Lloyd and Harms, 1915, p. 537).

A few years later, Stanton (1929) published a paper on the fauna of the Cannonball "Marine" Member of the "Lance" Formation. He placed the "Lance" Formationquestionably in the Tertiary System (p. 6), but stated that 40% of the molluscan fauna of the Cannonball "Marine" Member of the "Lance" Formation is of a Montanese fauna (p. 12). Further on in his discussion of the age of the Cannonball "Marine" Member he stated,

"Its fauna is strictly marine and includes 2 species of Foraminifera, 6 of corals, 15 of Mollusca, and two of sharks. While its molluscan fauna has a modern aspect, on account of the Mesozoic groups, it is connected with the preceding late Cretaceous faunas of the same region by the specific identity of 40 per cent of its species. No Becana species have been identified in it except one from the Fort Union.

Geographically and historically the Cannonball member is much more closely connected with the Cretaceous than with the Eocene, for the reason that it is in the midst of an area that was covered by the sea practically throughout Upper Cretaceous time, while it is a thousand miles distant from recognized marine Eocene deposits.

The conclusion is therefore reached that the Cannonball marine member and consequently the whole of the Lance formation is of Cretaceous age. (Stanton, 1929, p. 15, 16).

Previously most geologists had followed Knowlton, assigning the Lance, Hell Creek, Cannonball, Ludlow, Lebo, and Tullock Formations a Tertiary age. At this point most geologists began to follow Stanton and gave these same beds a Cretaceous age and placed all of beds under the name "Lance," a mistake stemming from Knowlton's (1909) combining of the "Lance" (Hell Creek), Tullock and Lebo beds in eastern Montana.

In 1921, Hancock described the geology of the Salem Lignite Field in northern Manton County, North Dakota. He divided what he called "Lance" into the Cannonball "Marine" Member and "undifferentiated Lance" below, presently called Hell Creek and Ludlow Formations. Knowlton
identified the leaf fossils collected as Tertiary in age (Hancock, 1921, p. 6). Hancock also mentioned that Stanton believed that the fauna of the Cannonball beds was a modified Fox Hills fauna (Hancock, 1921, p. 16).

Thom and Dobbin published a report on the "Lance" Formation of eastern Montana, North Dakota, and South Dakota in 1924. They divided the "Lance" Formation into four members: the Hell Creek, the Tullock, the Ludlow, and the Cannonball (Thom and Dobbin, 1924, p. 491-493). However, although they recognized the Tullock beds in some regions, they included the "lignite beds" (Tullock) of Barum Brown at the type section of the Hell Creek Formation, Garfield County, Montana, in their "Hell Creek" Member (Thom and Dobbin, 1924, p. 471). They believed (p. 497) the contact between the Tongue River and Sentinel Butte beds to be the Cretaceous-Tertiary boundary, thus they included the Tongue River beds in the Cretaceous Series for the first time.

Leonard and others, in 1925, reported that the "Lance" was divisible into two parts, an upper marine portion and a lower fresh-water portion (Leonard and others, 1925, p. 1, 2). They mentioned (p. 2) that the Cannonball fauna had affinities with the Fox Hills fauna. They did not mention the Ludlow beds.

In 1928, the U. S. Geological Survey published the report of Hares "The geology and lignite resources of the Marmarth Field, southwestern North Dakota." The field work, however, for this report was conducted much earlier in 1911 and 1912. He divided the "Lance" into two members, the Hell Creek and the Ludlow. He correlated the marine tongue found in the upper part of the Ludlow Member with the Cannonball Member to the east (Hares, 1925, p. 20-30). Hares assigned a "Tertiary (?)" age to
the "Lance" Formation and thus followed Knowlton (1909) and not Stanton (1920) or Thom and Dobbin (1924) who believed these beds to be of Cretaceous age. It is this paper of Harris that firmly established the name Hell Creek in North Dakota although the name had been applied earlier by Thom and Dobbin (1924) to North Dakota in their regional summary.

Dobbin and Meeside, Jr. (1929, p. 25) discussed the relationships between the Fox Hills Formation and the "Lance" Formation (Hell Creek). They concluded that the "Lance" and Fox Hills Formations were conformable. The erosion surfaces reported between them were concluded to be of local importance, probably stream channels.

In 1934, Dobbin and Larsen published a geologic and structure contour map of the Cedar Creek Anticline (Dobbin and Larsen, 1934, Map). They placed the Hell Creek Formation, therein called "Lance" in the "Eocene (?)," which was considered basal Tertiary.

Andrews in 1936 reviewed the literature and made some suggested "Lance" and Fort Union correlations. He mis-correlated the basal Fort Union (basal Tongue River) Formation of eastern Montana with the Cannonball and Ludlow Formations in North Dakota, and the Tullock Formation of eastern Montana with the top of the Hell Creek Formation in North Dakota (Andrews, 1936, p. 387).

R. W. Brown, in 1938, discussed the Cretaceous-Eocene boundary in Montana and North Dakota. He placed the Mesozoic-Tertiary boundary where it is placed today between the Hell Creek and Fort Union strata.

This was the first time it was placed at this position.

Carefully measured section checking and supplementing those given in the coal reports and other publications, together with identifications of new collections of fossil plants and animals from critical points on or adjacent to the disputed boundary,
indicate that the strata overlying the Hell Creek formation and underlying the Wasatch constitute a recognizable, measurable, andappable unit, carrying a distinctive flora and fauna differing significantly from those of the Hell Creek and Wasatch. . . . for it indicates more clearly than ever that the thin zone of interfingering beds at the upper limit of the Hell Creek formation and the base of the immediately overlying Fort Union in its emended sense, marks the boundary between the Mesozoic and the Cenozoic. (Brown, 1938, p. 422).

He raised the name Hell Creek to formational status in North Dakota. He also suggested the name Paleocene be employed for the age of the Fort Union since Paleocene was being accepted as equal in rank with other Tertiary epochs (Brown, 1938, p. 422).

In 1939, R. W. Brown described the Hell Creek Formation as directly overlying the Fox Hills Formation and stated that the Hell Creek Formation is uppermost Cretaceous in age on the basis of plant fossils (Brown, 1939b, p. 239, 244, 245).

Tisdale, in 1941, described the geology of the Heart Butte Quadrangle, North Dakota, and assigned a "Cretaceous (?)" age to the Cannonball Member of the "Lance" Formation. He thus followed the example set by Stanton (1920) rather than by Brown (1938 and 1939).

Ballard, in 1942, discussed the regional geology of the "Dakota Basin" (Williston Basin) and misplaced the Fort Union in the Eocene and the "Lance" in the Paleocene. His "Lance" included the Hell Creek or "Lower Lance" and the "Cannonball-Ludlow" Member of the "upper Lance" (Ballard, 1942, p. 1160).

Fox and Ross, in 1942, made a significant contribution when they identified the Foraminifera collected from the Cannonball Formation as Paleocene in age (Fox and Ross, 1942, p. 666). They also elevated (p. 662) the Fort Union to group status and listed the La Brea, Tullock, Ludlow, Cannonball, and Yonque River beds as formations. This is
essentially the present usage by the North Dakota Geological Survey. They (p. 662) also correlated the Hell Creek Formation with the Lance Formation in Wyoming as Barnum Brown had done in 1914.

Ebine (1942, p. 338, 355, 356) discussed the stratigraphy of North Dakota and continued to include the Hell Creek, Ludlow, and Cannonball beds as members of the "Lance" Formation. She considered them all to be Tertiary in age.

Seager and others (1942) gave a discussion of the stratigraphy of North Dakota. They (p. 1416) correlated the Sentinel Butte Shale Member of the Fort Union Formation with the lower Wasatch, a correlation considered incorrect by R. W. Brown (1962, Fig. 1). The Tongue River, Cannonball, and Ludlow Members of the Fort Union Formation were assigned a Paleocene Age on the basis of foraminifers found by Fox and Ross (1942), on the basis of megafossils collected by Stanton (1920), and upon the basis of plant fossils. The Hell Creek Formation was regarded as the youngest Cretaceous in North Dakota. They reported a marine tongue near the base of the Hell Creek Formation which was named later the same year by Laird and Mitchell (1942).

Laird and Mitchell (1942) published the geology of southern Morton County, North Dakota. They (p. 3, 9-14) considered the Hell Creek Formation latest Cretaceous in age. In addition, they (p. 14, 15) defined a thin unit of marine beds near the base of the formation which they called the Breaian Member of the Hell Creek Formation. They utilized the Cannonball, Ludlow, and Tongue River as formations and the Fort Union as a group (Laird and Mitchell, 1942, p. 15-23) as had Fox and Ross (1942). This stratigraphic nomenclature has since served as the standard for the North Dakota Geological Survey.
Lindberg (1944) studied the heavy minerals of the Fox Hills, Hall Creek, and Cannonball sediments of Morton and Sioux Counties, North Dakota. She found (p. 140-142) that the heavy minerals could be used for local correlations. She followed the stratigraphic nomenclature introduced by Laird and Mitchell (1942).

Laird (1944) reviewed the stratigraphy and structure of North Dakota. He (p. 4) used the same stratigraphic terminology and ages for the formations which he and Mitchell (1942) had used. In addition he correlated the Sentinel Butte Shale along with the "unnamed" formation with the lower Wasatch Group (Laird, 1944, p. 5). The correlation of the Sentinel Butte to the Wasatch is considered incorrect by R. W. Brown (see Brown, 1962, Fig. 1). Laird and Benson later named the "unnamed" formation the Golden Valley Formation (Benson and Laird, 1947, p. 1166, 1167).

R. W. Brown (1948) discussed the correlation of the Sentinel Butte Shale and assigned it to the Paleocene Series, not Eocene as had many previous authors. He considered the Lebo, Tullock, Tongue River, Ludlow, Cannonball, and Sentinel Butte to be members of the Fort Union Formation. He noted the Fort Union conformably overlies the Cretaceous Hall Creek Formation (Brown, 1948, p. 1266, 1271).

Benson (1951) compiled a geologic map of North Dakota south of the Missouri River. He mapped the Hall Creek and Fort Union as formations, the latter containing two members, the Ludlow and the Tongue River. These two members of the Fort Union were separated by the Cannonball Formation. He failed to make mention of the Sentinel Butte Shale although the type area is within the area covered.
R. W. Brown (1932) discussed the Fort Union Formation in eastern Montana, western North Dakota, and South Dakota, in respect to other Tertiary Strata. He divided the Fort Union Formation into 6 members, the Tulluck, Ludow, Ludlow, Cannonball, Tongue River, and Sentinel Butte and discussed their relationships (Brown, 1932, p. 91). The criteria for recognizing the Cretaceous-(Hell Creek)-Tertiary boundary was reviewed.

Cobban and Seaside, Jr. (1952) correlated the Hell Creek Formation of North Dakota, South Dakota, and eastern Montana with the Lance Formation of Wyoming and the St. Mary River Formation of northwest Montana (Cobban and Seaside, Jr., 1952, chart 10-6), and considered these formations to be latest Cretaceous in age.

Fisher (1952) describing the geology of Edmund County, North Dakota used the same terminology as Laird and Mitchell (1942). He, however, failed to find the Braen Member of the Hell Creek Formation (Fisher, 1952, p. 17-20) which the writer found to be widespread in this area but only well exposed in recent road cuts.

Bergstrom (1956) discussed the uranium prospects of southwest North Dakota. He described the Hell Creek beds as being the latest Cretaceous in that region. He described the Ludlow, Cannonball, and Tongue River beds as formations, and differentiated the upper part of the Tongue River Formation as the Sentinel Butte Shale Member.

Rainer (1956) summarized the geology of North Dakota on a very general level. He placed the Hell Creek Formation in the latest Cretaceous (Rainer, 1956, p. 18, 20), and divided the Fort Union Group into four formations, the Cannonball, Ludlow, Tongue River, and Sentinel Butte. The Cannonball and Ludlow Formations were shown as lateral
facies and the Sentinel Butte Formation was shown to interfinger with the upper part of the Tongue River Formation (Hainer, 1956, p. 18, 20).

In 1956, Hansen compiled a geologic map of North Dakota which showed the Hell Creek Formation as the uppermost Cretaceous formation and the Cannonball, Ludlow, and Tongue River as formations in the Paleocene Series. He made no mention of the Sentinel Butte Shale (Hansen, 1956).

Denson, Bachman, and Zeller (1959) published on the uranium coals of South Dakota and adjacent states. They used the name Hell Creek Formation for the uppermost Cretaceous beds of the region. Their Paleocene strata consisted of the Fort Union Formation which was divided into the Ludlow, Cannonball, Tongue River and Sentinel Butte Shale Members. They (p. 13) showed the Ludlow and Cannonball Members as stratigraphic equivalents and the Sentinel Butte Shale lying stratigraphically above the Tongue River Member. They apparently included the Tullock strata in the Hell Creek Formation for they say,

According to R. W. Brown (1952) the lignite beds here mapped as in the upper part of the Hell Creek should be placed in the lower part of the overlying Ludlow formation. Because there is not distinct lithologic difference between these rocks and the lower part of the Hell Creek they are here assigned to the Hell Creek Formation. (Denson, Bachman, and Zeller, 1959, p. 16, 17).

Jelezsky (1960b) placed the Hell Creek Formation of North Dakota in the latest Cretaceous (Upper Maastrichtian Series). He placed the Tullock, lower Lebo, all except a small portion of the upper Ludlow, and the lowermost Cannonball Formations in the Paleocene (Danian Series), while he placed the upper Lebo, uppermost Ludlow, and all but the lowermost Cannonball, and 'Tongue Rivers' (Tongue River) Formations in the Paleocene (Lower part of the Lowerian Series) (Jelezsky, 1960, p. 26).
The ages of the Paleocene sediments were determined by Foraminifera and mammals, while the ages of the Cretaceous beds were determined by ammonites and dinosaurs (Jeletzky, 1960, p. 26-33). He applied the Fort Union Group to all sediments from the top of the Hell Creek Formation to the top of an "Unnamed" Formation, including the Tullock, Lebo, Ludlow, Cannonball, "Tongue Rivers," and "Unnamed" Formations (Jeletzky, 1960, p. 28). The "Unnamed" Formation is unfamiliar to the writer unless Jeletzky is referring to (Seager, and others, 1942) or (Laird, 1944, p.4) where there are references to an "Unnamed" Formation. This formation was named the Golden Valley Formation by Benson and Laird (1947). If the above is correct, then there is discrepancy in interpretation between Jeletzky (1960) and K. W. Brown (1963, 1962) who placed the Golden Valley Formation in the Eocene.

K. W. Brown (1962) made no changes in his stratigraphy from his 1946 paper. He showed the Hell Creek as a formation equivalent to the Lance Formation and of latest Cretaceous age. The overlying Fort Union Formation was shown to be of Paleocene age and composed of the Tullock, Lebo, Tongue River, Ludlow, Cannonball, and Sentinel Butte Members (Brown, 1962, Fig. 1, p. 1-38).

Jeletzky (1962) used the same correlation chart which he used in 1960 and based his age determinations upon the same criteria (Jeletzky, 1962, p. 1096).

The writer (Prye, 1964), discussed several marine beds found in the Hell Creek Formation including the Brien Member. The Hell Creek Formation was described as being underlain by the Cretaceous Fox Hills Formation and overlain by the Paleocene Ludlow and Cannonball Formations.
The Hell Creek was considered to be latest Cretaceous in age (Frye, 1964, p. 167).

Niel S. Sherrod reported in his Masters Thesis which was concerned with the surficial geology of the western half of Sheridan County, North Dakota, that on the northeast side of the Prophets Mountains there were outcrops of both Hell Creek and Cannonball Formations which had been folded by glacial abuse.

Hanson and Kusa (1965) discussed the Upper Cretaceous and Paleocene sediments of Burleigh County, North Dakota. Their use of stratigraphic terms are similar to this paper but they consider the Ludlow and Cannonball Formations as one unit for mapping purposes since the Ludlow sediments are very thin in their area (Plate 2).
INTRODUCTION

The stratigraphy of the Hell Creek Formation is closely related to that of several Upper Cretaceous and Lower Paleocene formations as it is one in a series of complex sedimentary facies involving regression of a late Mesozoic sea and the advance and retreat of an early Cenozoic sea (Plate 3, folder). The Cretaceous Hell Creek Formation in North Dakota is a non-marine tongue of sediments resting between marine sediments. It is underlain by the shore-line deposits of the Fox Hills Formation and the deeper water deposits of the Pierre Shale (Plate 3, folder). This relationship forms a classic example of a regressive sea: marine shales (Pierre Shale) overlain by marine sandstones and beach deposits (Fox Hills Formation), in turn overlain by lagoonal, brackish water, fresh water, and flood plain deposits (Hell Creek Formation). In eastern Montana this sequence marked the end of marine sedimentation, however, in North Dakota and South Dakota the sea returned in the early Paleocene resulting in the deposition of the shore and lagoonal sediments of the Ludlow Formation and the shallow marine deposits of the Cannonball Formation. These deposits interfinger to the west in Montana with the non-marine sediments of the Tullock, Lebo, and Tongue River Formations (Plate 3, folder). The sea withdrew from North Dakota and South Dakota at the end of Cannonball time, but have not returned since. Overlying
the Cannonball Formation there is a thick sequence of non-marine strata, represented by the Tongue River and younger formations (Plate 3, folder).

The Hell Creek Formation was named by Barnum Brown in 1907 for the dinosaur-bearing beds found at Hell Creek, East Hell Creek, and adjacent portions of the Missouri Valley, Garfield County, Montana (Brown, 1907, p. 829). Since this time the name has been used in eastern Montana, northwestern and central South Dakota, and western and central North Dakota. The lithology and age of the Hell Creek Formation have been shown to be equivalent to the Lance Formation at its type locality, Lance Creek, Converse County, Wyoming.

METHODS OF CORRELATION

Correlation of the Hell Creek Formation in the past has been based upon fossils, heavy minerals, and gross lithologies. The writer has employed, in addition to these methods, radiometric dating by K-Ar, and the tracing of bentonites.

The reliability of the different methods depends upon many factors and each may be best under certain conditions. The greatest deterrent to the use of radiometric dating is cost, thus only two dates were obtained (courtesy of the Geochron Laboratories). Two isolated samples cannot give a complete picture and thus most of the stratigraphy is based upon the other methods.

Correlation by fossils in these sediments is seriously hindered by environmental factors; for the Hell Creek Formation contains marine, brackish-water, fresh-water, and land sediments. No fossil has been found in abundance in all four environments and the writer has found no
fossils in the Hell Creek Formation which may be used to zone the formation. All of the fossils appear to have a geologic range equal to or greater than that of the formation. Waage (1961, p. 229) has found it possible to zone the underlying Pierre Shale and the intertonguing Fox Hills Formations using ammonites and peneupeds. This information may be applied indirectly to the Hell Creek Formation where it interfingers with the Fox Hills Formation.

There is a sharp change in the nature of the fossils between the Cretaceous Hell Creek Formation and the Cenozoic formations which probably represents faunal evolution with time but environmental changes may also play an unknown role. No dinosaur remains have been found in the Cenozoic and the upper limit of dinosaur fossils appears to make a good time boundary. Similarly no ammonites are found in the Cenozoic Cannonball Formation.

Tracing of bentonites has proved very successful in correlating within the Hell Creek, Tullock, and Lebo sediments. The Lower Palocene Lebo beds appear to be an isochronous deposit resulting from an outburst of volcanism which produced pyroclastics yielding bentonitic sediments. The uppermost member of the Hell Creek Formation, the Pretty Butte Member, also appears to be a result of pyroclastic deposition yielding bentonites and bentonitic sediments. Many other bentonites were traced over great distances in these formations (Plate 5, folder). This method, supported by others, proved most successful in correlation within the Hell Creek Formation and may be found useful in correlations within the Cenozoic formations.

Several papers have been written concerning the occurrence of the heavy minerals of these beds (Stow, 1938; Lindberg, 1944; Stow, 1946).
Stow (1938, p. 749) found that of 21 non-opaque minerals only six (garnet, hornblende, kyanite, staurolite, tourmaline, and zircon) were of stratigraphic importance in the Lance, Fort Union, and Wasatch Formations in the Big Horn Basin. The Lance in this region is characterized by the abundance of zircon, the rarity of colorless garnet, and the absence of red garnet, staurolite, kyanite, and hornblende (Stow, 1938, p. 752). The Tullock and Lebo could not be distinguished from one another but were characterized by the rarity of red garnet, and the absence of kyanite and hornblende (Stow, 1938, p. 752-753). The Tongue River Formation could be recognized by the common occurrence of red garnet, the presence of kyanite, and the absence of hornblende (Stow, 1938, p. 753). Lindberg (1944, p. 138-143) found that she could divide the Fox Hills, Hell Creek, Ludlow, and Cannonball Formations in Morton and Sioux Counties, North Dakota, into 9 zones. The zones were based upon the frequencies of green and brown amphiboles, epidote, and garnet. Stow (1946, p. 634) studied the heavy minerals from the Hell Creek, Tullock, Lebo, and Tongue River Formations in the Beartooth mountains. He found that two sedimentary basins existed as early as Hell Creek time which correspond today to the Crazy Mountain Syncline, and the northward extension of the Big Horn Basin. Detailed studies revealed that the two basins had different source regions.

The writer found that in his attempts to correlate by heavy minerals between the Hell Creek Formation, in Garfield County, Montana (type section for the Hell Creek Formation); Glendive, Dawson County, Montana; Slope and Bowman Counties, North Dakota; Sioux County, North Dakota; and Emmons County, North Dakota, that it was possible to make correla-
tions over short distances, such as between Sioux and Ramona Counties, North Dakota, but correlations over larger distances were not successful. Differences over large distances are probably the result of different drainage systems and basins.

Correlation by gross lithologies, that is, by groups of beds of member status or larger, is extremely difficult since these lithologic units tend to be time transgressive. This method was used by the early geologists and still can be used to some extent, if the inherent problems are kept in mind. Thin units such as the Breden Member of the Hell Creek Formation represent essentially time lines because they are often found to be parallel to a bentonite. However other units such as the Colgate Member of the Fox Hills Formation is time transgressive (Waage, 1962, p. 229).

THE UPPER CONTACT OF THE HELL CREEK FORMATION

The upper limit of the Hell Creek Formation is the Mesozoic-Cenozoic boundary as that boundary is now defined in North Dakota, South Dakota, and eastern Montana. The Cretaceous Hell Creek Formation is overlain by the Paleocene Tullock Formation in Montana and western North Dakota, and by the Paleocene Ludlow and Cannonball Formations in central North Dakota.

The top of the Hell Creek Formation is considered a time boundary because different assemblages of fossils are found above and below it. Remains of animals such as dinosaurs and ammonites are found below this contact but not above it. The lithologic change at the top of the Hell Creek Formation is a time marker because the uppermost beds represent the products of an outburst of volcanism in the form of ash beds (now
altered to bentonites) which were deposited by the wind over the whole
region and in part reworked by running water to form bentonitic sedi-
ments.

The early workers expected to find a major unconformity between
Mesozoic and Cenozoic sediments. As far as the writer has been able to
ascertain, this major break does not exist anywhere in North Dakota,
South Dakota, or eastern Montana. This opinion is supported by R. W.
Brown (1962, p. 14-20) who studied thoroughly both the fossils and the
stratigraphy for many years.

The Hell Creek Formation was first defined by R. Brown, in 1907,
as the somber colored dinosaur beds. Much later Thom and Dobbin (1924,
p. 491) erroneously put the dark "somber colored" Tullock beds of eastern
Montana, which do not contain dinosaurs, into the Hell Creek Formation.
The top of the Hell Creek Formation, however, had been clearly defined
in eastern Montana by Calvert (1912a, p. 196, 197) when he introduced
the "lowest persistent bed of lignite" as a key to the base of the Paleoe-
cane sediments. The Hell Creek Formation in this region has no persis-
tent coals and the basal bed of the Paleocene sediments is almost always
a widespread coal lying upon dinosaur-bearing bentonites and bentonitic
shales. This key to the upper Hell Creek contact is also useful in many
parts of North Dakota, and South Dakota, though, there are large areas
of North Dakota, and South Dakota that have no lignite at the base of
the Paleocene formations. Here also the Hell Creek formation commonly
lacks sufficient dinosaur remains in the upper part to use this as the
definition and thus the upper Hell Creek boundary (Mesozoic-Cenozoic
boundary) in these regions must be defined otherwise.
In western North Dakota, Slope and Bowman Counties, the basal lignite of the Paleocene formations may be absent, a clay line, or a lignite up to 10 feet thick. If the lowest lignite is missing or if there is only a clay line it may well be overlooked in favor of a thicker lignite higher in the section. This was done by K. M. Brown (1962, Fig. 2) at Pretty Suts, North Dakota where he placed the upper Hell Creek contact and the Mesozoic-Cenozoic boundary over 150 feet above what is considered herein as its true position.

Identification of this boundary in Slope and Bowman Counties, North Dakota is based upon the occurrence of a remarkably light colored (light-yellowish-gray to light-yellowish-brown) bed of silt and sand in a sequence of dark and somber colored beds (Fig. 3a). This bed in all cases overlies a bentonite which contains dinosaur bones and abundant pods of purplish-brown, lignitic shale. The "yellow bed" is the basal bed of the Paleocene sediments except where the basal bed is a lignite — "the lowest persistent bed of lignite," which is then the basal bed of the Paleocene strata. The "yellow bed" intergrades with the "basal lignite" and may be replaced by the lignite from the top or bottom. On Cannonball Creek, east of North Dakota Route 19 in Slope County, the "yellow bed" is completely absent and the boundary is marked by a thick lignite.

In addition, bedding and color are helpful for the identification of this boundary in Slope and Bowman Counties, North Dakota. The Hell Creek Formation tends to be gray in color while the Paleocene sediments tend to be brown (Fig. 3b). Many individual beds in both
Figure 3a. Tullock-Hell Creek contact showing the "yellow bed." Arrows indicate the contact. Sec. 16, T. 133 N., R. 105 W., Slope County, North Dakota.

Figure 3b. Tullock Formation showing brown coloration and persistent bedding. Sec. 22, T. 233 N., R. 105 W., Slope County, North Dakota.
the Paleocene strata or the Cretaceous strata are exceptions to this rule. Bedding is somewhat more reliable. The Cretaceous Hell Creek sediments have a "dumped" appearance and the bedding is not pronounced nor persistent. The Paleocene Tullock sediments, on the other hand, exhibit flat and persistent bedding which is accentuated by the dark colored coals (Figs. 4a, 4b, and 5).

Further east, in central North Dakota in the Missouri Valley and its tributaries south of Bismarck, where the Hell Creek Formation is overlain by the Paleocene Ludlow and Cannonball Formations, there is often neither a coal nor a characteristic bed in the base of the Paleocene sediments. Lignite, lignitic sandstone, lignitic shale, or non-lignitic sandstones and shales which may contain minor amounts of glauconite occur as basal beds in the Paleocene strata. In this region, the upper sediments of the Hell Creek Formation only rarely contain dinosaur remains. Here the clue to the top of the Hell Creek Formation and the boundary between the Mesozoic and Cenozoic is the presence or absence of bentonites or bentonitic sediments. The Hell Creek Formation contains bentonitic sediments, the Paleocene sediments in the vicinity of the contact do not.

In summary, one should be cautious about using only one method to determine the top of the Hell Creek Formation (Mesozoic-Cenozoic boundary). The variability of this contact in North Dakota makes it impossible to use alone, Calvert's (1912a) and Brown's methods of identifying the Mesozoic-Cenozoic boundary by the "lowest persistent lignite," although they were able to do so in eastern Montana.
Figure 4a. Hell Creek and Tullock Formations in NE 1/4 sec. 2, T. 129 N., R. 105 W., Bowman County, North Dakota. Arrows indicate the contact. Note flat bedded nature of the Tullock Formation (above) and the absence of a prominent lignite at its base. Most of the Hell Creek beds exposed are those of the Pretty Butte Member. The sandstones in the foreground belong to the Huff Member.

Figure 4b. Arrows indicate Hell Creek-Tullock contact. Dinosaur bones may be seen behind the man in the foreground. Note the absence of lignite at the base of the Tullock Formation. Same locality as above.
Figure 5. Hell Creek, Tullock, and Ludlow Formations in sec. 4, T. 134 N., R. 106 W., Slope County, North Dakota. Arrow indicates the contact between the Hell Creek and Tullock Formations. Note the lignite at the base of the more persistently bedded Tullock Formation. Scoria of the T-Cross bed in the base of the Ludlow Formation may be found at the top of the highest butte.
The age of the top of the Hell Creek Formation (Mesozoic-Cenozoic boundary) was determined radiometrically in Slope County, North Dakota by the K-Ar method using biotite from bentonites. Biotite from 30 feet above the contact gave a date of 68 ± 3.2 m.y. (sec. 4, T. 133 N., R. 103 W., Slope County, North Dakota. Biotite collected from about 6 feet below the top of the Hell Creek Formation gave a date of 105 ± 15 m.y. (sec. 16, T. 134 N., R. 106 W., Slope County, North Dakota. Some weathered biotite in the later sample suggests this sample may have been contaminated, therefore giving an older than expected date.

THE LOWER CONTACT OF THE HELLCREEK FORMATION

The Hell Creek Formation in North Dakota, South Dakota, and eastern Montana rests upon the Fox Hills Formation. The contact varies from region to region from one of conformity, to disconformity, and paraconformity.

In the Missouri Valley and its tributary valleys south of Bismarck, North Dakota, the contact between the Hell Creek Formation and the underlying Fox Hills Formation is gradational and the formations exhibit an interfingering relationship. The basal beds of the Hell Creek Formation are frequently lignitic sandstone or a sandy lignitic shale which locally may have silicified tree stumps in place within them (Fig. 7). The Fox Hills Formation, on the other hand, is composed of gray, crossbedded sand (the Golgate Member) or interbedded gray sands, silts, and shales (the Bull Head Member). In several locations a volcanic ash bed may be found between the two formations
as in the SE 1/4 sec. 36, T. 134 N., R. 82 W., Sioux County, or in sec. 13, T. 135 N., R. 73 W., Hammons County, North Dakota. In SE 1/4 sec. 21, T. 134 N., R. 80 W., southern Morton County, North Dakota, the Hall Creek Formation may be seen to interfinger with the Bull Head Member of the Fox Hills Formation. The loss of basal Hall Creek beds through interfingering with the Fox Hills Formation amounts to 25 feet between Breien, south-central Morton County, and central Hammons County (Plate 4, folder; Appendix A, section 6, section 23). It has been known for a long time that the Hall Creek and Fox Hills Formations have an interfingering relationship. Stanton as early as 1910 reported a gradational contact between the Fox Hills Formation and the Hall Creek Formation for this region. Calvert and others (1914, p. 13) noted that the Fox Hills and Hall Creek Formations in this area exhibited an interfingering relationship. However, this is the first time the thickness of beds lost by the Hall Creek Formation has been determined directly from measured sections.

In western North Dakota, in the Little Missouri Valley in Slope and Bowman Counties, the contact of the Hall Creek Formation with the Colgate Member of the Fox Hills Formation may be gradational and show an interfingering relationship or it may be erosional (Figs. 6a, 6b). The basal beds of the Hall Creek Formation are usually lignitic shales or sandstones. The upper beds of the Colgate Member of the Fox Hills Formation are clay-rich, and often somewhat lignitic or bentonitic, crossbedded sands. In sec. 1, T. 129 N., R. 106 W., Bowman County, North Dakota, the Hall Creek-Fox Hills contact is gradational and large crossbeds of bentonitic shales and lignitic shales of the Hall
Figure 6a. The Hell Creek–Fox Hills contact in sec. 32, T. 132 N., R. 106 W., Bowman County, North Dakota. Arrows indicate the contact. The lignitic bentonitic Little Beaver Creek Member of the Hell Creek Formation overlies the sandy Colgate Member of the Fox Hills Formation. Note the basal lignitic sand and sandy lignite of the Hell Creek Formation.

Figure 6b. The Hell Creek–Fox Hills contact in sec. 32, T. 132 N., R. 106 W., Bowman County, North Dakota. Arrows indicate the contact. The lignitic bentonitic Little Beaver Creek Member of the Hell Creek Formation overlies the sandy Colgate Member of the Fox Hills Formation. Note the relief on the unconformity.
The Hell Creek Formation, the lowermost member of the Hell Creek Group, is a well-known interval between the Hell Creek and the overlying North Horn Ranch formations. It is characterized by extensive coal beds, which are present but the lower two members of the Hell Creek Group are not. The Hell Creek Formation is often used as a marker horizon due to its distinctive fossil content.

To the east in the Powder River Basin, the Hell Creek Formation is composed of eroded coal beds, and contains significant amounts of organic material. In contrast, the Hell Creek Formation to the west is more sandstone-dominated, with less organic matter.

In the Powder River Basin, the Hell Creek Formation is known for its high diversity of fossil remains, including dinosaurs and other organisms. Its study has provided valuable insights into the evolution of life during the Mesozoic era.

The Hell Creek Formation is also notable for its role in the development of the Powder River Basin. Its deposition was influenced by tectonic activity, resulting in the creation of a basin that was later filled with sediment. The fossil record from the Hell Creek Formation provides a snapshot of life during this time period, allowing scientists to understand the evolutionary history of the region.
Narmarth and Little Beaver Creek Members, are absent. The difference in thickness of the Hell Creek Formation between Glendive, Montana, and Slope and Bowman Counties, North Dakota, amounts to 230 feet. The total thickness of the missing Narmarth and Little Beaver Creek Members is 175 feet and their absence probably accounts for much of the loss in thickness.

Thinning of the upper three members can be demonstrated by the tracing of bentonites between Slope and Bowman Counties, North Dakota and Glendive, Montana, and accounts for much of the remaining loss (Plate 5, folder). These data suggest that the lower two members are missing in the Makoshika State Park section because of non-deposition on top of the Baker-Glendive Anticline (Cedar Creek Anticline) on which this section is located. There is no indication that the underlying Fox Hills Formation was affected which indicates that the Baker-Glendive Anticline at the beginning of Hell Creek time was a stable region surrounded by sinking regions which were receiving early Hell Creek sediments. Later during middle and late Hell Creek time western North Dakota and eastern Montana subsided as a whole, the area of the anticline a little less slowly because it contains thinner sediments. This differential subsidence produced what appears as a paraconformable relationship between the Hell Creek and Fox Hills Formations.

At the type section of the Hell Creek Formation, East Hell Creek, Garfield County, Montana, Barnum Brown (1907, p. 329) described an unconformity between the Hell Creek and Fox Hills Formation. He stated,
It [basal sandstone of Hell Creek] unconformably overlies the Fox Hills, as shown near the Creek ranch on Crooked Creek; also on Hell Creek. This unconformity is erosional in character.

More recently, in the Fort Peck region, just east of the type area of the Hell Creek Formation, Colton and Bateman (1956, map) indicated an unconformity at the base of the Hell Creek Formation. They showed that the basal sandstone unit of the Hell Creek Formation varies from 50 to 100 feet in thickness. Jansen and Varnes (1964, p. 722) stated that in Garfield, McCone, and Valley Counties, Montana,

Two types of evidence thus are combined to indicate an erosional unconformity between the Fox Hills sandstone and the Hell Creek Formation:

1. The sharp and channeled contact between the two formations (fig. 10) and the substantial local differences in thickness of the Fox Hills.
2. The abrupt and substantial differences across the contact in sedimentary and ecological characteristics.

The significance of the disconformity is difficult to assess; it may be a stratigraphic feature restricted to this part of Montana, and it may, moreover, represent an inconsequential gap in the geologic record. Almost certainly it means that the effects of the Laramide Revolution were being felt this far east.

Thus it has been shown by various workers, even in the early investigations, that an unconformity and probably a disconformity of unknown magnitude exists between the Hell Creek and Fox Hills Formations in the region of the type area of the Hell Creek Formation.

However, there were investigators who did not think there was an unconformity between the Hell Creek and Fox Hills Formations. Bobbin and Baseide (1929) came to the conclusion that no major unconformity existed anywhere between the Hell Creek and Fox Hills Formations.

The contact of the Lance and Fox Hills is everywhere essentially transitional.
All angular unconformities reported to exist between these formations are misinterpretations of faulting, crossbedding or slumping.

Erosional planes in the Fox Hills and Lance formations are unimportant chronologically, being merely evidence of local channeling of near-shore deposits by tidal currents and wave scour in the Fox Hills, or the flood-plain deposits by streams in the Lance - that is, the result of contemporaneous erosion and redeposition. (Dobbin and Reeside, 1929, p. 25.)

The writer believes that his and other investigators' results have shown that there are no simple conclusions to be made concerning this contact. Dobbin and Reeside's summary of the Fox Hills-Hell Creek contact appears to fit most of North Dakota and South Dakota. However, in eastern Montana, it has now been substantiated that the unconformities found between the Hell Creek and Fox Hills formations are not local but very widespread. In some regions such as near Glendive, it can be shown that substantial portions of the lower Hell Creek Formation are missing. In other regions such as near the type area of the Hell Creek Formation (Fort Peck area of Montana), it has been shown that both the lower Hell Creek and Fox Hills formations vary substantially in thickness. These facts would suggest that at least locally, this unconformity may represent significant geologic time.

The age of the contact between the Fox Hills Formation and the Hell Creek Formation varies. Waage (1961, p. 238, 239) shows by fossil zones in the Fox Hills Formation that the Hell Creek-Fox Hills contact in western South Dakota and Montana is older than in central North Dakota. From stratigraphic relationships it would appear that the lowermost Hell Creek sediments at Glendive, Montana, were somewhat younger than the lower Hell Creek sediments to the east or west and probably because of non-deposition during early Hell Creek time.
Thus, although the top of the Hail Creek Formation appears to be a time horizon, the bottom is time transgressive and the lower Hail Creek beds vary in age from place to place, a result of interfingering relationships, erosion, and non-deposition.
SUBDIVISION OF THE HELL CREEK FORMATION

INTRODUCTION

The Hell Creek Formation has been subdivided in North Dakota, both formally and informally. These subdivisions have been based upon gross lithology, marine fossils, the presence or absence of certain heavy minerals, and color (Leonard, 1911, p. 307; Seager and others, 1942, p. 1418; Laird and Mitchell, 1942, p. 14, 15; Lindberg, 1944, p. 140-142; Frye, 1964, p. 170, 171). The Hell Creek Formation has also been subdivided in South Dakota (Curtiss, 1954, map; Stevenson, 1954, map), and in Montana (Barnum Brown, 1907, p. 329-334).

Other workers have found the formation too variable laterally to subdivide.

There is the utmost variation in the rocks, both vertically and horizontally. Two detailed sections taken by the same person across the same stratigraphic interval and less than 100 feet apart would not show marked likeness, and if separated by a distance of a mile very likely they would be absolutely different. A shale may grade in any direction into a sandstone or a sandstone into a shale, and many of the lignite beds grade laterally into shale or are split up by shale partings. (Harea, 1928, p. 26).

The Hell Creek Formation has been subdivided here for purposes of description, correlation, history, and economics. It is useful to map thinner units than the formation because the formation contains, in certain strata, minerals such as clays which may become economically important. Still other horizons have the possibility of becoming important aquifers. From a geologic point of view, dividing the forma-
tion into several units is extremely useful when making internal correlations or interpreting historical events connected with the deposition of the formation.

CRITERIA USED FOR SUBDIVIDING THE HELL CREEK FORMATION

The proposed members of the Hell Creek Formation are based upon sandstone, shale, and lignite content, bedding, and color. It became apparent early in this study that the distribution of sandstone, bentonite, shale, and lignitic material was not random horizontally or vertically. Lithologic sections measured in the field and plotted to the nearest half-foot were compared. It was noted that there were recurrent patterns in the lithology, some of which were readily evident in the field, and were used as members.

As a further check, sandstone-shale-lignite ratios were computed for the members by adding the total footages of sandstone, shale, and lignite (or very lignitic shale) in a member and dividing by the total footages of the sandstone, shale, and lignite. Bentonites and mudstones were grouped with shales in these computations (Fig. 9). Not only were the proposed members found to have variable sandstone-shale-lignite ratios but were found to have distribution differences, that is, some members had a predominance of thick sandstone bodies while others had a predominance of thin sandstone bodies.

The ratios of lithologies were used successfully to determine differences between the Hell Creek and adjacent formations. This technique was especially useful in the study of differences between the Hell Creek and Tullock Formations (Fig. 9).
Color and bedding often proved very useful in recognizing a member in the field. Colors were most apparent when the beds were damp and were in bright sunlight. Bedding and thickness of beds was extremely useful.

It was hoped that heavy mineral studies would aid in the subdivision of the Hell Creek Formation, however they proved useless, giving only hazy indications of zonation. Local zonation appears possible on the basis of Lindberg (1944) and the writer's studies but correlation over long distances produced negative results suggesting several drainage and basin systems.

Bentonites were found to be persistent and several members are based on particularly widespread bentonites. Volcanism appears to have been sporadic in the source regions and produced several more bentonitic members in addition to the bentonite beds.

PROPOSED MEMBERS OF THE HELL CREEK FORMATION

For purposes of our discussion, southwestern North Dakota will be divided into the Little Missouri Valley and the Missouri Valley (Fig. 1). It is here proposed that the Hell Creek Formation in North Dakota be divided into eight members. Two members would be common to both the Missouri Valley and the Little Missouri Valley. In addition, each of the two areas would have three additional members mapped only in their respective regions. One of these members, the Bratton Member, has already been named (Laird and Mitchell, 1942) and is found along the Missouri Valley south of Bismarck, North Dakota.
New Members in the Little Missouri Valley

The Little Beaver Creek Member of the Bell Creek Formation

It is here proposed to call the lowest unit of the Bell Creek Formation in the Little Missouri Valley, North Dakota, the Little Beaver Creek Member of the Bell Creek Formation after Little Beaver Creek in northwestern Bowman County where it is found typically exposed. The following section, the type section, is located in the SW 1/4 sec. 7, T. 132 N., R. 106 W., Bowman County, along said creek several miles southwest of the town of Marward, Slope County, North Dakota.

### HELL CREEK FORMATION (MARMARTH MEMBER)

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.</td>
<td>Gray, brown weathering sands with limonitic sandstone lenses and siderite nodules weathering to limonite near the base</td>
<td>25.0</td>
</tr>
<tr>
<td>16.</td>
<td>Light-gray, bentonitic shale</td>
<td>0.5</td>
</tr>
</tbody>
</table>

### HELL CREEK FORMATION (LITTLE BEAVER CREEK MEMBER)

<table>
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<tr>
<th>Number</th>
<th>Description</th>
<th>Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.</td>
<td>Dark-purplish-brown, lignitic shale which breaks into irregular blocky plates</td>
<td>1.5</td>
</tr>
<tr>
<td>14.</td>
<td>Light-brownish-gray, bentonitic shales with siderite nodules weathering to limonite near the base</td>
<td>22.0</td>
</tr>
<tr>
<td>13.</td>
<td>Brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>12.</td>
<td>Medium-gray, bentonitic shale with siderite beds weathering to limonite</td>
<td>11.0</td>
</tr>
<tr>
<td>11.</td>
<td>Moderate-brown sandstone</td>
<td>0.5</td>
</tr>
<tr>
<td>10.</td>
<td>Light-brownish-gray, bentonitic shale</td>
<td>4.5</td>
</tr>
</tbody>
</table>
9. Light-gray, bentonitic shale with sandy lenses grading downward into sandstone with bentonitic shale partings. Calcareous sandstone lenses near the base ........................................ 18.0

8. Dark-purplish-brown to black, lignitic shale with a well-developed fissility ...................... 3.5


6. Dark-purplish-brown, lignitic shale with a well-developed fissility ............................ 3.0

5. Light-brownish-gray, lignitic sandstone ....................................................... 5.0

4. Light-brown, gray weathering, lignitic shale .................................................... 9.0

3. Moderate-brown, light-gray weathering, lignitic sandstone with occasional marcasite concretions in the lower half ......................................................... 10.0

2. Moderate-to dark-brown very lignitic sandstone and sandy lignite ........................................ 1.5

Total thickness of Little Beaver Creek Member .................. 105.0

FOX HILLS FORMATION (COLGATE MEMBER)

1. Light-gray, massive, clay-rich sandstone with some lignitic lenses ........................................ 29.5

Total thickness of the Colgate Member ......................... 29.5

(For a complete measured section of the beds at this locality see Appendix A, Part I).

The base of member is a very lignitic sandstone below which are the gray sandstones of the Colgate Member of the Fox Hills Formation. This lignitic sandstone is similar to the one found at the base of the Crowghost Member of the Hell Creek Formation in the Missouri Valley. In most localities this lignitic sandstone lies upon and unconformity with a local relief of five feet and this relationship may be observed in secs. 20, 29, and 32 of T. 132 N., R. 106 W., Bowman County, North Dakota (Fig. 6a and b). However, at another locality, sec. 1, T. 129 N.,
R. 106 W., Bowman County, North Dakota, the contact between the Little Beaver Creek Member of the Hell Creek Formation and the Colgate Member of the Fox Hills Formation is gradational with tongues of lignitic and bentonitic shales (Hell Creek lithologies) interfinger with the sandstones containing Ophiomorpha major (Fox Hills lithology). The top of the Little Beaver Creek Member is a persistent moderate-purplish-brown, lignitic shale which breaks into irregular blocky plates.

The Little Beaver Creek Member of the Hell Creek is only recognized in the Little Missouri Valley in North Dakota. It interfingers with the Fox Hills Formation to the east and is cut out by erosion or non-deposition to the west where the Hell Creek beds extend over the crest of the Cedar Creek Anticline. It may be found well developed at the following localities: C. sec. 1, T. 129 N., R. 106 W., Bowman County, North Dakota; sec. 7, T. 130 N., R. 105 W., Bowman County, North Dakota; and in NW 1/4 sec. 33, T. 132 N., R. 105 W., Bowman County, North Dakota.

The lithology of the Little Beaver Creek Member of the Hell Creek Formation is characterized by lignitic sediments. Included are many sandstone bodies, probably river channels, thinner than those found in the Harshaw Member. It often contains sandstones very similar to those found in the Colgate Member of the Fox Hills Formation. Between the channel sandstones there are shales and smaller sandstone bodies which are very lignitic and often have a purplish or lavender hue. There are several thin sandstones near the base of the member which are brown colored when fresh but weather to a very characteristic pale-lavender-brown which appears whitish at a distance. Bentonites are not as common
nor as persistent as in the upper part of the Hell Creek Formation, but
still compose an appreciable portion of the sediments.

Most of the Little Beaver Creek Member of the Hell Creek Forma-
tion is vegetated but where badlands do occur it forms rounded slopes
capping vertical cliffs of sandstone. A typical outcrop has the Colgate
member of the Fox Hills Formation exposed in the base as a vertical
cliff with lignitic sandstone (Hell Creek) weathering into relief above
followed upward by a series of benches supported by lignitic shales and
bentonites (Figs. 6a and b).

The outcrops studied yielded very few fossils though numerous
plant fragments in the shales would suggest that locations might be
found where one could obtain recognizable leaf fossils. No vertebrates
or invertebrates were found. Only one plant was collected, the cones
of Sequoia dactyloidea. The sediments and cones suggest this member is
largely terrestrial though it almost certainly contains marine beds, at
least near the base, where it interfingers with the Colgate Member of
the Fox Hills Formation which contains Ophiacantha major and sharks
teeth.

The Marmarth Member of the Hell Creek Formation

It is here proposed to call the beds containing thick channel
sandstones, lying directly above the Little Beaver Creek Member, the
Marmarth Member of the Hell Creek Formation. The name is taken from
the town of Marmarth, Slope County, North Dakota located on the banks
of the Little Missouri River near the Slope-Bowman County line. Out-
crops of the member may be seen in the cut banks of the Little Missouri
River nearly surrounding the town. The type section is taken just west
of the town in the SW 1/4 sec. 26, T. 133 N., R. 106 W., Slope County, North Dakota. The type section of the Marmarth Member may be reached by driving west from Marmarth on U. S. Route 12 to the second small bentonite-capped butte on the south side of the road. The type section is on the back (south) side of the butte next to Little Beaver Creek. The following section is the type section of the Marmarth Member of the Hell Creek Formation.

HELL CREEK FORMATION (BACON CREEK MEMBER)

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.</td>
<td>Bentonitic, yellowish-gray sandstone with bentonitic shale partings</td>
<td>20</td>
</tr>
<tr>
<td>9.</td>
<td>Medium- to light-gray bentonite</td>
<td>9</td>
</tr>
</tbody>
</table>

HELL CREEK FORMATION (MARMARTH MEMBER)

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.</td>
<td>Light-gray sand with bentonitic shale partings and a few calcareous sandstone lenses</td>
<td>45</td>
</tr>
<tr>
<td>7.</td>
<td>Dark-brown to black, lignitic shale and lignite with siderite nodules weathering to limonite</td>
<td>1</td>
</tr>
<tr>
<td>6.</td>
<td>Medium-gray bentonite</td>
<td>9</td>
</tr>
<tr>
<td>5.</td>
<td>Dark-grayish-brown, lignitic shale</td>
<td>1</td>
</tr>
<tr>
<td>4.</td>
<td>Medium-gray, bentonitic shale</td>
<td>4</td>
</tr>
<tr>
<td>3.</td>
<td>Light-brownish-gray sandstone with some rusty colored very light-gray, calcareous sandstone lenses</td>
<td>23</td>
</tr>
<tr>
<td>2.</td>
<td>Medium- to dark-gray bentonite</td>
<td>1</td>
</tr>
</tbody>
</table>

Total thickness of Marmarth Member | 74

HELL CREEK FORMATION (LITTLE BEAVER CREEK MEMBER)

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Moderate-purplish-brown, sandy to silty, lignitic shale which breaks into irregular blocky plates</td>
<td>11</td>
</tr>
</tbody>
</table>

(For a complete measured section of the beds at this locality see Appendix A, Part I).
The lower contact between the Marmarth and Little Beaver Creek Members of the Bell Creek Formation is sharp and is placed at the top of a persistent lignitic shale of a peculiar purplish-brown color which breaks into irregular blocky plates. This distinctive bed is the uppermost bed of the lignitic sequence which constitutes the Little Beaver Creek Member of the Bell Creek Formation. The upper contact between the Marmarth and Bacon Creek Members of the Bell Creek Formation is characterized by an interfingering relationship. The contact is drawn at the top of a prominent sandstone body in the uppermost portion of the Marmarth Member which lies below a series of shales and bentonitic shales in the Bacon Creek Member.

The Marmarth Member of the Bell Creek Formation is only recognized in the Little Missouri Valley, North Dakota, and is absent in the Glendive region, Dawson County, Montana. It is best developed in and around the town of Marmarth, and may be traced southeastward into Bowman County to within 10 miles of the South Dakota border where because of low relief exposures become poor and make it impossible to follow farther. It is found well developed on the east side of the Marmarth Bridge on the east side of town, on U. S. Route 12 and in the sandy buttes north of the highway between Marmarth and the North Dakota-Montana border on U. S. Route 12.

Lithologically the Marmarth Member consists of two thick sandstone bodies, probably channels of large rivers. The two channels are separated by a thin sequence of bentonites, bentonitic shales, and lignitic shales. The channels contain calcareous sandstone lenses which weather with high relief. The member is almost entirely sandstone (Fig. 9).
The Harmsworth Member occurs as cliffs along the Little Missouri River and its tributaries, and it is usually capped by a bentonite of the Bacon Creek Member. Away from the stream it develops a unique set of badlands characterized by haystack-like buttes composed of sandstones capped by a protective bentonite with long stretches of grass-lands between. This topography may be seen well developed 3 miles west of Harmsworth on the north side of the highway (U. S. Route 12).

Relatively few animal fossils were found in a preliminary search of this member. No invertebrates were found and only a few vertebrates. Plant fossils however were common and it is probable that there are many more species than those listed below which were collected and identified by the writer.

PLANTS

*Clinopogon larameanus* Ward  
*Drooppedium subfalcatum* Lesquereux  
*Viscum prostratum* Brown  
*Nymphaeastratus* (Berry) Bell  
*Gomus* sp., *cf. G. greekpressa* Knowlton

VERTEBRATES

*Cf. Tyrannosaurus rex* Osborn  
*Cf. Anatosaurs sp.*  
Unidentified reptile bones

These fossils indicate a terrestrial environment. Although the sandstones appear to have been deposited in a large river no aquatic animals were found. The dinosaurs and plants would indicate that these beds are of latest Cretaceous age.

The Bacon Creek Member of the Hell Creek Formation

It is here proposed to call the central part of the Hell Creek Formation in the Little Missouri Valley, North Dakota, the Bacon Creek
Member of the Hell Creek Formation. The member is characterized by vari-colored bentonites, bentonitic shales, and lignitic ash beds. The name is taken from Bacon Creek, Slope County, North Dakota where the shales are well exposed; however, the type section is located a short distance to the west, in SE 1/4 sec. 23, T. 133 N., R. 106 W., the only locality where the section may be measured in a single exposure. The following measured section is the type section of the Bacon Creek Member.

HELl CREEK FORMATION (BUFF MEMBER)  

<table>
<thead>
<tr>
<th></th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.</td>
<td>Sandstone with calcareous sandstone lenses</td>
</tr>
</tbody>
</table>

HELl CREEK FORMATION (BACon CREEK MEMBER)  

<table>
<thead>
<tr>
<th></th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.</td>
<td>Moderate-greenish-brown to gray bentonite</td>
</tr>
<tr>
<td>24.</td>
<td>Light-gray sandstone</td>
</tr>
<tr>
<td>23.</td>
<td>Dark- to medium-gray bentonite</td>
</tr>
<tr>
<td>22.</td>
<td>Light-gray sand with bentonitic shale partings and calcareous sandstone lenses</td>
</tr>
<tr>
<td>21.</td>
<td>Tannish-gray bentonite</td>
</tr>
<tr>
<td>20.</td>
<td>Dark-purplish-brown, lignitic shale</td>
</tr>
<tr>
<td>19.</td>
<td>Medium-gray bentonite</td>
</tr>
<tr>
<td>18.</td>
<td>Light-gray sandstone</td>
</tr>
<tr>
<td>17.</td>
<td>Medium-gray bentonite</td>
</tr>
<tr>
<td>16.</td>
<td>Light-gray sandstone</td>
</tr>
<tr>
<td>15.</td>
<td>Dark-purplish-brown, lignitic shale</td>
</tr>
<tr>
<td>14.</td>
<td>Medium-gray bentonite</td>
</tr>
<tr>
<td>13.</td>
<td>Medium- to light-gray sandstone</td>
</tr>
<tr>
<td>12.</td>
<td>Medium-gray to brown bentonite with white to rusty calcareous concretions</td>
</tr>
<tr>
<td>11.</td>
<td>Moderate-brown, lignitic, bentonitic sandstone</td>
</tr>
</tbody>
</table>
10. Dark-purplish-brown, sandy, lignitic shale ...... 1.0
9. Interbedded medium-gray sand and bentonite with siderite nodules near the base weathering to limonite ................. 10.3
8. Moderate-purplish-brown, lignitic shale ............ 1.0
7. Medium-gray bentonite ......................... 4.0
6. Yellowish-gray sands with calcareous sandstone lenses .... 7.0
5. Medium-gray bentonite ......................... 1.0
4. Yellowish-gray sandstone ........ ............... 4.0
3. Yellowish-gray sandstone with siderite nodules weathering to limonite near the base .... 5.0
2. Medium- to dark-gray bentonite .................. 11.0

Total thickness of Bacon Creek Member ........ 117.0

HELL CREEK FORMATION (MARMARTH MEMBER)

1. Light-gray sandstone ......................... 1.0

Covered

(For a complete measured section of the beds at this locality see Appendix A, Part I).

The base of the Bacon Creek Member is taken at the top of a thick sandstone body which is the upper unit in the Marmarth Member of the Hell Creek Formation. The top of the Bacon Creek Member is marked by a very persistent bentonite which is generally found at the base of a thick sandstone body at the base of the Huff Member of the Hell Creek Formation. Thus, in general terms, the Bacon Creek Member is a shaly unit between two sandstone units, the Huff and Marmarth Members (Fig. 9).

The contact between the Huff and Bacon Creek Members should be a time horizon since it is the top of a bentonite. The contact between the
Bacon Creek and Marmarth Members is gradational and the two members show an interfingering relationship.

The Bacon Creek Member has been mapped only in the Little Missouri Valley around Marmarth and south into Bowman County. It appears from preliminary studies that it may also be present in the Yellowstone Valley near Glendive, Montana, as the basal member at this locality. In the subsurface, the member theoretically could be traced eastward until the Breien Member was encountered and then the Norton, Breien, and Crowghost Members would be mapped (Plate 4, folder). The member may be seen well developed at the following localities: SW 1/4 sec. 35, T. 134 N., R. 106 W., Slope County, North Dakota; sec. 25, T. 134 N., R. 106 W., Slope County, North Dakota; along Bacon Creek, T. 133 N., R. 105 W., Slope County, North Dakota; and sec. 1, T. 13 N., R. 55 E., Makoshika State Park, Glendive, Dawson County, Montana.

The lithology of the Bacon Creek Member is characterized by bentonitic shale, bentonites, thin lignitic shales, and occasional sandstone channels. The member is basically a shale unit between the sandstone units of the Huff and Marmarth Members. The lignitic shales are seldom more than one foot thick and are usually a very fissile shale with a dark-purplish-brown to black color. The sandstones, where they occur, are generally thick and make the member appear very similar to the Huff and Marmarth Members.

Although the member is often exposed in badlands one can seldom measure a complete section at one locality. It forms rugged, steep sloped badlands with relatively few cliffs and many small benches which are supported by both bentonitic shales and bentonites. Where sandstones do occur they form cliffs usually capped by a bentonite.
only one vertebrate was collected: Triceratops sp. Invertebrates are very rare. Plants were not collected during this study, but many plant fragments are found in the shales and a large flora could possibly be found with some effort. From the fossil remains and the nature of the sediments it is concluded that these beds are non-marine. The one fossil collected, Triceratops sp., indicates that these beds are latest Cretaceous in age.

**New Members in the Missouri Valley**

**The Crowghost Member of the Hell Creek Formation**

It is here proposed to name the lowest set of beds in the Hell Creek Formation in the Missouri Valley that lie stratigraphically below the Basian Member of the Hell Creek Formation, the Crowghost Member. The name is taken from Crowghost Cemetery which is located on the Standing Rock Indian Reservation, center sec. 33, T. 134 N., R. 61 W., Sioux County, North Dakota. The type section is located at the above location which is also the location of the type section of the Basian Member of the Hell Creek Formation. The following measured section is the type section.

**Hell Creek Formation (Basian Member)**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.</td>
<td>Grayish-green, glauconitic sandstone weathering to a rusty brown, containing <em>Ophiomorpha major</em> and the internal molds of <em>Halacina wyomingensis</em></td>
</tr>
</tbody>
</table>

**Hell Creek Formation (Crowghost Member)**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.</td>
<td>Brown, lignitic shale</td>
</tr>
<tr>
<td>9.</td>
<td>Fine, gray sandstones with bentonitic shale partings</td>
</tr>
</tbody>
</table>
8. Dark-brown, lignitic shale and shaly lignite
   with siderite nodules weathering to limonite
   near the top ........................................ 2.0
7. Bentonitic, gray shale ............................ 4.0
6. Dark-brown, lignitic shale, and shaly lignite . 1.0
5. Gray, bentonitic shale ............................ 3.0
4. Black, lignitic shale and shaly lignite with
   sandy siderite concretions weathering to limonite
   and containing plant fossils ........................ 1.5
3. Medium-gray bentonite and bentonitic shale .... 5.0
2. Lignitic shale and sandstone with silicified
   tree stumps standing in position upon it with
   their roots extending through this bed and
   into the Fox Hills Formation below ................ 2.5

Total thickness of Crousehoft Member ................ 21.5

FOX HILLS FORMATION (COLGATE MEMBER)

1. Gray sandstones with a fluted weathering surface . 29.5

Covered

(For a complete measured section of the beds at this locality
see Appendix A, Part I).

The base of the Crousehoft Member is the contact between the Hell
Creek and Fox Hills Formations. The Crousehoft Member rests upon both
the Colgate and Bull Head Members of the Fox Hills Formation and has
been observed to interfinger with the Bull Head Member of the Fox Hills
Formation in the SW 1/4 sec. 21, T. 134 N., R. 80 W., Morton County,
North Dakota. The Crousehoft Member of the Hell Creek Formation thins
eastward loosing beds from the bottom to change from a thickness of
31 feet at its type section in Sioux County to 6 feet in central Emmans
County. The rapid thinning of the Crousehoft Member would suggest that
the overlying marine Breien Member represents a readvance of the "Fox
Hills Sea." Presumably, farther east, under the glacial sediments, the Crowghost Member thins out and the Breien Member of the Hall Creek Formation merges with sediments of the Fox Hills Formation (Plates 3 and 4, folder). The top of the Crowghost Member usually consists of lignitic shales which are overlain by glauconitic sands of the Breien Member. The Crowghost and Breien Members have not been observed to interfinger but it is probable that they do.

The Crowghost Member of the Hall Creek Formation is found in eastern Morton and Sioux Counties and in western Edmunds County. It is probably present in the subsurface in adjacent areas of eastern Grant County, central Morton and Sioux Counties, and southern Burleigh County, North Dakota, as well as in adjacent parts of South Dakota. The member may be found well developed at the following localities: NE 1/4 sec. 21, T. 134 N., R. 80 W., Morton County, North Dakota; NE 1/4 sec. 1, T. 133 N., R. 82 W., Sioux County, North Dakota; NW 1/4 NW 1/4 sec. 18, T. 131 N., R. 76 W., Edmunds County, North Dakota; and SW 1/4 sec. 27, T. 135 N., R. 78 W., Edmunds County, North Dakota.

The lithology of the Crowghost Member of the Hall Creek Formation is very similar to the Fort Rice Member of the Hall Creek Formation. It is composed of lignitic, bentonitic sediments, mostly shales, though a few sandstones are present. Siderite nodules which weather to limonite are common. The basal lignitic sandstone at the type section of the Crowghost Member is typical of the base of the member and has tree stumps upon it (Fig. 7). The only other occurrence of similar lithologies in the Hall Creek Formation is in the base of the Little Beaver Creek Member in the Little Missouri Valley, North Dakota. The sandstone is very lignitic, moderate-brown in color, and is better indurated.
Figure 7. Basal bed of the Craggosh Member of the Hell Creek Formation showing tree stump in position in sec. 17, T. 134 N., R. 61 W., Morton County, North Dakota. Note that the roots start in the Hell Creek Formation but penetrate the Colgate Member of the Fox Hills Formation.
than the surrounding sediments so that it usually projects as a shelf in a vertical exposure.

The member is generally poorly exposed except for the basal lignitic sandstone which often caps benches of badlands developed on the Colgate Member of the Fox Hills Formation. The lignitic shales and bentonites form benches above steep sloped sands in the badland areas.

Relatively few fossils were collected from the Crowghost Member of the Hell Creek Formation. This scarcity reflects both the amount of time spent looking for fossils in this member and the relative rarity of fossils. It is probable, however, that a large floras could be found in this unit if it were properly collected. The fossil list given below contains some fossils found in the base of the Hell Creek Formation in central South Dakota (p. 344-345). These basal beds are not known to be a part of the Crowghost Member but occupy a similar stratigraphic position in central South Dakota. The fossils were collected and identified by the writer.

PLANTS

Cinkgo laratianus Ward
Sequoia dakteae Brown
Arcecarites longifolia (Lesquereux) Brown
Dryophyllium subtaleatum Lesquereux
Virta stamtoni (Knowlton) Brown
Wood (several species)

INVERTEBRATES

Cf. Oatesia siabria Meek and Hayden
?Corbicula cytheriformis (Meek and Hayden)
VERTEBRATES

*Lungchidion selachus Leidy
*Eledaphus bipartitus Cope
*Lepisosteus occidentalis (Leidy)
*Fish vertebra
*Turtle fragments
*Leidyosuchus sternbergi Gilmore
*Brachychoerus montana Gilmore
*Cf. Dryptosaurus sp.
*Cf. Anatotaurus sp.
*Triceratops sp.
*Unidentified reptile bones

(*South Dakota fossils)

All of the vertebrates except Anatotaurus sp. and Leidyosuchus sternbergi were found only in South Dakota.

The list of fossils indicates that the member is a mixture of marine, brackish-water, fresh-water, and land-deposits. This is expected since the Hell Creek Formation, mostly fresh-water and land sediments, interfingers with the Fox Hills Formation which is mostly marine sediments. The fossils indicate a late Cretaceous age for these beds.

The Sreien Member of the Hell Creek Formation

The Sreien Member of the Hell Creek Formation was named by Laird and Mitchell (1942, p. 14, 15) for marine beds found near the base of the Hell Creek Formation in Morton and Sioux Counties, North Dakota. Seager, et al., (1942, p. 1414) mentioned these beds prior to Laird and Mitchell (1942) but did not name them. The name Sreien was taken from the town of that name, T. 134 N., R. 82 W., Morton County, North Dakota.

In their publication, Laird and Mitchell designated no type section, but listed several localities where the member could be found. It was, however, the authors' intentions that the exposures at Crouthoost Cemetery,
center sec. 33, T. 134 N., R. 32 W., serve as the type section (personal communication with Dr. Laird, and Mr. Mitchell). The measured section at the type exposure of the Breien Member of the Bell Creek Formation, given below, is similar to that given by Laird and Mitchell (1942, p. 28). The differences are probably the result of measuring the section at a slightly different location, since the member shows considerable lateral variation.

**HELL CREEK FORMATION (FORT RICE MEMBER)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>3.</td>
<td>Gray sandstone with siderite nodules which contain abundant molassean fossils and weather to limonite near the base</td>
</tr>
<tr>
<td>7.</td>
<td>Lignitic shale and shaly lignite containing dinosaur bones</td>
</tr>
</tbody>
</table>

**HELL CREEK FORMATION (BREIEN MEMBER)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>6.</td>
<td>Sanded, clay-rich, gray, medium-grained sandstone grading downward into soft, greenish-brown weathering, medium-grained, glauconitic sandstone containing <em>Ophiomorpha major</em></td>
</tr>
<tr>
<td>5.</td>
<td>A moderate-grayish-brown sandstone overlain by a concretionary siderite bed weathering to limonite</td>
</tr>
<tr>
<td>4.</td>
<td>Medium-gray bentonite</td>
</tr>
<tr>
<td>3.</td>
<td>Grayish-green, glauconitic sandstone weathering rusty-brown containing <em>Ophiomorpha major</em> and molds of &quot;Melanina&quot; Wyomingensis</td>
</tr>
</tbody>
</table>

Total thickness of Breien Member | 19.0

**HELL CREEK FORMATION (CROWCOST MEMBER)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>Brown, lignitic shale</td>
</tr>
<tr>
<td>1.</td>
<td>Fine, gray sandstones with bentonitic shale partings</td>
</tr>
</tbody>
</table>

(For a complete measured section of the beds at this locality see Appendix A, Part I)
In almost all cases, the base of the Breien Member is a glauconitic sand containing Ophiomorpha major. This bed is usually underlain by a lignitic shale and shaly lignite which is the upper bed of the Crowghost Member of the Hall Creek Formation. The contact between the Breien Member and the Crowghost Member is sharp. The top of the Breien Member of the Hall Creek Formation is often composed of sandy and silty clays which are banded and resemble the Bull Head Member of the Fox Hills Formation. These beds are almost always overlain by a lignitic shale, the basal bed of the Fort Rice Member of the Hall Creek Formation. The Breien Member has not been observed to interfinger with the Fort Rice Member.

The Breien Member is found in southeastern Morton County, eastern Sioux County, and western Emmons County, North Dakota. It is probably present in the subsurface in southern Burleigh County, central and western Morton County, eastern Grant County, central Sioux County, and in South Dakota near the Sioux County, North Dakota line. It may be found typically exposed at the following localities: Sec. 22, T. 131 N., R. 81 W., Sioux County, North Dakota; NE 1/4 sec. 1, T. 133 N., R. 82 W., Sioux County, North Dakota; SE 1/4 sec. 21, T. 134 N., R. 80 W., Morton County, North Dakota; SE 1/4 sec. 20, T. 133 N., R. 82 W., Morton County, North Dakota. For locations in Emmons County see Appendix A.

The lithology of the Breien Member is variable but is characterized by glauconitic sands containing Ophiomorpha major which weather a rusty brown and by the lack of lignitic sediments. A persistent bentonite is often found near the middle of the member but otherwise the member is non-bentonitic. The weathered surface is often soft,
weathering to a loose dusty surface which protects and often obscures the beds beneath.

The Breien Member is often covered by thick vegetation and then forms a rolling surface with relatively few gullies. Where the member is exposed it forms rounded badlands with a soft weathered surface. The member often displays a bench near its middle which is held up by a bentonite. Even where exposed in badlands, it often supports more vegetation than the adjacent strata, mostly annuals, but also sage brush.

The paleontology of the Breien Member is complex, for the unit contains marine, brackish-water, fresh-water, and land fossils, but is dominated by marine and brackish-water species. The flora and fauna as reported by Sæger et al. (1942, p. 1418) and Leird and Mitchell (1942, p. 15) is as follows:

- Halyxenites
- Ostrea glabra
- Dominosia (?) sp.
- Lingula sp.
- Unidentified microfossils

The writer (1984, p. 170) added the following species:

- Acanthosachmites sp.
- State teeth
- Shark teeth
- Worm tubes (possibly phoronids)

Acanthosachmites sp. listed above is now placed in the genus Discosachmites. Since the list was published many additional fossils have been identified from this member and the following list should give a much better idea of the fossil content of the member than the previously compiled lists. The following fossils have been found and identified by the writer in Breien Member of the Sail Creek Formation. The unnatural
Hennicoesaurus robustus (Marsh) was identified by W. A. Clemens (letter of April 20, 1965 to Dr. F. B. Holland, Jr.).

PLANTS

Sequoia dakotensis Brown
Carpolithia sp.
?Stems
Concretions around roots
Amber

INVERTEBRATES

Bryosoa (unidentified)
?Tancredia americana (Meek and Hayden)
Ostrea glabra Meek and Hayden
Ostrea sp., cf. O. glabra Meek and Hayden
Ostrea sp., cf. O. haydeni white
?Anemia micrantha Meek
?Valesella (Brachydontea) multiformis Meek
Scapharium sp., cf. S. hekathense Warren
Corbicula cytheriformis (Meek and Hayden)
Corbicula sp., cf. C. cytheriformis (Meek and Hayden)
?Corbicula cytheriformis (Meek and Hayden)
Corbula pyriformis Meek
Corbula subtrigonalis Meek and Hayden
Cf. Trigonocellata nebrascensis (Meek and Hayden)
?Tellina scitula Meek and Hayden
Unidentified clams
"Melania" wyomingensis (Meek)
Cf. "Melania" wyomingensis (Meek)
Lioplacodes tenacirinata (Meek and Hayden)
Unidentified gastropods
?Diecospiratites comrati (Kortor)
Cf. Phreinopsis sp.
?Worm tubes
Ophiomorpha major Lesquereux
Cf. Ophiomorpha major Lesquereux
Burrows
Unidentified regular objects (?concretions)

VERTEBRATES

Cf. Lampas cuspisata Agassiz
Cf. Orodus obliquus Agassiz
Myliodaphne binartitus Cope
Fish vertebra
Turtle fragments
Chasmosaurus sp., cf. C. natalor Parks
Cf. Chasmosaurus sp.
Leidyosuchus sternbergi Gilmore
Brachychampsa montana Gilmore
Cf. Cryptosaurus sp.
Cf. Tyrannosauru, rex Osborn
Cf. Triceratops sp.
Unidentified reptile bones
Coprolites
Numerousus robustus (Marsh)

If the above is compared to earlier fossil lists from this member two discrepancies appear. The earlier lists contain Lingula sp. and Dosinopsis (?) sp., which were not found by the writer. Since preservation of most bivalves is so poor (replaced by limonite) one might easily confuse fragments of Lingula with those of frequently encountered Ostrea glabra. Dosinopsis (?) sp. appears to be a misidentification of the internal molds of Corbicula cytheriformis. The writer collected both internal and external molds of this pelecypod in the same sample which made proper identification possible.

Many of the fossils found in the Breyen Member of the Heli Creek Formation are found in either marine or brackish-water. The two most commonly found fossils are Ophiomorpha major and Ostrea glabra. These fossils were found at nearly every location and would lead one to believe that probably all of the terrestrial and most of the fresh-water fossils were washed into a marine or brackish-water environment. The relatively good preservation of the fresh-water and terrestrial fossils would indicate that these fossils had not been transported very far and would suggest that the Breyen Member originated in an estuarine or lagoonal environment.

The age of the Breyen Member is latest Cretaceous as based upon the presence of Saccaria dakotensis, Corbicula cytheriformis, Corbula pumiformis, Corbula subtriangularis, "Malania" wyomingensis, ?Discococconites

The Fort Rice Member of the Hell Creek Formation

It is here proposed to call the beds composed essentially of shales, lying stratigraphically above the Breslin Member of the Hell Creek Formation and below the Huff Member of the Hell Creek Formation the Fort Rice Member of the Hell Creek Formation. The name is taken from the old Army Fort and town of that name located on the west side of the Missouri River, some 25 miles south of Bismarck, North Dakota, in Morton County. The member can be found well exposed just west of the town; however, the type section is taken a few miles to the north, about 1 mile north of the town of Huff, where it can be measured in its entirety in a single set of outcrops. The type section is located on both sides of the road in the N 1/2 sec. 1, T. 136 N., R. 30 W. The measured section of the member at the type locality is as follows:

HELL CREEK FORMATION (HUFF MEMBER)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.</td>
<td>Gray to brown sandstone with bentonitic shale partings near the top, lignitic sand lenses, and occasional light-gray calcareous sandstone lenses throughout</td>
<td>42.0</td>
</tr>
<tr>
<td>20.</td>
<td>Dark-brown, lignitic sandstone</td>
<td>1.0</td>
</tr>
</tbody>
</table>

HELL CREEK FORMATION (FORT RICE MEMBER)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.</td>
<td>Dark-gray bentonite and bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>18.</td>
<td>Dark-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>17.</td>
<td>Brown, bentonitic shale</td>
<td>4.5</td>
</tr>
<tr>
<td>16.</td>
<td>Brown sandstone</td>
<td>1.0</td>
</tr>
</tbody>
</table>
15. Dark-brown, lignitic shale .................. 0.5
14. Brown, gray weathering, bentonitic shale ........ 3.5
13. Brown sandstone .......................... 1.0
12. Gray sandstone with shale partings and lignitic sandstone lenses .............. 10.5
11. Medium-gray bentonite ...................... 3.5
10. Gray sandstone with siderite nodules weathering to limonite ................. 1.5
  9. Dark brown, lignitic shale and shaly lignite ........................ 1.0
  8. Gray sandstone ............................ 3.5
  7. Fine, gray sandstone with marcasite concretions and siderite nodules weathering to limonite near the top .................. 6.5
  6. Sandy, sideritic nodules weathering to limonite and containing plant fragments and snails .......................... 1.0
  5. Brown to gray bentonitic sandstone, silts, and clays ...................... 13.5
  4. Dark-brown, lignitic shale and lignite with siderite nodules near the top .... 1.5

Total thickness of the Fort Rice Member ................ 62.0

HELL CREEK FORMATION (BRAHLEN MEMBER)

  3. Brown to buff banded silts and clays ............ 10.0
  2. Dark-gray, bentonitic clay and bentonite ........ 3.0
  1. Dark-greenish-brown, brown weathering glauconitic sandstone with 2 inches thick siderite bed with Ostrea glabra weathering to limonite at the top .................. 4.5

Total thickness of the Brahlen Member ................ 19.5

(For a complete measured section of the beds at this locality see Appendix A, Part I)
The base of the member is the top of the Breien Member and is generally marked by lignitic shales, silts, or sandstones. The Breien Member is quickly recognized by its marine fauna, glauconitic sediments, and its lack of lignitic sediments. In no case were the two members seen to interfinger or could it be demonstrated conclusively by other means that the contact is time-transgressive. The top of the Fort Rice Member of the Hell Creek Formation is placed at the base of a prominent sandstone which generally occurs 40 to 60 feet above the Breien Member or about 80 feet below the top of the formation. The contact is characterized by extreme interfingering and cannot be considered a time horizon even locally.

The member as defined exists only where it is underlain by the Breien Member. This limits the geographic area where the member can be mapped to the Missouri Valley and its tributaries. The member has been recognized in Esmons, Morton, Sioux, and Grant Counties. In Grant County the Breien Member has not been found exposed, but it is probably present in the subsurface since it is found west to the Morton-Grant County line. The Fort Rice Member is generally only partially exposed. Numerous outcrops of the member can be found from just north of the town of Huff on the west bank of the Missouri River southward to the town of Fort Rice and then westward up the Cannonball River to the town of Breien. Here it is exposed the bases of the bluffs along the two rivers. Typical, well exposed sections may be found at the following localities: center sec. 33, T. 134 N., R. 81 W., Crowghost Cemetery, Sioux County, North Dakota; center sec. 34, T. 136 N., R. 81 W., Sioux County, North Dakota; sec. 16 T. 131 N., R. 82 W., Sioux County, North
Dakota; and NE 1/4 SE 1/4 sec. 20, T. 133 N., R. 52 W., Morton County, North Dakota.

The lithology of the Fort Rice Member of the Bell Creek Formation is variable, but is characterized by lignitic and bentonitic shales, thin sandstones, and siderite nodules which weather to limonite. The siderite nodules are concentrated in zones which appear to be locally persistent. Very dark colored lignitic shales and lignites are common and are locally persistent. They are easily traced by sight through badlands such as those south of the town of Brecken, Morton County, North Dakota.

The member is most often exposed in badlands near the base of cliffs or below steep-sloped badlands developed in the Ruff Member. The member usually weathers into small knobs, or a series of benches and less steep slopes at the base of a steep set of cliffs. The base of the member is often covered leaving the member only partially exposed. Where the member is vegetated, the topography is generally rolling but cut by gullies.

The paleontology of the Fort Rice Member is complex, containing plants, invertebrates, and vertebrates. No attempt was made to collect the flora and fauna completely; however, the writer believes he has collected most of the mollusks. The list of fossils below is those collected and identified by the writer except *Pachyccephalosaurus* sp. (letter to Dr. W. H. Laird from Nicholas Nottow, Ill., June 21, 1962).

**PLANTS**

*Silicopinna gibbosa* (Newberry) Hollick
*Cinkro larvianensis* Ward
*Taxodium ciliatum* (Heer) Chaney
*Metasequoia occidentalis* (Newberry) Chaney
Sequoia dakotensis Brown
Araucaria imbricata (Lesquereux) Dorf
Dryosobum subfalcatum Lesquereux
?Carex sp.
Ceratophyllum sp., cf. C. arctenum (Heer) Brown
?Ceratophyllum sp.
Trochodendroides sp.
Fremus sp., cf. F. corrugia Brown
Vitis stantonii (Knowlton) Brown
Dombeyopsis nebrascensis (Newberry) Bell
Carpolithus sp., cf. C. (Ceradinecarpus?) serratus (Knowlton)
Carpolithus kansasillensis Bell
Carpolithus sp. A
Carpolithus sp. B
?Carpolithus sp. C
?Seed pod or bark
?Unidentified seeds
?Concretion around roots
Leaf fragments
Wood
Amber

INVERTEBRATES

Cf. Denticulatum sp., ? D. (Laevidentalium) pauperulum
Maek and Nayden
Unio sp., cf. U. sandersoni Warren
Unio sp., cf. U. stantonii White
?Family Unionidae
Pleistioniptia sp. (?Undescribed)
?Pleistioniptia sp.
?Amosonta macomelli Russell
?Hurria halidiiformis Russell
Sphaerium sp., cf. S. hessethense Warren
Sphaerium sp. (?Undescribed)
Sphaerium sp., cf. S. sequeula Russell
Sphaerium sp., cf. S. fowleri Russell
Sphaerium sp., cf. S. gressel Tozer
?Corbicula sp.
?Ostraea glabra Maek and Nayden
Viviparous prudentius prudentius White
Viviparous sp., cf. V. pruidentius prudentius White
Viviparous sp., cf. V. orudentius villevensis Tozer
Viviparous sp., cf. V. planolatere Russell
Viviparous sp., cf. V. lesi (Maek and Nayden)
Viviparous sp., cf. V. tasauma Dyer
Viviparous sp., cf. V. zokowemania Tozer
Viviparous trochiferms (Maek and Nayden)
Viviparous sp. (?Undescribed)
Viviparous sp., cf. V. ramosii Tozer
Viviparous sp., cf. V. reiterans (Maek and Nayden)
Viviparous sp. A
?Viviparous sp. B
Campeloma admontanensia Tozer
Campelona sp. cf. C. admontanensia Tozer
Campelona nebrascensis nebrascensis (Meek and Hayden)
?Campelona sp.
Lioplacodes limaeformis (Meek and Hayden)
Lioplacodes sp. cf. L. limaeformis (Meek and Hayden)
Lioplacodes termicarinata (Meek and Hayden)
Lioplacodes sp. cf. L. stachei (White)
Lioplacodes sp.
Remedilla sp. cf. R. protea (Yen)
?Remedilla sp.
Physa bullatula White
Physa sp. cf. P. bullatula White
Physa sp. cf. P. lanabensis White
Physa sp. cf. P. canadensis White
Physa montanensis Yen
Unidentified snails
?Worm tubes
?Diacosachites sp.

VERTEBRATES

Cf. Megalops sp.
Fish vertebra
Turtle fragments
Champsosaurus sp. cf. C. natator Parks
Cf. Champsosaurus sp.
Leidyosaurus sternbergi Gilmore
Cf. Krystosaurus sp.
Pachycephalosaurus sp.
Cf. Triceratops sp.
?Pterosauria sp.
Unidentified reptile bones
Coprolites
?Coprolites

The fauna in the above fossil list indicates that the Fort Rice Member was a mixture of brackish-water, marine-water, fresh-water, and land fossils. The genera Pentium and Diacosachites are generally considered to be marine fossils. Datrea and Corbicula are usually brackish-water or marine but Corbicula may also be found in fresh-water. The remainder of the fossils are either fresh-water or terrestrial in origin. The marine or brackish-water conditions probably existed as
estuaries, since there is extreme mixing of marine, brackish-water and fresh-water species.

Such fossils as *Miocestus* sp., *Stenara* sp. cf. *O. glabra*, cf. *Dryptosaurus* sp., *Pachycephalosaurus* sp., cf. *Triceratops* sp., *Ginkgo lamproptera*, and *Sequoia dawotensis* all would indicate a late Cretaceous age for these beds.

**New Members of the Hell Creek Formation Common to both the Missouri and Little Missouri Valleys**

**The Huff Member of the Hell Creek Formation**

It is proposed here to call the beds containing thick channel sandstones which lie directly below the Pretty Butte Member and above the Fort Rice Member of the Hell Creek Formation the Huff Member of the Hell Creek Formation. The name is taken from the town of Huff, Morton County, North Dakota, located about 20 miles south of Mandan, Morton County, North Dakota, on the west bank of the Missouri River. The type section lies about 1 mile southwest of the town of Huff, SW 1/4 sec. 8, T. 136 N., R. 79 W., Morton County, North Dakota. The type section lies on the east side of the road on the steep slopes of a small area of badlands. The following description is that portion of the measured section found at this locality which contains the Huff Member.

**HELL CREEK FORMATION (PRETTY BUTTE MEMBER)***

```
6. Brown to gray, lignitic, bentonitic shales; sideritic nodules weathering to limonite; shales becoming very bentonitic near the base ........................................... 30.0

HELL CREEK FORMATION (HUFF MEMBER)**

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```
7. Light-yellowish-gray sandstone with occasional bentonitic shale partings ................ 38.5
```
6. Penecontemporaneous, sharpstone conglomerate composed of a sand matrix with pebbles of clay rich silt which are probably washed up and cracks

7. Light-yellowish-gray sandstone with sideritic nodules weathering to limonite and manganous oxides

4. Medium-gray bentonitic shale and silt with small gypsum crystals

3. Light-gray sandstone with well developed fluted weathering surface containing bentonitic shale partings and white calcareous sandstone lenses

Total thickness of Huff Member

HELL CREEK FORMATION (FORT RICH MEMBER)

2. Medium-gray shale with some silt and fine sand stringers

1. Moderate-brown, shaly lignite and lignitic shale

(For a complete measured section of the beds exposed at this locality see Appendix A, Part I.)

The base of the member in the southwestern part of North Dakota is picked at the top of a persistent bentonite (Plate 5, folder) which generally coincides with the base of a thick sandstone lying above a shale, bentonitic shale and bentonite sequence. In central North Dakota the base of the member is picked at the base of a thick sandstone lying above a shale, bentonitic shale, and lignitic shale sequence. The bentonite upon which the base of the Huff Member rests in the southwest part of North Dakota is probably the same bentonite(s) which are found in and just at the top of the breccia Member of the Hell Creek Formation in central North Dakota. If this is true, then the base of the member becomes younger in an easterly direction. In the southwest part of the state the lower contact is sharp and non-interfingering by

10.3

10.0

3.0

23.0

35.0
definition (top of a bentonite) but in central North Dakota the Huff Member intertongues extensively with the member below (Plate 4, folder). The top of the member shows a gradational contact with the Pretty Butte Member and intertongues with it extensively. The top of the member is picked at the top of the first thick sandstone below the top of the Hell Creek Formation. This is generally about 30 feet below the top of the formation.

This member has been recognized over all of the outcrop area of the Hell Creek Formation in North Dakota, and from preliminary studies, it appears to be equally extensive in eastern Montana. The member may be found well developed at the following locations: SW 1/4 sec. 27, T. 135 N., R. 78 W., Ramsey County, North Dakota; center sec. 29, T. 130 N., R. 83 W., Sioux County, North Dakota; sec. 28, T. 132 N., R. 82 W., Sioux County, North Dakota; bluffs on the north side of the Cannonball River between the towns of Selden and Breien, North Dakota; sec. 7, T. 132 N., R. 105 W., Bowman County, North Dakota; sec. 25, T. 134 N., R. 106 W., Slope County, North Dakota; and sec. 1, T. 15 N., R. 55 W., Makoshika State Park, Glendive, Dawson County, Montana.

The lithology of the member is variable but is characterized by the presence of thick sandstone bodies believed to be channels of large rivers. The sandstone bodies are separated both vertically and laterally by bentonites, and bentonitic shales. Lignite shales are generally absent in the southwestern part of North Dakota but may be found between the sandstone channels in central North Dakota (Fig. 13b).

The member is generally exposed as badland topography along hill sides, in bluffs along rivers, such as the Missouri River near the town of Huff, the Cannonball River between Selden and Breien, the Little
Missouri Valley in Slope and Bowman Counties, North Dakota, and the Yellowstone River Valley southeast of Glendive, Montana. The sandstones, especially where thick, make vertical to nearly vertical cliffs which are often capped by a bentonite in the base of the overlying Pretty Butte Member of the Hell Creek Formation.

The paleontology of the member is very complex and varies considerably from east to west, both in the nature of the fossils and their preservation. In central North Dakota, the member contains mollusk shells replaced by limonite and fragments of bones of reptiles and fish. In western North Dakota the member contains an extensive vertebrate fauna in addition to the mollusk shells. In eastern Montana, the member contains many vertebrates (not collected by the writer) and mollusks with the original shell material still intact. Below is a list of fossils collected and identified from the member by the writer, except for the mammals which were identified by W. A. Clemens (letter of April 20, 1965, to Dr. P. E. Holland, Jr.).

PLANTS

_Equisetum_ sp., cf. _E. parviflorum_ Cockerell
_Potamogeton_ sp., cf. _P. fructus_ Berry
_Sequoia dakotensis_ Brown
_Dryophyllum_ sp., cf. _D. subfalcatus_ Lasqueux
_Monocotyledonous leaves_
_Pterocarya_ sp., cf. _P. hispida_ Brown
_Corylus_ sp., cf. _C. insignis_ Heer
_Ceratophyllum_ sp., cf. _C. arcticum_ (Heer) Brown
_Anone_ sp., cf. _A. roboiti_ Berry
_Vitis stantoni_ (Knowlton) Brown
_Viburnum_ sp., cf. _V. tilioides_ Ward
_?Actinidia_ sp.,
_Carpolithus_ sp., cf. _C. (Cycadimorpus) carpellus_ (Knowlton)
_Carpolithus_ sp., cf. _C. (Cinknolus ?) fultonii_ Ball
_Carpolithus knaehillensis_ Ball
_Carpolithus_ sp. A
_Carpolithus_ sp. B
_?Carpolithus_ sp. C
Twig impressions
Imprint of bark or seeds
Root
Stem or root
Concretions around roots (fossil?)
Seed or fruit
Siebs which may be seeds
Seed pod
Amber

INVERTEBRATES

Unio stantoni White
Unio sp., cf. U. amarillensis Stanton
Unio pyramidatoides Whitfield
Unio holmesianus White
Unio sp., cf. U. holmesianus White
Plesielliptio sp., cf. P. brachyonisthys (White)
Plesielliptio (Undescribed species)
Plesielliptio sp., cf. P. primaus (Meek and Hayden)
Plesielliptio sp., cf. P. subapaculatus (Meek and Hayden)
Plesielliptio sp. A
Plesielliptio sp. B
Pselagon sp. (?Undescribed species)
Family Unionidae
Sphaerium sp., cf. S. heukeshienne Warren
Sphaerium sp., cf. S. fowleri Russell
Sphaerium sp., cf. S. sequale Russell
Sphaerium sp.
?Corbula sp.

Unidentified pelecypods
Viviparust prudentius prudentius White
Viviparust sp., cf. V. prudentius prudentius White
Viviparust sp., cf. V. prudentius willovenesis Tozer
Viviparust sp., cf. V. planolateres Russell
Viviparust sp., cf. V. molochynensis Tozer
Viviparust sp., cf. V. vaxtoni Tozer
Viviparust sp., cf. V. trochiformis (Meek and Hayden)
Viviparust sp., cf. V. tangina Dyer
Viviparust sp. (?Undescribed species)
Viviparust sp. A
Viviparust sp. B
Viviparust sp. C
Campeloma sp., cf. C. nebrascensis nebrascensis (Meek and Hayden)
Campeloma sp., cf. C. harlowtopensis (Stanton)
Campeloma amarillensis Stanton
Campeloma sp. A
Campeloma sp. B
Campeloma sp. C
Lionellodes sp., cf. L. limaciformis (Meek and Hayden)
Lionellodes tenuicarinata (Meek and Hayden)
Lionellodes mariana Yan
Lionellodes ataeai (White)
Lipolacodies sp.
Cnidobasis virginica (Coelis)
?Pleurotisinae sp.
Physo sp., cf. P. pleurotica White
Glyptodon retundata (Russell)
Gyrinella nigmaticens (White)
Unidentified gastropods
Cf. Ophiomorpha major Lasqueaux
Beetle remains (fossil?)
?Tail of crawfish-like animal
?Serpulid worm tubes
?Worm borings in bone

VERTEBRATES

Cf. Lomia sp.
Lonchidion gelaches Estes
Squatirhina americana Estes
Cf. Iahythrissa avonicola Estes
Mylemphora bipartitus Cope
Cf. Kindeliia fragosa Jordan
Cf. Protopsis sp.
Selonosaurus longirostris (Lambe)
Leptosaurus occidentalis (Leidy)
Cf. Paraechthys fibrillatus (Coekrall)
?Platycodon pumus Marsh
Unidentified genus and species of Elopidae
Unidentified genus and species of Albulidae
Unidentified fish bones
?Family Pelobatidae
Opiathoritton kaya Auffenberg
?Unidentified amphibian bones
Turtle bones
Cf. Gephyrosaurus giganteus Gilmore
Champosauroidea sp., cf. C. mutator Gilmore
Champosaurus sp. Marsh
Leptochampsida denticulatus (Gilmore)
Eostinus lanceolus Gilmore
Cf. Parasaniwa wyomingensis Gilmore
Cf. Paradonous logeri Estes
Palaeosaurus canadensis Gilmore
Leidyosaurus sternbergi Gilmore
Brachychampsa montana Gilmore
?Family Coeluridae
Cf. Erythosaurus sp.
Cf. Tyrannosaurus rex Osborn
Struthiomimus sp.
?Hadrosaurian dinosaur
Cf. Kritosaurus sp.
Hadarosaurus foulkii Leidy
Anatosaurus sp., cf. A. annectens (Marsh)
Cf. Anatosaurus annectens (Marsh)
Cf. Anatosaurus sp.
Cf. *Diclonius* sp.
?*Ankylosaurus* sp.
Cf. *Monoclonius recurvicornus* Cope
*Triceratops* sp., cf. *T. brevicornus* Hatcher
*Triceratops* sp., cf. *T. flavissimus* Marsh
*Triceratops* sp.
?*Dinosaur tooth*
Cf. *Pterosauria* sp.
Unidentified reptile bones
Crepolites
?*Wenoceras* sp.
*Pedimys threxii* Clemens
Horned tooth fragment

The fossils found in the Bluff Member appear to be a mixture of marine, brackish-water, and fresh-water forms. Such fossils as *Laena* sp. and *Uphigerina major* are generally considered marine. *Paleosalangus bipartitus* has generally been considered brackish-water or marine, but Katz (1964, p. 160) indicates that he believes it may be a permanent part of the fresh-water community. The writer has found this fossil in marine beds in the Brten Member. This, of course, does not preclude the possibility of individuals moving into fresh water, or even living in it for periods of time. The remainder of the animals can be classified as land or fresh-water animals. If marine or brackish-water did exist it was probably estuarian because of the association of fresh-water and land species with relatively few marine or brackish-water forms.

The Pretty Butte Member of the Hell Creek Formation

It is here proposed that the upper bentonitic beds of the Hell Creek Formation be referred to as the Pretty Butte Member of the Hell Creek Formation. The name Pretty Butte is taken from the butte of that name in Slope County, North Dakota (sec. 26 and 35, T. 134 N., R. 106 W.), about 12 miles north of the town of Marmarth on the "West Marmarth
Road (North Dakota Route 16). The type section is the southeast-facing slope on the northeast end of the butte on the west side of the "West Harwood Road" (SW 1/4 NW 1/4 sec. 26, T. 134 N., R. 106 W., Slope County, North Dakota). The measured section of the type section is as follows:

**TULLOCK FORMATION**

7. Dark-brown lignite weathering to a powder

**HELL CREEK FORMATION (PRETTY BUTTE MEMBER)**

6. Medium-gray bentonite with moderate-brown, lignitic shale lenses

5. Light-gray sandstone with calcareous sandstone lenses near the base

4. Light-gray bentonite

3. Brown, lignitic shale and shaly lignite

2. Medium-gray bentonite

Total thickness of the Pretty Butte Member

28.0

**HELL CREEK FORMATION (HUFF MEMBER)**

1. Yellowish-gray sandstone with limonite stained nodules and calcareous sandstone lenses

(For a complete measured section of the beds exposed at this locality see Appendix A, Part I).

The base of the Pretty Butte Member intertongues with the Huff Member below and the contact is picked at the top of a thick sandstone usually about 25 feet below the top of the Hell Creek Formation in western North Dakota, but which may be only 10 to 15 feet below the top of the formation in central North Dakota. The top of the member coincides with the top of the Hell Creek Formation and is defined as being the top of the uppermost gray bentonitic beds or gray bentonites below.
the "lowest persistent coal" (Paleocene). Where the Paleocene coal and is absent as in parts of Western North Dakota the upper boundary is defined by the base of a yellow-colored bed (Paleocene) of sandstone and siltstone which interfingers with the coal (see definition of upper Devil Creek boundary). In central North Dakota, where the coal and the "yellow bed" may both be missing, the top of the member is defined as being the top of the uppermost bentonitic beds below the Issel or Camasball Formations.

This member is found everywhere in western and central North Dakota. Preliminary field work also indicates that it is widespread in eastern Montana. There are several localities, other than the type section, where one may observe this member well developed. These are as follows: sec. 17, T. 130 N., R. 78 W., Benson County, North Dakota; sec. 23, T. 131 N., R. 79 W., Mountrail County, North Dakota; sec. 17, T. 130 N., R. 79 W., Morton County, North Dakota; sec. 1, T. 131 N., R. 79 W., Pembina County, North Dakota; and at the type section of the Devil Creek formation on East Devil Creek, sec. 28, T. 131 N., R. 78 W., Garfield County, Montana.

The lithology of this member is primarily bentonites and bentonitic shales in which small sandstone channels are common. The bentonites and bentonitic shales often contain pods of lignitic, non-bentonitic shales which are a moderate-chocolate brown in color. The bentonites, when dry, often show faint marlals, most frequently shades of purple and blue. Sedimentary coals, weathering to iron and manganese oxides, are common. The included sandstones in central North Dakota are gray but as one progresses westward they become more yellowish, so that in eastern Montana they are all yellowish-gray. The member generally becomes
lack bentonitic in an easterly direction, changing to lignitic shales.

The top of the member is generally exposed as a series of bentonites and bentonitic shales which form a bench above the steeper slopes of the Hild Member below. The bentonites can often be seen to have flowed down over the beds below, sometimes giving the impression that the member is actually thinner than it is. The member forms slopes which are convex upward.

The paleontology of the member has received only a preliminary study but appears to have a rather extensive flora and fauna. Below is a list of fossils collected and identified from various localities by the writer, except for Cimolodons utahensis Marsh which was identified by W. A. Claceus (letter of April 20, 1965, to Dr. R. B. Hulbert, Jr.).

**PLANTS**

*Caelopsis abortana* Lambe
*Carexiphium* sp., cf. *n. actigae* (beef) brown
*Carpulina* sp.

**Invertebrates**

*Onto* sp., cf. O. stantoni white
*Pentaptils* sp., cf. *P. subcarpus* (beach and sandy)
Polycyst fragments
*Viviparina* sp., cf. *V. stantoni* Tozer

**Vertebrates**

*?Ceratopsia longirostris* (Lambe)
*Leptosoma occidentale* (Leidy)
*?Plateosaurus canus* Marsh
*?Narrasaurus dilatus* Gilmore
*?Polacanthus kaya* Haffenberg
Turtle fragments
*Cheiropseaus* sp., cf. *C. notator* Parks
*cf. Cheiropseaus* sp.
*Leidyosaurus stenosori* Gilmore
*cf. Arctosaurus* sp.
*Triceratops* sp.
Unidentified dinosaur teeth
Unidentified reptile bones
Caprellites
Omphalos vitidus Marsh

The list of fossils indicates a late Cretaceous age since it contains dinosaurs as Triceratops sp. The fauna and flora indicate that the beds were deposited in fresh water, since they contain no saline or brackish-water species. The fauna and sediments would suggest a coastal plain with swampy conditions, at times covered by volcanic ash, and cut by small meandering streams.

Other Lithologic Units in the Hell Creek Formation

Lower Sandstone Beds of the Hell Creek Formation
in Eastern Montana

Over much of eastern Montana at the base of the Hell Creek Formation there is a series of sandstones which superficially resemble the Colgate Member of the Fox Hills Formation below but which are more cross-bedded and more coarsely grained. The writer does not intend to name these sandstones formally at this time because he has not studied them thoroughly enough; however, they appear to be widespread in locations studied by the writer and are mentioned widely in the literature by many authors (Catcher, 1893, p. 137; Brown, 1907, p. 829; Smith, 1910; Collier, 1913, p. 30; Bauer, 1924, p. 345; Brown and Lindvall, 1955, p. 39; Colton, 1955, map; Colton and Matson, Jr., 1956, map). The above would indicate that these sandstones form a valid unit of the Hell Creek Formation.

The sands are medium- to coarse-grained, yellow-brown in color, contain abundant calcareous sandstone "log" concretions which weather in relief and are usually limonite stained. At the type section of the
Hell Creek Formation, on East Hell Creek, Garfield County, Montana, the sandstones are somewhat bentonitic near the top and gray in color than in many exposures in the Fort Peck Region visited by the writer.

The unit is usually poorly exposed, covered by grass lands but in favorable places blowouts develop exposing the member showing its cross-beded and concretionary nature. Road cuts such as those south of the Fort Peck Dam on Montana Route 24 become rapidly expanded by wind erosion.

The unit is probably correlative with the Little Beaver Creek and Harsmuth Members of the Hell Creek Formation in North Dakota. The lower part of the unit is probably older than the lowermost portions of the Little Beaver Creek Member. No effort was made by the writer to collect fossils from this sandstone.
PETROLOGY OF THE HELL CREEK FORMATION

INTRODUCTION

The Hell Creek Formation is composed of many lithologies but is predominantly unconsolidated fine clastics—clay, silt, fine sand, and medium sand. The sediments are generally lignitic and bentonitic. The sandstones are "cemented" together by clay, silt, and zeolitic matrices. Locally the sandstone may be cemented by calcareous or opaline cement. Conglomerates and nodules are common; the most characteristic are the siderite nodules which weather it limonite and manganese oxides. The color of the sediments ranges through shades of olive-gray, greenish-gray, yellowish-gray, yellowish-brown, and often shows purplish where lignitic sediments are present. The sediments generally become more yellow and more brown in a westerly direction, because of the predominating dark colors of these sediments they have often been referred to as the "sorbor beds."

Thin-sections of the major lithologies were made and studied as were all of the varieties of concretions and nodules encountered. Heavy minerals in the sands were studied both from a petrographic and stratigraphic point of view. Percentages of sand, clay, and lignitic material were computed for the Hell Creek Formation and its members and compared to the Tullock Formation (Fig. 9). No sieve analyses were made though many sand samples were inspected under the binocular microscope and estimates were made as to the mode of the sand size. Some samples
were studied by X-ray diffraction to ascertain their mineralogy.

CONGLOMERATES OF THE HELL CREEK FORMATION

Conglomerates are rare in the Hell Creek Formation in North Dakota. Most are the result of the reworking of siderite nodules which may have formed on the bottom during sedimentation or very shortly after burial. Scattered among the siderite pebbles of the conglomerate are somewhat larger pebbles of orthoquartzite. The pebbles of orthoquartzite appear to be limited to the lower portions of the formation. The beds of conglomerate are lens-shaped in cross section but may well represent stream channels and thus would be much longer in a third dimension. The beds are generally 6 inches to about 18 inches thick although locally thinner beds have been found. The beds tend to be of rather uniform thickness until they pinch out very rapidly near their margins.

The petrography of the conglomerates is simple. Over 99% of the pebbles are composed of about 90% siderite or manganiferous siderite (oligonite) and 10% clay. The siderite pebbles are ellipsoidal to disk-shaped and range in maximum diameter from 1 to 4 cm. The larger siderite pebbles appear flattened, as if they were still plastic at the time of deposition. This hypothesis is supported by the fact most of the pebbles have sand grains free the matrix of the conglomerate pressed into them (Fig. 8).

The other pebble lithology present is a light-olive-gray (5 Y 6/1) orthoquartzite. These pebbles may be up to 6 cm in diameter. The pebbles are 99% quartz, occurring both as cement and as sand grains.
The sand grains range in maximum diameter from 0.32 to 0.48 mm. The cement occurs as secondary overgrowths, where sand grains are in contact with each other there is often a small degree of suturing of the contacts. Other minerals found in the orthoquartzite pebbles include feldspar, apatite, and garnet. The writer has found the orthoquartzite pebbles at only two localities in North Dakota: SW 1/4 sec. 25, T. 134 N., R. 85 W., Grant County, and SW 1/4 sec. 28, T. 132 N., R. 106 W., Bowman County. The conglomerates, however, are universally distributed throughout the Hell Creek Formation, although not very common.

The matrix of the conglomerates is composed of medium size sand grains, floating in or merely surrounded by, a sparry siderite cement composed of grains up to 0.016 mm. in maximum diameter (Fig. 9). The sand is 75% chert grains, 15% volcanic grains, and 10% quartz, plagioclase, and K. feldspar grains. A few grains of epidote and quartzitic schists were also found. In many cases the feldspar, chert, and volcanic grains were wholly or partially replaced by the sparry siderite. The glassy material of the volcanic grains appears to be preferentially replaced with respect to the feldspar phenocrysts leaving the latter protruding or completely surrounded by the siderite cement.

The conglomerates are a dark-yellowish-brown (10 YR 4/2) when fresh but rapidly weather to a shiny brownish-black (5 YR 2/1). The weathered material is limonite with traces of manganese oxides (see descriptions of siderite nodules).

Other writers who have mentioned conglomerates include Barnum Brown (1907) and Bauer (1925). Barnum Brown (p. 834), in the description of the type section of the Hell Creek Formation, reports "Beds of river-sorted gravel occur in these two strata. They invariably contain
water-worn fragments of bones and shells." No mention is made of quartzite or siderite pebbles. Sauer (p. 344-346) reports quartzite and porphyry pebbles 1/2 to more than 3 inches in diameter near the base of the Hell Creek Formation at Freedom Dome, about 13 miles south of Jordan, Garfield County, Montana. He describes them as being embedded in an impure limonite which contains small amounts of coarse sand. The writer has not seen this locality, but from the description would conclude that this occurrence is similar to those found in Grant and Bowmen Counties, North Dakota, with the exception that there are in addition to the quartzite pebbles also porphyry pebbles and that the siderite pebbles in North Dakota have not completely weathered to limonite.

SANDSTONES OF THE HELL CREEK FORMATION

Introduction

Sandstones comprise about 51% of the Hell Creek sediments. They are about 61% of the sediments of the Huff Member, 73% of the sediments in the Beiden Member, and 61% of the sediments in the Marmarth Member (Fig. 9). In the remaining members of the Hell Creek Formation sandstones comprise about 40% of the sediments.

Sedimentary Structures

The sandstone bodies are generally cross-bedded but this may not be apparent where they do not contain impurities such as bentonitic clay which accentuates the bedding (Fig. 10b). Ripple marks are uncommon but have been noted in some of the calcareous sandstone lenses (Fig. 11a). Rib-and-furrow structures have also been found in some of the calcareous sandstone lenses (Fig. 10a). Fazetto type cross-bedding appears to be the most common type of cross-bedding.
Figure 9. Clay-sand-lignite ratios for the Hell Creek Formation and the Tullock Formation.
Figure 10a. Rib-and-furrow cross bedding in a calcareous concretionary lens in the base of the Tullock Formation NW 1/4 sec. 33, T. 133 N., R. 106 W., Slope County, North Dakota.

Figure 10b. Cross bedding, accentuated by bentonitic shale partings, in the lower part of the Huff Member of the Bell Creek Formation sec. 8, T. 132 N., R. 105 W., Bowman County, North Dakota.
Figure 11a. Ripple marks in calcareous sandstone lenses in the upper part of the Buff Member of the Hell Creek Formation sec. 4, T. 134 N., R. 106 W., Slope County, North Dakota.

Figure 11b. Sandstone dikes intruding a bentonitic shale in the War- marth Member of the Hell Creek Formation in NW 1/4 sec. 5, T. 129 N., R. 105 W., Bowman County, North Dakota.
The sandstones often contain concretionary structures which have two dimensions nearly equal with a third much longer. They appear in outcrop as log-like features and have been called "log" concretions. If these structures are nearly equidimensional, the writer refers to them as calcareous sandstone lenses. In addition to these concretionary bodies limonite concretions, gypsum concretions, marcasite concretions, jarosite concretions are found along with siderite nodules.

Laterally the sandstones pinch out rapidly or they may interfinger with a shaly sequence. In either case, a sandstone some 20 or 30 feet thick may disappear completely in a lateral distance of only tens of feet. Siderite nodules with fossils, presently weathering to limonite, may often be found at the base of a channel as if deposited there and then later buried. In some places the sandstones have intruded the shales above, forming dikes as in NW 1/4 sec. 5, T. 129 N., R. 105 W., Bowman County, North Dakota (Fig. 11b).

Color of Hell Creek Sandstones

The color of the Hell Creek sandstones varies with geographical location. In eastern Montana and western North Dakota the sandstones tend to be shades of brown while those in central North Dakota tend to be shades of gray (Figs. 12, 13a, and 13b) (Appendix B). In Burleigh, Fergus, Morton, and Sheridan Counties, North Dakota, the sandstones tend to be more brown than in regions immediately west, such as Sioux and Grant Counties (Fig. 12). Gray appears to be their unweathered color. In the western parts of North Dakota and eastern Montana the browns appear to be the result of minute quantities of limonite whereas in central North Dakota the browns are the result of an increase in lignitic material.
Figure 12. Distribution of gray and brown colors for the Hell Creek and Tullock Formations from eastern Montana to central North Dakota.
Figure 13a. Hell Creek Formation in the type area, East Branch Hell Creek, Garfield County, Montana. Note brown coloration.

Figure 13b. Huff Member of Hell Creek Formation in sec. 14, T. 131 N., R. 82 W., Sioux County, North Dakota. Note predominance of gray coloration.
The increase in brown coloration in a western direction because of an increase in limonite may be either attributed to deeper and more intense weathering or to environmental conditions at the time of deposition of the Hell Creek sediments. At this time the writer has no positive evidence to support either hypothesis, however, the increase in brown color connected with an increase in lignite in an easterly direction would suggest that these sediments were transitional between the marine Fox Hills Formation and the non-marine parts of the Hell Creek Formation and represent coastal swamp deposits.

Size Analysis of Hell Creek Sandstones

No sieve analyses were made of sandstones sampled. If such analyses were to be made, wet sieving would be required, because the clay holds the sand grains firmly and they do not break apart, even after one hour in the Ro-Tap. In this study 124 samples of sand were inspected under the binocular microscope and classified as to size using the Wentworth Scale as a base (Table 1).

This study showed that medium grained sand most frequently was encountered in the Hell Creek Formation and that fine sand, coarse sand, and very fine sand were encountered in diminishing frequency (Table 1).

A sample was taken from each sandstone body in a section measured and a sandstone one foot thick therefore received equal weight with a 20 foot thick unit. This mode of sampling introduced a bias in favor of smaller sandstone bodies.

Classification of Hell Creek Sandstones

The classification of Hell Creek sandstones is complex because they contain pyroclastics and the diagenetic alteration products. The
### TABLE 1. A comparison of sand and silt grain sizes between the Fox Hills, Hell Creek, Tullock, Ludlow, and Cannonball Formations.

<table>
<thead>
<tr>
<th>Formation</th>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Very fine sand</th>
<th>Silt</th>
<th>% of Samples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FOX HILLS FORMATION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0%</td>
<td>5</td>
<td>37%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td><strong>HELL CREEK FORMATION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Montana</td>
<td>0</td>
<td>63%</td>
<td>3</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Western N. Dak.</td>
<td>33%</td>
<td>33%</td>
<td>8</td>
<td>7%</td>
<td>4%</td>
<td>27%</td>
</tr>
<tr>
<td>Central N. Dak.</td>
<td>40%</td>
<td>21%</td>
<td>3</td>
<td>8%</td>
<td>5%</td>
<td>11%</td>
</tr>
<tr>
<td><strong>TULLOCK FORMATION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>25%</td>
<td>1</td>
<td>7%</td>
<td>10%</td>
<td>1%</td>
</tr>
<tr>
<td><strong>LUDLOW FORMATION</strong></td>
<td></td>
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<tr>
<td></td>
<td>4</td>
<td>19%</td>
<td>7</td>
<td>19%</td>
<td>19%</td>
<td>19%</td>
</tr>
<tr>
<td><strong>CANNONBALL FORMATION</strong></td>
<td></td>
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<tr>
<td></td>
<td>6</td>
<td>29%</td>
<td>0</td>
<td>0%</td>
<td>1%</td>
<td>7%</td>
</tr>
</tbody>
</table>
classification used here is modified from Pettijohn (1957, p. 291).

The sandstones are divided into four major groups based upon the amount of pyroclastics present (Table 2): sandstones contain 100% detrital material other than pyroclastics; tuffaceous sandstones may have from a trace to 50% of the sandstone composed of pyroclastic material; impure tuffs have more than 50% but less than 75% of the rock pyroclastics; and in tuffs, more than 75% of the rock is composed of pyroclastic material.

The altered tuffaceous sediments are classified similarly to the unaltered sandstones (Table 3) and various adjectives are used to describe alteration, such as bentonitic or zeolitic.

Bentonite and zeolite rocks have been further classified by their contained impurities (Table 4). Some of the rocks studied have become secondarily sandy because of the post-depositional growth of calcite and other carbonates and in this case, the adjective autoelastic has been used.

Two differences exist between this classification and Pettijohn's (1957, p. 291). The first is, all chart grains in this classification are considered rock fragments because petrographic evidence indicates most are devitrified silica glass. In many instances this interpretation will change a rock name from an arkose under Pettijohn's classification to a graywacke under this classification. Secondly, these sediments cannot be applied directly to Pettijohn's genetic classification diagram (Pettijohn, 1957, p. 290, fig. 74), because the matrix of the sandstones in the Hell Creek Formation may not be a result of sedimentation but of diageneric alteration of volcanic glass.
<table>
<thead>
<tr>
<th>Pyroclastics present</th>
<th>Pyroclastics absent</th>
<th>Pyroclastics present</th>
<th>Pyroclastics absent</th>
<th>Pyroclastics present</th>
<th>Pyroclastics absent</th>
</tr>
</thead>
<tbody>
<tr>
<td>arkose</td>
<td>arkose</td>
<td>arkose</td>
<td>arkose</td>
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<tr>
<td>sub-tuffaceous</td>
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<td>feldsparite</td>
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<td>tuffaceous</td>
</tr>
</tbody>
</table>

**TABLE 2. Classification of sandstones, tuffaceous sandstones, tuffs, tuffaceous arkose, and tuffs.**

- **SANDSTONES:**
  - Rock fragments exceed detrital redbeds.
  - Rock fragments exceed detrital redbeds.
  - Rock fragments exceed detrital redbeds.

- **TUFFS:**
  - Vitric shards over 75%.
  - Vitric shards and rock fragments 25-50%.
  - Vitric shards and rock fragments over 75%.

- **SANDSTONES:**
  - Pyroclastics present.
  - Pyroclastics present.
  - Pyroclastics present.

- **TUFFS:**
  - Pyroclastics present.
  - Pyroclastics present.
  - Pyroclastics present.

- **SANDSTONES AND TUFFACEOUS:**
  - Pyroclastics present.
  - Pyroclastics present.
  - Pyroclastics present.

- **TUFFS:**
  - Pyroclastics present.
  - Pyroclastics present.
  - Pyroclastics present.
TABLE 2. (Continued from above)

<table>
<thead>
<tr>
<th>Matrix absent or scantly (under 15%)</th>
<th>pyroclastics present</th>
<th>pyroclastics absent</th>
<th>protoquartzite</th>
<th>tuffaceous protoquartzite</th>
<th>tuffaceous subarkose or feldspathic sandstone</th>
<th>orthoquartzite chert</th>
<th>orthoquartzite chert</th>
</tr>
</thead>
<tbody>
<tr>
<td>pyroclastics present</td>
<td>tuffaceous orthoquartzite chert</td>
<td>orthoquartzite chert</td>
<td>less than 5%</td>
<td>tuffaceous orthoquartzite chert</td>
<td>less than 5%</td>
<td>less than 5%</td>
<td>less than 5%</td>
</tr>
<tr>
<td>pyroclastics absent</td>
<td>tuffaceous orthoquartzite chert</td>
<td>orthoquartzite chert</td>
<td>less than 5%</td>
<td>tuffaceous orthoquartzite chert</td>
<td>less than 5%</td>
<td>less than 5%</td>
<td>less than 5%</td>
</tr>
</tbody>
</table>

*May be further subdivided by igneous rock composition—i.e., rhyolitic tuff.*
<table>
<thead>
<tr>
<th>Maternal Material</th>
<th>Less than 50% clays or zeolites</th>
<th>50-75% clays or zeolites</th>
<th>More than 75% clays or zeolites</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bentonitic or zeolitic sandstones</td>
<td>Areaceous impure bentonites or zeolite rocks</td>
<td>Bentonite or zeolite rocks</td>
</tr>
<tr>
<td>Matrix clay</td>
<td>Bentonitic feldspathic graywacke</td>
<td>Bentonitic feldspathic graywacke</td>
<td>Bentonite or zeolite rock</td>
</tr>
<tr>
<td>Matrix zeolites</td>
<td>Zeolitic feldspathic graywacke</td>
<td>Zeolitic feldspathic graywacke</td>
<td>Zeolite rock</td>
</tr>
<tr>
<td>Matrix absent or</td>
<td>Bentonitic arkose</td>
<td>Bentonitic subgraywacke</td>
<td>Subgraywacke arenaceous bentonite</td>
</tr>
<tr>
<td>Minor or chemical cement</td>
<td>Zeolitic arkose</td>
<td>Zeolitic subgraywacke</td>
<td>Subgraywacke arenaceous zeolite rock</td>
</tr>
</tbody>
</table>

Notes:
- BENTONITE OR ZEOLITIC SANDSTONES
- ARENEACOUS IMPURE BENTONITES OR ZEOLITE ROCKS
- BENTONITE OR ZEOLITE ROCKS
- Bentonites are those that weather to "pods" or "pillows".
<table>
<thead>
<tr>
<th>Matrix absent or agency (under 15%)</th>
<th>voids may be partially filled with chemically inorganic clays and zeolites, or in part with charcoal cement.</th>
</tr>
</thead>
<tbody>
<tr>
<td>matrix clay</td>
<td>bentonitic subarkose or feldspathic sandstone</td>
</tr>
<tr>
<td>usually bentonitic</td>
<td>bentonitic proto-quartzite</td>
</tr>
<tr>
<td>matrix zeolites</td>
<td>zeolitic subarkose or feldspathic sandstone</td>
</tr>
<tr>
<td>zeolitic proto-quartzite</td>
<td></td>
</tr>
<tr>
<td>matrix clay</td>
<td>bentonitic ortho-quartzite (chert &lt; 5%)</td>
</tr>
<tr>
<td>usually bentonitic</td>
<td>bentonitic ortho-quartzite (chert &gt; 5%)</td>
</tr>
<tr>
<td>matrix zeolites</td>
<td>zeolitic ortho-quartzite (chert &lt; 5%)</td>
</tr>
<tr>
<td>zeolitic ortho-quartzite</td>
<td></td>
</tr>
</tbody>
</table>

1. Any clay—rock names may be substituted if appropriate—i.e. montmorillonite.

2. If carbonates are present as "sand" grains (less than 50% of the rock), then prefix with autoclastic. If carbonates are present as "sand" grains (more than 50% of the rock), then it is called a bentonitic autoclastic calcite sandstone (see classification of bentonites, Fig. 17, p. 103).

3. Of doubtful existence.
TABLE 4. Classification of bentonites.

<table>
<thead>
<tr>
<th></th>
<th>autoclasts absent</th>
<th>autoclasts present but under 50%</th>
<th>over 50% autoclasts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autoclasts</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcite</td>
<td>calcareous</td>
<td>bentonitic calcite sandstone</td>
<td></td>
</tr>
<tr>
<td>Dolomite</td>
<td>dolomitic</td>
<td>bentonitic dolomite sandstone</td>
<td></td>
</tr>
<tr>
<td>Siderite</td>
<td>sideritic</td>
<td>bentonitic siderite sandstone</td>
<td></td>
</tr>
<tr>
<td>Foreign sand</td>
<td>Bentonite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less than 1%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>More than 1%</td>
<td>Arenaceous</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1Have not been observed (if other carbonates appear they may be treated likewise).

2May be prefixed by accessory igneous crystal fragments present—i.e. biotite bentonite.
Petrographic Descriptions of Hell Creek Sandstones

Introduction

Petrographic descriptions of the Hell Creek sandstones are primarily thin-section descriptions. Minerals were identified and visual estimates were made of their abundances. Mineral or rock grains occurring in quantities of less than 1% are listed together as minor constituents. Composition of the plagioclase sand grains was determined on the five-axis universal stage by the Rittman Zone Method (Emmons, 1943).

Subgraywackes

Subgraywackes, tuffaceous subgraywackes, and diagenetically altered tuffaceous subgraywackes were the most common types of the sandstones thin-sectioned. Six rocks were thin-sectioned of this general composition: 2 zeolitic subgraywacke, 1 tuffaceous subgraywacke, 1 glauconitic subgraywacke, 1 calcareous (concretionary) subgraywacke, and 1 limonitic (concretionary) subgraywacke.

One of the zeolitic subgraywackes (T. S. F57) was taken from the Crowbuster Member of the Hell Creek Formation, NE 1/4 sec. 26, T. 136 N., R. 76 W., Emmons County, North Dakota (Fig. 14). The rock is 5% quartz grains, 10% plagioclase grains (An_{23} - An_{70}) (sometimes myrmekitic), 50% chert grains, 20% volcanic grains, and minor amounts of biotite, chlorite (replacing volcanics), pumiceite, muscovite, limonite, hornblende, epidote, zircon, and tourmaline grains plus organic matter. The above sand grains are held together by opal cement, comprising 3% of the rock along with minor amounts of clay and zeolites. All of the sand grains were fresh.
Figure 14. Clear opal cement can be seen surrounding sand grains in thin-section number 57 (X50).
The other zeolitic subgraywacke (T.S. #56) was collected from the lower part of the Hell Creek Formation in sec. 25, T. 149 N., R. 73 W., Wells County, North Dakota, by George Faigle. The rock is 10% quartz grains, 15% plagioclase grains (An$_{20}$-An$_{55}$), 32% K-feldspar grains, 59% chert grains, 3% volcanic grains, and minor amounts of hornblende, zircon, epidote, sphene, garnet, muscovite, penninite, and glauconite grains. The matrix is opal cement, zeolites, and clays. The glauconite is both in the pellet form and as a replacement of silica glass in volcanics. All of the detrital grains are fresh and very angular.

The tuffaceous subgraywacke (T.S. #50) was taken from the Huff Member of the Hell Creek Formation in sec. 32, T. 136 N., R. 78 W., Roseau County, North Dakota. The rock is 5% quartz grains, 10% plagioclase grains, 22% K-feldspar grains, 40% chert grains, 30% volcanic grains, 12 volcanic glass shards, and minor amounts of epidote, hornblende, tourmaline, biotite, calcite, glauconite grains, and organic matter. The sandstone is held together by a clay matrix which comprises 13% of the rock and minor amounts of opal. The glass shards tend to be larger than the other sand grains. Two types of glass are readily recognizable, one moderate-brown, the other completely clear. The clear glass has an index of refraction between 1.495 and 1.500. The brown glass has an index of refraction between 1.500 and 1.505. This would indicate that both glasses are rhyolitic in composition (Rittenhouse, 1963, p. 1407-1408). The rounding of the shards indicates that they have been subjected to some water transportation. All of the other sand grains were fresh and angular.
The glauconitic subgraywacke (T.S. #49) was taken from the Huff
Member of the Hell Creek Formation, SE 1/4 sec. 11, T. 134 N., R. 32 W.,
Norton County, North Dakota. The rock is 5% quartz grains, 10% plagioclase grains (An$_{22-37}$), 3% K-feldspar grains, 50% chert grains, 25% volcanic grains (devitrified), 5% organic matter, and minor amounts of glauconite, lavender colored zircon, epidote, clinohumite, horn-
blende, apatite, gypsum, biotite, pyrobitite, muscovite, and mica quartz-
ite schist grains. The matrix of the rock consists of clays and zeolites (probably clinoptilolite and others). The glauconite is secondary
replacing glasy volcanic grains, and may well be one of the sepi-
chlorites and not the mineral glauconite. All of the other sand grains
are fresh. The schist, chert, and volcanic grains are sub-rounded while
all others show little or no rounding. The apatite and zircon grains
are subhedral and often exhibit a c-axis dimension more than three times
the length of the a-axes.

The calcareous, fossiliferous subgraywacke (T.S. #24) was col-
lected about 75 feet above the blue bentonite marker bed in sec. 28,
T. 21 N., R. 37 E., Garfield County, Montana at the type locality of
the Hell Creek Formation. The rock is 10% quartz grains, 5% plagioclase
grains (An$_{22-37}$), 5% K-feldspar grains, 20% chert grains and volcanic
grains, and minor amounts of muscovite, biotite, zircon, and quartzite
grains. Approximately 5% of the rock is fossil fragments and whole
fossils of gastropods and pelecypods. The sand and the fossils are held
together by a fine to sparry calcite cement, 30% of the rock, and a
clay, 10% of the rock. In most places the calcite cement is rather fine
grained, but in some places it is very coarse as the result of recrys-
tallization. The rock occurs as a discontinuous ledge bed, parts of
which are cemented by calcite, while other parts are only held together by clay. All of the bed is fossiliferous.

The limonitic subgraywacke (T.S. #29) was collected from the Har- 
sworth Member of the Hell Creek Formation in the 8 1/2 sec. 20, T. 133 
N., R. 106 W., Slope County, North Dakota. The rock is 52 quartz 
grains, 10% plagioclase grains (An_{25}-An_{65}), 5% K-feldspar grains, 20% 
chert grains, 30% volcanic grains, and minor amounts of penninite, 
biotite, muscovite, kyanite, sphene, zircon, siliceous schist, and 
quartzite grains. The matrix, a fine grained limonite cement, com-
prises about 30% of the rock. A possible reason for the concentrations 
of limonite in this sandstone might be found in the presence of leaf fos-
sils which have been replaced by limonite. The limonite appears to 
be limited to the fossiliferous beds.

Lithic Graywackes

Lithic graywackes, tuffaceous lithic graywackes, and dia-geneti-
cally altered tuffaceous lithic graywackes are the second most com-
monly encountered sandstone group found in the Hell Creek Formation. 
All of the lithic graywackes thin-sectioned contain either volcanic 
glass shards or their diagenetic alteration products, bentonitic clays 
and zeolites. Four thin-sections were made of this sandstone group 
from samples collected from the Hell Creek Formation. These were 2 
bentonitic lithic graywackes, 1 tuffaceous lithic graywacke, and 1 zeoli-
tic lithic graywacke.

One of the bentonitic lithic graywackes (T.S. #30) was collected 
from the Haff Member of the Hell Creek Formation in sec. 16, T. 131 N., 
R. 82 W., Sioux County, North Dakota. The rock is 5% quartz grains,
25% plagioclase grains, 5% K-feldspar grains, 35% chert and volcanic grains, and minor amounts of muscovite, biotite, penninite, zircon, and mica schist grains. The matrix of bentonitic clays and gypsum comprises 15% of the rock. All of the sand grains are fresh and angular, except for the chert and volcanic grains which are sub-rounded.

The other bentonitic lithic subgraywacke (T.S. #19) was collected from the Crowsnest Member of the Hell Creek Formation in the NW 1/4 sec. 26, T. 136 N., R. 76 W., Hamlin County, North Dakota. The rock is 5% quartz grains, 12% plagioclase grains (An$_{29}$-An$_{53}$) (some grains myrmekitic), 12% K-feldspar grains, 25% chert grains, 25% volcanic grains, and minor amounts of muscovite, biotite, chlorite, epidote, hornblende, and zircon grains. The matrix, a bentonitic clay, comprises 20% of the rock with minor amounts of organic matter, jarosite, and opal. All of the grains are fresh and angular except for the chert and volcanic grains which are sub-rounded.

The tuffaceous lithic graywacke (T.S. #19) was collected from the Crowsnest Member of the Hell Creek Formation in the NW 1/4 sec. 26, T. 136 N., R. 76 W., Hamlin County, North Dakota. The rock is 10% quartz grains, 10% plagioclase grains (An$_{22}$-An$_{63}$), 35% chert and volcanic grains, 5% metaquartzite grains and minor amounts of K-feldspar, hornblende, muscovite grains, and glass shards. The rock has 35% clays as a matrix along with minor amounts of organic matter, opal, and jarosite. All of the sand grains are fresh. The chert, volcanic, and quartzite grains are sub-rounded while the others are angular. The glass shards are fresh and show no signs of abrasion. Bedding in the sandstone is indistinct with only slight preferred orientation to the elongate grains.
The zeolitic lithic graywacke (T.S. J3153, U.S.D. Petrology Collection) was collected from the Crowghost Member of the Hell Creek Formation in the center of sec. 31, T. 134 N., R. 82 W., Sioux County, North Dakota. The rock is 52% quartz grains, 10% plagioclase grains (An$_{21}$-$\text{An}_5$), 2% K-feldspar, 60% chart and volcanic grains, and minor amounts of hornblende, epidote, clinozoisite, zircon, biotite, pessininite, glauconite, and calcite grains. The rock is 15% clay and 3% opal matrix with minor amounts of zeolites and organic matter. The opal is a very effective cement and makes this one of the hardest sedimentary rocks found at the surface in North Dakota. The sandstone immediately overlies a volcanic ash bed in the Colgate Member of the Fox Hills Formation which is probably the source of the silica for the opal. All of the detrital grains are fresh. The volcanic and chart grains are subrounded while all others are angular. The glauconite grains are well rounded pellets. Some of the quartz grains are extremely angular, exhibiting angular shards with outlines similar to those of freshly broken glass.

**Glaucocnitic Sandstones**

Glaucocnitic sandstones are common in the Grasien Member of the Hell Creek Formation. Glaucocnite often comprises over 50% of the rock, giving the sand a bright-green color where fresh; however, outcrops of the sandstone are rusty brown because of the weathering of the glauconite. None of these rocks were thin-sectioned so that their exact composition is not known, however, hand lens examination suggests they are probably graywackes or subgraywackes.
Tuffs

Only one tuff (T.S. #1) was thin-sectioned from the Hell Creek Formation. This sample was collected from the only tuff found in the Hell Creek Formation which is exposed in the SE 1/4, SW 1/4 sec. 13, T. 135 N., R. 78 W., Emmens County, North Dakota. The tuff lies in the contact between the Hell Creek and Fox Hills Formations making the contact a very gradational one. The rock is fine to coarse silt particles of volcanic glass shards with minor amounts of biotite, muscovite, chert, and feldspar grains. Biotite is rather conspicuous in the thin-section and one might classify this rock as a biotite vitric tuff. The glass shards of the tuff have an index of refraction ranging from n = 1.50 to n = 1.51 which indicates that they are a rhyolitic glass (Kittleman, 1963, p. 1407-1408). The glass shards are coated with a clay, probably montmorillonite, otherwise there is no matrix. In the outcrop the beds show many small contorted folds indicating slumping. This ash is different from other volcanic ashes found by the writer in that it is not associated with copious amounts of swelling clays.

Bentonites

Two bentonites were thin-sectioned from the Hell Creek Formation. A lithic, graywacke, arenaceous bentonite (T.S. #32) was collected from the Crowghost Member of the Hell Creek Formation, approximately 40 feet laterally from the biotite vitric tuff (T.S. #1) mentioned above, in the SE 1/4 sec. 13, T. 135 N., R. 78 W., Emmens County, North Dakota and an arenaceous, biotite, apatite bentonite (T.S. #54) was collected from the Pretty Butte Member of the Hell Creek Formation in sec. 22, T. 131 N., R. 81 W., Sioux County, North Dakota.
The lithic, graywacke, arenaceous bentonite (T.S. 632) is about 30% sand and about 70% swelling clays, probably montmorillonite. It grades laterally into a biotite vitric tuff (T.S. 91). This rock appears to be the result of the bentonization of a lithic graywacke tuff. The rock is 10% quartz grains, 3% plagioclase grains (An<sub>26</sub>-An<sub>57</sub>), 2% feldspar grains, and minor amounts of penninite, biotite, muscovite, hornblende, epidote, garnet, zircon, and glauconite grains. In addition to the dominating bentonitic clay matrix there are minor amounts of organic matter, opal, chalcedony, jasperite, limonite, and calcite. All of the sand grains are fresh and angular. The presence of garnet indicates that the tuff had been reworked by running water prior to its bentonization, since garnet is primarily a metamorphic mineral and not an igneous mineral. The deposit was apparently a shoreline deposit since it contains (?) Corbicula cytheriformis and many leaf fossils.

The arenaceous, biotite, apatite bentonite (T.S. 554) is 95% swelling clays, 2% silt size grains of quartz and feldspar, and 3% fine sand size grains of biotite. In addition there are apatite needles. The clay shows a pronounced optical orientation with the impurities distributed throughout. The biotite and apatite crystals show preferred parallel orientation with that of the clay grains. The biotite is warped as if folded around sand grains which probably were glass shards. The clay upon being wetted swells approximately 11 times it original dry volume.

SANDSTONES AND TUFFS OF THE FOX HILLS AND TULLOCK FORMATIONS COMPARED TO THOSE OF THE HELL CREEK FORMATION

The sandstones of the Tullock and Fox Hills Formations were compared with those of the Hell Creek Formation to ascertain if the sedi-
ments were different. Thin-sections made from the Fox Hills and Tullock Formations included 2 subgraywackes, 2 lithic graywackes, 2 vitric tuffs, and 3 bentonites.

**Subgraywacke**

Two subgraywackes were thin-sectioned from the base of the Tullock Formation. One, an opaline subgraywacke (T.S. #3), was taken from between two vitric tuffs in sec. 4, T. 133 N., R. 105 W., Slope County, North Dakota. The other, a friable subgraywacke (T.S. #4), was taken from the SW 1/4 sec. 3, T. 133 N., R. 105 W., Slope County, North Dakota.

The opaline subgraywacke (T.S. #3) is very much like the opaline rocks found in the Hell Creek Formation. It was closely associated with vitric tuffs, as was the opalized zeolitic lithic graywacke (T.S. #3135) from the Crowfoot Member of the Hell Creek Formation. The rock is 2% quartz grains, 10% plagioclase grains (An$_{27}$-An$_{57}$), 15% K-feldspar grains, 40% chert grains, 30% devitrified volcanic grains, 1% biotite grains, and minor amounts of muscovite, epidote, hornblende, glauconite, zircon, quartzite, and schist grains. The clay matrix is 1% of the rock and contains minor amounts of organic matter and opal cement which is in part altered to chalcedony. Most of the grains are fresh and angular except for the chert and volcanic grains which are subrounded.

The very friable subgraywacke (T.S. #4) is similar to many of the Hell Creek sandstones. It is 10% quartz grains, 5% plagioclase grains, 13% K-feldspar grains, 50% chert grains, 5% devitrified volcanic grains, 3% biotite grains, and minor amounts of muscovite, penumrites,
epidote, clinozoisite, glauconite, zircon, clinozoisite, chalcedony, schist, and granite grains. The clay matrix is 10% of the rock with minor amounts of organic matter. All of the grains are fresh and angular except for the chert and volcanic grains which are subrounded.

Differences between the Tullock subgraywackes and those of the Hell Creek Formation are the presence of greater amounts of K-feldspar and the presence of sand grains of granitic rocks, both of which indicate the uncovering of granitic bodies in the source regions.

**Lithic Graywackes**

Two bentonitic lithic graywackes were thin-sectioned. One bentonitic lithic graywacke (T.S. #16) was taken from the middle of the Tullock Formation in sec. 20, T. 135 N., R. 106 W., Slope County, North Dakota, and the other bentonitic lithic graywacke (T.S. #43) was taken from the Colgate Member of the Fox Hills Formation in the E 1/2 of sec. 1, T. 129 N., R. 106 W., Bowman County, North Dakota.

The bentonitic lithic graywacke from the Tullock Formation (T.S. #16) is very similar to the lithic graywackes found in the Hell Creek Formation. It is 10% quartz grains, 10% plagioclase grains (An$_{29}$-An$_{83}$), 10% K-feldspar grains, 23% chert grains, 3% volcanic grains, with minor amounts of biotite, muscovite, pinnacite, epidote, glauconite, apatite, rutile, zircon, garnet, and calcite grains. The rock is 40% bentonitic clay matrix (probably montmorillonite) with minor amounts of organic matter. The sand grains are fresh and angular except for the volcanic and chert grains which are subrounded. Again, as with the other Tullock sandstones, the K-feldspar content is higher, perhaps reflecting the uncovering of granitic rocks in the source regions.
The other bentonitic lithic graywacke (T.S. #42) taken from the Colgate Member of the Fox Hills Formation is very similar to the Hell Creek sandstones. The rock is 16% quartz grains, 16% plagioclase grains, 3% K-feldspar grains, 15% chert grains, 25% volcanic grains, 2% mica (biotite, muscovite, and penninite) grains, with minor amounts of apatite, epidote, and chalcedony grains. The rock is 25% clay (probably montmorillonite) matrix with minor amounts of opal and limonite. In some instances a green micaceous material (chlorite?) was seen to be replacing siliceous grains, particularly volcanic grains. All of the mineral grains are fresh and angular except for the volcanic and chert grains which are subrounded.

Tuffs

Two vitric tuffs were thin-sectioned. One is from the lower part of the Tullock Formation in sec. 4, T. 133 N., R. 105 W., Slope County, North Dakota (T.S. #2), and the other is from the upper part of the Fox Hills Formation (T.S. #3150, U. N. D. Petrology Collection) in the center of sec. 31, T. 134 N., R. 92 W., Sioux County, North Dakota. The latter is very similar to the vitric tuff that directly underlies the aeolitic lithic graywacke (T.S. #3155, U. N. D. Petrology Collection) in the Hell Creek Formation.

The vitric tuff collected from the Fox Hills Formation (T. S. #3150, U. N. D. Petrology Collection) may well be the same ash fall as the one thin-sectioned from the lower Hell Creek Formation in Van Buren County (T. S. #1). It is 98% glass shards (silt size). In addition there are minor amounts of silt sized grains of quartz and feldspars. Much of the glass has its exterior altered to clay. The glass has an
index of refraction of \( n = 1.50 \) to \( n = 1.51 \), the same as the glass from the Hell Creek Formation (T. S. 31). This index of refraction would indicate that it is a rhyolitic glass (Kittleman, 1963, p. 1407-1408). The glass shards appear to be broken, seldom showing any appreciable portions of bubbles. This is probably the result of wave action on a beach because the ash appears between the non-marine Hell Creek Formation and the marine Fox Hills Formation which is generally believed to be a beach deposit.

The vitric tuff from the Tullock Formation (T. S. 32) (Fig. 13) is dissimilar to the previously described tuffs by being much coarser (fine sand size particles). The tuff is composed of all admixtures of sand grains other than shards. The sample thin-sectioned contains 95% glass shards. K-Ar determinations of biotite, in the bentonite associated with the volcanic ash, gave an age of 68 ± 3.2 m.y. The feldspar, however, gave an age of 179 ± 5 m.y. A considerably older date which can be explained by reworking of the feldspar grains into the volcanic ash from an older source, before final deposition. The glass shards are often coated with a layer of clays, probably montmorillonite. The glass shards are large enough so that they often show parts of bubbles and occasionally whole bubbles. The glass is clear white and has an index of refraction of \( n = 1.49 \) to \( n = 1.50 \) which would indicate a rhyolitic composition (Kittleman, 1963, p. 1407-1408). This is slightly more acid than that of the ash falls from the Hell Creek and Fox Hills Formations. Associated with the glass shards are finer (less than 0.1 mm in diameter) nearly equal-dimensional silt grains of unaltered quartz, K-feldspar (sanidine ?), plagioclase, hornblende, and zircon. It is estimated that the rock is 3% bentonitic clays which were
Figure 15. Thin-section number 2 is of a vitric tuff showing glass shards (x40).
derived from the alteration of the glass. The size and freshness of the glass and the fact that it shows no abrasion would indicate that it was transported to the region by air and only slightly reworked locally by running water. However, the size of the glass shards, fine sand, is exceptional if it were transported from central Montana or even the Black Hills of South Dakota.

The literature concerning size of particles with respect to distance from source of historic catastrophic volcanic explosions reports only one instance where grains of greater than 0.1 mm in diameter transported by winds over 75 miles (Joly, 1884; Pirsson, 1915; Ross, Rimer, and Stephenson, 1929; Moore, 1934; Carey and Frye, 1952; Thorarinsson, 1954; Rigg and Gould, 1957; Gorshkov, 1959; Wilcox, 1959; Eaton, 1964; and Fisher, 1964). This occurred during the eruption of Krakatoa in 1883. Joly described ash collected from the eruption of Krakatoa aboard a ship anchored at Great Komulus Island some 75 miles northeast of Krakatoa. He found in the sample 1 mm feldspar grains, 1 mm augite grains, and 4 mm hypersthene grains (Joly, 1884, p. 291-292, and 296).

The closest possible source for the Tullock volcanic ash is the Black Hills, South Dakota, some 175 miles away. Central and western Montana was the most probable source for the ash because of known volcanism in that area at this time. If the source area is correct then this region was subjected to volcanic explosions greater than any of those in recorded history, with the possible exception of Krakatoa, 1883.

Bentonites

Thin-section number 5 is from the same locality as the vitric tuff described above (T. S. 82), sec. 4, T. 133 N., R. 105 W., Slope County,
North Dakota. Thin-section number 12 comes from the same bentonite about 1/4 of a mile away in sec. 3, T. 133 N., R. 105 W., Slope County, North Dakota. Thin-section number 53 is from the same bentonite several miles away in sec. 9, T. 133 N., R. 105 W., Slope County, North Dakota.

Thin-section number 5, a silty, calcareous, autoclastic bentonite, was collected in close association with a vitric tuff (T. S. #2) and represents a portion of the tuff which had been altered to a bentonite. The bentonite is extremely fossiliferous at this locality, yielding many good leaf fossils along with twigs and bark. The rock is 95% swelling clays (swelling 16 times in water their original dry volume), which have been identified as essentially montmorillonite by X-ray analysis. The remainder of the rock is 2% authigenic calcite, 1% biotite, 1% quartz and feldspars (silt size), and 1% organic material concentrated in leaf fossils. In addition, trace amounts of feldspar, muscovite, epidote, and opaque silt grains are found. Relic shards are common. The sand and silt grains are fresh. The calcite occurs as independent crystals or groups of crystals and may represent incipient growth of concretions. No calcareous concretions were found in the bentonite at this locality. The calcite grains appeared to be randomly positioned. Most of the calcite grains were of coarse silt size. The biotites from this sample gave a K-Ar date of 68.5 ± 3.2 m.y., which agrees closely with other dates from rocks which are probably correlative. The feldspars, on the other hand, gave a much older K-Ar date 170 ± 5 m.y. reflecting the contamination of the volcanic feldspars by fluvial transported feldspars reworked into the volcanic ash before final deposition. The major differences between this bentonite and the ones thin-sectioned from the Hell Creek Formation (T. S. #1 and #32) is the presence of calcite.
Calcite is a very common constituent of the Tullock bentonites although previous literature suggests that calcite is rare in bentonites. Calcium may be derived internally from the devitrification of the glass shards and deposited by solutions locally as calcite.

Thin-section number 12, an arenaceous, bentonitic, autoclastic sandstone, was collected from lenses of sandstone-appearing material in a non-sandy bentonite. The rock is 75% calcite in the form of authigenic sand grains, 12 quartz and feldspar grains, and minor amounts of chert, schist, volcanics, biotite, muscovite, glaucophane, brown tourmaline, apatite, rutile, epidote, zircon, and sphene grains. Between the sand grains is a matrix of swelling clays (probably montmorillonite) which is about 20% of the rock. Such large quantities of calcite have not hitherto been described from bentonites (montmorillonite). Calcite is concentrated in lenses of the bentonite and perhaps represents an initial stage in the development of a concretion. Calcareous, stellate concretions have been found in bentonites in the Bell Creek Formation in sec. 22, T. 131 N., R. 81 W., Sioux County, North Dakota, and in the Tullock Formation from this same bentonite in sec. 23, T. 134 N., R. 106 W., Slope County, North Dakota.

Thin-section number 53 was a more massive clay than the other two samples thin-sectioned from this bentonite and was composed of nearly 100% clay. Minor amounts of sericite, biotite, feldspar, zircon, sphene, epidote, organic matter, and finely divided calcite were found. The only sign of bedding in the outcrop is color banding. The clay of this specimen swelled to about 10 times its original volume when soaked in water. This bentonite appeared to be similar to many of the benton-
items found in the Hell Creek Formation except for the presence of finely divided calcite.

SANDSTONES OF THE LUDLOW AND CANNONBALL FORMATIONS
COMPARED WITH THOSE OF THE HELL CREEK FORMATION

No thin-sections were made of Ludlow or Cannonball sandstones. Unlike the Tullock and Fox Hills sandstones they differ greatly from the Hell Creek and are nearly completely free of tuffs, tuffaceous sandstones, and their diagnostic alteration products. The sandstones from the Colgate Member of the Fox Hills Formation, from the Hell Creek Formation, and from the Tullock Formation weather into badlands and form intricately rilled slopes. Sandstones from the Ludlow and Cannonball Formations on the other hand do not form badlands or rilled slopes but weather to a soft sand which rapidly becomes soil even on the steeper slopes. The Ludlow sands in central North Dakota almost invariably contain pelletal glauconite, at times in enough quantity to make green-sands. The Cannonball sands also contain minor amounts of glauconite which weathers to give the sediments a rusty-yellow color though it is seldom present in enough quantity to give the sand a greenish aspect.

In western North Dakota the Ludlow Formation contains some very distinctive sand and silt beds. These beds are free of dark colored clasts which are characteristic of the Fox Hills, Hell Creek, and Tullock Formations. They often contain minor amounts of muscovite which glinten in the sun. Their colors are generally of yellowish-brown or tan and their appearance is like that of loess, which has led some authors to describe them as loess-like sands or silts. These beds
are also occasionally found in the Tullock Formation, but never in the
Hell Creek Formation.

SILTSTONES OF THE HELL CREEK FORMATION

Although siltstones comprise an appreciable portion of the Hell
Creek Formation only one was thin-sectioned. This sample was from the
Little Beaver Creek Member of the Hell Creek Formation in sec. 7, T. 130
N., R. 105 W., Bowman County, North Dakota. The specimen is about 70%
silt grains, 20% clay and 10% organic matter as matrix. The silt grains
are composed of quartz, plagioclase, K-feldspar, chert, muscovite, gar-
net, zircon, and epidote. An appropriate name for the rock would be a
feldspathic graywacke silt (T. S. #11). In the outcrop the rock appears
to be massive but upon closer examination it is minutely cross-bedded,
often with laminae less than 1/2 inch long.

Most of the siltstones of the Hell Creek Formation are non-lignitic
and contain large portions of clay. They often resemble very fine
sandstones with which they may easily be confused. They weather much
like the sandstones, forming steep slopes in badland territories.

SILTSTONES OF THE LUDLOW FORMATION COMPARED TO THOSE OF THE
HELL CREEK FORMATION

Two siltstones were studied from the Ludlow Formation. One was
mounted by sprinkling its powder on a slide with Lakeside 70 (T. S. #22).
The other was thin-sectioned (T. S. #47).

Slide number 22 was collected from the NW 1/4 sec. 26, T. 135 N.,
R. 61 W., Morton County, North Dakota. In outcrop the siltstone appeared
as a white bed a fraction to several inches in thickness and never over
2-1/2 inches in thickness. It was very widespread and was interpreted
as a volcanic ash by Laird and Mitchell (1942, p. 31). The writer thought it was a clay when it was collected for it was very plastic and thixotropic. Later when the sample dried out it became a loose dust unlike the cohesive solid typical of most clays. Settling velocities were observed and it was found to be composed of fine and medium silt with only very minor amounts of clay present. The slide of mounted material revealed under the microscope, quartz, feldspars, calcite, organic material, and clays. X-ray analysis indicated that almost no clays were present and that plagioclase, orthoclase, and quartz made up the bulk of the sample along with minor amounts of clay (undetermined) and calcite. No other bed similar to this bed has been found in the Fox Hills, Hell Creek, Tullock, Ludlow, or Cannonball beds studied by the writer. The only explanations the writer can entertain are that it is either a loess deposit caused by deflation of a large river bed during exceptionally low water or a flood overbank deposit of an exceptionally widespread flood covering many hundreds of square miles. The former seems more plausible to the writer because of the widespread thin nature of the deposits.

Thin-section number 47 is of a siltstone collected from sec. 16, T. 131 N., R. 82 W., Sioux County, North Dakota. The rock is 70% quartz grains, 5% chert grains, 2% muscovite grains, and minor amounts of biotite, pyroxene, plagioclase, K-feldspar, and volcanic grains. The rock is composed of 15% non-swelling clays, 5% zeolites (Clinoptilolite ?) and 3% organic material as a matrix. The rock is a feldspathic graywacke silt. The major difference between this siltstone and the one collected from the Hell Creek Formation (T. 8, #11) is in the amount of quartz. The silt from the Ludlow Formation is much more quartz-rich.
Perhaps of equal importance is the smaller quantities of chert in the Ludlow Formation. No sweeping conclusions should be made from these few thin-sections, but the absence of chert in the Ludlow Formation, at least the dark-colored chert, appears to be a distinctive characteristic.

**Shales of the Hell Creek Formation**

Only one shale was thin-sectioned (T. S. #55) from the Hell Creek Formation other than the bentonites previously mentioned. The shales of the Hell Creek Formation, although common, do not lend themselves well to thin-section studies because of their fine grained nature. Most of the Hell Creek shales are gray fissile bentonitic shales with or without plant remains. In addition to these shales there are finely fissile lignitic shales which are often very silty, dark purplish brown, and locally persistent in comparison with the gray shales.

The shale thin-sectioned (T. S. #55) was collected from the Crooked Horse of the Hell Creek Formation in the NW 1/4 sec. 18, T. 131 N., R. 78 W., Sioux County, North Dakota. The shale was collected because it contained the mineral jarosite. The shale was found to contain silt grains of quartz and feldspar though clay composed over 95% of the rock. Finally there was disseminated organic material, calcite, and jarosite. The jarosite was also found to be in clumps throughout the specimen and in fractures and was identified by X-ray analysis. It has been suggested by Waage (1961, p. 229) that jarosite is related by occurrence to glauconite in the Fox Hills Formation but no evidence for such a relationship was in the Hell Creek Formation. Jarosite occurs elsewhere as concretions in the formation where there is considerable evidence that it did not form with any connection to glauconite.
SHALE OF THE LUDLOW FORMATION COMPARED TO SHALES OF THE
WELL CREEK FORMATION

Because shales are too fine grained to work with under the petro-
graphic microscope only one of the Ludlow shales was thin-sectioned
(T. S. #45), although shales are very common. Two types of shales are
found in the Ludlow Formation; one, a gray clay shale with or without
plant remains, the other, a fissile, very lignitic shale, often silty.
A thin-section was prepared of the latter to compare it to similar
shales in the Well Creek Formation.

The lignitic shale was collected from sec. 31, T. 130 N., R. 88 W.,
Grant County, North Dakota. The shale is predominantly clay and lig-
nitic material but also is about 2% silt in the form of quartz, feld-
spar, biotite, and sericite. In addition there is limonite along the
fractures.

From studies of outcrops, hand specimens, and these few thin-
sections, it would appear that the lignitic shales of the Ludlow
Formation were less silty than those of the Well Creek Formation.
Otherwise there are very few differences.

SCORIA

Scoria is found rather extensively in the Ludlow Formation and
has a spotty distribution in the Tullock Formation of western North
Dakota. It is found as far east as western and central Sioux County
in the Ludlow Formation. The Well Creek, on the other hand, contains
no scoria anywhere in central and western North Dakota and eastern
Montana. The scoria is formed by burning of underlying coals which
bakes the shales and sandstones above to a natural brick or in many
cases generates sufficient heat to melt the sediments. Only one thin-
section was made of this very common pyrometamorphic rock because it
does not occur in the Nell Creek Formation. The sample thin-sectioned
was taken from the base of the Tullock Formation in the T 1/2 sec. 4,
T. 134 N., R. 106 W., Slope County, North Dakota where the "lowest per-
sistent lignite" has burned forming a "scoria" above it. The specimen
collected (T. 3, Sq8) was of natural brick. The texture was too fine
to study mineralogically under the petrographic microscope though one
could identify silt grains of quartz and feldspars composing about 12
of the rock. The remainder of the rock was apparently clays stained
with hematite. The latter gave the rock a 5 YR 7/4 bright orange color.

CONCRETIONS OF THE NELL CREEK FORMATION

Introduction

The Nell Creek Formation contains a variety of concretions and
nodules which may be classified according to their mineralogical com-
positions and forms. The concretions and nodules may be divided into
two groups: 1. those which contain mainly calcite--the calcareous
concretions and nodules, and 2. those which weather to limonite--the
"limonitic" concretions and nodules. The calcareous concretions and
nodules include calcareous sandstone lenses ("log" concretions), radial
calcareous concretions, fibrous calcareous lenses, calcite "roses,"
calcareous blebs, and calcareous nodules. The "limonitic" concretions
include the limonite concretions, jarosite concretions, gypsum-marcasite
concretions, marcasite nodules, and siderite nodules,
Calcareous Concretions and Nodules

Calcareous Sandstone Lenses

Calcareous sandstone lenses, known also as "log" concretions are very common in the Hell Creek Formation in southwestern North Dakota and eastern Montana. They occur, but are infrequent, in the Hell Creek Formation in central North Dakota. The largest ones are tens of feet long and may be several feet in diameter. They range in shape from egg-shaped to elongate log-like structures over 50 feet long. Beding and other sedimentary structures are usually preserved within these concretions. Three thin-sections were made of these concretions from the Hell Creek Formation (Figs. 16a and 16b).

Thin-section number 25 was taken from a calcareous sandstone lens in the SW 1/4 of sec. 33, T. 131 N., R. 105 W., Bowman County, North Dakota from the Harmanth member of the Hell Creek Formation. The concretion is about 35% calcite, both fibrous and sparry. The sparry calcite fills fractures which cut through the concretion. The sparry calcite is of particular interest because it contains biaxial calcite with a low 2V (less than 10°), and has an anomalous blue interference color. The included sand grains are composed of quartz, plagioclase, orthoclase, chert, and minor amounts of garnet, zircon, epidote, glauco-

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Figure 16a. Calcareous sandstone lenses showing crossbedding in the Huff Member of the Hell Creek Formation in NW 1/4 of sec. 25, T. 134 N., R. 106 W., Slope County, North Dakota.

Figure 16b. Thin-section of a calcareous sandstone lens from sec. 16, T. 131 N., R. 82 W., Sioux County, North Dakota. Calcite light colored, clays dark colored. Note elongate plagioclase grain broken by forceful growth of calcite. (X50)
feldspar laths would be broken. Because the feldspar laths were not in contact with other sand grains and their broken parts were not much reoriented with respect to one another, this was taken as evidence that the growth of the fibrous calcite had shoved the feldspar laths, breaking them by differential growth pressure. In other instances, plumose calcite, perpendicular to bedding, was noted between laminae in sandstones indicating that the calcite had grown between the laminae forcing them apart.

Thin-section number 26 was collected from the buff Member of the Hall Creek Formation in the SE 1/4 of sec. 11, T. 234 N., R. 32 W., Morton County, North Dakota. The specimen was taken from a calcareous sandstone lens in which the uninterrupted crossbedding extended through the calcareous lens into the sediments above and below. The concretion is 80% calcite which exhibits sparry (both fine and coarse grained) and fibrous habits. In many cases the calcite can be observed to have partially replaced silicate grains. In other instances fibrous growth of calcite on one side of the grains indicates that it was forcibly shoving the grain aside. In addition to the calcite the rock is 22% quartz grains, 7% plagioclase grains (An$_{26}$-An$_{67}$), 3% K-feldspar grains, 8% chert grains, and minor amounts of garnet, zircon, epidote, glauco- phase, biotite, muscovite, volcanic, siliceous schist, and quartzite.

The sample for thin-section number 34 was collected from the buff Member of the Hall Creek Formation in sec. 10, T. 131 N., R. 82 W., Sioux County, North Dakota. The specimen again was from a calcareous sandstone lens which showed no signs of the bedding being disrupted by the concretion. The specimen is about 75% calcite cement which has both fibrous and sparry habits. In addition the rock is 15% clay, 3%
quartz grains, 2% plagioclase grains, 11 K-feldspar grains, 4% chert grains, and minor amounts of muscovite, biotite, hornblende, epidote, sphene, zircon, apatite, garnet, organic matter, and limonite. Most of the silicate grains show some evidence of replacement by calcite. Again there is evidence of the grains of sand being pushed aside by the growth of calcite as indicated by the fibrous habit of the calcite, on only one side of the grain and broken sand grains (Fig. 16b).

It is difficult to explain a concretion over 75% secondary calcite which was developed in a sandstone almost without disruption of the bedding. The noticeable difference, other than the presence of calcite, between the concretions and the host rock, is the almost complete absence of clay in the concretions. Thus, if the calcite had completely replaced the clay, as it appears to have, then about 25% to 35% of the volume of the rock composed of calcite can be accounted for without moving sand grains. In addition, it will be noted that most of the concretions contain only a few per cent volcanic and chert grains while the sandstones of the Hell Creek Formation contain usually more than 50% chert and volcanic grains. It is therefore possible to assume that the calcite has replaced many of the chert and volcanic grains, especially since remnant grains are replaced to all degrees by calcite. If the chert and volcanic grains plus the clay have been replaced by the calcite, then the calcite has made room for itself without disrupting the bedding simply by replacement of existing rock. The sand grains that show signs of having been forcibly moved were only moved about their own diameters as indicated by the fibrous calcite. The intact bedding indicates that expansive growth of the concretion played a very small role in its development.
Radial Calcereous Concretions

Radial calcereous concretions were collected but not thin-sectioned from the Pretty Butte Member of the Hell Creek Formation in sec. 22, T. 131 N., R. 81 W., Sioux County, North Dakota. These were taken from the same bentonite as thin-section number 54. They are subspherical, sellarate, fibrous, calcereous concretions with a diameter between 2 and 6 inches. Their growth appears to be forceful causing disruption of bedding.

Fibrous Calcereous Concretionary Lenses

Fibrous, calcereous, concretionary lenses are a development of fibrous calcite, essentially between bedding planes with the fibers oriented normal to the bedding. Their thickness varies from a fraction to several inches with a diameter usually less than 2 feet. Occasionally several thin beds of sand may be included though generally the included beds are only several grains in thickness.

Thin-section number 27 of a fibrous, calcereous, concretionary lens was taken from the Huff Member of the Hell Creek Formation in the No 1/4 of sec. 23, T. 133 N., R. 82 W., Sioux County, North Dakota. This specimen is 95% calcite which is fibrous to fibro-plumose with fibers perpendicular to bedding. Included sand grains are composed of quartz, plagioclase, K-feldspar, chert, volcanic grains, muscovite, and biotite. The sand grains are floating isolated in the calcite in bands parallel to the bedding. Calcite has grown between layers in the bands of muscovite and biotite grains forcing the flakes apart. Many of the silicate grains show evidence of being replaced by the calcite.
Thin-section number 38, another fibrous, calcareous, concretionary lens, more weathered than thin-section number 27, was collected from T. 132 N., R. 82 W., Sioux County, North Dakota from the Huff Member of the Hell Creek Formation. The specimen came from a flaggy sandstone which was not lens-shaped but composed of a series of overlapping lenses. The thin-section is 80% fibre-plumose calcite with the fibers orientated perpendicular to the bedding. In addition the rock is 3% quartz grains, 4% plagioclase grains (An_{20}-An_{57}), 12% feldspar grains, 7% chert grains, 3% volcanic grains, and minor amounts of biotite, muscovite, epidote, clay, and organic matter (Fig. 17b). The forceful growth of calcite is well illustrated in the splitting apart of mica books, and the thin layers of sand separated by fibrous calcite. Calcite also replaces plagioclase feldspars (Fig. 17a).

Calcite "Roses" and Calcite Blebs

Calcite "roses" are interpenetrating disks of fibre-plumose calcite which superficially resemble a rose blossom. Most of these concretions are less than 2 cm. in maximum diameter. The calcite blebs are nondescript balls of fibrous calcite a few millimeters in thickness which may occur separately or in aggregates. Aggregates may be up to 6 cm. in diameter.

Thin-section number 33 was made from a calcite "rose" collected from the upper part of the Fort Rice Member of the Hell Creek Formation in sec. 32, T. 131 N., R. 81 W., Sioux County, North Dakota. This is the only locality where this type of concretion was found in abundance. The concretions are 99% calcite with the remaining portion of the concretion composed of included clay. The concretions appear fibrous when
Figure 17a. Thin-section number 38 showing a broken plagioclase crystal partially replaced by calcite. (X100)

Figure 17b. Thin-section number 38 showing volcanic grains partially replaced by calcite. Note zoned plagioclase crystals in partially devitrified glassy matrix. (X100)
the thin-section is parallel to the fibers and granular when across the fibers. Each "petal" of the calcite "rose" is composed of two layers of fibrous calcite radiating from the central plane.

Thin-section number 37 is of an aggregate of calcite blebs. It was collected from the Huff Member of the Hell Creek Formation in sec. 3, T. 132 N., R. 81 W., Sioux County, North Dakota. The thin-section appears to be composed of many tiny calcite balls from about 0.25 to 1 mm. in diameter. All of the calcite appears to be fine-grained with little structure except where the thin-section cuts through the center of a ball one can see that the calcite is fibrous and radiates from a sand grain sand-grain which acted as a nucleus for the growth of the calcite. The thin-section is 95% calcite and 5% included sand and silt. The sand and silt is composed of quartz, plagioclase, K-feldspar, chert, volcanic grains, and epidote. The sand and silt grains are partially replaced by calcite but the concretions appear to have expanded and made room for themselves by pushing the surrounding sediments aside.

Calcereous Nodules

Calcereous nodules are masses of calcite found in bentonites as sandstone-like lenses which probably originate by the growth of calcite in bentonites (T. S. #5 and #12) to a stage where the grains become interlocking.

Thin-section number 23 is from a calcereous nodule found in the Baco Creek Member of the Hell Creek Formation in sec. 2, T. 133 N., R. 105 W., Slope County, North Dakota. It is 90% calcite of a granular habit except where it surrounds clay balls. Here it is fibrous, forming a ring of fibrous calcite about 0.5 mm. thick around the clay balls.
In addition the nodule is 2% quartz grains, 3% feldspar, 4% chert grains, and traces of muscovite, biotite, epidote, and organic matter. This type of body is rare and was only collected from this one locality.

"Limonite" Concretions and Nodules

"Limonite" concretions and nodules, that is, these concretions and nodules which weather to limonite, are very common in the Hell Creek Formation and are represented by a large assortment of concretions and nodules. Minerals commonly present in these concretions and nodules are siderite, jarosite, marcasite, limonite, and gypsum. They include limonite concretions, jarosite concretions, gypsum-marcasite concretions, marcasite nodules, and siderite nodules.

Limonite Concretions

Truly limonite concretions, other than concretionary structures weathered to limonite, are rather rare in the Hell Creek Formation. This type of concretion was found only in the Breisen Member of the Hell Creek Formation in the NW 1/4 sec. 26, T. 136 N., R. 76 W., Emmons County, North Dakota. This concretion is composed of dark-yellowish-orange 10 YR 6/6 to moderate-yellowish-brown 10 YR 5/4 concentric shells of limonite with intervening shells of gypsum and sand. The thin-section (T. S. #40) is 50% limonite which occurs as partial shells with much included sand. Between the limonite shells there is gyspiferous sand. The gypsum composes about 12% of the concretions and cements the sand between the limonite shells. The remainder of the concretion is 62% quartz grains, 3% plagioclase grains, 20% chert grains, 20% glauconite pellets, and minor amounts of muscovite and biotite grains. Traces of a mineral which might be jarosite was found along fractures,
Jarosite Concretions

Jarosite concretions are found in two forms. The first may be described as being nodular, flattened, and irregularly tabular in shape. The second occurs as hollow, or clay and silt filled, egg-shaped to rod-shaped masses. The jarosite surrounds the mass like a bark of a tree or a shell of an egg. The layer of jarosite is usually about 3/8 of an inch thick and includes much sand.

Thin-section number 18, a flattened nodular jarosite concretion, was collected from the Fort Rice Member of the Hell Creek Formation in the NE 1/4 sec. 1, T. 132 N., R. 82 W., Sioux County, North Dakota, and is about 80% cryptocrystalline jarosite. In places the jarosite appears to be fibrous but most is granular. The remainder of the concretion is 2% quartz grains, 5% plagioclase grains (An\textsubscript{25}-An\textsubscript{74}), 32% feldspar grains, 10% chert grains, and minor amounts of epidote, zircon, muscovite, penninite, biotite, volcanic grains, and quartzite grains. In one very small portion of the concretion gypsum has replaced jarosite.

Jarosite has replaced the clay of the sediments and in some instances is found partially replacing silicate grains. Some of the jarosite probably made room for itself by pushing the surrounding sediments aside.

Thin-section number 31, of a hollow, egg-shaped, jarosite concretion, was taken from the Huff Member of the Hell Creek Formation in sec. 35, T. 130 N., R. 105 W., Bowman County, North Dakota. This type of concretion was noted only at one other locality (Fort Rice Member of the Hell Creek Formation, sec. 3, T. 129 N., R. 81 W., Sioux County, North Dakota). The central part of the concretion is filled with unconsolidated silt. The concretionary shell is about 60% jarosite which is fibrous to granular and cryptocrystalline. In addition, the
concretion is 10% quartz grains, 5% plagioclase grains (An$_{23}$-An$_{47}$), 5% K-feldspar grains, 20% chert grains, and minor amounts of muscovite, siren, volcanic grains, and organic matter. The sand grains are floating in the jarosite and an absence of clay would indicate that it has been replaced by jarosite. Many of the silicate grains also show partial replacement by the mineral jarosite (Fig. 18a).

Gypsum-Marcasite Concretions

Only one gypsum-marcasite concretion (T. S. 152) was thin-sectioned. This concretion was collected from sec. 22, T. 131 N., R. 81 W., Sioux County, North Dakota. This type of concretion is rather common and usually, as in this case, the marcasite has weathered out leaving only stains and white sulphate blooms. The outward appearance is that of a sub-spherical ball with a reticulate raised pattern of fractures filled with gypsum and a yellowish color from limonite stains. Included in the gypsum are masses of clay and sand grains of quartz, plagioclase (An$_{23}$-An$_{47}$), K-feldspar, chert, volcanic grains, muscovite, glaucomite, epidote, glaucophane, opalite, garnet, and siren. In addition, there are minor amounts of jarosite and organic matter. All grains are floating in gypsum which in some instances appears to be replacing the silicate grains. It is hypothesized that most of the gypsum is secondary after marcasite, or is filling fractures because little weathered concretions contain less gypsum and more marcasite. This hypothesis would not require the gypsum to replace either clay or silicate sand grains on any great scale and would permit concretion development without disruption of bedding.
Figure 18a. Thin-section number 31 showing a plagioclase grain partially replaced by jarosite (X100).

Figure 18b. Thin-section number 28 showing radial calcite around sand grains (X50).
Narcasite Nodules

Narcasite nodules found in the Hell Creek Formation were of two general forms. First, spherical masses from a fraction of an inch to several inches in diameter occur in the sandstones of western North Dakota and eastern Montana and second flattened Ophiomorpha-like masses found in one locality in central North Dakota.

The spherical narcasite masses were not thin-sectioned. They are sandy balls of narcasite which occur in sandstone bodies throughout the Hell Creek Formation in eastern Montana and somewhat less commonly in western North Dakota. They were not observed in central North Dakota.

The Ophiomorpha-like narcasite nodules (T. B. 936) were collected only from the Buff Member of the Hell Creek Formation in the cut bank of the Missouri River at the low water level in the SW 1/4 sec. 11, T. 137 N., R. 80 W., Burleigh County, North Dakota. The concretions are elongate flattened masses with numerous small spherical protuberances. The mostly opaque thin-section viewed in reflected light revealed several pellet-like masses within the nodules which might indicate that the shape of the nodule was organically controlled and was probably a burrow. The organic remains probably influenced the growth of the narcasite. The thin-section is about 50% narcasite as the concretionary mineral. In addition the rock is 15% quartz grains, 5% feldspar grains (plagioclase An$_{26}$-An$_{57}$), 10% chert grains, 10% volcanic grains with minor amounts of chalcedony, muscovite, and epidote grains and is about 12 clay matrix which occurs as patches between sand grains where it has not been replaced by the narcasite. The narcasite does not seem to have forced the sand grains apart, disrupting the bedding, but only to have replaced the clay matrix of the sand. In the field the
concretions are covered by a film of limonite and white soluble (?) sulphate which was lost during thin-sectioning.

Siderite Nodules

Siderite nodules are characteristic of the Hall Creek Formation. They are heavy elongate dark-brownish black nodules, ranging from a few inches to several feet in thickness and are found in almost every outcrop of the Hall Creek Formation. The color of the nodules is a result of a rind composed mainly of limonite and hence the names "limonitic" nodule, "limonitic" concretion, "ironstone" nodule, and "ironstone" concretion.

Thin-section number 20 was made from a rare type of siderite nodule from the Huff Member of the Hall Creek Formation in the SE 1/4 sec. 11, T. 134 N., R. 32 W., Morton County, North Dakota. The sampled nodule is 20 feet long, 1 foot wide, and 6 inches deep and occurs in a thick channel sand with several other similar nodules. In hand specimen the nodule appears to be a limonitic sandstone but the thin-section revealed it to be composed of tiny siderite rosettes surrounded by limonite weathered from the siderite. The nodule is difficult to explain since it does not disrupt the surrounding bedding in the sandstone. The bedding simply abuts sharply against the nodule.

The most common type of siderite nodule is composed of gray cryptocrystalline siderite with all admixtures of clay, silt, and sand which weathers with a dark-brownish-black 5 YR 2/1 rind. The rind is composed of (Abbott in Laird and Mitchell, 1942, p. 11):
The writer performed qualitative chemical tests upon the gray interiors of several nodules and found iron, manganese, calcium, and carbonate ions along with silica. It is suspected that the calcium and the manganese shown by test are present as a substitute for iron in the mineral siderite, perhaps forming oligonite. The SiO₂ is present in clay, silt, and sand found as impurities in the nodules. Many of the siderite nodules contain impurities of fossil matter such as wood, leaves, snails, clams, and bones in addition to the sand, silt, and clay. Often this is the only place these fossils are preserved.

Thin-section number 21 was taken from a typical siderite nodule collected from the Huff Member of the Hell Creek Formation in the SW 1/4 sec. 10, T. 129 N., R. 81 W., Sioux County, North Dakota. The nodule is about 86% cryptocrystalline siderite, 10% limonite and manganese oxides, 12 silt, and 1% organic matter. The limonite occurs as a rind and as patches in the interior where impressions of plant fossils have developed porosity which allowed the interior to weather. The silt grains are composed of feldspars, chert, epidote, zircon, and muscovite.

Thin-section number 14 was made from a nodule collected from the Huff Member of the Hell Creek Formation in T. 132 N., R. 105 W., Bowman County, North Dakota. The nodule is a dusky-yellowish-brown 10 YR 2/2. The nodule is about 50% limonite matrix, 2% calcite fossil mold fillings, 3% quartz grains, 2% plagioclase grains (An₂₅-An₆₇), 5% K-feldspar grains, 25% chert grains, and minor amounts of muscovite, perminite.
epidote, and volcanic sand grains. The distribution of sand grains indicates either bedding or flowage or both. Sares (1928, p. 21) said that none of the specimens collected from these concretions showed bedding planes, however, the writer has found that most of the sandy specimens exhibit bedding or flow structure, at least where observed in thin-section. The lack of siderite in this specimen is explained by its sandy, porous nature which allowed the siderite to weather very rapidly when the concretion neared the surface. The calcite which filled the fossil molds is considered to be a very late event, perhaps so late as to be a surface phenomenon.

Thin-section number 44 was made from a nodule collected from the lower part of the Huff Member of the Bell Creek Formation in the SW 1/4 sec. 10, T. 129 N., R. 61 W., Sioux County, North Dakota. The thin-section of the concretion is 80% limonite matrix, 4% quartz grains, 3% plagioclase grains, 2% K-feldspar grains, 10% chert grains, and 1% calcite and a trace of zeolites (clinoptylolith?) present as fillings of the molds of fossils. Again, as in the nodule of thin-section 14, the sand content of the nodule has increased the porosity so that all of the siderite has weathered to limonite. The included molluscan fossils, wood fragments, and sand grains give a lineation in the hand specimen that gives the specimen the appearance of having been rolled up while still in the plastic condition.

Thin-section number 13 was made from a peculiar variation of a siderite nodule collected from the Huff Member of the Bell Creek Formation in sec. 35, T. 130 N., R. 105 W., Bowman County, North Dakota. The nodule is a dark-yellowish-brown 10 RY 4/2 in color and is covered with yellow dots about 2 mm. in diameter which, in some cases, weather out.
forming a scoraceous appearing mass. The thin-section is about 40\% limonite matrix, 40\% radiating fibrous calcite which forms the yellow
dots, 12\% quartz grains, 2\% feldspar grains, 5\% chert grains, and a trace
of muscovite and aicron silt grains. The silt grains exhibit flow struc-
ture or bedding although they are floating in the limonitic matrix. The
growth of the calcite was forceful, pushing the silt grains aside (Fig.
19) and the bedding planes or flowage planes bend around each rosette
of calcite. The nodule was probably originally a siderite nodule which
weathered to limonite and the calcite growth was much later and may have
been a near surface phenomenon.

There appears to be considerable evidence that the common type of
siderite nodule was formed early in the history of the Bell Creek sedi-
ments. In the field there is no evidence that the nodules forced the
enclosing strata apart as the bedding seems to be broken off sharply at
the contact with the nodules. Nodules tend to be found along bedding
planes between sedimentary units although they are also found within
sedimentary units. They have been observed to grade laterally into ligo-
nitic shales. They often include fossil matter although the surrounding
sediments are apparently barren. Conglomerates composed of fragments
of the same material as the nodules may grade laterally into beds of
siderite nodules. The conglomerates also contain foreign quartzite
pebbles. Sand grains and other included matter often show what could be
interpreted as lines of flowage. This evidence would indicate that the
nodules formed on the bottom at the sediment-water interface, probably
as a jell. Current action then formed the variants of these nodules by
rolling them on the bottom and incorporating sand and fossils or break-
ing them up to form conglomerates.
Figure 19. Thin-section number 13 showing radial growths of calcite in a limonite matrix. (X40)
Siderite nodular beds are also found in the Breien Member of the Hell Creek Formation. These beds contain siderite nodules which appear to be primary siderite or iron-rich calcite and are interbedded with glauconite sands. In addition to this primary siderite secondary siderite fills Ophiomorpha major tubes.

Thin-section number 42 was taken from a nodular siderite bed in the Breien Member of the Hell Creek Formation in the NE 1/4 sec. 6, T. 136 N., R. 79 W., Morton County, North Dakota (Fig. 20b). The bed sampled is a moderate-olive-brown 5 4 4/4 to a yellowish-brown 10 YR 4/4. The siderite is patchy in distribution and comprises about 50% of the rock, the remainder of which is a glauconite sand. Glauconite comprises about 20% of the rock and is mixed with grains of quartz, plagioclase (An21-An55), K-feldspar, chert, volcanic grains, biotite, muscovite, and epidote. Gypsum occurs within fractures and comprises about 1% of the rock. The pellets of glauconite range up to a millimeter in diameter, are lobe shaped and often have the appearance of micro-fossils. In many cases the glauconite grains have shrunk so that they no longer fill the original cavity. Some of the glauconite is vermicular and exhibits a high birefringence indicating that perhaps it has been altered from biotite (Fig. 20a). Limonite stains the rock and locally has replaced fossils such as Ostrea glabra. The overall rock has the appearance of having flowed because the glauconitic sands seem to have been folded into the siderite. This relationship indicates some type of slumping, probably on the bottom of a lagoon, and would necessitate much of the siderite being primary. This hypothesis is further supported by siderite fecal pellets (Fig. 20b) which are probably droppings
Figure 20a. Thin-section number 42. Note two types of glauconite. Large grain has well developed crystallinity and cleavage. Smaller grains are very fine grained and have poor crystallinity. (X40)

Figure 20b. Thin-section number 42 of siderite pellets in siderite matrix. Note glauconite grain—lower left. (X40)
from animals living upon and in the siderite ooze. Some of the siderite appears, however, to be secondary, especially that which is found in the Ophiomorpha major tubes. The replacement of Ostracidae shells by limonite also indicates indirectly that some of the siderite was secondary having replaced the shell material before it weathered to limonite.

CONCRETIONS AND NODULES OF THE TULLOCK, LIDLAW, AND TONGUE RIVER FORMATIONS COMPARED TO THOSE OF THE HELL CREEK FORMATION

Introduction

The concretions of the Ludlow, Tullock, and Tongue River Formations are similar to those found in the Hell Creek Formation. These formations, like the Hell Creek Formation, have concretions and nodules that are calcareous and limonitic.

Calcareous Concretions and Nodules

Calcareous concretions from the Tullock, Ludlow, and Tongue River Formations like those of the Hell Creek Formation consist of calcareous sandstone lenses ("log" concretions), nodular limestone beds, and fibrous stellite calcite concretions.

Calcareous Sandstone Lenses

A series of thin-sections were made of a "log" shaped calcareous sandstone lens with the intent of determining its origin. A typical concretion was chosen from the middle of the Tullock Formation in sec. 28, T. 135 N., R. 106 W., Slope County, North Dakota. Three thin-sections were made, one from the middle of the concretion (T. S. #10), one from the base of the concretion (T. S. #9), and one from the sand below
the concretion (T. S. 216). The result of the mineralogic study is shown in Table 5.

From Table 5 one can see that the calcite has replaced all of the clay which is about 40% of the original sediment. It has also replaced most of the chert and volcanic grains which may have been about 25% of the original sediment. The loss of chert, volcanic grains, and clay through replacement by calcite could account for 65% of the concretion being calcite. Because the concretion is 80% to 90% calcite it is postulated that some of the calcite has crystallized in place and has expansively forced the sediments apart. This expansion is not noticeable in the outcrop as the bedding appears to continue through the lense with no interruption despite the gross lithologic changes.

If the calcite has replaced the clay, chert, and volcanic grains, there should be some evidence for this in the thin-sections. One can only surmise the clay has been replaced for it is missing in the concretions. However, one can find relic chert grains that are partially replaced by calcite. Relic volcanic grains can be found with the feldspar phenocrysts partially replaced and the groundmass almost completely replaced by calcite. Other common silicate grains appear to have been replaced only along their margins and along their cleavage traces.

All of the "log" concretions are oriented parallel to one another within a single sandstone channel (Figs. 21a and 21b) and most of the "log" concretions within a given group of beds are subparallel. This common orientation would indicate that their deposition was controlled by primary sedimentary structures. Cross-bedding indicates that they are oriented parallel to the direction of currents which deposited the channels and they thus may be useful for determining directions of
**TABLE 5. A comparison of mineral content of samples taken from the middle, base, and below a calcareous sandstone lense of a log-shape.**

<table>
<thead>
<tr>
<th>Center of Concretion</th>
<th>Base of Concretion</th>
<th>Sand below Concretion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MATRIX</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>clay ................. 0%</td>
<td>clay ............... 0%</td>
<td>clay ............... 40%</td>
</tr>
<tr>
<td>calcite ............. 90%</td>
<td>calcite ........... 80%</td>
<td>calcite ........... tr.</td>
</tr>
<tr>
<td>organics ............ tr.</td>
<td>organics ........... tr.</td>
<td>organics ........... 1%</td>
</tr>
<tr>
<td><strong>MINERAL SAND GRAINS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>quartz ............ tr.</td>
<td>quartz ............ 2%</td>
<td>quartz ............ 10%</td>
</tr>
<tr>
<td>plagioclase ....... 2%</td>
<td>plagioclase ....... 6%</td>
<td>plagioclase ....... 10%</td>
</tr>
<tr>
<td>(An\textsubscript{25}-An\textsubscript{47})</td>
<td>(An\textsubscript{31}-An\textsubscript{50})</td>
<td>(An\textsubscript{29}-An\textsubscript{63})</td>
</tr>
<tr>
<td>orthoclase .......... 2%</td>
<td>orthoclase .......... 2%</td>
<td>orthoclase .......... 10%</td>
</tr>
<tr>
<td>biotite ........... tr.</td>
<td>biotite ........... tr.</td>
<td>biotite ........... tr.</td>
</tr>
<tr>
<td>muscovite ........ tr.</td>
<td>muscovite ........ tr.</td>
<td>muscovite ........ tr.</td>
</tr>
<tr>
<td>epidote ........... tr.</td>
<td>epidote ........... tr.</td>
<td>epidote ........... tr.</td>
</tr>
<tr>
<td>zircon ........... tr.</td>
<td>zircon ........... tr.</td>
<td>zircon ........... tr.</td>
</tr>
<tr>
<td><strong>ROCK SAND GRAINS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>chert ........... tr.</td>
<td>chert ........... 10%</td>
<td>chert ........... 25%</td>
</tr>
<tr>
<td>volcanics ....... tr.</td>
<td>volcanics ....... tr.</td>
<td>volcanics ....... tr.</td>
</tr>
<tr>
<td>quartzite ....... tr.</td>
<td>quartzite ....... tr.</td>
<td>quartzite ....... tr.</td>
</tr>
<tr>
<td>schist ........... tr.</td>
<td>schist ........... tr.</td>
<td>schist ........... tr.</td>
</tr>
</tbody>
</table>
Figure 21a. "Log" concretions in the lower Tullock Formation in sec. 33, T. 133 N., R. 106 W., Slope County, North Dakota.

Figure 21b. "Log" concretions in the lower Tullock Formation in sec. 33, T. 135 N., R. 106 W., Slope County, North Dakota.
paleo-drainage. It is postulated that perhaps greater permeability of the sediments in zones parallel to direction of drainage may have controlled the flow of ground water through the sediments and thus the precipitation of the concretion-forming calcite.

The concretions probably formed late in the history of the beds since there is no sign of compaction of sediments around them. The source of calcite is difficult to determine though it is postulated that much of it came through the devitrification of volcanic glass which produced the bentonite common in these sediments. Additional sources might include the solution of rather calcic plagioclase which abounds in these sediments.

Thin-section number 28, from another "log" concretion, was collected in the Tullock Formation in sec. 28, T. 133 N., R. 105 W., Slope County, North Dakota (Fig. 18b). The piece sectioned came from near the upper edge of the concretion and was very similar to thin-section number 9, just described. The rock is 75% calcite, 2% quartz grains, 5% plagioclase grains (An$_{22}$-An$_{35}$), 3% K-feldspar grains, 10% short grains, 5% volcanic grains, and minor amounts of muscovite, biotite, chlorite, chaledony, epidote, sphaera, zircon, quartzite, and siliceous schist grains. The chlorite appears to be an alteration product of some of the volcanic grains.

"Log" concretions occur in the Ludlow Formation but differ from those in the Hall Creek and Tullock Formations by being laterally more continuous and tending to form sheets. They are thicker, being as much as 6 feet thick at some localities, and have a tendency to weather to somewhat flaggy sandstone ledges. Thin-section number 56 was taken from
one of these concretions in the SE 1/4 of sec. 3, T. 136 N., R. 78 W.,
Emmons County, North Dakota. The concretionary lenses are a grayish-
orange 10 yr 6/4 and are about 85% granular to fibrous calcite. The
remainder of the rock is 3% quartz grains, 2% plagioclase grains, 1%
K-feldspar grains, 5% chart and quartzite grains, and 2% volcanic grains,
and minor amounts of glauconite (pellets), penninite, biotite, muscovite,
and epidote sand grains and about 2% interstitial organic matter.
The presence of glauconite may indicate that these structures developed
in tidal channels and not river channels as did those of the Ball Creek
and Tullock Formations. The growth of the calcite seems to have been
accomplished by replacement of silicate grains and to some degree by
pushing aside the sediments. This is indicated by partially replaced
silicate grains, the absence of clay, and the fibrous growth of calcite
on only one side of a sand grain.

The basal sandstone of the Tongue River Formation appears to be
much thicker and much more continuous, being composed of a concretionary
sandstone similar to those just discussed. Thin-section number 40 was
made from a sample collected from just south of the town of Flasher,
Grant County, North Dakota, where this bed occurs in the butte tops.
The thin-section is 60% granular to fibrous calcite as the concretionary
mineral. In addition the rock is 10% quartz grains, 5% plagioclase
grains (An₄₂–An₄₅), 5% K-feldspar grains, 15% chart grains, 5% volcanic
grains, and minor amounts of glauconite (as pellets), hornblende, biotite,
muscovite, garnet, and zircon grains. It is not known whether the glau-
conite indicates a marine phase in the basal Tongue River Formation or
is reworked from the underlying Cattenball Formation. The glauconite
does not appear to have been transported very far for it is still as smooth pellets (Light, 1952, p. 72).

**Redular Limestone Beds**

Several isolated nodular limestone beds, 1 to 3 inches thick, were found in the Tullock Formation. They weather to a rusty-brown surface but are light-gray in fresh surfaces. Thin-section number 8 was cut from a sample taken from one of these beds in the lower part of the Tullock Formation in T. 133 N., R. 108 W., Slope County, North Dakota. The bed is about 98% calcite which is granular to fibrous. Minor amounts of quartz, plagioclase, K-feldspar silt grains and organic matter are present. The silicate grains are very fresh but have been nearly replaced by the calcite. The external form of the beds is smooth and the beds are continuous but thin which would suggest that they are primary (not concretionary), having developed upon the bottom of a body of water. Later during their diagenetic history they have become in part concretionary through recrystallization and perhaps through the addition of more calcite.

**Fibrous Stellate Calcite Concretions**

Fibrous, stellate, calcite concretions from a few inches to more than 2 feet in diameter are found in a bentonite in the lower part of the Tullock Formation in southwestern North Dakota. Calcite radiates in large fibrous spars from the centers of the concretions, and from a distance the mass looks like petrified wood.

Thin-section number 6 was cut from one of these concretions taken from sec. 4, T. 133 N., R. 103 W., Slope County, North Dakota. The thin-section is nearly 100% fibrous calcite with minor amounts of
included clay and organic matter. The calcite fibers are nearly perfectly parallel.

Thin-section number 7 was made from a fibrous stellate calcite concretion from the same bentonite as thin-section number 6 but from T. 134 N., R. 106 W., Slope County, North Dakota. The thin-section is calcite which radiates from a center and exhibits a plumose habit. Included within the concretion are very minor amounts of clay and organic matter. The blebs of clay appear to be concentrated between bundles of radiating, plumose fibers of calcite.

"Limonitic" Concretions and Nodules

The "limonitic" concretions and nodules found in the Tullock and Ludlow Formations are very similar to those found in the Hell Creek Formation, especially those found in the Tullock Formation and in the Lebo bed of the Ludlow Formation. "Limonitic" concretions and nodules found in these beds include gysiferous concretions, jarosite concretions, marcasite concretions, and siderite nodules.

Only one thin-section was made from this group of concretions. This was taken from a marcasite concretion (T. 8, §46) found in the Ludlow Formation in sec. 18, T. 135 N., R. 82 W., Grant County, North Dakota. The thin-section is 50% marcasite which occurs as the concretionary mineral. The concretion contains much sand which is evenly dispersed throughout the thin-section and individual grains appear to be in contact with each other. In addition to marcasite, the rock is 10% quartz grains, 7% plagioclase grains (An25–An31), 3% K-feldspar grains, 20% chert grains, 10% volcanic grains, and minor amounts of muscovite, epidote, quartzite, and mica schist grains. There are minor
amounts of included clay where it has not been replaced by marcasite. The thin-section very much resembled the thin-section of the marcasite concretion from the Hell Creek Formation (T. S. J36) but the marcasite concretion from the Ludlow Formation was elongate and nodular. The marcasite in this concretion, as in the Hell Creek concretion, appears to have made room for itself by replacing clay and perhaps by some slight expansive growth.

HEAVY MINERALS

Introduction

Sand was collected and studied for its heavy mineral content from the Fox Hills, Hell Creek, Tullock, Ludlow, Cannonball, and Tongue River Formations in hopes that this study might have some stratigraphic significance. The study, in general, proved inconclusive for correlation purposes but yielded some important facts about the sedimentary history of the Hell Creek Formation as well as giving some important information concerning the sources of sediments (Appendix C).

Twenty-three different translucent or transparent heavy mineral species were recognized, plus additional opaque components which consisted mostly of magnetite, ilmenite, and some unidentified grains. Since many of the minerals displayed multiple habits and colors it was possible to divide this group of 23 basic minerals into 55 different species and subspecies (Appendix C).

Samples were collected from five geographic locations: Hell Creek State Park, Garfield County, Montana (type area for the Hell Creek Formation); Makoshika State Park, Glendive, Dawson County, Montana; Slope and Bowman Counties, North Dakota; Sioux County, North Dakota; and
Emmons County, North Dakota. These collections gave a cross-section of the sediments from northwestern Montana to southwestern North Dakota to southcentral North Dakota.

**Laboratory Procedures**

Sieving of the sands for study was found to be unnecessary because they were so fine grained that no sand grain was too large for use. The samples were washed in a solution of sodium bicarbonate and water to free them from the frequently bentonitic clay matrix. By decanting the clay, and most of the silt, one rapidly obtains the fine and medium sand which was then dried. Samples were not washed in dilute HCl to remove carbonates and limonite because the heavy mineral suite contained soluble minerals such as apatite. Most of the samples contained very little carbonates or limonite which if present occurred as a cementing agent.

A small number of samples contained aggregate grains cemented together by limonite but these aggregates were removed by sieving. The heavy mineral fraction of the sand grains was separated from the sample by using the heavy liquid tetrabromomethane with a specific gravity of 2.955 to 2.965.

Part of the heavy mineral fraction from each sample was mounted in Lakeside-70 on a glass slide. The remaining portion of the sample was retained for inspection under the binocular microscope and for identification by oil immersion methods under the petrographic microscope. From each prepared slide 300 mineral grains were identified and counted.

**Description of Mineral Suite**

**Amphiboles:** Amphiboles are common but tend to be spotty in distribution and their abundance appears to be controlled by sedimentation
factors rather than source areas. Where they occur, they are almost always the dominant heavy mineral present.

Six different amphiboles were recognized on the basis of color and habit: reddish-brown, brown, green, pale-greenish-brown (hornblendes), clear (tremolite), and bluish-green (?paragasite). In addition to these, the mineral glauco phane was recognized.

The green hornblende has a fibrous to splintery cleavage and shows pleochroism X = yellow-green, Y = moderate-green, and Z = dark-green. The brown hornblende exhibits a hackley cleavage and shows pleochroism X = straw-yellow, Y = greenish-brown, and Z = brown. The pale-greenish-brown hornblende exhibits a hackley cleavage and shows pleochroism X = pale-yellow, Y = pale-brown, and Z = pale-greenish-brown. The reddish-brown hornblende has a coarse splintery cleavage and exhibits pleochroism X = orange, Y = orangish-brown, and Z = dark-reddish-brown.

The ?paragasite appears to have secondary overgrowths upon coarse cleavage fragments. There are no dust rings but the splinters of cleavage grains appear to have developed crystal faces. The mineral shows pleochroism X = greenish-yellow, Y = emerald-green, and Z = greenish-blue. The tremolite exhibits a hackley to fibrous cleavage and is without pleochroism. It has a small extinction angle equal to approximately 10°. The mineral glauco phane exhibits coarse splintery cleavage and is often filled with opaque inclusions. It shows pleochroism X = neutral, Y = violet, and Z = blue.

**Andalusite**: Andalusite is found in minor amounts in many samples. It generally occurs as well rounded water worn grains that are partially altered. The grains show no pleochroism and are usually full of inclusions.
Apatite: Apatite is one of the common heavy minerals found in the upper Cretaceous, and lower Paleocene sediments of western and central North Dakota and eastern Montana. It is nearly always present and occasionally composes appreciable percentages of the sample. In one sample it composed 17% of the total sample of heavy minerals.

The mineral occurs as both highly rounded grains and as fresh, sharp, euhedral crystals displaying complex pyramidal terminations cutting first and third order prisms and pinacoids or more simple crystals displaying first order prisms, and dipyramids, and a pinacoid. Many of the crystals are so perfect that they appear to have suffered no abrasion. The apatite grains come in a variety of colors: clear, reddish-orange, green, brown, and lavender. Some of the colored varieties show marked pleochroism.

The clear apatite crystals usually exhibit the most complex crystallography. The smaller grains show the greatest degree of crystal perfection with the smallest amount of breakage and rounding. Reddish-orange apatite occurs randomly throughout the stratigraphic section and always in very small quantities. It usually occurs as round euhedral crystals without pleochroism. The crystal often shows etching from partial solution of the grains. Green apatite is always granular and very fine grained and it would appear that this variety is always authigenic. Because of the fine grained nature of this species the aggregate grains are translucent, not transparent, to transmitted light. Brown apatite is rare, seldom constituting a measurable quantity of the sample. Its distribution is random, perhaps only reflecting its rarity. The crystals are usually euhedral and somewhat rounded. It is pleochroic
ranging in color from brown to orangish-brown. Pleochroic apatite may readily be distinguished from tourmaline by its low birefringence. The lavender apatite occurs as somewhat rounded euhedral crystals with a simple crystal habit. Pleochroism is variable from almost none to shades varying from yellowish-brown to lavender.

Biotite: Biotite is one of the most common heavy minerals encountered and its occurrence appears to be controlled by sedimentologic factors rather than source regions. Biotite and amphibole grains appear to be nearly mutually exclusive, each being the dominant mineral where it appears. This phenomenon appears to represent current velocities at the time of deposition, the biotite being deposited by the slowest currents, the amphibole by faster currents.

The biotite grains usually have their largest diameter more than twice the diameter of associated grains. Grains range from irregular flakes to nearly perfect hexagonal plates. Biotite comes in many colors: red, green, brown, black. The red biotite has the largest, but still small 2V angle of nearly 15°. Brown biotite has an intermediate 2V angle and green biotite has the smallest 2V angle which gives it the appearance of being uniaxial. Black biotite was opaque even in the thinnest books and therefore the 2V angle could not be measured.

Much of the biotite may be of volcanic origin because it is a very common constituent of bentonites studied. Most of the bentonites have only one color of biotite present which might enable one to trace the different colored biotites to a particular eruption or series of eruptions.

Calcite: Calcite occurs in a few of the sands as cleavage fragments or rhombohedral crystals (?). Calcite often forms the matrix of
calcaceous sandstone lenses but this cement does not appear to be the source of these grains and it appears that these calcite grains are related in origin to the isolated calcite crystals found in some bentonites.

Climaxolite: This mineral occurs as cleavage fragments and is identified by its anomalous interference colors, relief, and habit. Climaxolite has a relatively ubiquitous distribution but composes a very small portion of the sample.

Corundum: Corundum is a very rare mineral in these sediments. It occurs as blue basal plates and mottled yellow fragments.

Epidote: Epidote is perhaps the most common heavy mineral found and is present in every sample studied for its heavy mineral content. Epidote occurs in two distinct habits, as crystals, crystal fragments, and cleavage fragments and as fine-grained aggregates which are semi-translucent except near their margin where they can be seen to be comprised of numerous small grains. The fine-grained epidote appears to authigenic. Epidote can readily be recognized by its yellowish-green color, high relief, and relatively high birefringence.

Garnet: Garnet is a common but never abundant constituent of the sediments studied. Garnet occurs clear and in a number of colors: red, orange, pink, and bluish-brown. The red and orange garnet occurs as angular fragments, the bluish-brown garnet as partly rounded euhedral crystals to sharp non-rounded euhedral crystals, and the clear garnet as angular fragments with numerous opaque inclusions.

Jarosite: Jarosite occurs as aggregate grains and as cement. It has a spotty distribution. The aggregate grains are opaque except for
translucent edges. Under high magnification, it is a greenish-yellow mineral with very high relief, and high birefringence.

**Kyanite:** Kyanite is a rare mineral in the suite studied and has a spotty distribution. It occurs as slightly rounded pinacoidal cleavage fragments. Under the binocular microscope it appears pale-blue but in transmitted light it is colorless.

**Limonite:** Limonite is a very persistent constituent of the heavy mineral suite but only occasionally comprises appreciable amounts of the sample. It is nearly opaque but strong transmitted light filters through the edges which are translucent and they appear orange, orangish-brown, or yellowish-brown. Under high magnification aggregations of grains can be seen to be composed of very small and fine-grained crystals with very high relief.

**Magnetite:** Magnetite occurs as small rounded opaque grains about one half the diameter of most of the other heavy mineral grains present. The grains are usually anhedral but occasional rounded crystal forms occur. Magnetite is nearly always present as a minor constituent in the sample.

**Marcasite:** Marcasite was encountered only in one sand sample, but it frequently occurs as concretions in the Hell Creek Formation. In reflected light it is yellow and exhibits a fibrous habit.

**Pseudomorphite:** Pseudomorphite occurs as ragged flakes and is most frequently in those samples which contain large amounts of biotite. It is green in transmitted light, and frequently shows anomalous "Berlin blue" interference color in polarized light. The grains are often bent, giving an
unidirectional extinction. The ST angle is always small; the mineral appears uniaxial.

Talc: Talc occurs throughout the section in very minor amounts and is often absent from any given sample. It occurs as dark red grains with extremely high relief and parallel extinction.

Sphene: Sphene is nearly ubiquitous in the samples studied, although never composing a large percentage. The mineral is found in several colors: honey-colored, orange, wine-red, and clear. All of the grains show a well developed cleavage and little or no rounding from abrasion.

The honey-colored sphene exhibits pleochroism X = nearly colorless, Y = pale-yellow, and Z = honey-colored. The orange sphene exhibits pleochroism X = pale-yellow, Y = honey-yellow, and Z = dark-yellowish-brown. The wine-red sphene exhibits very slight pleochroism in shades of deep red and brownish-red. The sphene grains may be quickly recognized by their shape, relief, birefringence and pleochroism.

Siderite: Siderite was found at several localities and occurs as subhedral grains. Siderite can readily be distinguished from the other carbonates by the presence of the iron oxides that develop with weathering.

Sillimanite: Sillimanite occurs infrequently in the sediments sampled. It occurs as well rounded oblong grains with a fibrous habit.

Staurolite: Staurolite occurs as highly altered, well rounded, slightly pleochroic grains.

Tourmaline: Tourmaline is a very common mineral in the samples studied but never composes appreciable portions of the heavy mineral
samples. It occurs in six varieties and habits: metallic blue, subhedral, slightly rounded prisms; brown, anhedral, well rounded grains; brown, anhedral grains that show little or no rounding; black, subhedral, moderately rounded, nearly opaque grains; green, anhedral to well rounded grains; and lavender to brownish-lavender, subhedral, slightly rounded grains.

Table 6 shows the pleochroism exhibited by the different colored tourmaline grains. Tourmaline is easily recognized by its high relief, parallel extinction, high birefringence, and extreme pleochroism.

Zircon: Zircon is another nearly ubiquitous mineral species found in the heavy mineral samples which often composes several percent of the minerals present. Zircon grains occur in five varieties: clear, red to orange, ruby red, light-brown to yellow, and lavender to lavender-brown. Clear, white zircons are more common than all other species. The crystals are primarily first order dipyrmaids and prisms, with prisms being the dominant form. Most of the colored crystals are slightly rounded though some are sharp, whereas, most of the clear crystals are sharp or only very slightly rounded. Occasionally clear well rounded zircon grains are found. All zircon crystals showed at least some of their faces. The zircon grains showed no pleochroism or were only very faintly pleochroic in thick deeply colored grains.

Unidentified mineral grains: In several samples there are occasional single grains which were not identified because of their rarity.

Possible Sources for the Heavy Minerals

To determine the nature of the source areas and the possible regions which may have contributed the bulk of the sediments, the heavy
TABLE 6. Pleochroism exhibited by tourmaline crystals collected from upper Cretaceous and lower Paleocene sediments in North Dakota and eastern Montana.

<table>
<thead>
<tr>
<th>Basilin</th>
<th>Omega</th>
</tr>
</thead>
<tbody>
<tr>
<td>brown</td>
<td>black</td>
</tr>
<tr>
<td>blue-gray</td>
<td>brownish-blue</td>
</tr>
<tr>
<td>greenish-brown</td>
<td>brown to opaque</td>
</tr>
<tr>
<td>pale-green</td>
<td>brown</td>
</tr>
<tr>
<td>pale-lavender</td>
<td>lavender-brown</td>
</tr>
</tbody>
</table>
minerals found are organized into the following possibly genetically related groups (Ford, [Dana], 1958).

Minerals of the Igneous Rocks

Pegmatites and hydrothermal veins

Apatite
Biotite
Corundum
Garnet
Jarosite
Magnetite
Marcasite
Penninite
Tourmaline

Quartz-bearing Igneous Rocks

Amphiboles
Glaucophane
Hornblende
Fayalite
Apatite
Biotite
Epidote
Garnet
Ilmenite
Magnetite
Rutile
Sphene
Zircon

Quartz-saturated or Quartz-deficient Igneous Rocks

Amphiboles
Glaucophane
Hornblende
Fayalite
Apatite
Clinohumite
Corundum
Epidote
Garnet
Ilmenite
Magnetite
Rutile
Sphene
Zircon
Minerals of Metamorphic Rocks

Contact Metamorphic Minerals of Aluminous Rocks

Amphibole
  Hornblende
Andalusite
Apatite
Biotite
Corundum
Carnet
Ilmenite
Magnetite
Rutile
Tourmaline

Contact Metamorphic Minerals of Carbonate Rocks

Apatite
Biotite
Calcite
Corundum
Carnet
Ilmenite
Siderite
Tourmaline

Regional Metamorphic Minerals (Low Grade Metamorphism)

Calcite
Clinohumite
Epidote
Ilmenite
Magnetite
Penninite
Rutile

Regional Metamorphic Minerals (Intermediate Grade Metamorphism)

Amphiboles
  Caenohumite
  Hornblende
Apatite
Biotite
Calcite
Clinohumite
Epidote
Carnet
Ilmenite
Magnetite
Rutile
Regional Metamorphic Minerals (High Grade Metamorphism)

- Amphiboles
  - Glaucophane
  - Hornblende
- Apatite
- Biotite
- Calcite
- Clinomosite
- Epidote
- Garnet
- Ilmenite
- Kyantite
- Magnetite
- Rutile
- Sphene
- Sillimanite
- Staurolite
- Tourmaline
- Zircon

Minerals of Sedimentary Rocks

Authigenic Minerals

- Amphiboles
  - Pargasite
- Apatite
- Calcite
- Epidote
- Jarosite
- Limonite
- Marcasite
- Siderite

The lists above show that the heavy minerals collected have possible igneous, metamorphic, and sedimentary origins. It is also apparent that many of the mineral species in the samples studied could occur in several provinces.

Study of possible lithologic sources of the mineral grains collected indicates the following origins for the heavy minerals identified:

Amphiboles:

Glaucophane: This amphibole is primarily a metamorphic mineral which is found in regions of highly metamorphosed igneous alkaline rocks.
Hornblende: Most of the hornblende grains are probably igneous and more particularly volcanic in origin because they are very fresh cleavage fragments found associated with and in volcanic ash and bentonites.

Pargasite: Nearly every grain of pargasite encountered showed evidence for secondary overgrowths, indicating a partial authigenic origin. The original grains probably had an igneous origin.

Apatite: Apatite occurs in several habitats. The well rounded grains were probably of igneous origin and were transported to the places of deposition by water. However the fine perfectly euhedral crystals found in both sands and bentonites probably had a volcanic origin and were brought in by the winds with the volcanic ash. In addition, there are very fine needles of apatite in the clay matrices of many sandstones which probably were authigenic.

Biotite: The biotite appears to be of metamorphic, igneous, and volcanic origins. Fresh biotite is a very common constituent of the bentonites and volcanic ash beds. Chloritized biotite may be found in many of the sandstones and may be of igneous or metamorphic origin.

Calcite: The calcite is authigenic and occurs in the sediments as individual grains and as the concretionary mineral in many of the concretions.

Glaucophane: This mineral is developed when calcareous muds are subjected to low or intermediate grades of regional metamorphism but also occurs in rocks subjected to a high degree of metamorphism and as a deuteritic mineral in some igneous rocks. Because it is often associated with glaucophane in metamorphic rocks and because glaucophane occurs in these sediments, a metamorphic source is assumed.
Corundum: This mineral occurs in both igneous and metamorphic quartz-free rocks. The sapphire variety of corundum is found today in the Helena region of Montana in andesite dikes (Ford, 1958, p. 483) and sapphire corundum found in these sediments may have come from this area.

Epidote: Epidote is a very common mineral in these sediments. The fine-grained epidote is of authigenic origin. The grains composed of a single crystal may have originated as a deuteric mineral in an igneous rock or as a metamorphic mineral in low to high grade, calc-silicate, metamorphic rocks.

Garnet: This is a very common mineral in metamorphic rocks and is also found in igneous rocks. Since very few of the garnets observed exhibited crystal form it is presumed that most of them were derived from pre-existing sedimentary rocks. Others showed partial crystal forms or were very angular which indicates that they were first generation detrital minerals. The garnets found were probably originally derived from metamorphic rocks because they contain many inclusions.

Ilmenite: This is a common metamorphic or igneous mineral.

Jarosite: Jarosite occurs as an authigenic mineral in these sediments. Elsewhere it has been found in volcanic and igneous rocks as a late hydrothermal mineral. This association may indicate that it was formed in these sediments through the reaction of meteoric waters with the abundant volcanic glass in the sediments.

Kyanite: This mineral is known only to develop under conditions of moderate to high grade regional metamorphism.

Limonite: This is an authigenic mineral developed during the weathering of iron-bearing minerals.
Magnetite: Magnetite is a very common accessory mineral of igneous and metamorphic rocks.
Marcasite: In these sediments the marcasite is authigenic and occurs in concretionary masses.
Penninite: This mineral most often occurs as an alteration product of other silicate minerals. It is also found in chlorite and other crystalline schists which result from low temperature regional metamorphism.
Rutile: This mineral is a very common accessory mineral in metamorphic rocks and in some igneous rocks.
Sphene: This is a very important accessory mineral in many igneous rocks and in some metamorphic rocks.
Siderite: This mineral is of authigenic origin in these sediments. It occurs in concretions, as cement in sandstones, and as isolated crystals.
Sillimanite: This is a high temperature, high pressure mineral produced by regional metamorphism and the source of these mineral grains must be high grade metamorphic rocks.
Stauroplite: Stauroplite occurs only in aluminous schists which have been subjected to intermediate to high degrees of regional metamorphism.
Tourmaline: This mineral is most commonly found in metamorphic rocks but is also present in later phase, magmatic intrusions such as pegmatites and greisens. The tourmaline in these sediments ranges from well rounded grains to sharp euhedral crystals which would indicate that some of the tourmaline was in the nth cycle of sedimentation and its source was other sedimentary rocks. Other grains were probably derived directly from metamorphic and perhaps igneous rocks.
Zircon: This mineral is very common in grained igneous rocks. There are obviously several sources for the zircons in these sediments because
the zircons vary in color and degree of rounding. There are a few well rounded zircons in the samples studied and these must have come from pre-existing sedimentary rocks. Most of the zircons are sharp euhedral crystals which have a length several times their greatest width. Because the zircons in the sandstones are very similar to those in the volcanic ashes and bentonites it is assumed that the zircons are largely derived from these sediments.

From the above one can conclude that part of the heavy mineral suite is of volcanic origin and was probably brought into the area of sedimentation as volcanic ash. Another large part of the minerals are of igneous origin being both derived from acid and basic rocks and fine to coarse grained rocks. Additional small quantities of definitely metamorphic minerals were derived from low to high grade metamorphic rocks. A small minority of all these minerals show a high degree of rounding which would indicate that they were derived from pre-existing sedimentary rocks and have been through several generations of sedimentation.

Stow (1938, p. 756) states that the Hell Creek sediments in the Big Horn Basin were derived chiefly from sedimentary rocks though small percentages of heavy minerals from crystalline rocks are present. He also believed this to be true of the Tullock and Lebo beds but found the Tongue River sediments contained an increase in crystalline rock waste (Stow, 1938, p. 756-757).

Stow (1946, p. 682) found that west of a line between Roscoe and Reed Point, Montana, there were no minerals of direct metamorphic derivation in the Hell Creek, Tullock, Lebo, or Tongue River sediments, but that east of this line there are minerals which were derived directly
from metamorphic rocks. Augite and hornblende, in the western area, he traced to volcanic agglomerates between the Yellowstone River on the north, the Beartooth Mountains on the south, the Boulder River on the west, and Bridger Creek on the east (Stov, 1946, p. 682). He believed that much of the zircon, tourmaline, and rutile were derived from pre-existing sedimentary rocks, but garnet could not be traced to a definite source.

It is apparent from these studies and those of others that the Fox Hills, Hell Creek, Tullock, Cannonball, and lower Tongue River sediments had multiple sources, and these sources consisted of pre-existing sedimentary rocks, low to high grade metamorphic rocks, and volcanic and intrusive igneous rocks. It is also probable that the geographic source area for most of the sediments, now found in North Dakota, was western Montana and adjacent parts of Wyoming. The sediments were probably shed from "hills" developed by pulses of the Laramide Orogeny in this source region. The Black Hills in South Dakota was disregarded as a major source because of its small size with respect to the large volume of sediments composing these formations.

**Maturity of Upper Cretaceous and Lower Cenozoic Sediments in North Dakota as Indicated by their Heavy Mineral Suites**

Much has been written upon the stability of heavy minerals (Thoulet, 1913; Boswell, 1933; Russell, 1937; Goldich, 1938; Pettijohn, 1941; Smithson, 1941; Dryden and Dryden, 1946; Allan, 1948; Goldstein, 1950). By applying this information to the Fox Hills, Hell Creek, Tullock, Liddow, Cannonball, and lower Tongue River sediments we find these sediments contain some very unstable minerals in eastern Montana and North Dakota.
Smithson (1941, p. 97-112) suggested the following stability list for certain minerals from Triassic and Jurassic rocks.

Stable
- Zircon
- Rutile
- Tourmaline
- Apatite

Somewhat Stable
- Monazite

Unstable
- Garnet
- Staurolite
- Kyanite

Very Unstable
- Ferromagnesian Minerals

This same year Pettijohn (1941) constructed a list of minerals showing their relative persistence in sediments with respect to geologic time. Minerals which were more commonly reported from older rocks were given (p. 618-619) negative persistence values.

- 3 Anatas
t- 2 Muscovite
- 1 Rutile

1 Zircon
2 Tourmaline
3 Monazite
4 Garnet
5 Biotite
6 Apatite
7 Ilmenite
8 Magnetite
9 Staurolite
10 Kyantite
11 Epidote
12 Hornblende
13 Andalusite
14 Topaz
15 Sphene
16 Zoisite
17 Augite
18 Sillimanite
19 Hypersthene
20 Diopside
21 Actinolite
22 Olivine

In 1950, Goldstein studied the sandstones of the Front Range in Colorado, which included the Fox Hills and Laramie beds. Since these formations are equivalent to part of the lithologic units studied in North Dakota, this heavy mineral study is particularly pertinent. Goldstein (1950, p. 98) constructed the following stability series for certain minerals found in these Cretaceous sandstones:

1. Zircon
2. Tourmaline
3. Rutile
4. Staurolite
5. Magnetite
6. Limonite
7. Garnet
8. Muscovite
9. Biotite
10. Sphene
11. Epidote

In general, the above lists differ only in details and mineral constituents. Perhaps most noteworthy is the different position of muscovite in Goldstein's and Pettijohn's lists.

Comparing the minerals found in the Fox Hills, Bell Creek, Tullock, Ludlow, Cannonball, and basal Tongue River formations, in west and central North Dakota and eastern Montana, with the above lists, several points of interest appear. All of the minerals in Smithson's list were found except monazite. Even members of the most unstable ferromagnesian group are present. Only three, monazite, topaz, and augite, out of the first 16 positive minerals, are missing from Pettijohn's list. Only rutile of the negatively rated minerals, was found. All of the minerals proposed for the stability list by Goldstein are present in the North Dakota and eastern Montana sediments.
Such a suite of minerals, as those found in the sediments being studied in eastern Montana and North Dakota, could only occur in very young sediments, a conclusion which is supported by the presence of Cretaceous and Paleocene fossils. The presence of the more unstable minerals also indicates very immature sediments, because these minerals would have been lost to weathering and abrasion through repeated sedimentary cycles if the sediments were mature.

**SOURCES FOR UPPER CRETAUCEOUS AND LOWER PALEOCENE SEDIMENTS AS INDICATED BY THE PLAGIOCLASE FELDSPARS**

Plagioclase feldspars were studied to determine the type of volcanic rocks which supplied most of the sediments for the Hell Creek, Tullock, Lebo, and Ludlow Formations. Many of the authors of the early Lignite reports have referred to these sediments as being andesitic in nature or suggested they were derived from andesitic volcanics and ash falls. The writer, studying the composition of the volcanic glass by the oil immersion method, found that the volcanic glass encountered in these sediments is of rhyolitic and not andesitic composition as suggested by earlier reports.

To help substantiate or discredit these reports of andesitic sediments the writer studied the plagioclase feldspars found within these sediments. The composition of the plagioclase feldspars was determined by the use of a five axis, universal stage. The method used was to orient the plagioclase grain normal to the albite twin plane and the 100 plane and then to determine its extinction angle with respect to the albite twin plane according to the Rittman Zone Method (Emmons, 1943). Plagioclase was studied in thin-sections from the Fox Hills, Hell Creek, Tullock, and Ludlow Formations. One thin-section from the lower Tongue
River sediments was also studied. Ten grains were selected from each thin-section and their extinction angles determined. The composition of the feldspar was then derived from tables (Simmons, 1943, Fig. 58, p. 121) in terms of the two members of the plagioclase series, albite and anorthosite. Graphic results of this study may be found in Figures 22a, 22b, 23a, and 23b.

The plagioclase feldspars were divided into several groups dependent upon their stratigraphic location and the carbonate content of the sediments. A comparison of these plagioclase grains found in the Cretaceous Hall Creek and Fox Hills Formations (Fig. 23a) with those grains found in the Tertiary Ludlow, Tullock, and Tongue River Formations (Fig. 22a) indicates that there is very little change in the composition of the plagioclase across the systemic boundary. Both figures show the plagioclase composition to be bimodal with one high near the oligoclase-andesine boundary (An 30%), while the other high is near the calcic end of the andesine feldspar member (An 50%). This is also true of the plagioclase from the Fox Hills Formation. If these curves are compared with the curve for the composition of the plagioclase feldspar found in the carbonate sediments, such as those found in calcareous sandstone lenses, one sees that the high near the calcic end of the andesine member is subdued. This loss of calcic plagioclase is probably the result of the differential replacement of the pure calcic plagioclase by calcite. If this is the case, then the peak near the calcic end of the andesine member should be higher in the Hall Creek-Fox Hills curve and Fox Hills curve than in the Tullock-Ludlow-Tongue River curve because the latter curves include determinations from calcareous sediments. This is the case.
Figure 22a. Composition of Ludlow, Tullock, and Tongue River plagioclase feldspars.

Figure 22b. Composition of plagioclase feldspars found in carbonate cements.
Figure 23a. Composition of Hell Creek and Fox Hills plagioclase feldspars.

Figure 23b. Composition of Fox Hills plagioclase feldspars.
The composition of the plagioclase feldspars studied ranges from 20% to 70% anorthite with modes around 30% and 48% anorthite. These figures indicate that most of the studied feldspars were not derived from rhyolitic volcanics as the abundant included rhyolitic volcanic ash might indicate. Rhyolitic volcanics have a plagioclase composition varying between that of acid andesine (An 30-40%) and oligoclase (An 10-30%) zoned crystals. This composition corresponds to the first peak in the graphs and may account in part for its height. However, much of the zoned plagioclase is more calcic. Plagioclase in andesite has an average plagioclase composition of andesine (An 40%), with zoned crystals, but the plagioclase may vary in composition from (An 10-30%) to (An 70-90%), depending upon the variety of andesite. The hornblende andesites have anorthite poor plagioclases while the olivine andesites have the anorthite rich calcic plagioclases. The presence of hornblende in the sediments suggests at least some of the anorthite poor plagioclase may have been derived from hornblende andesites as well as from rhyolites. More basic andesites are common in the source areas of western Montana and probably account for the occurrence of the more anorthite rich calcic plagioclase.

An andesitic source for the plagioclase feldspars and thus for the majority of the sediments is further supported by the ratios between plagioclase, quartz, and K-feldspar. The percentage of plagioclase in these sediments is often greater than the combined percentages of quartz and K-feldspar and indicates a major andesitic source and not a rhyolitic source with its much greater quantities of quartz and K-feldspar.

The presence of only rhyolitic glass in the sediments may be explained by two hypotheses. One possibility is that the rhyolitic
glass is preserved because it does not alter to clays and zeolites as fast as the more basic glasses. This concept would be supported by the Goldich (1938, p. 36) weathering series, although this series does not apply directly to glassy rocks. Secondly one might explain the occurrence of the rhyolitic glasses by the differentiation by the wind. The heavier and more basic glasses would settle out before they reached eastern Montana and North Dakota while the lighter more acid glasses were carried into these areas. The more basic plagioclase was then carried into these areas by streams and mixed with the rhyolitic ash falls. The evidence to support this hypothesis is the presence of large quantities of rhyolitic glass in North Dakota and the absence of the more basic glasses.
INTRODUCTION

During the field studies of the Hell Creek Formation many fossils were collected from this formation and the adjacent Fox Hills, Tullock, and Ludlow beds. Fossils collected from the Fox Hills Formation were limited to plants, to compare with plants found in the Hell Creek Formation. Collections from the Tullock and Ludlow Formations were mainly plants and invertebrates from a few but prolific collecting localities. Scattered vertebrate remains were also collected in these units though no attempt was made to collect the Fox Hills, Tullock, or Ludlow Formations systematically or extensively. The Hell Creek Formation was searched intensively for mollusks but the plants and vertebrates were collected only from exceptional localities. Because of the very large size of the dinosaurs, and the very small size of small reptiles and mammals it was unfeasible to collect these groups systematically during the time spent in the field.

Fossil localities are listed in Appendix B according to formation and member. In addition, fossil lists are given for each member of the Hell Creek Formation under the descriptions of the new members. Below is the list of fossils as collected and identified by the writer, unless otherwise stated. Principal references used for identification were:

Bell, 1949; Brown, 1939a, 1939b, 1962; Chasen, 1951; Clemens, Jr., 1963;
Dorf, 1942; Estes, 1954; Henderson, 1935; Russell, 1931; Stanton, 1920; Tezer, 1956; White, 1883; and Ycn, 1946, 1948.

FOSSIL LISTS

Fox Hills Formation

PLANTS

SEEDLESS PLANTS

Equisetaceae

Equisetum perlascigatum Cockerell

Polypodiaceae

Sphenopteris (Desmatoaestia) burlei Bell

SEED PLANTS

GYMNOSPERMS

? Taxodiaceae

Unidentified species

ANGIOSPERMS

MONOCOTYLEDONS

Several unidentified species of leaves

DICOTYLEDONS

Fagaceae

Cf. Dryophyllum subfalcatus Lesquereux

Vitaceae

Cf. Vitis stantonl (Knowlton) Brown

Bignoniacae

Cf. Dendrogonis colostensis Brown

Bull Creek Formation

PLANTS

SEEDLESS PLANTS

Equisetaceae

Equisetum sp., cf. E. perlascigatum Cockerell

SEED PLANTS

GYMNOSPERMS

Cycadaceae

Nifisosia gibbata (Newberry) Hollick

Ginkgoaceae

Ginkgo larvianensis Ward

Araucariaceae

Aracentus longifolia (Lesquereux) Brown

Taxodiaceae

Taxodium olivi (Beer) Brown

Sequoia daisetensis Brown

Metasequoia occidentalis (Newberry) Chaney
ANGIOPSERA
MONOCOTYLEDONS
Unidentified monocotyledonous leaves
Unidentified monocotyledonous wood
Cyperaceae
Cyperus sp.

DICOTYLEDONS
Juglandaceae
? Fraxinus hispida Brown
Betulaceae
Corylus insigne Beem
Fagaceae
Dryophyllum subfalcatum Lesquereux
Moraceae
Ficus pumicocarpa Brown
Tiliaceae
Celtis occidentalis Lesquereux
Nympheaceae
? Nympheoites strictus (Berry)
Ceratophyllaceae
Ceratophyllum sp., cf. C. arcticum (Beem) Brown
Trochodendraceae (?)
Trochodendroidae sp. (?Ceratophyllum ellipticum
Brown)
Amaranthaceae
? Amaranthus berardi Berry
Rosaceae
Prunus sp., cf. P. corrugata Brown
Vitaceae
Vitis setouchi (Knowlton) Brown
Cornaceae
? Cornus praeinpresso Knowlton
Caprifoliaceae
? Viburnum tilioides Ward
Rhamnaceae
Dombeyopsis nebrascensis (Newberry) Bell
Incetaceae sedis
? Actinidia sp.
Carpolithus sp., cf. C. (Cypselinocarps) aceratops
(Knowlton)
Carpolithus sp., cf. C. (Ginkgoites?) fulvinct Bell
Carpolithus huschilosisa Bell
Carpolithus sp.
? Carpolithus sp.
Root and Twig Impressions
Amber
Wood

ANIMALS
INVERTEBRATES
PHYLUM BRYOZOA
Unidentified genus and species
PHYLUM MOLLUSCA
CLASS SCAPHOPODA

? Dentalium (Lasidentalium) pancerulum Meek and Hayden

CLASS PELECTYPODA

Superfamily Ostracacea

Ostrea gibba Meek and Hayden

Ostrea sp., cf. O. haydeni White

Superfamily Nautilacea

Unioidae

Unio stantoni White

Unio sp., cf. U. amarillensis Stanton

Unio sp., cf. U. sandersoni Warren

Unio pyramidoides Whitfield

Unio balansinicus White

? Plesiia lubricata subconstricta (Meek and Hayden)

Plesiia lubricata sp., cf. P. brachyphana (White)

Plesiia lubricata sp., cf. P. priscus (Meek and Hayden)

Plesiia lubricata sp. (? undescribed species)

Pedalion sp. (? undescribed species)

? Anadonta macconelli Russell

? Harrisia miadiformis Russell

Unidentified clam fragments

Superfamily Anomacea

? Anomia micronoma Meek

Superfamily Mytilacea

? Volsella (Brachydonata) multilinigera Meek

Superfamily Cyrenacea

Corbiculidae

Corbicula cytoriformis (Meek and Hayden)

Sphaeriidae

Sphaerium sp., cf. S. haeckeliana Warren

Sphaerium sp., cf. S. kowleri Russell

Sphaerium sp., cf. S. sequale Russell

Sphaerium sp., cf. S. gibba Tozer

Sphaerium sp. (? undescribed species)

Superfamily Lucinacea

? Terebralia americana (Meek and Hayden)

Superfamily Veneracea

Cf. Trigonoecista nebrascensis (Meek and Hayden)

Superfamily Tellinacea

? Tellina acetula Meek and Hayden

Superfamily Myacea

Corbula pyriformis Meek

Corbula subtriangularis Meek and Hayden

Inversae media

Unidentified clam fragments

CLASS GASTROPODA

Viviparidae

Viviparus sp., cf. V. wassonii Tozer

Viviparus sp., cf. V. planolatera Russell

Viviparus prudentius prudentius White

Viviparus sp., cf. V. prudentius velleterina Tozer

Viviparus trochiformis (Meek and Hayden)
Viviparus sp., cf. V. sokoanensis Toser
Viviparus sp., cf. V. tenebrosa Dyer
Viviparus sp., cf. V. leai (Meek and Hayden)
Viviparus sp., cf. V. rustumay (Meek and Hayden)
Viviparus sp. (? unidentified species)
Campeloma nebranensis nebranensis (Meek and Hayden)
Campeloma sp., cf. C. harlowtonensis (Stanton)
Campeloma spuriilennis Stanton
Lioiplacodes tenuicarinata (Meek and Hayden)
Lioiplacodes muriata Tten
Lioiplacodes stachli (White)
Lioiplacodes limaiaeformis (Meek and Hayden)

Pleuroceridae

Conochasis virginica (Mil'lin)
"Valonia" ovumiegensis (Meek)

Lymanellidae

? Pleurolymanella sp.

Pilidae

Eosida sp., cf. R. protea (Tten)

Physidae

Physa bullata White
Physa montanaiesi Tten
Physa sp., cf. P. plicatilis White
Physa sp., cf. P. canadensis White
Physa sp., cf. P. lamellosa White

Relictoglyptidae

? Glyptaspis rotundata (Russel)

Cenaphidae

Oreelia unisustanthesi (White)
Insertae sedis

Unidentified gastropods

CLASS CEPSALOPODA

Order Amaonitida

Cf. Diocoocaphites coxadi (Morton)

PHYLUM VERMES

? Serpulid worm tubes

? Worm borings in bone

PHYLUM PHoronida

Cf. Phoronopsis sp.

PHYLUM ARTHROPODA

CLASS CRUSTACEA

SUBCLASS MALACOSTRACAE

Ophiomorpha major Lesquereux
Cf. Ophiomorpha major Lesquereux
? Tail to crowfish-like animal

SUBCLASS MALACOSTRACAE

PHYLUM VERTEBRATA

CLASS KLASMATODERMA

Lamnidae

Cf. Lamna sphyraena Agassiz
Cf. Lamna sp.
Cf. Oreodus obliquus Agassiz

Order Heterodontiformes
Hybodontidae

Louxichion selachae Estes

Order Isuriformes
Orectolobidae

Equatorhinus americana Estes

Order Rajiformes
Pristidae
Gamoprisciidae
Cf. Ischyryzus avenicola Estes
Daeyatidae
Hylecapus bipartitus Cope

CLASS OSTEICHTHYES

Order Actinopterygii
Amiidae
Cf. Kinsela fragoa Jordan
Cf. Protanida sp.

Order Aspidorhynchiformes
Aspidorhynchidae

Halonemodus longirostris (Lambe)

Order Lepisosteiformes
Lepisosteidae

Lepisosteus occidentalis (Leidy)
Cf. Paractichthyes furillatus (Cockerell)

Order Clupeiformes
Elopidae
Cf. Megalepis sp.
Unidentified genus and species

Albulidae
Unidentified genus and species

Order Perciformes
Scianidae

? Platacodon name Marsh
Incertae sedis
Fish vertebra
Unidentified fish bones

CLASS AMPHIBIA

Order Salientia
? Pelobatidae
Unidentified genus and species

Order Urodela
Sirenidae
Cf. Necturus dilatus Gilmore
Plathodonta? ?

Classognathinae ?
Ophiosthiron kavi Auffenberg

CLASS REPTILIA

Order Chelonia
Unidentified turtle remains

Order ? Eosuchia
Champsauridae

Champsosaurus sp., cf. C. mutator Parks
Incertae sedis
Glyptosauridae

Cf. *Glyptosaurus giganteus* Gilmore

Order Sauria

Suborder Scincosauria

Teiidae

*Chamaeleo regalis* Marsh

Leptocleidus denticulatus (Gilmore)

Suborder Anguimorpha

Infra Order Diploglossa

Nanosauridae

*Enosaurus lanceolatus* Gilmore

Infraorder Platynota

Parasauridae

Cf. *Parasaurus weberensis* Gilmore

Cf. *Parasaurus bogerti* Bates

Varanidae

*Palaeosaurus canadensis* Gilmore

Order Crocodilia

Crocodylidae

Crocodylinae

*Leidyosuchus sternbergi* Gilmore

Alligatoridae

Brachychampsa montana Gilmore

Order Saurischia

Infraorder Theropoda

? Coeluridae

Unidentified genus and species

Pachycephalosauridae

*Pachycephalosaurus* sp.

Infraorder Carnosauria

Megalosauridae

Cf. *Brachiosaurus* sp.

Tyranosauridae

Cf. *Tyranosaurus rex* Osborn

Incertae sedis

Cf. *Struthiosaurus* sp.

Order Ornithischia

Hadrosauridae

*Hadrosaurus foulkii* Leidy

*Apatosaurus* sp., cf. *A. annaeae* (Marsh)

Cf. *Kritosaurus* sp.

Cf. *Diplodocus* sp.

Ankylosauridae

? *Ankylosaurus* sp.

Sauropodidae

Cf. *Melanosaurus recurvirostrum* Cope

*Triceratops* sp., cf. *T. brevicornis* Hatcher

*Triceratops* sp., cf. *T. flabellatus* Marsh

Order Incertae sedis

Unidentified dinosaur tooth

Order Pterosauria

Unidentified genus and species
Order incertae sedis
  Unidentified reptile bones
  Coprolites

CLASS MAMMALIA
SUBCLASS ALLOTHERIA
Order multituberculata
  Ptilodontidae
  Ptilodontinae
    Nasodon sp.
    Cimolodon altidens Marsh

Ptilodontidae, incertae sedis
  Haplochasma robustum (Marsh)
  Pedicles sp. (New species)
  (New genus and species)
  Unidentified tooth fragments

Luskow Formation

PLANTS
SEEDLESS PLANTS
  Equisetales
    ? Equisetum sp.
  Isoetales
    Isoetes herrigae (Dawson) Brown

SEED PLANTS
GYMOSPERMS
  Taxodiaceae
    Glyptostrobus nordmannioides (Beer) Brown
    Metasequoia occidentalis (Newberry) Chaney
  Cupressaceae
    ? Pohlia catesbiana (Bell) Brown

ANGIOSPERMS
MONOCOTYLDONEA
  Hydrocharitaceae
    Hydrocharis expansa (Beer) Mamkto
  Cyperaceae
    ? Carex sp.
    Zonolites sedis
  Palmae
    ? Palaeococos plicata (Lesquereux) Knowlton
    ? Salal pumeli Knowlton

DICOTYLDONEA
  Juglandaceae
    Floragrya hispida Brown
  Ulmaceae
    Ulmus rhamnifolia Ward
  Moraceae
    Ficus ceratea Knowlton
  Platanaceae
    Platanus raynoldi Knowlton
ANIMALS

PHYLUM VERTEBRATA
CLASS ELASMOBRANCHII
Lamnidae
Cf. Lamna cypriaca Agassiz

CLASS REPTILIA
Order Crocodilia
Crocodylidae
Crocodilinae
Leidyosuchus sternbergi Gilmore

Tullock Formation

PLANTS
SEED PLANTS
ANGIOSPERMS
MONOCOTYLEDONS
Hydrocharitaceae

? Hydrocharis sp.

Nyssaceae
Nyssa sylvatica var. hastata

Pterospermataceae (seed) Ward
Melastomaceae
Melastoma montanum Brown

Incertae sedis
Carrollithus sp.

DICOTYLEDONS
Ulmaceae
Ulmus rubra (Newberry)

Moraceae
Ficus carica Linn. Lesquereux

Ficus altissima Linn. Lesquereux

Ficus subhispida Linn. Lesquereux

Ficus montanum Brown

Platanaceae

Platanus cambarus Newberry

Lauraceae
Persea preussiana Lesquereux

Cercidiphyllaceae
Cercidiphyllum japonicum (New) Brown

Magnoliaceae
Magnolia magnolia Knutson

Borussiaeaceae
Eucalyptus serrata (Newberry) Brown
Rosaceae
  Prunus caroliniana Brown
  Prunus sp.
Vitaceae
  Ampelopsis scurfolia (Newberry) Brown

Caprifoliaceae
  ? Viburnum sp.
  Lonicera sp.
  ?Carpolischna sp.

ANIMALS

INVERTEBRATES

PHYLUM MOLLUSCA

CLASS PELECYPODA
  Super Family Cyrenacea
  Sphaeriidae
  Sphaerium sp., cf. S. hakeshame Warren

CLASS GASTROPODA
  Viviparidae
    Viviparus sp., cf. V. prudentius willowensis Tozer
    Viviparus sp., cf. V. taqgina Dyar
  Campeloma nebrascensia nebrascensia (Meek and Hayden)
  Anisylidae
    ? Ferrisia minuta (Meek and Hayden)

VERTEBRATES

CLASS OSTEOCHONDRITES
  Order Amiiformes
  Amiidae
    Cf. Proteania sp.

CLASS REPTILIA
  Order Chelonia
    Unidentified turtle remains
  Order ? Eusuchia
    Champsosauridae
    Champsosaurus sp.
  Order Crocodylia
    Crocodylidae
      Crocodylinae
      Leidwysuchus sternbergi Gilmore
Figure 24. Partially exposed skeleton of Triceratops, sec. 32, T. 135 N., R. 106 W., Slope County, North Dakota. This nearly complete skull was found about 25 feet below the top of the Pretty Butte Member of the Halk Creek Formation. The skull is now housed at the University of North Dakota.
Plate I

Numbers 1-4. Teeth of *Hylecodon: bipartitus* Cope; X2
5-8. Teeth of *Brachyshampus montana* Gilmore; X2
9-11. Vertebrae of *Cf. Protamia* sp.; X.5
12-14. Teeth of *Leidrocnus starnbergi* Gilmore; X1.5
15,17. Reptile vertebra; X1
16. Reptile claw; X1
18,19. Parietal plates of *Lepiscactus occidentalis* (Leidy); X1
20,21. Teeth of *Triceratops* sp.; X1
22-29. Scales of *Lepiscactus occidentalis* (Leidy); X1
Plate I. Selected typical vertebrate fossils of the Bull Creek Formation.
Plate II

Numbers 1-3. Cones of *Sequoia dakotensis* brown; x1.5
4. Lower right front of jaw of *Leidyosuchus sternbergi*
   Gilmore; x.5
5,6. Shell of *Ontrea alabre* Meek and Hayden from the Eocene
   Member of the Bell Creek Formation; x.75
Plate II. Selected typical fossils of the Hell Creek Formation.
CORRELATION OF THE LATEST CRETACEOUS HELL CREEK
FORMATION WITH THE EUROPEAN
STANDARD SECTION

The Hell Creek Formation contains numerous fossils of the genus
Triceratops Marsh and the Hell Creek and Lance beds are widely known as
the Triceratops beds or zone (e.g., Cobban and Heside, 1952, p. 1021).

European authors have almost invariably considered the Triceratops
zone to be of Danian Age because it overlies the marine Fox Hills Sand-
stone of Maastrichtian Age (Jeletzky, 1960, p. 26). The cephalopod
faunas of the marine members of the type Fox Hills Formation allow a
very close correlation with the belemnite and ammonite zones of the
Maastrichtian Stage of northwestern Europe (Cobban and Heside, 1952,
p. 1021).

The Discocarphites nebrascensis zone of North America contains
D. conradi in the Prairie Bluff Chalk of Texas (Jeletzky, 1960, p. 30-
31). The Prairie Bluff Chalk also contains Pachydiscus sp., cf. P.
gollelliwillicus (d'Orbigny). Any representative of the Pachydiscus
gollelliwillicus-neubergicus species group is considered diagnostic of
lower Maastrichtian beds in Europe (Jeletzky, 1960, p. 31). Therefore,
the D. nebrascensis zone and the species D. conradi are of lower Maes-
trichtian Age. The D. nebrascensis zone occurs in the type Fox Hills
Formation near the top of the Timber Lake Member and contains in Elmwood
County, North Dakota, D. conradi (Personal communication with K. M.
Feldmann). This occurrence indicates that the upper part of the Timber
Lake Member and also perhaps the lower parts of the Bull Head and Col-
gate Members of the upper Fox Hills Formation are of lower Maastrich-
tian Age in Elmwood County, North Dakota (Fig. 25).
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Figure 25.

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l{ESTERN AND CENTRAL

NORTH DAKOTA

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Dracoclaenus

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Hell Creek Formation

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The presence of an ammonite, cf. *D. conradi*, in the Breien Member of the Hell Creek Formation would indicate an early, or perhaps middle Maastrichtian Age for these beds, since they lie stratigraphically above the Fox Hills Formation. The fact that cf. *D. conradi* is found in the Breien Member of the Hell Creek Formation is not surprising when one considers that the Hell Creek Formation interfingers with the Bull Road and Colgate Members of the upper Fox Hills Formation (Fig. 25).

*Triceratops* sp. has not been found in the Breien Member of the Hell Creek Formation but it has been found in the overlying Fort Rice, Huff, and Pretty Butte Members of the Hell Creek Formation and in the underlying Crowghost and Bacon Creek Members. *Triceratops* has never been found above the top of the Pretty Butte Member of the Hell Creek Formation, the uppermost member of the Hell Creek Formation, nor has it been found by the writer in the Little Beaver Creek, and Marmarth Members, the lower members of the Hell Creek Formation in the Little Missouri Valley. However, an associated dinosaur fauna was found in the Marmarth Member. This range of occurrence indicates that the base of the *Triceratops* zone lies somewhere in the upper part of the Fox Hills Formation in central North Dakota although no specimens of *Triceratops* sp. have been found in these beds and that the base of the *Triceratops* zone perhaps lies within the basal beds of the Hell Creek Formation in western North Dakota. Therefore, the lower part of the *Triceratops* zone appears to be equivalent to the early or perhaps early middle Maastrichtian of northwestern Europe (Fig. 25).

The upper part of the *Triceratops* zone is somewhat more difficult to compare with the European standard section. Locally the top of the
Triceratops zone coincides with the top of the Hell Creek Formation in North Dakota and probably in Montana. The age of the upper part of the Cannonball Formation, which conformably overlies both the Ludlow (in west central North Dakota) and the Hell Creek Formation (in central and eastern North Dakota), is late Danian-Montian Age as determined from Foraminifera collected by Fox and Ross (1942) (Jeletzky, 1963, p. 33).

Except for one sample which was collected from the middle part, the samples of Foraminifera were collected from the upper part of the Cannonball Formation (Fox and Ross, 1942, p. 867). The Cannonball-Ludlow interval is 300 feet thick in central North Dakota and thickens westward to about 450 feet thick in western North Dakota. Because of the thickness it is reasonable to assume that the Cannonball and Ludlow Formations represent much of the Danian (?)(Fig. 25).

If the Cannonball and Ludlow Formations represent all of Danian time and the lower part of the Hell Creek Formation is of early perhaps middle Maastrichtian time, then the upper part of the Hell Creek Formation must have been deposited in late, and perhaps middle and late, Maastrichtian time. If this is true the Triceratops zone found in the Hell Creek and Lance Formations is of early (perhaps late early), middle, and late Maastrichtian Age (Fig. 25).

A COMPARISON OF FOX HILLS, HELL CREEK, TULLOCK, AND LUDLOW FLORAS AND FAUNAS

Flora

Table 7 gives a comparison between the Fox Hills, Hell Creek, Tullock, and Ludlow floras as collected by the writer. Since the collections do not represent the total floras of the formations involved, but are only a preliminary sampling of the floras in the state of North
<table>
<thead>
<tr>
<th>Species</th>
<th>Fox Hills</th>
<th>Hill Creek</th>
<th>Tulloct</th>
<th>Ludow</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equisetum perlavaigatum</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Sphenopteris (Dennstaedtia) burlingi</td>
<td>x</td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Isoetes herridus</td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Nilssonia gibbali</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td>Ginkgo larieniensis</td>
<td>x</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Araucaria longifolia</td>
<td>x</td>
<td>x</td>
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<td></td>
</tr>
<tr>
<td>Sequoia dakovensis</td>
<td>x</td>
<td></td>
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</tr>
<tr>
<td>Metasequoia occidentalis</td>
<td>?</td>
<td>x</td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>Glyptostrobus nordenskjoeldi</td>
<td>x</td>
<td></td>
<td></td>
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<tr>
<td>Taxodium olriki</td>
<td>x</td>
<td></td>
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<td></td>
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<tr>
<td>Hydromyaria expansa</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Carex sp.</td>
<td>x</td>
<td></td>
<td>x</td>
<td>x</td>
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<tr>
<td>Unidentified reeds</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Pseudoxelotes plicatus</td>
<td>x</td>
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<tr>
<td>Sabel powelli</td>
<td>x</td>
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<tr>
<td>Dryophyllum subfalcatus</td>
<td>?</td>
<td>x</td>
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<tr>
<td>Pterocarya hispida</td>
<td>?</td>
<td>x</td>
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<tr>
<td>Ulmus rhamnifolia</td>
<td>x</td>
<td>x</td>
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<tr>
<td>Corylus insignis</td>
<td>x</td>
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<tr>
<td>Ficus cerateae</td>
<td>x</td>
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<tr>
<td>Ficus arctoraceoides</td>
<td>x</td>
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<tr>
<td>Ficus planicostata</td>
<td>x</td>
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<tr>
<td>Ficus subtruncata</td>
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<tr>
<td>Ficus montanensis</td>
<td>x</td>
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<tr>
<td>Ficus preantaraceoides</td>
<td>x</td>
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<tr>
<td>Platysus raynoldi</td>
<td>x</td>
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<tr>
<td>Cuspidopanopaeas saportana</td>
<td>x</td>
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<tr>
<td>Nymphaea stratiotes</td>
<td>?</td>
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<tr>
<td>Nimbium montanum</td>
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<tr>
<td>Parangpamopaeas crassifolia</td>
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<tr>
<td>Parmaa breslana</td>
<td>x</td>
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<tr>
<td>Corexidophyllum arcticum</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td></td>
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<tr>
<td>Trochodendroides sp.</td>
<td>x</td>
<td></td>
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<td></td>
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<tr>
<td>Amora roberti</td>
<td>x</td>
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<tr>
<td>Magnolia magifolia</td>
<td>x</td>
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<tr>
<td>Eucommia serrata</td>
<td>x</td>
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<tr>
<td>Prunus sargentia</td>
<td>x</td>
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<tr>
<td>Prunus corregla</td>
<td>x</td>
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<tr>
<td>Vitus stantoni</td>
<td>?</td>
<td>x</td>
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<tr>
<td>Ampelopsis acerofolia</td>
<td>x</td>
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<tr>
<td>Clasus marginata</td>
<td>x</td>
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<tr>
<td>Cornus prst emissus</td>
<td>?</td>
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<tr>
<td>Pterospermates cordatus</td>
<td>?</td>
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<tr>
<td>Helastomites montanensis</td>
<td>?</td>
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<tr>
<td>Viburnum tilodes</td>
<td>?</td>
<td>x</td>
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<tr>
<td>Sorbeyopsis nebrascensis</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Dombeyopsis colgatensis ........................ ?
Actinida sp. ........................................ ?
Carpolithus (Cycadinecarpus) caratops .............
Carpolithus (Ginkgoites ?) fultoni .................
Carpolithus kneehillensis ...........................
Carpolithus sp. ........................................

Table 7. A comparison of Fox Hills, Bell Creek, Tullock, and Ludlow Flora collected by the writer.
Dakota, many of the species probably have a greater range than that indicated here. It is interesting to note, however, that only 7 out of the 32 species listed cross the Mesozoic-Cenozoic boundary.

One of the species, *Cercidiphyllum arcticum* (Heer) Brown, is described by Brown (1952, Fig. 1) as being characteristic of the Paleocene. Fruits of *C. sp.*, cf. *C. arcticum* have been found in the Hell Creek and Tullock Formations. Leaves of *C. arcticum* have only been found in the Tullock and Ludlow Formations. A leaf from the Fort Rice Member of the Hell Creek Formation, herein referred to as *Trochodendroides sp.* may well be *Cercidiphyllum ellipticum* (Newberry) Brown. The fruits of *Cercidiphyllum sp.* from the Hell Creek and Tullock Formations, herein referred to as *C. sp.*, cf. *C. arcticum*, show gradations of characteristics with those of *C. ellipticum*, which depend upon preservation. Those best preserved are similar to *C. ellipticum* in showing the transverse ribs and less prominent longitudinal ribs while more poorly preserved specimens are similar to *C. arcticum* exhibiting only transverse ribs (see Brown, 1939a, Plates 52 and 54; and 1952, p. 70-71 and Plate 38). Either it is impossible to distinguish the fruits of *C. arcticum* from *C. ellipticum* by external sculpture or *C. arcticum* is a common member of the plant community of the Cretaceous Hell Creek Formation and not a good indicator of the Paleocene as Brown (1952, Fig. 1) has indicated.

A second fossil *Ficus caracata* Knowlton is described by Brown (1952, Fig. 1) as being characteristic of the Cretaceous. The writer found one specimen in the base of the Ludlow Formation. Its position in the base of a channel with other seeds and fruits, suggests that this fossil, presumably of Cretaceous age, could have been reworked and redeposited in Ludlow sediments.
Fauna

Invertebrates

Table 8 shows a comparison of Bell Creek and Tullock invertebrate faunas collected by the writer. The fossils of the Tullock Formation have not been collected thoroughly enough to permit definite statements concerning the ranges of the invertebrates and their relationships to the Mesozoic-Cenozoic boundary but it is interesting to note that 3 out of 4 species of gastropods collected from the Tullock Formation are also found in the Bell Creek Formation. This range of occurrence suggests that the fresh-water gastropods will prove to be of little assistance in delimiting the upper Cretaceous boundary in North Dakota.

Vertebrates

Table 9 shows a comparison of the Fox Hills, Bell Creek, Tullock, and Ludlow vertebrates from the writer's collections. A concentrated vertebrate collecting effort will certainly yield much larger vertebrate faunal lists from these formations in North Dakota in the future.

Although the writer spent considerable effort looking for dinosaur fossils in the bases of the Cenozoic Tullock and Ludlow Formations, no dinosaur remains were found. Other large reptiles, such as Champsosaurus sp. and Leidyosuchus sternbergi, survived the end of the Mesozoic Era and are abundantly preserved in the lower parts of the Tullock, and Ludlow Formations.
<table>
<thead>
<tr>
<th>Species</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dentalium (Levidentalium) pampearulum</td>
<td>x</td>
</tr>
<tr>
<td>Ostra la gabra</td>
<td>x</td>
</tr>
<tr>
<td>Ostra haydeni</td>
<td>?</td>
</tr>
<tr>
<td>Unio stantoni</td>
<td>x</td>
</tr>
<tr>
<td>Unio amarillensis</td>
<td>?</td>
</tr>
<tr>
<td>Unio sanderseni</td>
<td>x</td>
</tr>
<tr>
<td>Unio pyramidaceoides</td>
<td>x</td>
</tr>
<tr>
<td>Unio holmeianus</td>
<td>x</td>
</tr>
<tr>
<td>Plesielliptio subpatulatus</td>
<td>?</td>
</tr>
<tr>
<td>Plesielliptio brachypinclus</td>
<td>?</td>
</tr>
<tr>
<td>Plesielliptio priscus</td>
<td>?</td>
</tr>
<tr>
<td>Plesielliptio sp. (Undescribed)</td>
<td>x</td>
</tr>
<tr>
<td>Pedalion sp. (Undescribed)</td>
<td>x</td>
</tr>
<tr>
<td>Anadonta marconelli</td>
<td>?</td>
</tr>
<tr>
<td>Muria naisiformis</td>
<td>?</td>
</tr>
<tr>
<td>Ancama micromae</td>
<td>?</td>
</tr>
<tr>
<td>Volsella (Arachyodontes) multilinigera</td>
<td>?</td>
</tr>
<tr>
<td>Corbula cytheriformis</td>
<td>x</td>
</tr>
<tr>
<td>Sphaerium baskethense</td>
<td>?</td>
</tr>
<tr>
<td>Sphaerium fowleri</td>
<td>?</td>
</tr>
<tr>
<td>Sphaerium aquale</td>
<td>?</td>
</tr>
<tr>
<td>Sphaerium gietzii</td>
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</tr>
<tr>
<td>Sphaerium sp. (Undescribed)</td>
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</tr>
<tr>
<td>Tancredia americana</td>
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<tr>
<td>Trigonocallista nebrascensis</td>
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<tr>
<td>Tellina scitula</td>
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</tr>
<tr>
<td>Corbula pyriformis</td>
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</tr>
<tr>
<td>Corbula subtrigonalis</td>
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<td>Viviparana westoni</td>
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</tr>
<tr>
<td>Viviparana prudentius prudentius</td>
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<tr>
<td>Viviparana prudentius willovensis</td>
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</tr>
<tr>
<td>Viviparana trochiformis</td>
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<tr>
<td>Viviparana plicatere</td>
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<tr>
<td>Viviparana mokowanensis</td>
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</tr>
<tr>
<td>Viviparana taquina</td>
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</tr>
<tr>
<td>Viviparana leai</td>
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</tr>
<tr>
<td>Viviparana rustus</td>
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</tr>
<tr>
<td>Viviparana sp. (Undescribed)</td>
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<td>Campeloma nebrascensis nebrascensis</td>
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<td>Campeloma harlowtonensis</td>
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</tr>
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<td>Campeloma amarillensis</td>
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</tr>
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<td>Campeloma edmontonensis</td>
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<td>Lioplacodes temucarinae</td>
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</tr>
<tr>
<td>Lioplacodes marians</td>
<td>x</td>
</tr>
<tr>
<td>Lioplacodes stachai</td>
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<tr>
<td>Species</td>
<td>Hell Creek</td>
</tr>
<tr>
<td>---------------------------------</td>
<td>------------</td>
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<tr>
<td>Lioplacaes limaiformis</td>
<td></td>
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<tr>
<td>Coniobasis virginica</td>
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<tr>
<td>&quot;Helasia&quot; wyomingensis</td>
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<td>Plagioseptus sp.</td>
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<td>Restigella protea</td>
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<td>Physa bullatula</td>
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<td>Physa montanensis</td>
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<td>Physa pleuromala</td>
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<td>Physa camadensis</td>
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<tr>
<td>Physa kanabensis</td>
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<td>Glyptopoea rotundata</td>
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<td>Orebichlis namicentensis</td>
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<td>Ferrissia minuta</td>
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</tr>
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<td>Discocapsites conradi</td>
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<td>Serpulid worm tubes</td>
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<td>Phvromopsis sp.</td>
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<td>Ophiomorpha major</td>
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Table 8. A comparison of Hell Creek and Tullock invertebrates collected by the writer.
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<thead>
<tr>
<th>Fossil Site</th>
<th>Poa Hills</th>
<th>Hall Creek</th>
<th>Tullock</th>
<th>Ludlow</th>
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<tbody>
<tr>
<td><em>Lamia cuspidea</em></td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td><em>Lamia sp.</em></td>
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<td>x</td>
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<td><em>Otodus obliquus</em></td>
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<tr>
<td><em>Lungchidion selachae</em></td>
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<tr>
<td><em>Squatirhina americana</em></td>
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<td></td>
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<td>x</td>
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<tr>
<td><em>Ischyrops avonica</em></td>
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<td>?</td>
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<tr>
<td><em>Mylopharopus bipartitus</em></td>
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<td><em>Kindeis fragosa</em></td>
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<tr>
<td><em>Protania sp.</em></td>
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<td>x</td>
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<tr>
<td><em>Balancatanus longirostris</em></td>
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<td></td>
<td></td>
<td>x</td>
</tr>
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<td><em>Lipiscates occidentalis</em></td>
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<td><em>Paractichthys fibrillatus</em></td>
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<td></td>
<td>?</td>
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<td><em>Megades sp.</em></td>
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<tr>
<td>Family <em>Albaulidae</em> (Unidentified genus and species)</td>
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<tr>
<td><em>Platodon anus</em></td>
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<tr>
<td>Family <em>Palaeotidae</em> (Unidentified genus and species)</td>
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<tr>
<td><em>Habrosaurus dilatus</em></td>
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<td>?</td>
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<td><em>Oposhtolitien hayi</em></td>
<td>x</td>
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<td></td>
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<tr>
<td>Order <em>Chelonia</em> (Unidentified turtle remains)</td>
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<td>x</td>
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<td><em>Chompsaurus matator</em></td>
<td>x</td>
<td></td>
<td></td>
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<td><em>Glyptosaurus giganteus</em></td>
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<tr>
<td><em>Champsa saguin</em></td>
<td>x</td>
<td></td>
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<td><em>Leptochamps denticulatus</em></td>
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<td><em>Mosectine lamosina</em></td>
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<td></td>
<td></td>
<td></td>
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<td><em>Parasauria wyomingensis</em></td>
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<td><em>Paraderma bogerti</em></td>
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<tr>
<td><em>Palaeosenia carolensis</em></td>
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<tr>
<td><em>Leidysauchus sternbergi</em></td>
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<td>x</td>
<td>x</td>
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<td><em>Brachychamps montana</em></td>
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<td><em>Pachycyphaleosaurus sp.</em></td>
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<tr>
<td><em>Dryptosaurus sp.</em></td>
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<td><em>Tyannosaurus rex</em></td>
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<td><em>Struthiomimus sp.</em></td>
<td>x</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><em>Habrosaurus feulkii</em></td>
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<tr>
<td><em>Anatosaurus uncommon</em></td>
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<td><em>Kritosaurus sp.</em></td>
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<td><em>Diplomia sp.</em></td>
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<td><em>Ankylosaurus sp.</em></td>
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<td><em>Nesosaurus recurvispinus</em></td>
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<td><em>Triceratops brevicornis</em></td>
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<tr>
<td><em>Triceratops flabellatus</em></td>
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<td>Unidentified dinosaur teeth</td>
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<td>Order <em>Pterosauria</em> (Unidentified species)</td>
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<tr>
<td></td>
<td>Fox Hills</td>
<td>Hell Creek</td>
<td>Tullock</td>
<td>Ludlow</td>
</tr>
<tr>
<td>----------------</td>
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</tr>
<tr>
<td>Cimolodon nitidus</td>
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<td>Manisodon robustus</td>
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<tr>
<td>Padonmys sp.</td>
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Table 9. A comparison of Fox Hills, Hell Creek, Tullock, and Ludlow vertebrates collected by the writer.
Paleoecology of the Hell Creek Formation

Sedimentary Environment of the Hell Creek Formation in Central North Dakota

In the Missouri Valley, in central North Dakota, the Hell Creek Formation is a mixture of marine, brackish-water, fresh-water, and land deposits as shown by the presence of fossil plants, invertebrates, and vertebrates.

The Breien Member of the Hell Creek Formation contains bryozoa, Discocactites sp., cf. D. conradi, an ammonite; Ophioceras major, a crustacean burrow; Lamna sp., cf. L. guamidens, a shark; and Oedea obliquum, also a shark; all of which indicate a normal marine environment. In addition, in the lower beds of the Fort Rice Member of the Hell Creek Formation ?Dentatium (Leavedentalium) pumpeculum, a scaphopod, another marine environment indicator was found.

The Breien and Crowfoot Members of the Hell Creek Formation have fossils of Ostrea gilabra, an oyster; Ostrea sp., cf. O. haydeni, an oyster; Corbicula cytheriformis, a clam; Corbicula pyriformis, a clam; Corbicula subtrigonalis, a clam; cf. Phoroneopsis, a phoronid worm; and Myledaphas bipartitus, a skate; all of which are indicators of a brackish-water environment.

In the Fort Rice, Huff, and Pretty Butte Members of the Hell Creek Formation there are many invertebrate indicators of a fresh-water environment. These include the clams Unio, Plesielliptia, Sphaerium, and the gastropods Viviparus, Campeloma, Limplacodes, and Physa.

In the Pretty Butte, Huff, Fort Rice, and Crowfoot Members of the Hell Creek Formation there are abundant remains of trees such as Ginkgo larasianae Ward, Sequoia dakotensis Brown, Metasequoia occidentalis.
(Newberry) Chamney, Armeria maritima Lam. (Lesquereux) Dorf, Bryophyllum
rubrum Lesquereux, and Cercidiphyllum sp. cf. C. arifrons (Gise) Brown, all of which indicate a land environment.

Sediments also give considerable insight into the environments of
deposition found in the Bell Creek Formation. The presence of pelletal
claystone is generally taken as an indicator of marine or perhaps
brackish water sedimentation. This mineral is abundant in the Avad
Member of the Bell Creek Formation which supports the fossil evidence
that this member is a marine and brackish water deposit. Claystone is
also found in the non-fossiliferous sandstones of the Huff Member of the
Bell Creek Formation in Laramie County, and sometimes in Morton and Sioux
Counties, North Dakota. This would suggest that some of the sandstone
bodies in these counties were of estuarine rather than fluvial origin.
Claystone was also found in shales and sandstones of the Croughest
Member of the Bell Creek Formation supporting the concept that some of
these beds were marine or brackish water as indicated by the fossil
evidence.

The presence of widespread lignitic deposits indicates that the
land surface was one of low relief and probably very swampy. Numerous
channel sandstones indicate that the low swampy surface was cut by many
meandering rivers and estuarine channels. The interfingering of marine
and non-marine sediments indicates that the Bell Creek in this region
was a coastal plain deposit which included the deposits of many minor
advances and retreats of the sea in the form of lagoonal, estuarine, and
occasional marine deposits.
Environments of Sedimentation in the Hell Creek Formation of Western North Dakota and Eastern Montana

In western North Dakota and eastern Montana there is a mixture of fresh-water, (?) brackish-water, and land sediments in the Hell Creek Formation as indicated by their fossil content.

The Huff Member of the Hell Creek Formation contains fossils of cf. Leman sp., a shark; cf. Propterus major, a crustacean burrow; Hylocaeanus bipartitus, a skate; and ? Corbula sp., a clam. All of these genera and species are considered to be indicators of brackish water.

The Huff and Pretty Butte Members of the Hell Creek Formation contain many fresh water invertebrates and vertebrates. These include: Unio, Plesielliptia, Schuuerus, fresh water clams; Viviparus, Campeuron; Limnacodes, fresh water gastropodas; Lamprocastus occidentalis, a ganoid fish; Champsosaurus, a crocodile-like animal; Leidyosuchus sternbergi, a crocodile; and Eusuchians, a montana, an alligator.

All of the members of the Hell Creek Formation in western North Dakota and eastern Montana contain plants and vertebrates that indicate a land environment. These include: Sequoia dakotensis Brown, Cordillerphylites sp., cf. S. arkansana (Bear) Brown, Gravipoa lasqueana Las-Quereux, Glyco laurinensis Ward, Metasequoia occidentalis (Newberry) Chaney, Prunus sp., cf. P. corrugata Brown, Araucaria longifolia (Las-Quereux) Brown, Ficus preartocarpoides Brown, all trees; Cf. Tyrannosaurus rex Osburg, Hadrosaurus foulkii Leidy, Anatosaurus sp., cf. A. annectans (Marsh), Triceratops sp., Pachycephalosaurus sp., all land dinosaurs.

The presence of brackish water species in sandstone channels suggests that the origin of these sands may have been estuarine. Western
North Dakota appears to have been the westernmost extension of the marine channels.

Lignite beds in the Hell Creek Formation are not as common in western North Dakota and eastern Montana as they are in central North Dakota, indicating that the environment of deposition was less coastal swamp and lagoon, and more like that of a coastal plain. This coastal plain environment is reflected in the fauna which has fewer brackish-water and marine species in western North Dakota than in central North Dakota.

**Hell Creek Climate**

The climate during Hell Creek time in North Dakota is somewhat more difficult to ascertain than the environments of deposition. Land plants and animals should be the most reliable indicators because they would be exposed to the greatest daily and seasonal changes of weather. Fresh-water invertebrates should be the second most reliable group because many of them lived in small bodies of water which could have great seasonal changes. Lastly, the marine and brackish-water faunas could give some indications about the land climate but are more useful in determining what the seas were like.

In the Hell Creek Formation there are many genera of plants and animals which are alive today. Care must be taken, if one is to use these animals and plants as climatic indicators, because living genera may now have separate species living in entirely different climates.

Modern plant genera which lived in Hell Creek time include: *Ginkgo*, *Metasequoia*, *Sequoiadendron*, *Erucastrum*, monocotyledonous wood, *Pothos*, *Corylus*, *Caryocyclus*, *Vitis*, *Viburnum*, *Prunus*, *Carmine*, and *Ficus*. 
Today these genera are found to range from cold temperate to tropical climates. Flora and monocotyledonous wood are found in warm temperate to tropical climates (Porter, 1959, p. 174-175, 226-227). *Eucalyptus*, *Ginkgo*, *Ptelea
teton*, *Corylus*, *Vitis*, *Viburnum*, and *Cornus* are found in cool or even cold temperate regions to warm temperate regions. *Nata-
sequens* and *Cascadiellimum* are found in a warm, summer wet, temperate climate where there are few if any frosts (Chu and Cooper, 1930, p. 287). A warm, summer moist, temperate climate is the only climate where all of these genera may be found together today. This would suggest that the climate during Hell Creek time was warm, summer moist, and temperate.

Land animals found in the Hell Creek Formation include Triceratops
sp., cf. *Tyrannosaurus rex* Osborn, cf. *Dryptosaurus* sp., *Pachycephalo-
saurus* sp., and hadrosaurian dinosaurs (all dinosaurs), *Nodosaurus* sp., *Gorgosaurus nitidus* Marsh, *Hemisuchus robustus* (Marsh), *Podionyx* sp., and unidentified teeth (all mammals), *Leidyosuchus sternbergi* Gilmore (a crocodile), *Champeasaurs* sp., cf. *C. natator* Parks (a crocodile-like animal), *Brachychampsa montana* Gilmore (an alligator), turtles, and many others.

The large dinosaurs, since they were (?) cold blooded, probably lived in a climate that did not have hard frosts. Because many of them were herbivores they required abundant plant life which necessitates a humid climate or at least plenty of water. Today all crocodiles and alligators are found in warm temperate to tropical climates. Very little may be said about the mammals, since today mammals are very widespread, and show a great deal of tolerance to气候. Turtles today are very widespread in most temperate and tropical climates. Although turtles
may occur in areas which have thick ice in the wintertime, they are more
abundant in warmer climates.

The climate of the Bell Creek time, as indicated by individual
land animals, might range from cold temperate to tropical but only in
the warm temperate climate could all of these animals be found together.
This supports the evidence for the warm temperate climate indicated by
the plants.

Fresh-water, invertebrates in the Bell Creek Formation included
such snails as Viviparus sp., Campeloma sp., Lioplacodes sp., Goniodoris
sp., ?Pleurolisthens sp., Pseusilla sp., Physa sp., and such clams as
Unio sp., Pleistachyon sp., Pedalia sp., ?Anadonta sp., and Tresarmorid
sp.

These genera exhibit a wide range of climatic tolerance and even
individual species within a genus are often found to have a wide degree
of climatic tolerance. None, or any combination of these genera indi-
cates a climate narrower than temperate, and therefore, they are of
little use for precise climate determination. The major prerequisite
for these genera is water and indicates that the Bell Creek Formation
had an adequate water supply for these organisms. This conclusion is
supported by the river and swamp deposits which are widespread in these
sediments.

Marine and brackish-water deposits found in the Bell Creek Forma-
tion are only slightly more definitive for climate than the fresh-water
deposits. Cretas giabra found in these sediments appears to be very
similar to Cretas giabra virginica found along the Gulf Coast and north-
ward along the Atlantic Coast to Canada (Abbott, 1961, p. 130).
Although this species is common in cool temperate climates, most of its
climatic range may be found in a warm temperate climate. This species
is also a good depth indicator and is only found in littoral to sub-
littoral areas (Barrill, et al., 1985, p. 398).

In conclusion it may be said that the Hall Creek Formation sup-
ported the type of vegetation and animals that would likely be found
today in a warm, summer moist, temperate climate. The types of deposits
found would further suggest that the flora and fauna thrived in a wet
climate where there were numerous swamps and rivers; probably a coastal
plain region of low relief, because many thin persistent, marine,
brackish-water (probably both lagoonal and estuarian) deposits are found
throughout the Hall Creek Formation in central North Dakota.

A Comparison of Hall Creek and Ludlow-Tullock Climates
in North Dakota

The climates of Ludlow and Tullock time should have been similar,
since their beds are stratigraphic equivalents in the same geographic
region. The Ludlow Formation is composed of lagoonal and coastal
swamp deposits, while the Tullock Formation is composed of more land-
ward, coastal plain deposits.

Plants found in the Ludlow Formation include: Glycostrobus
arizonakoidi, Metasequoia occidentalis, Hydrurus expanse,
?Palaredonites olicinus, ?Sabal powelli, Phrareya hiannida, Ulmus
rhemifolia, Ficus cartagena, Platanes raynoiidae, Halimblum montanum,
Parasphena cressifolia, Ceratinosilurus arcticus, Cissus marginata,
and Melastomites montanensis. Of the genera present, Sabal and
Palaredonites are palms and are only common in tropical and subtropical
climates (Porter, 1959, p. 174) but may be found in warm temperate
regions of no frost. Ficus is also a common tree of the tropics and
...-218-
subtropics but has a few members in temperate climates (Porter, 1959, p. 226). *Metasequoia* and *Cercidiphyllum* are trees found in a warm, summer moist, temperate region (Gue and Cooper, 1950, p. 267; Chaney, 1951, p. 224) where there are few if any frosts. *Ulmus*, however, is not a tropical or subtropical tree but is typical of the temperate climates (Porter, 1959, p. 221) and may be found in the cold temperate regions where there are long cold winters. Thus, palms are found alongside *Ulmus*. This could only occur in a warm temperate climate. In addition, the fact that *Metasequoia* is only found in a warm, summer moist, temperate climate today indicates that the Ludlow time must have had a warm, summer moist, temperate climate.

In the Tullock Formation the following plants were found: *Ulmus rhamaifolia*, *Ficus arctocarpoides*, *Ficus planicostata*, *Ficus subtruncata*, *Morus montanaea*, *Platanus raynoldsi*, *Peroea brasiiana*, *Cercidiphyllum arcticum*, *Magnolia magnifolia*, *Eucommia serrata*, *Prunas carydburzis*, *Amphelopsis acutifolia*, and *Viburnum* sp. Of these genera *Peroea*, *Magnolia*, *Ficus*, and *Morus* are typical of tropical and subtropical regions but are also found in temperate regions (Porter, 1959, p. 226, 242, 252). *Viburnum* is a common shrub or tree of the temperate climates today (Porter, 1959, p. 400). *Cercidiphyllum* grows today in a warm, summer moist, temperate climate. *Prunas* and *Ulmus* are trees of the temperate regions and are often found in regions of severe winters. The only climate in which all of these plants could be found associated must have been warm, temperate climate that had a moist summer. This is the same climate that was deduced for the Ludlow time and is to be expected since they are lateral equivalents in the same geographic region.
Supporting evidence for a warm temperate climate in Tullock time is found in the vertebrate fauna which included *Leidyosuchus sternbergi*, a crocodile, and *Champsosaurus* sp., a crocodile-like animal. Crocodiles live today only in tropical to warm temperate regions.

Thus Tullock and Ludlow time had a warm, summer moist, temperate climate which is the same climate as that of Bell Creek time. This could indicate that the large change in plants and animals between Mesozoic and Cenozoic times was not the result of climate but due to some other cause.
SUMMARY OF HELL CREEK HISTORY

The Hell Creek Formation is a volcanic, non-marine wedge of sediments extending eastward from central and western Montana into North Dakota and South Dakota. Its equivalent, the Lance Formation of eastern Wyoming, western Nebraska, and Colorado is a non-marine, volcanic wedge of sediments extending from western and central Colorado and central Wyoming.

In the early Cretaceous, pulses of the Laramide Orogeny first began to be felt in northern Utah and southern Idaho and this activity was reflected in the Interior Sedimentary Basin by deposition of non-marine wedges of sediments which began displacing the early Cretaceous seas. The first of these clastic wedges was the Canebrake Group (Alexander, et al., editors, 1953) which was followed by others in the early and middle Cretaceous such as the Ely Island, Muddy, Frontier, and Hesperian Formations. By middle and late Cretaceous time the center of tectonic activity had moved to western Montana where major volcanism developed and continued into early Cenozoic time. Many thousands of feet of Upper Cretaceous andesitic volcanics, called the Livingston Series (McGinnis, 1955), were deposited in this area and these volcanics represent the culmination of the Laramide Orogeny in this region. Eastward extensions of these volcanic, non-marine sediments include the Upper Cretaceous Hell Creek Formation and the Lower Paleocene Tuliock, Lebo, and Tongue River Formations.
The Hell Creek Formation comprises only a small part of this sequence. It is underlain by the Fox Hills Formation which is in turn underlain by the bentonitic Pierre Shale. The Fox Hills Formation is a series of off-shore bar and beach deposits which separate the non-marine Hell Creek Formation from the marine Pierre Shale (Neimer, 1961, p. 82-97). The Hell Creek Formation may be visualized as the subaerial top-set beds of a giant delta whose marine top-set beds are the Fox Hills Formation, and whose fore-set and bottom-set beds are the Pierre Shale. The Pierre Shale consists of the land derived sediments shed from western Montana during volcanism connected with the Livingston Series and through uplift associated with the Laramide Orogeny. The region of Hell Creek deposition acted like a huge conveyer-belt for these sediments, keeping some, but carrying most to the sea where they were deposited in the Pierre Delta. The Fox Hills Sandstone represents the wave-winned upper portions of the delta where the fine sediments were carried out to sea leaving behind the sand deposits of the Fox Hills Formation. This environmental relationship developed a very complex series of facies in which the basal Hell Creek as well as the Fox Hills Sandstone transgressed time as these units are traced in an easterly direction. The Hell Creek interfingers with the Fox Hills Formation, and the Fox Hills Formation in turn interfingers with the Pierre Shale.

In central North Dakota the interfingering relationship between the Hell Creek Formation and the Fox Hills Formation is well developed and exposed and one can see the basal Hell Creek Formation finger out into Fox Hills sediments. Over a distance of a few tens of miles from south-central Morton County to central Ramsey County, the basal beds of the Hell Creek Formation, the Crowfoot Member, thin from 30
feet to several feet in thickness indicating that the directly overlying marine Breien Member of the Hell Creek Formation is a tongue of the Fox Hills sandstone, the marine, top-set beds of the Pierre delta. Numerous occurrences of glauconite in the Morton and Huff Members of the Hell Creek Formation in Emusus County indicate that this was as far east as the non-marine, Hell Creek, top-set beds were deposited upon the Pierre Delta for here they are rapidly giving way to marine top-set beds of the Fox Hills Formation.

At the end of Hell Creek time (at the beginning of the Paleocene Epoch) the sea flooded over the eastern sub-aerial top-set beds of the Pierre Delta in North Dakota and South Dakota but non-marine and volcanic sedimentation continued in eastern Montana forming the Tullock, Lobo, and Tongue River sediments. The invasion of the sea was of short duration. To the west and landward the beach and lagoonal deposits of the Ludlow Formation were deposited which were followed in turn by marine Cannonball sediments. The Paleocene Cannonball Sea was apparently a later continuation of the Pierre-Fox Hills Sea which persisted through Hell Creek time as indicated by the glauconite beds in the middle and upper Hell Creek beds of Emusus County, North Dakota. In western North Dakota the lagoonal and beach deposits of the Ludlow Formation inter-digitate with the non-marine coastal plain deposits of the Tullock, Lobo, and Tongue River Formations to the west, and the marine Cannonball Formation to the east. At the end of Cannonball time the sea withdrew and have since not covered this part of the mid-continent. Non-marine alluvial plain sedimentation followed with the deposition of the Tongue River, Sentinel Butte Formations in the Paleocene, and the Golden Valley and White River Formations during the Eocene and Oligocene Epochs.
The climate during Hell Creek times in North Dakota was warm, summer moist, temperate, and probably with no frosts. This is indicated by such plants as *Metasequoia*, *Cercidiphyllum*, *Ficus*, and *Magnolia*, and by such animals as ammonites, dinosaurs, crocodiles, and alligators. The climate of the early Paleocene appears to have changed little, if any, from the climate which prevailed during deposition of the Hell Creek Formation. This is indicated by the continuance into the Paleocene of such plant genera as *Cercidiphyllum* and *Metasequoia* which grow in a warm, summer moist, temperate climate, and by the presence of crocodiles.

The cause of the extinction of the dinosaur and ammonite groups at the end of Hell Creek time still remains a mystery. These studies would indicate that climate had very little effect upon their extinction since there is no evidence that it changed greatly; and, to the contrary, there is considerable evidence that it remained much the same. The possibility that their food became extinct and they were unable to change diets is also remote; because, although many of the plant species changed about this time, most of the genera of the plant community remained the same. Volcanism has been suggested as a cause for the extinction of the dinosaurs and may well have played an important role, but there was considerable volcanism all through Hell Creek times. Why should it suddenly become important at the end of Hell Creek time?

There is still much to be learned from the upper Hell Creek and lower Paleocene rocks of North Dakota and perhaps the answers to such puzzling questions as why the dinosaurs and ammonites died out at the end of Hell Creek time, and what caused the explosive development of the mammals at the beginning of the Tertiary.
APPENDIX A  (PART I)

TYPE SECTIONS OF WELL CREEK FORMATION AND MEMBERS

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 1</td>
<td>Type Section of Well Creek Formation</td>
<td>225</td>
</tr>
<tr>
<td>Section 2</td>
<td>Type Section of Well Creek Formation</td>
<td>228</td>
</tr>
<tr>
<td>Section 3</td>
<td>Type Section of Pretty Butte Member</td>
<td>230</td>
</tr>
<tr>
<td>Section 4</td>
<td>Type Section of Huff Member</td>
<td>233</td>
</tr>
<tr>
<td>Section 5</td>
<td>Type Section of Port Rice Member</td>
<td>234</td>
</tr>
<tr>
<td>Section 6</td>
<td>Type Sections of Brazen and Crowghost Members</td>
<td>237</td>
</tr>
<tr>
<td>Section 7</td>
<td>Type Section of Bacon Creek Member</td>
<td>239</td>
</tr>
<tr>
<td>Section 8</td>
<td>Type Section of Marmarth Member</td>
<td>241</td>
</tr>
<tr>
<td>Section 9</td>
<td>Type Section of Little Beaver Creek Member</td>
<td>243</td>
</tr>
</tbody>
</table>

*For locations of these sections see Plate 6, in folder.*
### TULLOCH FORMATION
(Lignite beds of Brown, 1907)

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>32</td>
<td>Gray, limonite stained sand with calcareous sandstone lenses</td>
<td>37.5</td>
</tr>
<tr>
<td>31</td>
<td>Gray, brownish-brown bentonite sand</td>
<td>7.5</td>
</tr>
<tr>
<td>30</td>
<td>Light-gray shale, in places bentonitic, and sandy; siderite nodules weathering to limonite near the base</td>
<td>10.5</td>
</tr>
<tr>
<td>29</td>
<td>Light-brownish-gray sand</td>
<td>4.5</td>
</tr>
<tr>
<td>28</td>
<td>Medium-brownish-gray bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>27</td>
<td>Gray, bentonitic sand</td>
<td>14.0</td>
</tr>
<tr>
<td>26</td>
<td>Moderate-brown bentonite and bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>25</td>
<td>Moderate-brown sand with calcareous sandstone lenses</td>
<td>23.0</td>
</tr>
<tr>
<td>24</td>
<td>Dark-brown to black lignite and lignitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Total thickness of Pretty Butte Member</td>
<td>109.0</td>
</tr>
</tbody>
</table>

### HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>33</td>
<td>Dark-gray bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>32</td>
<td>Light-grayish-brown bentonitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>31</td>
<td>Medium-brownish-gray bentonite with white bloom</td>
<td>4.0</td>
</tr>
<tr>
<td>30</td>
<td>Medium-brownish-brown bentonite</td>
<td>2.0</td>
</tr>
<tr>
<td>29</td>
<td>Medium-brownish-gray bentonite with white bloom</td>
<td>4.0</td>
</tr>
<tr>
<td>28</td>
<td>Medium-purpleish-gray bentonite</td>
<td>2.0</td>
</tr>
<tr>
<td>27</td>
<td>Medium-gray to light-yellowish-gray bentonite</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>Total thickness of Pretty Butte Member</td>
<td>30.0</td>
</tr>
</tbody>
</table>
### HELL CREEK FORMATION (?? Huff Member)

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>26.</td>
<td>Yellowish-gray sands</td>
<td>13.0</td>
</tr>
<tr>
<td>25.</td>
<td>Gray bentonites with lignitic lenses</td>
<td>33.0</td>
</tr>
<tr>
<td>24.</td>
<td>Yellowish-brownish-gray sand with calcareous sandstone lenses</td>
<td>35.0</td>
</tr>
<tr>
<td>23.</td>
<td>Moderate-purplish-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>22.</td>
<td>Medium-gray bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>21.</td>
<td>Brown, lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>20.</td>
<td>Medium-gray bentonite</td>
<td>13.0</td>
</tr>
<tr>
<td>19.</td>
<td>Brown sand</td>
<td>1.0</td>
</tr>
<tr>
<td>18.</td>
<td>Brownish-gray bentonite with white bloom</td>
<td>10.0</td>
</tr>
<tr>
<td>17.</td>
<td>Yellowish-gray sand</td>
<td>9.0</td>
</tr>
<tr>
<td>16.</td>
<td>Yellowish-gray to brownish-gray bentonite with marenite and calcareous concretions near the base. (Equivalent to bentonite at top of Bacon Creek Member in Slope and Bowman Counties, North Dakota)</td>
<td>22.0</td>
</tr>
<tr>
<td>15.</td>
<td>Brown, lignitic, calcareous sands with many mollusks</td>
<td>5.0</td>
</tr>
<tr>
<td>14.</td>
<td>Brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>13.</td>
<td>Yellowish-brownish-gray sand with calcareous sandstone lenses</td>
<td>18.0</td>
</tr>
<tr>
<td>12.</td>
<td>Light-yellowish-gray, bentonite sand</td>
<td>11.0</td>
</tr>
<tr>
<td>11.</td>
<td>Yellowish-brownish-gray sand with shale partings</td>
<td>12.5</td>
</tr>
<tr>
<td>10.</td>
<td>Moderate-purplish-brown, lignitic shale</td>
<td>2.5</td>
</tr>
<tr>
<td>9.</td>
<td>Yellowish-brown sand with calcareous sandstone lenses near the base</td>
<td>35.0</td>
</tr>
</tbody>
</table>

**Total thickness of (?) Huff Member** | 227.0
HELL CREEK FORMATION (? BACON CREEK MEMBER)

6. Light-brown, bentonitic shale......................... 4.0
7. Yellowish-brown, lignitic silt ....................... 4.0
6. Moderate-grayish-brown bentonite ................... 6.0
5. Light-brown, bentonitic shale ....................... 3.0
4. Medium-brownish-gray bentonite ..................... 6.0
3. Bluish-gray bentonite (Blue Marker Bed of Brown, 1907) .................. 3.0
2. Dark-purpleish-gray, bentonitic shales ............. 6.0

Total thickness of (?) Bacon Creek Member ........... 34.0

HELL CREEK FORMATION (lower sand unit)

1. Yellowish-brown, cross-bedded sands ............... 25.0

Total 25.0

Covered

Thickness of Hell Creek Formation measured .......... (316.0)
### SECTION 2

Sec. 14, T. 21 N., R. 37 E., Garfield County, Montana

(TYPE SECTION FOR BELL CREEK FORMATION)

**BELL CREEK FORMATION (7 BACON CREEK MEMBER)**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Bluish-gray bentonite</td>
<td>2.0</td>
</tr>
<tr>
<td>2.</td>
<td>Yellowish-gray, fine sand</td>
<td>2.0</td>
</tr>
<tr>
<td>3.</td>
<td>Medium-purplish-gray bentonite</td>
<td>3.5</td>
</tr>
<tr>
<td>4.</td>
<td>Medium-yellowish-gray bentonite</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**Rocks 13 through 15 "blue marker bed" of Brown (1937)**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.</td>
<td>Yellowish-brown sand</td>
<td>13.5</td>
</tr>
<tr>
<td>6.</td>
<td>Light-bluish-gray bentonite</td>
<td>2.0</td>
</tr>
<tr>
<td>7.</td>
<td>Medium-purplish-gray bentonite with some</td>
<td>14.0</td>
</tr>
<tr>
<td></td>
<td>limonitic shale</td>
<td></td>
</tr>
<tr>
<td>8.</td>
<td>Yellowish-gray bentonite</td>
<td>3.5</td>
</tr>
<tr>
<td>9.</td>
<td>Light-brown bentonite</td>
<td>7.5</td>
</tr>
<tr>
<td>10.</td>
<td>Yellowish-gray, fine sand</td>
<td>1.0</td>
</tr>
<tr>
<td>11.</td>
<td>Medium-purplish-gray bentonite</td>
<td>11.0</td>
</tr>
<tr>
<td>12.</td>
<td>Yellowish-gray, fine sand</td>
<td>1.0</td>
</tr>
<tr>
<td>13.</td>
<td>Medium-purplish-gray bentonite</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Total 66.0

**BELL CREEK FORMATION (lower sand unit)**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.</td>
<td>Light-brown to gray, cross-bedded sand with bentonitic shale partings and</td>
<td>24.0</td>
</tr>
<tr>
<td></td>
<td>siderite nodules weathering to limonite at the base</td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Moderate-orangeish-brown sand with numerous</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>calcareous sandstone lenses</td>
<td></td>
</tr>
</tbody>
</table>

Total thickness of lower sand unit 49.0

Thickness of Bell Creek Formation measured (115.0)
FOXL MILLS FORMATION (Undifferentiated)

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Light-brown sands with shale partings</td>
<td>35.0</td>
</tr>
<tr>
<td>2. Fine calcareous sandstone</td>
<td>2.0</td>
</tr>
<tr>
<td>1. Light-gray sand and shale</td>
<td>23.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>30.0</strong></td>
</tr>
</tbody>
</table>

Covered
**SECTION 3**

Sec. 26, T. 134 N., R. 106 W., Slope County, North Dakota

(TYPE SECTION FOR PRETTY BUTTE MEMBER OF HELL CREEK FORMATION)

**LUDLOW FORMATION**

<table>
<thead>
<tr>
<th>Foot</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.0</td>
<td>Sandy &quot;scoria&quot;</td>
</tr>
<tr>
<td>16.0</td>
<td>Shaly &quot;scoria&quot;</td>
</tr>
<tr>
<td>7.5</td>
<td>White ash (Y-Cross bed of Harca, 1928)</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>42.5</strong></td>
</tr>
</tbody>
</table>

**TULLOCH FORMATION**

<table>
<thead>
<tr>
<th>Foot</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.0</td>
<td>Light-yellowish-brown, interbedded silts and shales</td>
</tr>
<tr>
<td>1.0</td>
<td>Light-tan, calcareous sandstone ledge</td>
</tr>
<tr>
<td>16.5</td>
<td>Light-brown, interbedded shales, silts, and fine sands</td>
</tr>
<tr>
<td>1.0</td>
<td>Dark-brown lignite and lignitic shale</td>
</tr>
<tr>
<td>14.0</td>
<td>Buff, fine sand</td>
</tr>
<tr>
<td>1.0</td>
<td>Dark-brown, shaly lignite</td>
</tr>
<tr>
<td>16.0</td>
<td>Tan, fine sand</td>
</tr>
<tr>
<td>4.0</td>
<td>Dark-brown to black, shaly lignite</td>
</tr>
<tr>
<td>21.5</td>
<td>Buff, fine sand, and silt with calcareous sandstone lenses 4 feet above the base and a calcareous sandstone ledge 2 feet above the base</td>
</tr>
<tr>
<td>3.5</td>
<td>Dark-brown to black lignite</td>
</tr>
<tr>
<td>3.0</td>
<td>Light-brown, interbedded silt and shale</td>
</tr>
<tr>
<td>10.0</td>
<td>Gray, bentonitic shale</td>
</tr>
<tr>
<td>6.5</td>
<td>Rusty-brown bentonite with calcareous concretions near the base</td>
</tr>
<tr>
<td>6.5</td>
<td>Brownish-gray, somewhat bentonitic, cross-bedded sand</td>
</tr>
<tr>
<td>1.0</td>
<td>Rusty colored bentonite</td>
</tr>
<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>33</td>
<td>Brown lignite and lignitic shale which changes laterally to a pale yellowish-brown silt</td>
</tr>
<tr>
<td>32</td>
<td>Light-bluish-gray, clay-rich sand</td>
</tr>
<tr>
<td>31</td>
<td>Rusty-brown silt and bentonitic shales with siderite nodules weathering to limonite near the base</td>
</tr>
<tr>
<td>30</td>
<td>Dark-brown lignite</td>
</tr>
<tr>
<td>29</td>
<td>Gray bentonite</td>
</tr>
<tr>
<td>28</td>
<td>White calcareous sandstone ledge</td>
</tr>
<tr>
<td>27</td>
<td>Brown sand with rust colored bentonite partings and siderite nodules weathering to limonite at the base</td>
</tr>
<tr>
<td>26</td>
<td>Brownish-gray bentonite</td>
</tr>
<tr>
<td>25</td>
<td>Brown lignite and lignitic shale</td>
</tr>
<tr>
<td>24</td>
<td>Light-yellowish-gray bentonite and bentonitic shale</td>
</tr>
<tr>
<td>23</td>
<td>Gray sand with lignitic lenses, very-light-gray, calcareous sandstone lenses and siderite nodules weathering to limonite in the lower portions</td>
</tr>
<tr>
<td>22</td>
<td>Brown lignite and lignitic shale</td>
</tr>
<tr>
<td>21</td>
<td>Limonite stained, brown, bentonitic shale</td>
</tr>
<tr>
<td>20</td>
<td>Gray sand</td>
</tr>
<tr>
<td>19</td>
<td>Grayish-brown, bentonitic shale</td>
</tr>
<tr>
<td>18</td>
<td>Brown, lignitic sand</td>
</tr>
<tr>
<td>17</td>
<td>Gray bentonite</td>
</tr>
<tr>
<td>16</td>
<td>Brown lignite and lignitic shale</td>
</tr>
<tr>
<td>15</td>
<td>Gray, bentonitic shale</td>
</tr>
<tr>
<td>14</td>
<td>Light-yellowish-brown, fine sand and silt - &quot;Yellow bed&quot;</td>
</tr>
</tbody>
</table>
13. Dark-brown lignite - "lowest persistent lignite" .......................................... 3.5

Total thickness of the Tullock Formation ..................................................... 160.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)
(Type section)

12. Brownish-gray bentonite ................................................................. 8.5
11. Light-gray sand with calcareous sandstone lenses near the base ................. 7.5
10. Light-gray bentonite ............................................................................. 4.0
 9. Brown, lignitic shale ............................................................................ 2.0
 8. Medium-gray bentonite ......................................................................... 8.0

Total thickness of the Pretty Butte Member .............................................. 28.0

HELL CREEK FORMATION (BUFF MEMBER)

7. Gray sand with siderite nodules weathering to limonite near the top and bottom, and calcareous sandstone lenses just above the bottom ........................................... 47.0

6. Brownish-gray bentonitic shale grading downward into bentonitic sand with siderite nodules weathering to limonite. Mostly sandy 10 feet below the top ...................................................... 28.5

5. Brown, lignitic shale and lignite ............................................................ 1.5

4. Gray, bentonitic shale which is replaced by a lignitic shale lens at the base ................................................................. 4.0

3. Lignitic shale ......................................................................................... 9.0

2. Medium-gray, bentonitic shale .............................................................. 7.0

1. Light-brown, lignitic shale ..................................................................... 2.0

Total 99.0

Covered

Total thickness of Hell Creek Formation measured ....................................... (127.0)
SECTION 4

Sw 1/4 sec. 3, T. 136 N., R. 79 W., Morton County, North Dakota
(TYPE SECTION FOR HUFF MEMBER OF HELL CREEK FORMATION)

FOOT

LUDLOW FORMATION

9. Brown to gray, lignitic shales .................. 15.0

Total 15.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

6. Brown to gray, lignitic, bentonitic shales
with siderite nodules weathering to limonite.
Beds become more bentonitic near the base ........ 30.0

Total thickness of Pretty Butte Member ........ 30.0

HELL CREEK FORMATION (HUFF MEMBER)
(Type Section)

7. Light-yellowish-gray sands with occasional
bentonite shale partings ........................... 38.5

5. Sharpstone conglomerate with a matrix of sand
same as bed 7. Pebbles of clay-rich, fine sand.
They appear to be disrupted and-cracks ........... 10.5

3. Light-yellowish-gray sands with siderite
nodules weathering to limonite .................... 10.0

4. Medium-gray, bentonitic shale, and silt with
 gypsum crystals ................................. 3.0

2. Light-gray sand with fluted weathering, cal-
carneous sandstone lenses, and bentonitic
shale partings .................................... 22.9

Total thickness of the Huff Member ............. 85.0

HELL CREEK FORMATION (FORD RICK MEMBER)

1. Medium-gray shale with some silt, and fine
sand partings ...................................... 10.0

Total 15.0

Covered

Thickness of Hell Creek Formation measured ......(130.0)
SECTION 5

N 1/2 sec. 1, T. 136 N., R. 86 W., Morton County, North Dakota (from top of hill, west side of road to further side of railroad tracks, east side of road)

(TYPE SECTION FOR FORT RICE MEMBER)

CANNONBALL FORMATION

| 46.  | Gray to buff, brown weathering shale   | 5.0 |

Total 5.0

LUDLOW FORMATION

| 45.  | Dark-gray, lignitic shale             | 1.5 |
| 44.  | Buff, lignitic sand                   | 3.3 |
| 43.  | Dark-brown, lignitic, interbedded shales and sands | 3.0 |

Total thickness of Ludlow Formation 10.9

KELL CREEK FORMATION (PRETTY BUTTE MEMBER)

<p>| 42.  | Gray, slightly bentonitic shale with plant fossils and siderite nodules weathering to limonite | 5.0 |
| 41.  | Black, lignitic shale                  | 1.0 |
| 40.  | Gray shale with plant fragments        | 1.5 |
| 39.  | Brown, lignitic shale                  | 1.5 |
| 38.  | Light-gray sand                        | 2.0 |
| 37.  | Brown, lignitic, bentonitic sand       | 5.5 |
| 36.  | Gray to brown, bentonitic shale with siderite nodules weathering to limonite | 8.5 |
| 35.  | Dark-purplish-brown, lignitic shale    | 3.0 |
| 34.  | Gray, brown weathering, bentonitic shale, sandy near the base | 7.5 |
| 33.  | Dark-brown, lignitic shale             | 1.3 |
| 32.  | Dark-gray, bentonitic shale            | 1.5 |</p>
<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>31.</td>
<td>Dark-brown, lignitic shale</td>
<td>10.0</td>
</tr>
<tr>
<td>30.</td>
<td>Dark-gray, bentonitic shale with siderite nodules weathering to limonite</td>
<td>30.0</td>
</tr>
<tr>
<td>Total thickness of the Pretty Butte Member</td>
<td></td>
<td>39.0</td>
</tr>
</tbody>
</table>

**HELL CREEK FORMATION (BUFF MEMBER)**

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.</td>
<td>Medium-gray shale with siderite nodules weathering to limonite</td>
<td>16.0</td>
</tr>
<tr>
<td>28.</td>
<td>Medium-gray, bentonitic shale</td>
<td>9.0</td>
</tr>
<tr>
<td>27.</td>
<td>Brown, interbedded sands and shales with siderite nodules weathering to limonite near the top</td>
<td>5.0</td>
</tr>
<tr>
<td>26.</td>
<td>Grayish-brown shale</td>
<td>5.0</td>
</tr>
<tr>
<td>25.</td>
<td>Brown sand with shale partings and siderite nodules weathering to limonite at the top</td>
<td>3.0</td>
</tr>
<tr>
<td>24.</td>
<td>Brown to gray, bentonitic shale, more bentonitic at the base</td>
<td>4.0</td>
</tr>
<tr>
<td>23.</td>
<td>Brown to gray, bentonitic, lignitic shale</td>
<td>5.5</td>
</tr>
<tr>
<td>22.</td>
<td>Gray to brown sand with bentonitic shale partings near the top, lignitic sandstone lenses, and calcareous sandstone lenses</td>
<td>42.0</td>
</tr>
<tr>
<td>21.</td>
<td>Dark-brown, lignitic sand</td>
<td>1.0</td>
</tr>
<tr>
<td>Total thickness of the Buff Member</td>
<td></td>
<td>87.5</td>
</tr>
</tbody>
</table>

**HELL CREEK FORMATION (PORT RIGE MEMBER)**

(Type section)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.</td>
<td>Dark-gray bentonite and bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>19.</td>
<td>Dark-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>18.</td>
<td>Brown, bentonitic shale</td>
<td>4.5</td>
</tr>
<tr>
<td>17.</td>
<td>Brown sand</td>
<td>1.5</td>
</tr>
<tr>
<td>16.</td>
<td>Dark-brown, lignitic shale</td>
<td>0.5</td>
</tr>
<tr>
<td>15.</td>
<td>Brown, gray weathering, bentonitic shale</td>
<td>3.5</td>
</tr>
<tr>
<td>14.</td>
<td>Brown sand</td>
<td>1.0</td>
</tr>
</tbody>
</table>
13. Gray sand with shale partings and lignitic lenses ........................................... 10.5
12. Medium-gray bentonite ................................................................. 3.0
11. Gray sand with siderite nodules weathering to limonite ..................................... 1.5
10. Dark-brown, lignitic shale and shaly lignite ............................................... 1.0
9. Gray sand ......................................................................................... 8.0
8. Fine, gray sands with marcasite concretions and siderite nodules weathering to limonite near the top ................................................................. 6.0
7. Siderite nodules (4 feet above the road on both sides) containing fossil snails ............. 1.0
6. Brown to gray, bentonitic sands and shales ........................................ 13.0
5. Dark-brown, lignitic shale and lignite with siderite nodules weathering to limonite near the top ............................................................................. 1.5

Total thickness of the Fort Rice Member ................................................ 62.0

HELL CREEK FORMATION (BRIEFC MEMBER)

4. Brown to buff, banded silts and shales ....................................................... 10.0
3. Dark-gray, bentonitic shale and bentonite .................................................... 5.0
2. Green, brown weathering, glauconitic sands with a siderite bed weathering to limonite at the top ................................................................................. 4.5

Total thickness of the Briefer Member ...................................................... 19.5

HELL CREEK FORMATION (GROWINGHOT MEMBER)

1. Shaly lignite, and lignitic shale .................................................................. 1.5

Covered

Thickness of Bell Creek Formation measured ........................................ (209.5)
SECTION 6

C. sect. 13, T. 134 N., R. 81 W., Crowghost Cemetery, Sioux County, North Dakota
(TYPE SECTIONS FOR THE BREHEN AND CROWGHOST MEMBERS OF THE HELL CREEK FORMATION)

HELL CREEK FORMATION (BUFF MEMBER)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>23.</td>
<td>Light-brown sand</td>
<td>15.0 feet</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>15.0</strong></td>
</tr>
</tbody>
</table>

HELL CREEK FORMATION (FORT RICE MEMBER)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.</td>
<td>Brownish-gray, bentonitic shale with siderite nodules weathering to limonite at the top</td>
<td>5.0 feet</td>
</tr>
<tr>
<td>21.</td>
<td>Brown sands with bentonitic shale partings</td>
<td>13.5 feet</td>
</tr>
<tr>
<td>20.</td>
<td>Dark-brown, lignitic sand and shaly lignite</td>
<td>1.5 feet</td>
</tr>
<tr>
<td>19.</td>
<td>Medium-gray sand</td>
<td>2.0 feet</td>
</tr>
<tr>
<td>18.</td>
<td>Gray, lignitic shale with siderite nodules weathering to limonite at the top and bottom</td>
<td>3.0 feet</td>
</tr>
<tr>
<td>17.</td>
<td>Moderate-brown lignite and lignitic shale</td>
<td>1.9 feet</td>
</tr>
<tr>
<td>16.</td>
<td>Medium-gray, bentonitic shales</td>
<td>15.0 feet</td>
</tr>
<tr>
<td>15.</td>
<td>Gray sands with a few siderite nodules weathering to limonite</td>
<td>4.5 feet</td>
</tr>
<tr>
<td>14.</td>
<td>Lignitic shale and shaly lignite with siderite nodules weathering to limonite near the top</td>
<td>2.5 feet</td>
</tr>
<tr>
<td></td>
<td><strong>Total thickness of Fort Rice Member</strong></td>
<td><strong>53.0</strong></td>
</tr>
</tbody>
</table>

HELL CREEK FORMATION (BREHEN MEMBER)
(TYPE section)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.</td>
<td>Gray, clay-rich, banded, medium grained sands grading downward into soft, greenish-brown, brown weathering, clayey siltite sands with <em>Ophiomorpha major</em></td>
<td>9.0 feet</td>
</tr>
<tr>
<td>12.</td>
<td>Siderite bed weathering to limonite underlain by moderate-grayish-brown sand</td>
<td>1.5 feet</td>
</tr>
<tr>
<td>11.</td>
<td>Moderate-gray bentonite</td>
<td>1.5 feet</td>
</tr>
</tbody>
</table>
10. Grayish-green, glauconitic sand weathering rusty brown, containing Ophiomorpha walteri, and gastropod molds near the top ........................ 7.0

Total thickness of Avila Member ................................ 19.0

HELL CREEK FORMATION (CROWFOOT MEMBER)
(Type section)

9. Brown, lignitic shale ........................................ 2.5
8. Gray, fine sands with bentonitic shale partings ........ 8.0
7. Dark-brown, lignitic shale, and shaly lignite with siderite nodules weathering to limonite near the top ..................................... 2.0
6. Dark-brown, lignitic shale and shaly lignite .......... 1.0
5. Gray, bentonitic shale ..................................... 5.0
4. Black, lignitic shale and shaly lignite with siderite nodules weathering to limonite near the base. Siderite nodules contain plant fossils .......................... 1.5
3. Medium-gray, bentonitic shale and bentonite ......... 5.0
2. Lignite shale and sandstone with silicified tree stumps standing upon it in position, their root systems occasionally extending into beds below .......... 2.5

Total thickness of Crowfoot Member ....................... 29.5

Thickness of the Hell Creek Formation measured ... (118.5)

FOX HILLS FORMATION (COLGATE MEMBER)

1. Gray sandstones ............................................ 29.5

Covered.
**SECTION 7**

SE 1/4 sec. 23, T. 133 N., R. 106 W., Slope County, North Dakota  
*(Type section of Bacon Creek Member of the Hell Creek Formation)*

**Hell Creek Formation (Buff Member)**  

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.</td>
<td>Buff sands with calcareous sandstone lenses</td>
<td>15.0</td>
</tr>
<tr>
<td>20.</td>
<td>Medium-gray, bentonitic shale</td>
<td>5.5</td>
</tr>
<tr>
<td>19.</td>
<td>Dark-gray bentonite with siderite nodules weathering to limonite near the top</td>
<td>1.5</td>
</tr>
<tr>
<td>18.</td>
<td>Light-gray, interbedded bentonitic sand and sandy bentonite</td>
<td>11.0</td>
</tr>
<tr>
<td>17.</td>
<td>Medium-gray bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>16.</td>
<td>Sand with calcareous sandstone lenses</td>
<td>36.0</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td>70.0</td>
</tr>
</tbody>
</table>

**Hell Creek Formation (Bacon Creek Member)**  
*(Type section)*

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.</td>
<td>Moderate-greenish-brown to gray bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>24.</td>
<td>Light-gray sand</td>
<td>0.5</td>
</tr>
<tr>
<td>23.</td>
<td>Medium-gray bentonite</td>
<td>14.5</td>
</tr>
<tr>
<td>22.</td>
<td>Light-gray sand with bentonitic shale partings and calcareous sandstone lenses</td>
<td>14.0</td>
</tr>
<tr>
<td>21.</td>
<td>Tanish-gray bentonite</td>
<td>6.0</td>
</tr>
<tr>
<td>20.</td>
<td>Dark-purplish-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>19.</td>
<td>Medium-gray bentonite</td>
<td>4.6</td>
</tr>
<tr>
<td>18.</td>
<td>Light-gray sand</td>
<td>1.0</td>
</tr>
<tr>
<td>17.</td>
<td>Medium-gray bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>16.</td>
<td>Light-gray sand</td>
<td>1.0</td>
</tr>
<tr>
<td>15.</td>
<td>Dark-purplish-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>14.</td>
<td>Medium-gray bentonite</td>
<td>2.0</td>
</tr>
<tr>
<td>13.</td>
<td>Medium- to light-gray sand</td>
<td>6.0</td>
</tr>
</tbody>
</table>
12. Moderate-grayish-brown bentonite with white
to rusty colored calcareous concretions . . . . . . . 17.0
11. Moderate-brown, lignitic, bentonitic sand . . . . 1.5
10. Dark-purplish-brown, sandy, lignitic shale . . . . 1.0
9. Medium-gray, interbedded sands and bentonites
with siderite nodules weathering to limonite
near the base . . . . . . . . . . . . . . . . . . . . . 10.3
8. Moderate-purplish-brown, lignitic shale . . . . . 1.0
7. Medium-gray bentonite . . . . . . . . . . . . . . . 4.0
6. Yellowish-gray sand with calcareous sandstone
lenses . . . . . . . . . . . . . . . . . . . . . . . . . 7.0
5. Medium-gray bentonite . . . . . . . . . . . . . . . 1.0
4. Yellowish-gray sand . . . . . . . . . . . . . . . . 4.0
3. Yellowish-gray sand with siderite nodules
weathering to limonite at the base . . . . . . . . . 5.0
2. Medium-gray bentonite . . . . . . . . . . . . . . . 11.0
Total thickness of Hanson Creek Member . . . . . . . 117.0

HELL CREEK FORMATION (HARMARKA MEMBER)

1. Light-gray sand . . . . . . . . . . . . . . . . . . . . 1.0

Total 1.0

Covered

Thickness of Hell Creek Formation measured . . . . . . . (188.0)
### SECTION 6

Sec. 26, T. 133 N., R. 106 W., Slope County, North Dakota
(TYPE SECTION OF THE WARMARTH MEMBER OF THE HELL CREEK FORMATION)

#### HELL CREEK FORMATION (BACON CREEK MEMBER)

<table>
<thead>
<tr>
<th>Formation Description</th>
<th>Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>31. Calcareous sandstone lenses lying on top of butte</td>
<td>1.0</td>
</tr>
<tr>
<td>30. Medium-gray to brown bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>29. Light-rusty-brown bentonite</td>
<td>2.0</td>
</tr>
<tr>
<td>28. Dark-gray bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>27. Medium-gray to brown bentonite</td>
<td>6.0</td>
</tr>
<tr>
<td>26. Light-gray, fine sand</td>
<td>1.0</td>
</tr>
<tr>
<td>25. Light-gray, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>24. Light-greenish-brown to gray bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>23. Light-grayish-brown, clay-rich, lignitic sand</td>
<td>4.0</td>
</tr>
<tr>
<td>22. Sandy, lignitic shale and lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>21. Medium-gray bentonite</td>
<td>2.5</td>
</tr>
<tr>
<td>20. Medium-yellowish-gray bentonite</td>
<td>1.5</td>
</tr>
<tr>
<td>19. Medium-gray, bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>18. Dark-purple-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>17. Medium-gray, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>16. Moderate- to light-brown, lignitic shale and shaly lignite</td>
<td>1.5</td>
</tr>
<tr>
<td>15. Medium-gray bentonite</td>
<td>9.5</td>
</tr>
<tr>
<td>14. Medium-yellowish-gray bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>13. Yellowish-gray, bentonitic sands with bentonitic shale partings</td>
<td>29.0</td>
</tr>
<tr>
<td>12. Medium- to light-gray bentonite</td>
<td>9.0</td>
</tr>
</tbody>
</table>

**Total** 75.0
HELL CREEK FORMATION (HARMARITH MEMBER)
(Type Section)

11. Light-gray sand with bentonitic shale partings
    and a few calcareous sandstone lenses ........ 45.0

10. Dark-brown to black, lignitic shale and lignite
    with siderite nodules weathering to limonite ... 1.0

  9. Medium-gray bentonite ..................... 9.0

  8. Dark-grayish-brown, lignitic shale .......... 1.0

  7. Medium-gray, bentonitic shale ............. 4.0

  6. Light-brownish-gray sand with some rusty to
    whitish calcareous sandstone lenses .......... 23.0

  5. Medium- to dark-gray bentonite ............. 1.0

Total thickness of Harmarith Member ............ 74.0

HELL CREEK FORMATION (LITTLE BEAVER CREEK MEMBER)

4. Moderate-purplish-brown, sandy, silty, lignitic
    shale which breaks into blocky plates ........ 11.0

3. Light-gray silt with bentonitic shale partings ... 1.5

2. Medium- to dark-gray bentonite ............. 6.3

1. Light-gray sand with bentonitic shale partings ... 11.0

Total 30.0

Covered

Thickness of Hell Creek Formation measured ........ (179.0)
SECTION 9

SW 1/4 sec. 7, T. 132 N., R. 106 W., Bowman County, North Dakota
(TYPE SECTION OF THE LITTLE BEAVER CREEK MEMBER OF THE HELL CREEK FORMATION)

HELL CREEK FORMATION (HARMARTH MEMBER)

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>19. Gray, brown weathering sand with limonitic,</td>
<td>25.0</td>
</tr>
<tr>
<td></td>
<td>calcareous sandstone lenses and siderite nodules</td>
</tr>
<tr>
<td></td>
<td>weathering to limonite near the base</td>
</tr>
<tr>
<td>18. Light-gray, bentonitic shale</td>
<td>0.5</td>
</tr>
<tr>
<td>Total</td>
<td>25.5</td>
</tr>
</tbody>
</table>

HELL CREEK FORMATION (LITTLE BEAVER CREEK MEMBER)
(Type Section)

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Dark-purplish-brown, lignitic shale</td>
<td>1.5</td>
</tr>
<tr>
<td>16. Light-brownish-gray, bentonitic shale with siderite nodules weathering</td>
<td>22.0</td>
</tr>
<tr>
<td></td>
<td>to limonite near the base</td>
</tr>
<tr>
<td>15. Brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>14. Medium-gray, bentonitic shale with siderite</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>bed weathering to limonite</td>
</tr>
<tr>
<td>13. Moderate-brown sand</td>
<td>0.5</td>
</tr>
<tr>
<td>12. Light-brownish-gray, bentonitic shale</td>
<td>4.5</td>
</tr>
<tr>
<td>11. Light-gray, bentonitic shale with sandy lenses</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td>grading downward into sand with bentonitic shale partings</td>
</tr>
<tr>
<td></td>
<td>calcareous sandstone lenses near the base</td>
</tr>
<tr>
<td>10. Dark-purplish-brown to black, thinly fossil, lignitic</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>shale</td>
</tr>
<tr>
<td>9. Brown, white to pale-lavender weathering, lignitic</td>
<td>14.5</td>
</tr>
<tr>
<td>8. Dark-purplish-brown, thinly fossil, lignitic</td>
<td>3.0</td>
</tr>
<tr>
<td>7. Light-brown to gray, lignitic sand</td>
<td>5.0</td>
</tr>
<tr>
<td>6. Light-brown, gray weathering, lignitic shale</td>
<td>9.0</td>
</tr>
</tbody>
</table>
3. Moderate-brown, light-gray weathering, lignitic sandstone with occasional oreoidite concretions in the lower half.

4. Moderate- to dark-brown, very lignitic sandstone and sandy lignite.

Total Thickness of the Little Beaver Creek Member = 105.6

Thickness of the Bell Creek Formation measured = 130.5

FOX HILLS FORMATION (COLGATE MEMBER)

3. Light-gray, clay-rich, massive sand with some lignitic lenses.

Total thickness of Colgate Member = 29.6

FOX HILLS FORMATION (Undifferentiated)

2. Dusty-brown sands with Ophiomorpha walter, occasional siderite beds weathering to limonite, and lignitic lenses. The sands become interbedded with gray shales near the base.

Total thickness of undifferentiated Fox Hills beds = 50.0

Total thickness of Fox Hills Formation = (79.5)

PIERRE SHALE

1. Gray, bentonitic shales.

Covered

Total 2.0
### APPENDIX A (PART II)

**MEASURED SECTIONS OF HELL CREEK AND RELATED FORMATIONS**

<table>
<thead>
<tr>
<th>County, North Dakota</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bowmen</td>
<td>246</td>
</tr>
<tr>
<td>Dawson, Montana</td>
<td>265</td>
</tr>
<tr>
<td>Bowman</td>
<td>270</td>
</tr>
<tr>
<td>Grant</td>
<td>277</td>
</tr>
<tr>
<td>Morton</td>
<td>283</td>
</tr>
<tr>
<td>Sioux</td>
<td>294</td>
</tr>
<tr>
<td>Sheridan, North Dakota</td>
<td>321</td>
</tr>
<tr>
<td>Slope</td>
<td>323</td>
</tr>
</tbody>
</table>

*For locations of measured sections see Plate 6 in folder.*
Rufus County, North Dakota

Section 10

Sec. 1, T. 129 N., R. 105 W., Ruffus County, Montana

TULLOCK FORMATION

<p>| 54. Light-yellowish-brown silt | 13.0 |
| 53. Black lignite and dark-brown, lignitic shale | 2.5 |
| 52. Yellowish-gray, fine, loose-like sand | 12.5 |
| 51. Flaky, calcareous sandstones | 2.5 |
| 50. Yellowish-gray, silty sand | 3.5 |
| 49. Light-gray shale | 8.0 |
| 48. Moderate-brown, lignitic shale | 4.5 |
| 47. Light-yellowish-gray silt, and fine sand with siderite nodules weathering to limonite near the base | 4.5 |
| 46. Gray shale | 1.5 |
| 45. Black lignite | 1.0 |
| 44. Moderate-brown, lignitic shale | 5.0 |
| 43. Shaly, lignitic sand | 3.0 |
| 42. Light-gray, bentonitic shale | 5.0 |
| 41. Moderate-brown to black lignite and lignitic shale | 1.0 |
| 40. Brownish-gray silt | 6.0 |
| 39. Gray shale | 2.0 |
| 38. Dark-brown to black lignite and lignitic shales | 6.0 |
| 37. Medium-gray, bentonitic shale with siderite nodules near the base | 9.5 |
| 36. Moderate-brown, lignitic shale | 7.5 |</p>
<table>
<thead>
<tr>
<th></th>
<th>Lithology</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.</td>
<td>Moderate-grayish-brown, bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>34.</td>
<td>Moderate-brown, lignitic shale</td>
<td>16.0</td>
</tr>
<tr>
<td>33.</td>
<td>Moderate-brown, lignitic sand</td>
<td>1.0</td>
</tr>
<tr>
<td>32.</td>
<td>Light-gray, bentonitic shale</td>
<td>8.0</td>
</tr>
<tr>
<td>31.</td>
<td>Light-gray shale</td>
<td>2.0</td>
</tr>
<tr>
<td>30.</td>
<td>Brown to black, lignitic shale, and lignite</td>
<td>2.5</td>
</tr>
<tr>
<td>29.</td>
<td>Moderate-grayish-brown, bentonitic shale</td>
<td>2.5</td>
</tr>
<tr>
<td>28.</td>
<td>Light-brown, lignitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>27.</td>
<td>Moderate-grayish-brown, bentonitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>26.</td>
<td>Black to dark-gray lignite and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>25.</td>
<td>Light-gray, bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>24.</td>
<td>Light-gray to light-brown, bentonitic, somewhat lignitic sand</td>
<td>11.0</td>
</tr>
<tr>
<td>23.</td>
<td>Light-grayish-brown sand with calcareous sandstone lenses - &quot;log concretions&quot;</td>
<td>30.0</td>
</tr>
<tr>
<td>22.</td>
<td>Lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>21.</td>
<td>Light-gray, bentonitic shale with siderite nodules, weathering to lignite near the middle</td>
<td>14.0</td>
</tr>
<tr>
<td>20.</td>
<td>Moderate-purple-brown, lignitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>19.</td>
<td>Purplish-brown, bentonitic, lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>18.</td>
<td>Orangish-brown, bentonitic, lignitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>17.</td>
<td>Medium-gray bentonitic shale with brown lignitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>16.</td>
<td>Light-gray, bentonitic sand with bentonitic shale partings</td>
<td>7.0</td>
</tr>
<tr>
<td>15.</td>
<td>Moderate-brown, lignitic, somewhat bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>14.</td>
<td>Medium-gray, bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Thickness</td>
</tr>
<tr>
<td>---</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>13</td>
<td>Medium-gray, bentonitic sand with calcareous sandstone lenses</td>
<td>3.0</td>
</tr>
<tr>
<td>12</td>
<td>Bentonitic shale with limonite stains and siderite beds weathering to limonite along with small nodules of siderite weathering to limonite and 3 inch brown lignitic shale beds</td>
<td>9.0</td>
</tr>
<tr>
<td>11</td>
<td>Moderate-purplish-brown, lignitic shale — “lowest persistent lignite”</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong> 245.0</td>
<td></td>
</tr>
</tbody>
</table>

**Bell Creek Formation (Pretty Butte Member)**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Moderate-greenish- to yellowish-gray bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>9</td>
<td>Brownish-gray, bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>8</td>
<td>Medium-yellowish-gray bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>7</td>
<td>Moderate-grayish-brown, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>6</td>
<td>Moderate-brown, lignitic shale lenses</td>
<td>3.5</td>
</tr>
<tr>
<td>5</td>
<td>Light-yellowish-gray bentonite and bentonitic shale</td>
<td>6.5</td>
</tr>
<tr>
<td>4</td>
<td>Moderate- to light-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>Medium-gray, bentonitic shale, and bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>2</td>
<td>Light-brown, lignitic shale lenses</td>
<td>1.0</td>
</tr>
<tr>
<td>1</td>
<td>Medium-gray bentonite, and bentonitic shale</td>
<td>4.3</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong> 33.3</td>
<td></td>
</tr>
</tbody>
</table>

Covered

Thicknss of Bell Creek Formation measured 33.3 (33.3)
## Section II

Sec. 2, T. 129 N., R. 105 W., Bowman County, North Dakota

### Tullock Formation

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>25.</td>
<td>Sandy &quot;scoria&quot;</td>
<td>20.0</td>
</tr>
<tr>
<td>24.</td>
<td>&quot;Scoria,&quot; white ash, and natural coke</td>
<td>2.0</td>
</tr>
<tr>
<td>23.</td>
<td>Gray, bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>22.</td>
<td>Light-gray, bentonitic sand with calcareous sandstone lenses</td>
<td>18.0</td>
</tr>
<tr>
<td>21.</td>
<td>Moderate-grayish-brown, bentonitic shale and bentonite</td>
<td>6.0</td>
</tr>
<tr>
<td>20.</td>
<td>Dark-purple-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>19.</td>
<td>Medium-yellowish-gray, limonite stained, thin bedded bentonitic sands</td>
<td>10.0</td>
</tr>
<tr>
<td>18.</td>
<td>Dark-purple-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>17.</td>
<td>Medium-brownish-gray, bentonitic shale</td>
<td>6.0</td>
</tr>
<tr>
<td>16.</td>
<td>Light-grayish-brown, limonite stained, fine, bentonitic sand with calcareous sandstone lenses, and siderite nodules weathering to limonite</td>
<td>32.0</td>
</tr>
<tr>
<td>15.</td>
<td>Dark-brown, lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>14.</td>
<td>Bentonitic, fine sands with siderite beds weathering to limonite, and white calcareous sandstone concretions</td>
<td>3.0</td>
</tr>
<tr>
<td>13.</td>
<td>Dark-gray, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>12.</td>
<td>Medium-gray, fine, bentonitic sands</td>
<td>2.0</td>
</tr>
<tr>
<td>11.</td>
<td>Dark-gray, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>10.</td>
<td>Medium-gray, fine, bentonitic sand</td>
<td>2.0</td>
</tr>
<tr>
<td>9.</td>
<td>Dark-gray, lignitic shale</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Total 107.0
### HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

1. Medium-gray bentonite and bentonitic shale, brownish or yellowish in places containing occasional large siderite nodules weathering to limonite ...
2. Light-brown lignitic shale ...
3. Medium-gray, bentonitic shale ...
4. Light-brown, lignitic shale ...
5. Medium-yellowish-gray bentonite ...

**Total thickness of Pretty Butte Member** ...

### HELL CREEK FORMATION (HUFF MEMBER)

6. Light-yellowish-gray sand ...
7. Medium-gray bentonite and bentonitic shale with siderite nodules weathering to limonite ...
8. Light-yellowish-gray sand ...

**Total** ...

**Covered**

**Thickened of HELL CREEK Formation measured** ...

### Section 12

C. sec. 1, T. 129 N., R. 106 W., Bowman County, North Dakota

### HELL CREEK FORMATION (LITTLE BEAVER CREEK MEMBER)

9. Gray, limonite stained, bentonitic shale ...
10. Greenish-gray sand with siderite pebbles weathering to limonite near the base ...
11. Light-gray, bentonitic shale ...
12. Light-gray sand ...
13. Moderate to dark-brown, lignitic, bentonitic shale ...
14. Tan sand ...

**Footnotes**
11. Moderate-brown to gray, bentonitic shale .................. 13.0
10. Light-gray, limonite stained sands .......................... 6.0
  9. Dark-purplish-brown, lignitic shale ....................... 4.5
  8. Moderate-brown, light-purplish-brownish-gray
     weathering, lignitic shale ............................. 0.5
  7. Light-brown, pale-lavender-brown weathering,
     lignitic sand ........................................ 17.5
  6. Brown weathering, gray bentonitic shale ................. 2.3
  5. Thinly bedded, alternating fine sands and silts
     with bentonitic shales with lignitic sand lenses,
     Large scale cross beds ................................ 30.0

  Total 90.0

FOX HILLS FORMATION (COLCATE MEMBER)

  4. Light-gray sands with lignitic lenses, limonite
     stains, very-light-gray, calcareous sandstone
     lenses, and Ophiomorpha major ....................... 40.0

  Total 40.0

3. Covered ................................................. (33.0)

FOX HILLS FORMATION (LOWER MEMBER)

2. Yellowish-gray sands with some interbedded
   medium-gray shales near the base ....................... 13.0

  Total 13.0

  Total thickness of Fox Hills Formation ................. (66.0)

PIERRE SHALE

1. Gray, bentonitic shale .................................. 2.0

  Total 2.0
**Section 11**

Sec. 7, T. 130 N., R. 105 W., Bowman County, North Dakota

**HELL CREEK FORMATION (LITTLE BEAVER CREEK MEMBER)**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>Greenish-gray to brown sand with light gray calcareous sandstone lenses</td>
<td>27.0</td>
</tr>
<tr>
<td>21</td>
<td>Moderate-grayish-brown, bentonitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>20</td>
<td>Moderate-brown, sandy lignite, and lignitic sand</td>
<td>1.0</td>
</tr>
<tr>
<td>19</td>
<td>Moderate-brown to gray, bentonitic shale inter-bedded with sands of the same color</td>
<td>14.5</td>
</tr>
<tr>
<td>18</td>
<td>Grayish-brown sands becoming silty and more lignitic near the base. The lower portions contain sideritic nodules weathering to limonite</td>
<td>22.5</td>
</tr>
<tr>
<td>17</td>
<td>Moderate-greenish-brown, limonite stained bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>16</td>
<td>Dark-purple-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>15</td>
<td>Dark-brown to gray bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>14</td>
<td>Brown, whitish weathering, lignitic sand with bentonitic scale partings</td>
<td>9.0</td>
</tr>
<tr>
<td>13</td>
<td>Light-gray bentonitic shale</td>
<td>6.0</td>
</tr>
<tr>
<td>12</td>
<td>Dark-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>11</td>
<td>Brown, lignitic sand weathering whitish</td>
<td>13.0</td>
</tr>
<tr>
<td>10</td>
<td>Moderate-brown, lignitic sand</td>
<td>2.0</td>
</tr>
<tr>
<td>9</td>
<td>Light-gray, lignitic, bentonitic sand</td>
<td>2.5</td>
</tr>
<tr>
<td>8</td>
<td>Brown, lignitic sand weathering a very pale purplish brown</td>
<td>5.0</td>
</tr>
<tr>
<td>7</td>
<td>Dark-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>Brown, lignitic, bentonitic sand</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>Moderate-brown, lignitic sandstone and sandy lignite</td>
<td>2.3</td>
</tr>
</tbody>
</table>

**Total 123.5**
FOX HILLS SANDSTONE (COLGATE MEMBER)

4. Pale-brownish-gray, somewhat lignitic sands with occasional bentonitic shale partings .. 18.5
   Total 18.5
3. Covered ........................................ (10.0)
2. Dark-gray bentonite ......................... 1.0
1. Gray sand ...................................... 1.0
   Total 30.3

Covered

SECTION 14

Sec. 35, T. 130 N., R. 105 W.,Bowman County, North Dakota

YELLOMY FORMATION

37. Yellowish-gray bentonitic shale ............. 2.0
36. Moderate- to dark-brown, lignitic shale and lignite ................. 3.0
35. Light-yellowish-gray, limonite stained sand ................ 2.0
34. Light-brown, lignitic shale ................ 3.0
33. Medium-brownish-gray, bentonitic shale .......... 3.0
32. Light-gray, bentonitic shale ............... 4.5
31. Light-purpleish-brown bentonite .......... 1.0
30. Yellowish-gray, bentonitic sand with siderite nodules weathering to limonite near the base .. 9.5
29. Medium-gray, bentonitic shale ............... 3.0
28. Yellowish-gray bentonitic sand ............. 5.0
27. Dark-brown lignite and lignitic shale .......... 1.0
26. Light-grayish-brown, fine sand ............. 4.0
25. Dark-brown, bentonitic shale .............. 6.0
<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.</td>
<td>Black lignite</td>
<td>4.0</td>
</tr>
<tr>
<td>23.</td>
<td>Medium-gray bentonite, and bentonitic shale</td>
<td>13.0</td>
</tr>
<tr>
<td>22.</td>
<td>Light-gray bentonitic sands with some lignitic lenses, and calcareous sandstone lenses</td>
<td>51.0</td>
</tr>
<tr>
<td>21.</td>
<td>Black to dark-brown lignite</td>
<td>3.0</td>
</tr>
<tr>
<td>20.</td>
<td>Medium-gray, bentonitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>19.</td>
<td>Medium- to light-gray, bentonitic sand with siderite beds weathering to limonite, and calcareous sandstone lenses</td>
<td>45.0</td>
</tr>
<tr>
<td>18.</td>
<td>Black lignite and brown, lignitic shale</td>
<td>7.0</td>
</tr>
<tr>
<td>17.</td>
<td>Brown sand</td>
<td>2.0</td>
</tr>
<tr>
<td>16.</td>
<td>Moderate-brown, light-grayish-brown weathering bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>15.</td>
<td>Light-gray, bentonitic sand</td>
<td>1.0</td>
</tr>
<tr>
<td>14.</td>
<td>Dark-brown, lignitic shale, and lignite</td>
<td>0.5</td>
</tr>
<tr>
<td>13.</td>
<td>Brownish-gray, bentonitic shale</td>
<td>1.5</td>
</tr>
<tr>
<td>12.</td>
<td>Dark-brown to black lignite, and lignitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>11.</td>
<td>Light-brown sand</td>
<td>1.0</td>
</tr>
<tr>
<td>10.</td>
<td>Light-gray, bentonitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>9.</td>
<td>Dark-brown lignite and lignitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>8.</td>
<td>Moderate-grayish-brown, bentonitic shale with siderite beds weathering to limonite</td>
<td>8.5</td>
</tr>
<tr>
<td>7.</td>
<td>Moderate-grayish-brown, bentonitic sand with light-gray calcareous sandstone lenses</td>
<td>8.5</td>
</tr>
<tr>
<td>6.</td>
<td>Dark-brown lignite and lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>5.</td>
<td>Bentonitic sand with siderite beds weathering to limonite, and light-gray, calcareous sandstone lenses</td>
<td>9.5</td>
</tr>
</tbody>
</table>
HILL CREEK FORMATION (PRETTY BUTTE MEMBER)

1. Yellowish-gray bentonite ...................... 5.0
2. Dark-brown, lignitic shale .................... 1.5
3. Yellowish- to greenish-gray bentonite .......... 2.0

Total 8.5

Covered

Section 15

SW 1/4 sec. 24, T. 130 N., R. 106 W., Bowman County, North Dakota

HILL CREEK FORMATION (LITTLE SLAYER CREEK MEMBER)

10. Brownish-gray, bentonitic shale ............ 1.5
9. Gray to buff sand with light-gray, calcareous sandstone lenses .......... 17.0
8. Grayish-brown, bentonitic shale ............. 3.5
7. Gray to buff sand with light-gray, calcareous sandstone lenses .......... 11.0
6. Dark-purplish-brown, lignitic shale .......... 0.5
5. Brown, lignitic sand, weathering very-light-purplish-gray and containing upright stones ........ 3.0
4. Dark-gray, weathering light-gray, slightly bentonitic shale .......... 3.3
3. Moderate-purplish-brown, lignitic shale .... 3.0
2. Buff sand .................................... 0.5
1. Medium-gray shale ............................ 1.5

Total 31.5
7. Brown, gray weathering, lignitic sand

6. Slightly indurated, lignitic sand and
sandy lignite

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brown, gray weathering, lignitic sand</td>
<td>3.0</td>
</tr>
<tr>
<td>Slightly indurated, lignitic sand and sandy lignite</td>
<td>1.2</td>
</tr>
<tr>
<td>Total</td>
<td>7.2</td>
</tr>
</tbody>
</table>

**FOX HILLS FORMATION (COLGATE MEMBER)**

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray, massive sand</td>
<td>19.0</td>
</tr>
<tr>
<td>Bentonitic and lignitic shale tongue in sand</td>
<td>1.0</td>
</tr>
<tr>
<td>Gray, massive sands</td>
<td>21.0</td>
</tr>
<tr>
<td>Total thickness of Colgate Member</td>
<td>43.0</td>
</tr>
</tbody>
</table>

**FOX HILLS FORMATION (Undifferentiated)**

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Limonitic sands with <em>Ophiomorpha major</em>, vary such cross-beded becoming flat banded near the base and containing bentonitic shale beds</td>
<td>15.0</td>
</tr>
<tr>
<td>Total thickness of Undifferentiated Fox Hills Formation</td>
<td>15.0</td>
</tr>
<tr>
<td>Total thickness of Fox Hills Formation</td>
<td>(68.0)</td>
</tr>
</tbody>
</table>

**PIERRE SHALE**

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gray, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>Total</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Covered

**Section 16**

**TULLOCK FORMATION**

<table>
<thead>
<tr>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light-brown shale with siderite bed near the middle of the bed weathering to limonite</td>
<td>5.0</td>
</tr>
<tr>
<td>Gray, very slightly bentonitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>Light-brown shale with siderite bed weathering to limonite at the base</td>
<td>4.0</td>
</tr>
<tr>
<td>Grayish-brown slightly bentonitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>Number</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>34</td>
<td>Light-brown shale</td>
</tr>
<tr>
<td>33</td>
<td>Moderate-grayish-brown, somewhat bentonitic shale</td>
</tr>
<tr>
<td>32</td>
<td>Light-brown sand</td>
</tr>
<tr>
<td>31</td>
<td>Moderate-brown lignite and lignitic shale</td>
</tr>
<tr>
<td>30</td>
<td>Light-yellowish-gray, slightly bentonitic shale</td>
</tr>
<tr>
<td>29</td>
<td>Light-brown sand with calcareous sandstone lenses and siderite nodules</td>
</tr>
<tr>
<td></td>
<td>weathering to limonite near the top</td>
</tr>
<tr>
<td>28</td>
<td>Bentonitic, lignitic shale</td>
</tr>
<tr>
<td>27</td>
<td>Brown sand</td>
</tr>
<tr>
<td>26</td>
<td>Dark-purpleish-brown, lignitic shale and lignite</td>
</tr>
<tr>
<td>25</td>
<td>Light-gray shale</td>
</tr>
<tr>
<td>24</td>
<td>Light-brown shale grading downward into light-brown sand and containing</td>
</tr>
<tr>
<td></td>
<td>gypsum crystals</td>
</tr>
<tr>
<td>23</td>
<td>Moderate-brown, slightly bentonitic shale</td>
</tr>
<tr>
<td>22</td>
<td>Lignite</td>
</tr>
<tr>
<td>21</td>
<td>Light-grayish-brown, bentonitic shale</td>
</tr>
<tr>
<td>20</td>
<td>Black lignite and lignitic shale sometimes burned to ash and &quot;scoria&quot; -</td>
</tr>
<tr>
<td></td>
<td>&quot;lowest persistent lignite&quot;</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

**Hell Creek Formation (Pretty Butte Member)**

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>19</td>
<td>Moderate-grayish-brown, bentonitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>18</td>
<td>Medium-gray bentonite</td>
<td>18.3</td>
</tr>
</tbody>
</table>

**Total thickness of Pretty Butte Member** 18.3

**Hell Creek Formation (Buff Member)**

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>Light-gray, bentonitic sand, somewhat lignitic</td>
<td>29.5</td>
</tr>
</tbody>
</table>
16. Black, lignitic shale with a siderite bed weathering to limonite ........................................ 1.0

15. Medium-gray bentonite and bentonitic shale with brown, lignitic shale patches and siderite nodules weathering to limonite near the base ..................................................... 13.0

14. Medium-gray, bentonitic shale with limonite stains, grading downward into interbedded silts and sands near the base .............................................................. 40.0

13. Medium-gray bentonite with some lignitic shale lenses .................................................. 21.5

12. Light-gray, bentonitic sand .................................................. 2.5

11. Medium-gray bentonite, and bentonitic shale .................................................. 2.0

10. Light-gray, bentonitic sand .................................................. 2.0

9. Brown, lignitic shale .................................................. 1.0

8. Light-gray, bentonitic sand .................................................. 1.0

7. Light-brown, lignitic shale .................................................. 1.0

6. Medium-gray, bentonitic shale .................................................. 12.0

5. Light-brown, lignitic, shaly sand .................................................. 2.0

Total thickness of the Buff Member .................................................. 132.5

**HELL CREEK FORMATION (RACCOON CREEK MEMBER)**

4. Medium-gray bentonite .................................................. 3.0

3. Light-brownish-gray sand .................................................. 6.0

2. Medium-gray bentonite with siderite nodules near the top weathering to limonite .................................................. 14.0

1. Light-brown sand with calcareous sandstone lenses .................................................. 18.0

Total 41.0

**Covered**

Thickness of Hell Creek Formation measured .................................................. (132.0)
Section 17
Sec. 7, T. 132 N., R. 105 W., Bowman County, North Dakota

TULLOCK FORMATION

34. Yellowish-brown fine sand and silt \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 6.0
33. Black lignite and lignitic silt \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 4.0

Total 10.0

WELL CREEK FORMATION (PRETTY BUTTE MEMBER)

32. Medium- to dark-gray bentonite with siderite nodules at base weathering to limonite \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 8.0
31. Brown, shaly lignite, and lignitic shale \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 1.5
30. Medium-gray, bentonite, lighter colored near the base \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 4.5
29. Brown lignitic shale \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 1.0
28. Medium-gray bentonite \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.0

Total thickness of Pretty Butte Member \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 23.0

WELL CREEK FORMATION (HOFF MEMBER)

27. Bentonitic silts and fine sands with limonite stains. Siderite nodules weathering to limonite near the top \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 13.0
26. Limonite stained, gray sands with bentonitic shale partings and light gray calcareous sandstone lenses \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 33.0
25. Medium-gray bentonite \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.0
24. Brown, lignitic, bentonitic shale \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 1.0
23. Dark-gray bentonite \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 1.0
22. Medium-gray sand \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 0.5
21. Medium-gray, bentonitic shale \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 1.0
20. Medium-gray bentonite \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 13.0
19. Brown, lignitic, bentonitic shale \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 1.0
18. Medium-gray bentonite with siderite nodules weathering to limonite ........................................... 3.0
17. Gray, massive sands with light-gray, calcareous sandstone lenses near the base ............................ 14.0
16. Dark-brown lignite, and lignitic shale ......................................................................................... 1.0
15. Medium-gray bentonite, and bentonitic shale .............................................................................. 6.0
14. Thinly bedded bentonite, silt, and fine sand .................................................................................. 4.0
13. Light-gray bentonite .................................................................................................................... 3.5
12. Light-gray silt ............................................................................................................................ 2.5
11. Light-gray bentonitic shale ......................................................................................................... 7.0
10. Light-brown, fine, lignitic sand ................................................................................................... 1.0
 9. Calcareous sandstone lenses in fine sand with small sideritic nodules weathering to limonite ...... 2.0
 8. Medium-gray shale .................................................................................................................... 2.5
 7. Medium-gray bentonite ................................................................................................................ 2.5
 6. Light-brown, lignitic silt and clay .............................................................................................. 1.5
 5. Medium-gray, slightly bentonitic shale ....................................................................................... 3.0
 4. Fine, buff to gray sand with bentonitic shale partings and light-gray, calcareous sandstone lenses ................................................................................................................................. 7.5
Total thickness of Buff Member ........................................................................................................ 128.5

HELL CREEK FORMATION (BACON CREEK MEMBER)

 3. Medium-gray bentonite and bentonitic shale with a few thin, light-gray sand lenses and a few siderite nodules weathering to limonite ................................................................. 30.0
 2. Bentonitic, lignitic shale and silt .................................................................................................. 3.5
 1. Light-gray bentonite ..................................................................................................................... 6.3

Covered

Thickness of Hell Creek Formation measured .............................................................................. (153.5)
Section 18
Sec. 22, T. 132 N., R. 105 W., Bowman County, North Dakota

TULLOCK FORMATION

39. Brown, loose-like sand .......................... 4.0
38. Brown, gray weathering, bentonitic shale ........ 4.5
37. Lignite with gypsum crystals ........................ 5.5
36. Gray shale with plant fossils ................. 2.0
35. Gray, weathering brownish-gray, shale .......... 3.0
34. Lignite ............................................. 1.0
33. Yellow sand ......................................... 0.5
32. Brown to black lignite, and lignitic shale with gypsum and jarosite .......................... 12.0
31. Gray shale with siderite concretions weathering to limonite .......................... 5.0
30. Brown lignite, and lignitic shale with gypsum crystals, and jarosite .......................... 7.5
29. Gray to brown, lignitic shale with siderite concretions weathering to limonite, and jarosite .......................... 9.0
28. Black lignite ........................................ 0.5
27. Dark-gray shale .................................... 2.0
26. Brown, fine sand, and silt with light-gray, calcareous sandstone lenses .......................... 9.0
25. Black lignite ........................................ 0.5
24. Dark-gray, bentonitic shale ........................ 5.0
23. Brown, shaly lignite .............................. 1.5
22. Gray, brownish-gray weathering shale .......................... 2.0
21. Moderate-grayish-brown bentonite .......................... 5.0
20. Light-grayish-brown, lignitic, clay-rich sand with light-gray, calcareous sandstone lenses .......................... 9.0
<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.</td>
<td>Gray sand with bentonitic shale partings, and &quot;log,&quot; calcareous sandstone lenses near the top</td>
<td>7.5</td>
</tr>
<tr>
<td>18.</td>
<td>Banded, bentonitic shale, and silt</td>
<td>15.0</td>
</tr>
<tr>
<td>17.</td>
<td>Brown, shaly lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>16.</td>
<td>Dark-gray bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>15.</td>
<td>Tan, limonite stained, bentonitic shale with occasional siderite nodules weathering to limonite</td>
<td>4.0</td>
</tr>
<tr>
<td>13.</td>
<td>Gray, limonite stained bentonitic shale with occasional siderite nodules weathering to limonite</td>
<td>6.5</td>
</tr>
<tr>
<td>12.</td>
<td>Brown, shaly lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>11.</td>
<td>Banded, limonitic, bentonitic shales, silty near the top, with calcareous, cone-in-cone concretions near the base</td>
<td>9.0</td>
</tr>
<tr>
<td>10.</td>
<td>Dark-brown, lignitic shale and lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>9.</td>
<td>Gray, bentonitic shale</td>
<td>1.5</td>
</tr>
<tr>
<td>8.</td>
<td>Brownish-yellow silts, and fine sands</td>
<td>5.5</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>152.0</strong></td>
</tr>
</tbody>
</table>

**BELL CREEK FORMATION (PRETTY BUTTE MEMBER)**

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.</td>
<td>Gray bentonite</td>
<td>5.5</td>
</tr>
<tr>
<td>6.</td>
<td>Brown, bentonitic, lignitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>5.</td>
<td>Light-brown lignite, and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>4.</td>
<td>Dark- to light-gray, bentonitic shale with siderite concretions weathering to limonite</td>
<td>15.5</td>
</tr>
<tr>
<td>3.</td>
<td>Brown, shaly lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>2.</td>
<td>Dark-gray bentonite</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**Total thickness of Pretty Butte Member** | 30.5
### HELL CREEK FORMATION (BUFF MEMBER)

1. Fine, gray sand with siderite nodules weathering to limonite \( \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots 7.5 \)

Covered

Thickness of Hell Creek Formation measured \( \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (38.6) \)

### Section 19

W 1/4 sec. 33, T. 132 N., R. 105 W., Bowman County, North Dakota

### HELL CREEK FORMATION (LITTLE BEAVER CREEK MEMBER)

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>21. Yellowish-gray sand with siderite nodules weathering to limonite near the middle of the bed and calcareous sandstone lenses near the base of the bed</td>
<td>15.0</td>
</tr>
<tr>
<td>21. Grayish-brown bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>20. Brown, lignitic shale and lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>19. Light-gray, fine sand, and silt</td>
<td>4.0</td>
</tr>
<tr>
<td>18. Purplish-brown bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>17. Yellowish-gray bentonite</td>
<td>6.5</td>
</tr>
<tr>
<td>16. Medium-gray bentonite</td>
<td>2.5</td>
</tr>
<tr>
<td>15. Fine, bentonitic sand and silt</td>
<td>2.5</td>
</tr>
<tr>
<td>14. Medium-gray bentonite</td>
<td>5.5</td>
</tr>
<tr>
<td>13. Light-gray, fluted weathering sand with calcareous sandstone lenses near the middle of the bed</td>
<td>14.0</td>
</tr>
<tr>
<td>12. Brown lignite, and lignitic sand</td>
<td>1.0</td>
</tr>
<tr>
<td>11. Medium-gray bentonite</td>
<td>2.0</td>
</tr>
<tr>
<td>10. Brown, lignitic shale with gypsum</td>
<td>5.5</td>
</tr>
<tr>
<td>9. Medium-gray bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>8. Light-gray, fine, lignitic sand and silt</td>
<td>2.0</td>
</tr>
<tr>
<td>Layer Description</td>
<td>Feet</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1. Light-gray sand</td>
<td>15.0</td>
</tr>
<tr>
<td>2. Brown, lignitic sand, and sandy lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>3. Brown, fine, lignitic sand weathering gray</td>
<td>4.5</td>
</tr>
<tr>
<td>4. Dark-brown to dark-gray, lignitic shales, and lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>5. Gray, lignitic shales, somewhat bentonitic</td>
<td>9.0</td>
</tr>
<tr>
<td>6. Brown lignite and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>7. Medium-gray, lignitic, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>Total</td>
<td>91.0</td>
</tr>
</tbody>
</table>

**Fox Hills Formation (Colgate Member)**

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Light-gray sand</td>
<td>15.0</td>
</tr>
</tbody>
</table>

Total 16.0

Covered
Dawson County, Montana

Section 20

Sec. 1, T. 15 S., R. 53 E., Makoshika State Park, Glendive, Dawson County, Montana

TULLOCK FORMATION

41. Gray, yellowish-brown weathering sand with calc-
careous sandstone lenses - "log concretions" ........ 63.0

40. Moderate-grayish-brown, lignitic shale with siderite nodules weathering to limonite below
   the top .................................................. 6.0

39. Light-grayish-brown sand ................................. 2.0

38. Gray bentonite ............................................. 2.0

37. Medium-gray sand with calcareous sandstone
   lenses .................................................... 10.0

36. Moderate-gray toward yellowish-brown bentonite with siderite
   nodules weathering to limonite ......................... 4.0

35. Moderate-brown lignite, and lignitic shale ............ 1.0

34. Gray, bentonitic shale .................................... 10.0

33. Brownish-gray sand with calcareous sandstone
   lenses .................................................... 28.0

31. Black lignite, and lignitic shale -
   "lowest persistent lignite" ............................ 2.0
   Total 131.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

31. Medium-gray to light-yellowish-gray bentonite
   with siderite nodules weathering to limonite
   near the base ......................................... 16.5
   Total thickness of the Pretty Butte Member ........... 14.5

HELL CREEK FORMATION (BUFF MEMBER)

30. Light-yellowish-gray sand which is bentonic
   near the top ............................................ 29.5
<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>29.</td>
<td>Medium-brownish-gray, lignitic, bentonitic sand</td>
<td>14.8</td>
</tr>
<tr>
<td>28.</td>
<td>Light-gray sand with calcareous sandstone lenses</td>
<td>15.0</td>
</tr>
<tr>
<td>27.</td>
<td>Medium-gray bentonite with subly siderite nodules near the top</td>
<td>5.0</td>
</tr>
<tr>
<td>26.</td>
<td>Medium-yellowish-gray sand</td>
<td>3.5</td>
</tr>
<tr>
<td>25.</td>
<td>Medium-gray bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>24.</td>
<td>Light-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>23.</td>
<td>Medium-gray bentonitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>22.</td>
<td>Gray sand with some calcareous sandstone lenses near the top</td>
<td>38.5</td>
</tr>
<tr>
<td>21.</td>
<td>Moderate-brown, sandy limestone</td>
<td>1.0</td>
</tr>
<tr>
<td>20.</td>
<td>Light-brown sand</td>
<td>1.0</td>
</tr>
<tr>
<td>19.</td>
<td>Light-brown, lignitic shale</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Total thickness of the Buff Member: 144.5

SELL CREEK FORMATION (SACOM CREEK MEMBER)

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>18.</td>
<td>Medium-gray bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>17.</td>
<td>Light-grayish-brown, somewhat bentonitic sand</td>
<td>9.0</td>
</tr>
<tr>
<td>16.</td>
<td>Moderate-purpleish-brown, lignitic, bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>15.</td>
<td>Light-yellowish-gray, bentonitic, sandy shale</td>
<td>3.0</td>
</tr>
<tr>
<td>14.</td>
<td>Yellowish-brown sand with calcareous sandstone lenses</td>
<td>3.0</td>
</tr>
<tr>
<td>13.</td>
<td>Light-bluish-gray to yellowish-gray bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>12.</td>
<td>Light-yellowish-gray bentonitic sand</td>
<td>3.0</td>
</tr>
<tr>
<td>11.</td>
<td>Black, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>10.</td>
<td>Medium-gray to yellowish-gray bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>9.</td>
<td>Dark-brown, lignitic shale</td>
<td>1.0</td>
</tr>
</tbody>
</table>
8. Medium-gray bentonite ............................................. 13.0
7. Dark-brown, lignitic shale, and black lignite ........... 1.0
6. Medium-brownish-gray to purplish gray
   bentonite, and bentonitic shale .............................. 7.5
5. Medium-yellowish-gray, bentonitic sand ................... 11.5
4. Dark-purplish-brown, lignitic, bentonitic shale .......... 3.5
3. Light-gray, bentonitic, slightly lignitic sand .......... 11.5
2. Medium-gray, bentonitic shale ................................. 1.0
Total thickness of the Bacon Creek Member ................. 100.0
Thickness of the Wall Creek Formation measured ........... (130.0)

FOX HILLS FORMATION (COLUMBIA MEMBR)

1. Light-brown sand with very-light-gray,
calcareous sandstone lenses .................................. 13.0
   Covered

   Total 13.0

Section 21
SN 1/4 sec. 18, T. 15 N., R. 36 E., Sanookika State Park, Cleavine,
Lewis County, Montana

PIONEER RIVER FORMATION

21. Sandy "scoria" .......................................................... 10.9
   Total 10.9

End 21, T-Cross "scoria" in North Dakota

Covered ................................................................. (5.0)

TULLOCK FORMATION

20. Brown, fine, loose-like sand ................................. 6.0
   Covered ............................................................... (6.0)
19. Light-gray to light-brown, fine sand ........................................... 34.0

   Covered .......................................................................................... 34.0

18. Light-grayish-brown sand with calcareous sandstone lenses .................. 29.0

17. Light-grayish-brown, bentonitic shale ............................................. 6.0

16. Moderate-brown, lignitic shale ....................................................... 1.0

15. Moderate-grayish-brown, bentonitic shale ....................................... 1.0

14. Medium-gray, limonite stained bentonite ........................................ 6.3

13. Gray shale ..................................................................................... 2.5

12. Moderate-purplish-brown, lignitic shale ......................................... 1.0

11. Medium-brownish-gray, limonite stained bentonite ............................ 16.5

10. Dark-brown, lignitic shale ............................................................ 1.0

  Light-brown sand ........................................................................... 1.0

8. Light-brown to black lignite, and lignitic shale ................................ 3.6

7. Moderate-grayish-brown bentonite ................................................. 4.0

6. Medium-yellowish-gray, bentonitic silt ........................................... 6.0

5. Black lignite ................................................................................. 2.0

4. Moderate-grayish-brown, bentonitic shale badly slumped ................. 15.0

3. Moderate-brown to black lignite and lignitic shale ............................ 2.0

   Total 90.0

   Covered .......................................................................................... 90.0

2. Dark-brown, lignitic shale - "lowest persistent lignite" ...................... 2.0

   Total 2.0

Total thickness of Tullock Formation .............................................. 261.0
HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

1. Dark-gray bentonite ........................................ 2.0

Total 2.0

Section continues but not measured since Hell Creek section is measured nearby (see section 20, p. 265).
Emmons County, North Dakota

Section 22

SW 1/4 NW 1/4 sec. 18, T. 131 N., R. 78 W., Emmons County, North Dakota

HELL CREEK FORMATION (BRIGHAM MEMBER)

7. Dark-brown lignite, lignitic shale, and lignitic sand ........................................... 2.0
6. Brown and gray shale with plant fragments, jarosite, and gypsum ................................ 3.5
5. Brown, lignitic, limonitic, jarositive shales, and sands ........................................... 5.5
4. Gray, salt-and-pepper sands interbedded with sandy lignite and lignitic sands ............. 8.5

Total thickness of Crowghost Member .................................. 20.5

Thickness of Hell Creek Formation measured ................................... (27.0)

POX MILLS FORMATION (COLUMBIA MEMBER)

3. Greenish-gray sands with some lignitic lenses ........................................ 15.5
2. Gray shale with plant fossils ....................................................................................... 1.0
1. Greenish-gray, weathering brown sands with Ophiomorpha major ................................ 16.0

Covered

Total 32.5
### Section 24

**No 1/4 NW 1/4 sec. 26, T. 136 N., R. 76 W., Benson County, North Dakota**

**Hell Creek Formation (Meyer Member)**

7. Buff sands .............................................. 1.0

6. Greenish-brown sands with limonite stains and *Ophiomorpha major* ...................................... 4.0

Total 5.0

**Hell Creek Formation (Crowfoot Member)**

5. Greenish-gray, sandy shale with limonite-sulfate concretions ........................................... 4.0

4. Dark-brown lignite, and lignitic shale .......................................................... 2.5

Total thickness of Crowfoot Member ...................................................... 5.5

Thickness of Hell Creek Formation measured ........................................ (11.5)

**Fordville Formation (Colgate Member)**

3. Gray sandstone with lignitic plant fragments ...................................... 2.0

2. Greenish-gray, salt-and-pepper sands with lignitic lenses ........................................... 10.5

1. Greenish-gray, salt-and-pepper, cross-beded sands ........................................ 15.5

Total 18.0

Covered

### Section 24

**No 1/4 sec. 27, T. 135 N., R. 76 W., Benson County, North Dakota**

**Hell Creek Formation (Hoff Member)**

23. Brown to gray, buff weathering sands, and shales with siderite concretions weathering to limonite at the top ........................................ 14.0

22. Dark-brown, gray weathering, sandy shale with marcasite concretions .................................. 7.0

21. Dark-brown to gray shale, bentonitic near the top ........................................ 9.0
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Light-brown, gray weathering sands</td>
<td>9.0</td>
</tr>
<tr>
<td>19</td>
<td>Gray to buff, lignitic sands with some shale partings</td>
<td>5.0</td>
</tr>
<tr>
<td>18</td>
<td>Medium-gray bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>17</td>
<td>Gray, somewhat bentonitic shale</td>
<td>6.0</td>
</tr>
<tr>
<td>16</td>
<td>Dark-brown lignite, and lignitic shales</td>
<td>3.0</td>
</tr>
<tr>
<td>15</td>
<td>Medium-gray bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>14</td>
<td>Brown, sandy shale with lignitic lenses, and marcasite concretions</td>
<td>30.0</td>
</tr>
<tr>
<td>13</td>
<td>Gray, cross-bedded sands with lignitic lenses, gypsum, and marcasite concretions</td>
<td>55.0</td>
</tr>
</tbody>
</table>

**Total 146.0**

**Hill Creek Formation (Fort Ritchie Member)**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Brown to gray shale with siderite nodules weathering to limonite at the top of bed</td>
<td>2.5</td>
</tr>
<tr>
<td>11</td>
<td>Dark-brown lignite and lignitic shale</td>
<td>2.3</td>
</tr>
<tr>
<td>10</td>
<td>Gray shale with siderite concretions weathering to limonite containing vertical holes 3/8&quot; in</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>diameter</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Gray, limonite stained shale with siderite nodules weathering to limonite containing wellwells</td>
<td>10.0</td>
</tr>
<tr>
<td>8</td>
<td>Dark-brown lignite, and lignitic shale</td>
<td>1.5</td>
</tr>
<tr>
<td>7</td>
<td>Fine, clay-rich sand with limonite cemented lenses, and gypsum crystals in joints</td>
<td>6.0</td>
</tr>
<tr>
<td>6</td>
<td>Dark-brown lignite, and lignitic shale</td>
<td>1.3</td>
</tr>
<tr>
<td>5</td>
<td>Fine, clay-rich sand with some limonite cemented lenses</td>
<td>6.5</td>
</tr>
</tbody>
</table>

**Total 36.0**

Covered (20.0)
HELL CREEK FORMATION (BRENNER MEMBER)

4. Brown sands with *Ophiomorpha major* ........................................ 4.5

Total 4.5

HELL CREEK FORMATION (CROWFOOT MEMBER)

3. Dark-brown, lignite, and lignitic shales with jarosite .................................. 13.5

Total thickness of Crowfoot Member ........................................ 13.5

Thickness of Hell Creek Formation measured .................................. (218.0)

FOX HILLS FORMATION (COLGATE MEMBER)

2. Sandstone with plant fragments .................................................. 10.0

Total thickness of Colgate Member ........................................ 10.0

FOX HILLS FORMATION (BULL HEAD MEMBER)

1. Gray, banded shale, silt, and fine sand ........................................ 26.5

Covered

Thickness of Fox Hills Formation measured .................................. (36.5)

Section 25

NE 1/4 sec. 8, T. 136 N., R. 78 W., Cassoum County, North Dakota

CANNONBALL FORMATION

11. Limonitic, gray shale with gypsum ........................................ 3.0

Total 3.0

LUDLOW FORMATION

10. Black lignite ............................................................... 0.5

9. Medium-gray, somewhat bentonitic shale .................................... 2.0

8. Lignitic sands and shales .................................................. 2.0
7. Buff sands ............................................... 2.0
   Total 8.3
   Covered .................................................. (11.5)
6. Buff, calcareous, cross-beded sandstone .............. 2.0
   Total 2.0
   Covered .................................................. (26.8)
5. Gray to black, fissil shale ................................ 0.5
4. Black lignite and lignitic shale ........................... 3.5
   Total 5.5

Total thickness of Ludlow Formation .................. 51.3

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

3. Dark-gray bentonite .................................... 1.0
2. Light-brown shale, and fine sand ......................... 25.0
   Total thickness of Pretty Butte Member ............... 26.0

HELL CREEK FORMATION (BUFF MEMBER)

1. Light-brown sands with some lignitic fragments ...... 15.0
   Covered ...................................................
   Thickness of Hell Creek Formation measured ........... (41.0)

Section 26

S6 1/4 sec. 32, T. 136 N., R. 78 W., Ramsey County, North Dakota

HELL CREEK FORMATION (BUFF MEMBER)

22. Medium-gray shale ....................................... 5.0
21. Medium-gray sand, and shale with lignitic
    lenses, siderite concretions weathering to
    limonite, and marcasite concretions .................. 7.5
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Footage</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Brown to gray sand with lignitic lenses and shale partings</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td><em>Total</em></td>
<td>20.5</td>
</tr>
<tr>
<td>19</td>
<td>Dark-brown lignite, and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>18</td>
<td>Brown, bentonitic, gyspiferous shale with some sand lenses</td>
<td>7.5</td>
</tr>
<tr>
<td>17</td>
<td>Moderate-brown, lignitic sand</td>
<td>1.5</td>
</tr>
<tr>
<td>16</td>
<td>Dark-brown lignite, and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>15</td>
<td>Moderate-brown, lignitic shale</td>
<td>6.0</td>
</tr>
<tr>
<td>14</td>
<td>Dark-brown, shaly lignite, and lignitic shale</td>
<td>0.5</td>
</tr>
<tr>
<td>13</td>
<td>Dark-brown, lignitic shale</td>
<td>3.5</td>
</tr>
<tr>
<td>12</td>
<td>Yellow sand</td>
<td>0.5</td>
</tr>
<tr>
<td>11</td>
<td>Moderate-brown, lignitic shales</td>
<td>5.0</td>
</tr>
<tr>
<td>10</td>
<td>Gray sand with shale partings</td>
<td>3.0</td>
</tr>
<tr>
<td>9</td>
<td>Light-gray sand with fluted weathering, lignitic sand lenses, and some shale partings</td>
<td>9.0</td>
</tr>
<tr>
<td>8</td>
<td>Medium-gray shale with sand partings</td>
<td>2.5</td>
</tr>
<tr>
<td>7</td>
<td>Gray, limonite stained clays with siderite concretions weathering to limonite</td>
<td>10.5</td>
</tr>
<tr>
<td>6</td>
<td>Gray sand with fluted weathering, lignitic sand lenses, shale partings, and siderite concretions weathering to limonite both at base and throughout</td>
<td>7.5</td>
</tr>
<tr>
<td>5</td>
<td>Medium-gray, limonite stained bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>Dark-brown, lignitic shale, and lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>Gray, somewhat bentonitic shales with marcasite concretions and sand partings, siderite concretions near the base weathering to limonite</td>
<td>17.0</td>
</tr>
</tbody>
</table>
2. Dark-brown, lignitic shale, and shaly lignite .......... 1.0

Total 1.0

HELL CREEK FORMATION (SUTIAN MEMBER)

1. Brown sands with lignitic lenses and
   gray shale partings .................................... 1.0

Total 1.0

Covered

Thickness of Hell Creek Formation measured .......... (1.0)
Section 27

Secs. 31 and 32, T. 130 N., R. 58 W., along road and stream, Grant County, North Dakota

CANNONBALL FORMATION

1. Buff sand with limonitic, calcareous sandstone lenses .................................................. 20.5

Total 20.5

LUBLOW FORMATION

10. Dark-brown sandy lignite .......................................................... 0.3
9. Gray to brown, lignitic shales ...................................................... 4.0
8. Gray to brown, lignitic shales interbedded with sands ..................... 13.0
7. Lignite, and lignitic sand with gypsum crystals ......................... 1.0
6. Light-brown, lignitic sands ......................................................... 11.0
5. Lignitic shale with grass-like fossils ....................................... 3.5
4. Light-brown sandstone, whitish at a distance .................................. 2.6
3. Moderate-brown, lignitic shales ............................................... 9.0
2. Greenish-brown, slightly bentonitic shale .................................. 1.0
1. Light-brown to gray sands with lignitic lenses, and numerous stems in place .................................................. 14.9

Total 61.9

Covered

Section 28

Sec. 1/4 sec. 33, T. 130 N., R. 58 W., Grant County, North Dakota

CANNONBALL FORMATION

1. Medium-gray sand with limonite stains ........................................ 3.3

Total 3.3
LUDLOW FORMATION

4. Moderate-purple-brown lignite, and lignitic shale ........................................ 26.0

Total thickness of Ludlow Formation ........................................ 26.0

SHELL CREEK FORMATION (PRETTY BUTTE MEMBER)

3. Dark-gray bentonite ........................................ 1.5

2. Medium-gray, somewhat bentonitic shale with siderite nodules weathering to limonite at the base ........................................ 3.0

1. Brownish-gray sands with shale beds ........................................ 3.0

Total 14.3

Covered

Section 29

S2 1/4 sec. 29, T. 131 N., R. 63 W., Grant County, North Dakota

CANNONBALL FORMATION

31. Light-buff, flaggy sandstone ........................................ 1.0

30. Buff sand ........................................ 4.0

29. Medium-gray shale ........................................ 4.0

Total 9.0

LUDLOW FORMATION

28. Dark-gray to dark-brown lignite, and lignitic shales ........................................ 7.0

27. Light-brown, lignitic sand with gray shale beds, and gypsum crystals ........................................ 12.0

26. Dark-brown to bluish-black, brecciated lignite, and lignitic shale (show signs of flowage and may represent the base of a Pleistocene landslide) ........................................ 12.0

Total thickness of Ludlow Formation ........................................ 31.0
HILL CREEK FORMATION (PRETTY BUTTE MEMBER)

25. Medium-brownish-gray, bentonitic shales with siderite nodules weathering to limonite at the top .................................................. 10.0
24. Medium-gray, silty shale ....................................................... 4.0
23. Moderate-brown, lignitic shale, and lignite ............................. 1.0
22. Moderate-brown, somewhat bentonitic, silty shale with siderite nodules weathering to limonite at the top .................................................. 4.5
21. Light-buff, limonite stained sandstone lenses with siderite nodules weathering to limonite .................................................. 1.0
20. Light-gray, fine sand with bentonitic shale partings .................. 14.5
19. Medium-gray bentonite ....................................................... 3.0
18. Light-gray, silty shale with lignite fragments .......................... 1.0
17. Dark-brown lignite and lignitic shale ..................................... 1.0
16. Dark-purple-brown, lignitic shale ........................................ 4.0
15. Light-gray, silty shale ....................................................... 1.0
14. Dark-purple-brown, lignitic shale ........................................ 3.0
13. Medium-gray bentonite ....................................................... 4.0

Total thickness of Pretty Butte Member .................................... 52.0

HILL CREEK FORMATION (BUFF MEMBER)

12. Medium-gray sand with shale partings, gypsum crystals, cone-in-cone concretions, calcareous sandstone lenses, lignitic sand lenses, and occasional siderite nodules weathering to limonite .................................................. 75.5
11. Lignitic shale, and lignite ................................................... 1.0
10. Medium-gray bentonite ....................................................... 3.5
9. Dark-brown to black lignite, and lignitic shale ....................... 1.0
8. Medium-gray bentonite ....................................................... 4.0
7. Gray sands with shale partings .......................... 12.6
6. Light-gray shale with sand beds .......................... 4.0
5. Dark-brown lignite, and lignitic shale .................. 1.0
4. Moderate-grayish-brown, lignitic shale ................ 3.0
3. Medium-gray, bentonitic shale .................................. 7.0
2. Medium- to light-gray silts, and shale ................... 9.0
1. Light-gray sand ................................................. 10.0

Total 32.6

Covered

Thickness of Hall Creek Formation measured ...........(184.0)

Section 30

SW 1/4 sec. 18, T. 132 N., R. 59 W., Grant County, North Dakota

LUDLON FORMATION

11. Limonite stained sands with limonite cemented lenses of sand, and lignite fragments .............. 9.0
10. Conglomerate of limonite replaced pebbles, seeds and wood fragments ..................................... 1.0

Total 10.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

9. Brown, somewhat bentonitic shales .......................... 5.0
8. Lignite, and lignitic shale ...................................... 2.3

Total thickness of Pretty Butte Member ................. 7.3

HELL CREEK FORMATION (BUFF MEMBER)

7. Gray sand exhibiting fluted weatherings .................. 20.5
6. Brown, lignitic shales with gypsum crystals ................ 1.0
5. Gray sands with bentonitic shale partings ................. 9.0
4. Black lignite, and lignitic shale ............................. 0.5
<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Gray, bentonitic shale</td>
<td>1.5</td>
</tr>
<tr>
<td>3. Brown, lignitic sand</td>
<td>1.0</td>
</tr>
<tr>
<td>2. Gray, cross-beded sand</td>
<td>11.5</td>
</tr>
<tr>
<td>1. Brown, limonitic, lignitic shale</td>
<td>4.5</td>
</tr>
</tbody>
</table>

**Total** 49.0

**Thickness of Hell Creek Formation measured**  (56.5)

---

**Section 31**

SW 1/4 NE 1/4 sec. 29, T. 132 N., R. 86 W., Grant County, North Dakota

**Cannonball Formation**

20. Gray sands with 1/4 inch shale beds               20.0

**Total** 20.0

---

**Ludlow Formation**

18. Buff sands with calcareous sandstone lenses       6.5
17. Gray, sandy shale                                 3.5
16. Gray to black, lignitic shales, and lignite interbedded with buff sands all of which are partially burned and baked to natural brick 13.5
15. Buff to brownish-gray sand                        7.5
14. Buff sands with lignitic shales, lignites and natural brick 5.0

**Total thickness of the Ludlow Formation** 43.5

**Hell Creek Formation (Pretty Butte Member)**

13. Light-gray, bentonitic shale                       7.5
12. Tan, bentonitic shales                             7.0

**Total thickness of the Pretty Butte Member** 14.5
HELL CREEK FORMATION (HUFF MEMBER)

<table>
<thead>
<tr>
<th></th>
<th>Thickness in Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Medium-gray, bentonitic shale</td>
</tr>
<tr>
<td>2.</td>
<td>Brown lignite, and lignitic shale</td>
</tr>
<tr>
<td>3.</td>
<td>Brown sand, weathering gray</td>
</tr>
<tr>
<td>4.</td>
<td>Limonitic, conglomeratic sand with plant fragments</td>
</tr>
<tr>
<td>5.</td>
<td>Light-gray sand</td>
</tr>
<tr>
<td>6.</td>
<td>Light-brown, lignitic sands with gray bentonitic shale partings</td>
</tr>
<tr>
<td>7.</td>
<td>Light-brown, gray weathering, somewhat bentonitic shale</td>
</tr>
<tr>
<td>8.</td>
<td>Dark-gray to black lignite, and lignitic shale</td>
</tr>
<tr>
<td>9.</td>
<td>Grayish-brown, bentonitic shales</td>
</tr>
<tr>
<td>10.</td>
<td>Black lignite, and lignitic shale</td>
</tr>
<tr>
<td>11.</td>
<td>Gray, clay-rich, silty, somewhat bentonitic sand</td>
</tr>
</tbody>
</table>

Covered

Thickness of Hell Creek Formation measured (79.5)
Horton County, North Dakota

Section 32

SE 1/4 SE 1/4 sec. 10, T. 133 N., R. 32 W., Morton County, North Dakota

HELL CREEK FORMATION (PORT RICK MEMBER)

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>9. Gray sand</td>
<td>4.5</td>
</tr>
<tr>
<td>8. Brownish-gray, fissile, lignitic shale</td>
<td>6.5</td>
</tr>
<tr>
<td>7. Light- to medium-gray sands with light-gray calcareous sandstone lenses near the base</td>
<td>13.0</td>
</tr>
<tr>
<td>6. Gray, bentonitic shale</td>
<td>6.5</td>
</tr>
<tr>
<td>5. Limonite stained shales, and sands, thinly bedded, with siderite nodules weathering to limonite 2 feet above the base</td>
<td>6.5</td>
</tr>
<tr>
<td>4. Dark-brown lignite and lignitic shale</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Total 38.0

HELL CREEK FORMATION (BRETHEN MEMBER)

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Thickness</th>
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</thead>
<tbody>
<tr>
<td>3. Light-gray sand shale</td>
<td>2.0</td>
</tr>
<tr>
<td>2. Buff sands with worn tubes</td>
<td>1.5</td>
</tr>
<tr>
<td>1. Gray, bentonitic shales</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Total 6.5

Covered

Thickness of Hell Creek Formation measured . . . . . (44.5)

Section 33

SE 1/4 SE 1/4 sec. 17 - NW 1/4 SW 1/4 sec. 26, T. 133 N., R. 32 W., Morton County, North Dakota

CANNONBALL FORMATION

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>34. Buff colored, cross-bedded sands</td>
<td>5.0</td>
</tr>
<tr>
<td>33. Buff sands with calcareous sandstone lenses</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Description</td>
</tr>
<tr>
<td>---</td>
<td>------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>32.</td>
<td>Buff, cross-bedded sands</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
</tr>
<tr>
<td>31.</td>
<td>Gray shales, and shaly lignites</td>
</tr>
<tr>
<td>30.</td>
<td>Buff sand with several inches of limonitic sandstone at the base which may be up to 15 feet thick, locally containing many seeds at the base</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
</tr>
</tbody>
</table>

**LUBLOCK FORMATION (PRETTY BUTTE MEMBER)**

| 29.| Medium-gray, lignitic, bentonitic shales (may be only 5 inches thick locally) | 17.0 |
|    | **Total**                                                                    | 17.0 |

**HILL CREEK FORMATION (HUFF MEMBER)**

| 28.| Yellowish-gray, cross-bedded sands                                           | 28.0 |
| 27.| Brown, lignitic sands, lignitic shales, and lignites                        | 2.0  |
| 26.| Yellowish-gray, bentonitic shales with siderite nodules weathering to limonite at the base | 6.0  |
| 25.| Brown, lignitic shale with siderite nodules weathering to limonite at the base | 7.0  |
| 24.| Light-gray sands, and shales                                                 | 3.5  |
| 23.| Black lignite, and lignitic shales                                           | 1.0  |
| 22.| Brown lignite, and lignitic shale                                            | 2.0  |
| 21.| Gray sand with siderite nodules weathering to limonite at the base           | 5.5  |
| 20.| Medium-gray, bentonitic shales, and lignitic shales                          | 12.5 |
| 19.| Light-gray, sandy shale, and shaly sand with siderite nodules at the base weathering to limonite | 10.0 |
### BELL CREEK FORMATION (PORT RICE MEMBER)

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>16. Light-gray sands with siderite nodules at the base weathering to limonite</td>
<td>6.5</td>
</tr>
<tr>
<td><strong>Total thickness of Buff Member</strong></td>
<td><strong>117.0</strong></td>
</tr>
<tr>
<td>15. Brown to gray, lignitic, gypseiferous, bentonitic shale with siderite nodules</td>
<td>9.5</td>
</tr>
<tr>
<td>14. Medium-gray, bentonitic shale</td>
<td>4.5</td>
</tr>
<tr>
<td>13. Brown, massive lignite, and lignitic sand</td>
<td>2.5</td>
</tr>
<tr>
<td>12. Medium-gray, somewhat bentonitic shale with siderite nodules weathering to</td>
<td>10.0</td>
</tr>
<tr>
<td>limonite at the base</td>
<td></td>
</tr>
<tr>
<td>11. Yellowish-gray, bentonitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>10. Gray, limonite stained, fine sands with siderite nodules weathering to</td>
<td>5.5</td>
</tr>
<tr>
<td>limonite at the base</td>
<td></td>
</tr>
<tr>
<td>9. Gray, fine sand</td>
<td>5.5</td>
</tr>
<tr>
<td>8. Limonite stained, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>7. Dark-gray, lignitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>32.5</strong></td>
</tr>
<tr>
<td>Covered</td>
<td>(20.0)</td>
</tr>
<tr>
<td>6. Gray, limonite stained, bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4.0</strong></td>
</tr>
<tr>
<td><strong>Total thickness of the Port Rice Member</strong></td>
<td><strong>76.5</strong></td>
</tr>
</tbody>
</table>

### BELL CREEK FORMATION (SQUIRES MEMBER)

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. Buff to green, gypseolithic sands with siderite</td>
<td>9.0</td>
</tr>
<tr>
<td>bed weathering to limonite containing oysters at the base</td>
<td></td>
</tr>
</tbody>
</table>
4. Gray sands, silts, and shales ........................................ 11.5
3. Gray sands with plant fragments, and a siderite bed weathering to limonite with oysters in the middle ........................................... 2.5

Total thickness of the Breien Member .................................. 23.5

**Hill Creek Formation (Crowghost Member)**

2. Lignite and lignitic shale ........................................... 1.5
1. Gray shale with plant fragments ........................................ 1.5

Total ................................................................. 3.0

Covered

Thickness of Hill Creek Formation measured .................. (236.5)

**Section 34**

38 1/4 sec. 21, T. 134 N., R. 80 W., Morton County, North Dakota

**Hill Creek Formation (Fort Rice Member)**

15. Gray sand .......................................................... 8.0
14. Buff sand .......................................................... 2.0
13. Gray shale .......................................................... 3.5
12. Brown lignite, and lignitic shale ................................ 1.0

Total ................................................................. 14.5

**Hill Creek Formation (Breien Member)**

11. Gray shale .......................................................... 2.5
10. Buff, sandy shale with siderite nodules near the base weathering to limonite...................................................... 5.0
9. Buff to gray sands with lignitic lenses, shale partings, sharks teeth, skate teeth, and Ophiomorpha worn .................................................. 19.0

Total thickness of Breien Member .................................. 26.5
GULL CREEK FORMATION (CROUGHOOT MEMBER)

3. Dark-brown lignite, one lignitic shale ............................. 1.5
7. Gray shale and sands ................................................ 8.0
6. Dark-brown, lignitic shale with siderite concentrations, weathering to lignite ............................................ 1.0

Total 11.0

Remaining beds 3, 4, and 5 of the Croughoot Member interfinger with the Fox Hills Formation which is composed of banded gray shales, silts, and sands ....................................................... (9.0)

3. Gray, bentonitic shale with siderite concentrations, weathering to lignite near the base ........................................ 3.0
4. Gray, bentonitic shale ................................................... 2.0
3. Dark-brown lignite and lignitic shale .................................. 3.0

Total 8.0

Total thickness of Croughoot Member ................................ 11-20

Thickness of Gull Creek Formation measured ....................... (52-61)

FOX HILLS FORMATION (BULL HEAD MEMBER)

2. Banded, gray shales, silts, and sands .................................. 89.0

Total 89.0

Total thickness of Bull Head Member ................................ 89-98

FOX HILLS FORMATION (TYGER LASS MEMBER)

1. Green to brown sand and sandstone .................................. 86.0

Covered

Thickness of Fox Hills Formation measured ....................... (169-173)
Section 35
SE 1/4 sec. 11, T. 134 N., R. 82 W., Southeast end of "Ship Rock,"
Morton County, North Dakota

HIDALGO FORMATION

6. Brown to black lignite .................................................... 1.0

Total 1.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

5. Gray shale, and sand, siderite nodules
   weathering to limonite at base ........................................... 2.0

4. Yellowish-gray sand with light-gray calcsilicate
   and some limonite lenses near the top ................................. 2.5

3. Yellowish-gray, slightly bituminous shales,
   and sand with siderite nodules weathering to
   limonite at the top .......................................................... 4.5

2. Slightly- to light-gray shales coarsely intercalated
   with lignitic and bituminous beds ...................................... 32.0

Total thickness of Pretty Butte Member ................................ 61.0

HELL CREEK FORMATION (BUFF MEMBER)

1. Light-gray sand with some shale partings,
   and siderite nodules weathering to limonite
   in the lower 6 feet of the bed ......................................... 42.0

Total 42.0

Covered

Thickness of Hell Creek Formation measured ........................... (102.0)

Section 36
Sec. 7, T. 135 N., R. 79 W., Morton County, North Dakota

CAMPBELL FORMATION

15. Buff sand with siderite nodules weathering
to limonite ........................................................................ 7.5

Total 7.5
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>14</td>
<td>Lignite, lignitic shales, and lignitic silt</td>
<td>3.2</td>
</tr>
<tr>
<td></td>
<td>Total thickness of Leduc Formation</td>
<td>3.0</td>
</tr>
<tr>
<td>23</td>
<td>Gray bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>22</td>
<td>Lignite, lignitic shale and lignitic silt</td>
<td>5.0</td>
</tr>
<tr>
<td>21</td>
<td>Grayish-brown bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>20</td>
<td>Fine sand with gypsum crystals</td>
<td>0.5</td>
</tr>
<tr>
<td>19</td>
<td>Dark- to medium-gray, bentonitic shale</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>Total thickness of Pretty Butte Member</td>
<td>11.5</td>
</tr>
<tr>
<td>18</td>
<td>Sands with gypsum crystals, lignitic lenses and lignitic stains</td>
<td>7.0</td>
</tr>
<tr>
<td>17</td>
<td>Gray, bentonitic shales with sand stringers,</td>
<td>23.5</td>
</tr>
<tr>
<td></td>
<td>gypsum crystals and siderite nodules weathering to limonite</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>Lignite sand</td>
<td>2.0</td>
</tr>
<tr>
<td>15</td>
<td>Cross-bedded, lignitic sand</td>
<td>8.0</td>
</tr>
<tr>
<td>14</td>
<td>Buff sands with bentonitic shale partings and</td>
<td>23.0</td>
</tr>
<tr>
<td></td>
<td>siderite nodules weathering to limonite</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Light-gray sand</td>
<td>1.0</td>
</tr>
<tr>
<td>12</td>
<td>Brown, lignitic, bentonitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>11</td>
<td>Creamish-gray sand</td>
<td>4.5</td>
</tr>
<tr>
<td>10</td>
<td>Brown, bentonitic, lignitic shale</td>
<td>9.5</td>
</tr>
<tr>
<td>9</td>
<td>Lignite sands</td>
<td>7.0</td>
</tr>
<tr>
<td>8</td>
<td>Yellowish-gray, bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>7</td>
<td>Dark-brown lignite and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>Gray sand</td>
<td>3.0</td>
</tr>
<tr>
<td>Layer Description</td>
<td>Feet</td>
<td></td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>------</td>
<td></td>
</tr>
<tr>
<td>5. Dark-brown lignite, and lignitic shale</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>4. Brown, bentonitic shale</td>
<td>5.5</td>
<td></td>
</tr>
<tr>
<td>3. Gray sands with shale partings</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>2. Brown, lignitic sand lenses</td>
<td>2.0</td>
<td></td>
</tr>
<tr>
<td>1. Gray sand</td>
<td>15.0</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>136.0</td>
<td></td>
</tr>
<tr>
<td>Covered</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thickness of Mall Creek Formation measured</td>
<td>(149.3)</td>
<td></td>
</tr>
</tbody>
</table>

**Section 37**

SE 1/4 sec. 26, T. 135 N., R. 31 W., Morton County, North Dakota

**CAMEOSBALL FORMATION**

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>4. Brown sand, and shale</td>
<td>3.0</td>
</tr>
<tr>
<td>Total</td>
<td>3.0</td>
</tr>
</tbody>
</table>

**LUDLOW FORMATION**

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Brown, lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>2. Dark-brown lignite, and lignitic shale with a white &quot;clay&quot; fine silt bed at the base (unknown origin)</td>
<td>8.0</td>
</tr>
<tr>
<td>Total thickness of Ludlow Formation</td>
<td>10.0</td>
</tr>
</tbody>
</table>

**MALL CREEK FORMATION (PRETTY BUTTE MEMBER)**

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Bentonitic, lignitic shale</td>
<td>6.5</td>
</tr>
<tr>
<td>Total</td>
<td>6.5</td>
</tr>
<tr>
<td>Covered</td>
<td></td>
</tr>
</tbody>
</table>
Section 18

NW 1/4 NW 1/4 sec. 17, T. 138 N., R. 79 W., Morton County, North Dakota
(Road cut)

CANNONBALL FORMATION

6. Buff sand ................................................. 2.0+

Total 2.0+

LUDLOW FORMATION

5. Brown, lignitic sands, and shales ...................... 2.0
4. Dark-brown, lignite and lignitic shale .............. 6.0
3. Buff, sandy shale ........................................ 1.5
2. Lignite, lignitic sand, and lignitic shale .......... 7.0

Total thickness of Ludlow Formation .................. 16.5

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

1. Gray, bentonitic shale .................................. 3.5

Total 3.5

Covered

Section 39

NW 1/4 sec. 7, T. 137 N., R. 80 W., Morton County, North Dakota

CANNONBALL FORMATION

21. Light-brown sands ..................................... 1.0

Total 1.0

LUDLOW FORMATION

20. Gray shale with plant fossils ....................... 1.0
19. Lignite and lignitic sands .......................... 4.5

Total 5.5

Covered .......................................................... (11.0)
18. Brown, lignitic shales, and sands with siderite nodules weathering to limonite and gypsum crystals ....................................... 2.0

Covered .............................................................. (2.5)

Total 9.0

**BELLE CREEK FORMATION (PRETTY WHITE MEMBER)**

17. Gray bentonite .................................................. 2.0

16. Fine gray sand (covered by flowed bentonite) at the base of which are siderite nodules weathering to limonite ........................................ 3.5

15. Brown, lignitic shale ......................................... 1.0

14. Brownish-gray, gray weathering sand with siderite nodules weathering to limonite ........................................ 8.0

13. Dark-gray bentonite ............................................ 3.0

Total 14.5

**BELLE CREEK FORMATION (BUFF MEMBER)**

12. Light-gray sand (covered by flowed bentonite) ........ 8.0

11. Very-light-gray bentonitic shale ............................. 4.5

10. White clay ...................................................... 0.5

9. Dark-brown shale .............................................. 1.0

8. Light-gray to brown bentonitic shale ...................... 4.0

7. Light-brown, lignitic shale and dark-brown, shaly lignite ........................................ 19.0

6. Gray, bentonitic shale ........................................ 2.5

5. Brown, lignitic sand .......................................... 3.5

4. Dark-brown, sandy lignite .................................... 9.5

3. Brown, lignitic sand .......................................... 2.5
2. Dark-brown, lignitic shale ............. 0.5
1. Light-brownish-gray shales and silts ....... 15.5

Total 43.0

Covered

Thickness of Well Crust Formation measured ..... (64.5)
Sioux County, North Dakota

Section 40

34 1/4 sec. 9, T. 129 N., R. 61 W., Sioux County, North Dakota

CANNONBALL FORMATION

47. Sulfur sands with siderite nodules weathering to limonite near the base ********** 23.8

Total 23.8

LUDLOW FORMATION

46. Brown, lignitic shale ********** 7.0
45. Light-brown sand ********** 3.5
44. Lignite, and lignitic shale ********** 1.5

Total thickness of Ludlow Formation ********** 12.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

43. Light-brownish-gray bentonitic shale ********** 2.3
42. Gray shale with plant fragments ********** 3.0
41. Light-gray, bentonitic shale ********** 6.5
40. Brownish-gray, shaly sands ********** 4.0
39. Light-gray, bentonitic shale ********** 1.9
38. Yellowish-gray sands with bentonitic shale partings, and siderite nodules weathering to limonite near the middle ********** 12.5
37. Dark-gray, bentonitic, lignitic shales ********** 2.3
36. Gray sand ********** 1.0
35. Light-gray, sandy, bentonitic shales ********** 4.5

Total thickness of Pretty Butte Member ********** 37.6

HELL CREEK FORMATION (NUFF MEMBER)

34. Brown, gray weathering sands ********** 5.0
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>33.</td>
<td>Yellowish-gray sand</td>
<td>3.0</td>
</tr>
<tr>
<td>32.</td>
<td>Moderate-brown, sandy lignite</td>
<td>0.5</td>
</tr>
<tr>
<td>31.</td>
<td>Gray, sandy, lignitic shales</td>
<td>3.5</td>
</tr>
<tr>
<td>30.</td>
<td>Moderate-brown, lignitic sand, and sandy lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>29.</td>
<td>Light-brownish-gray, bentonitic shale</td>
<td>2.5</td>
</tr>
<tr>
<td>28.</td>
<td>Medium-brownish-gray, fissil, bentonitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>27.</td>
<td>Light-brown bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>26.</td>
<td>Light-gray, sandy shales</td>
<td>1.0</td>
</tr>
<tr>
<td>25.</td>
<td>Light-gray, somewhat bentonitic shales with siderite nodules weathering to limonite at the base</td>
<td>10.5</td>
</tr>
<tr>
<td>24.</td>
<td>Brown to black, lignitic shales</td>
<td>4.0</td>
</tr>
<tr>
<td>23.</td>
<td>Gray, silty shales</td>
<td>1.0</td>
</tr>
<tr>
<td>22.</td>
<td>Light-brownish-gray, slightly bentonitic shale</td>
<td>7.0</td>
</tr>
<tr>
<td>21.</td>
<td>Moderate-grayish-brown, fissil shale</td>
<td>5.5</td>
</tr>
<tr>
<td>20.</td>
<td>Light-grayish-brown, sandy shale</td>
<td>2.3</td>
</tr>
<tr>
<td>19.</td>
<td>Gray sands with siderite nodules weathering to limonite</td>
<td>9.0</td>
</tr>
<tr>
<td>18.</td>
<td>Dark-brown, lignitic shales, and lignite with siderite nodules weathering to limonite at the base</td>
<td>2.0</td>
</tr>
<tr>
<td>17.</td>
<td>Light-gray silty shales</td>
<td>5.0</td>
</tr>
<tr>
<td>16.</td>
<td>Dark- to moderate-brown lignite, and lignitic shales</td>
<td>1.5</td>
</tr>
<tr>
<td>15.</td>
<td>Light-gray, bentonitic shale with sandy lenses</td>
<td>7.0</td>
</tr>
<tr>
<td>14.</td>
<td>Moderate- to dark-brown, lignitic shales</td>
<td>4.5</td>
</tr>
<tr>
<td>13.</td>
<td>Medium-gray, bentonitic shale</td>
<td>3.5</td>
</tr>
<tr>
<td>12.</td>
<td>Moderate-brown, lignitic shale, and lignite</td>
<td>1.5</td>
</tr>
</tbody>
</table>
11. Light-gray sandstone with bentonitic shale partings, and siderite nodules weathering to limonite at the base .................................................. 9.0
10. Medium-gray, somewhat bentonitic shale ........................................ 6.5
  9. Dark-grayish-brown, lignitic shale ............................................. 1.0
  8. Light-gray shale with silty layers ............................................. 6.5
  7. Buff sands with siderite concretions weathering to limonite at the top .................................................. 6.0
  6. Dark-grayish-brown, lignitic shale ............................................. 2.0
  5. Light-gray, silty shale, sandy at the base ..................................... 7.5
  4. Moderate-brown sands and shales with small siderite nodules weathering to limonite throughout but concentrated near the base ............................. 7.0
  3. Light-gray sand ........................................................................... 4.5

  Total 141.0

Thickness of Bell Creek Formation measured at this location .................. (178.0)

Covered (measured by altimeter) to jet, Routes 6 and 24, 1-1/2 miles north .................................................. (55.0)

**WELL CREEK FORMATION (GHOST GHOST MEMBER)**

  2. Dark-brown lignite and lignitic shales ........................................ 6.0

  Total 6.0

  Total thickness of Bell Creek Formation measured from both locations .......................... (239.0)

**FOX HILLS FORMATION (HILL HEAD MEMBER)**

  1. Gray banded silts and shales ................................................... 1.0

  Total 1.0

Covered
Section 41

1/4 sec. 5, T. 129 N., R. 35 W., Sioux County, North Dakota

CANDONBALL FORMATION

19. Large calcareous sandstone lenses .................................................. 2.9
    Total 2.9
    Covered ........................................................................................................ (120.0)
18. Medium-gray shales .................................................................................. 16.5
17. Buff, calcareous, flaggy sandstone ........................................................ 0.5
16. Gray weathering, buff sand ..................................................................... 3.0
    Total 141.5

LUDLOW FORMATION

15. Light- to moderate-purplish-brown, lignitic shale, and lignite ............... 3.5
14. Buff sands with some thin beds of shales ............................................... 7.5
13. Black lignite .............................................................................................. 1.0
12. Moderate-purplish-brown, lignitic shale ................................................ 3.2
    Total thickness of Ludlow Formation ..................................................... 13.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

11. Medium-gray bentonite ........................................................................... 1.0
10. Light-grayish-brown, fine sand, gray shales and lignites ....................... 12.0
  9. Moderate-brown lignite, and lignitic shale ............................................. 1.0
  8. Medium-gray shale with siderite nodules containing plant fossils and weathering to lignite ......................................................................................... 2.5
  7. Moderate-brown, lignite, and lignitic shales .......................................... 2.5
  6. Medium-gray bentonite ........................................................................... 4.5
    Total thickness of Pretty Butte Member ................................................ 23.0
HELL CREEK FORMATION (HUFF MEMBER)

3. Brownish-gray, silty sand with siderite nodules weathering to limonite near the base 15.3

4. Dark-brown lignite, and lignitic shale 1.0

3. Dark-gray shale 3.5

2. Moderate-brown lignite, and lignitic shale 3.5

1. Medium-gray shales, and silts 10.0  

Total 32.5

Covered

Thickness of Hell Creek Formation measured (35.3)

Section 42

NE 1/4 NE 1/4 sec. 16, T. 129 N., R. 88 W., Sioux County, North Dakota

CANNONBALL FORMATION

4. Buff sand with calcareous sandstone lenses 1.0  

Total 1.0

Covered (10.0)

LINCOLN FORMATION

3. Gray to brown lignitic shale 3.5

2. Lignite with some gypseous and ash. Gypsum turned white by burning 2.0

1. Light-brown sand and white ash 2.5  

Total 6.0

Covered
Section 42
C. sec. 3, T. 129 N., R. 59 W., Sioux County, North Dakota

CANNONBALL FORMATION

16. Buff sands with calcareous sandstone
concretions near the top .................................. 15.0

Total 15.0

LINDLAR FORMATION

15. Light-brown, lignitic shales .......................... 5.0
14. Dark-brown lignite, and lignitic shale .......... 1.0
13. Light-brown, weathering multiash sand with
fossil plant roots over one foot long ................. 14.0
12. Black lignite, and lignitic shale ................... 1.0
11. Buff sands with lignitic lenses ..................... 3.5
10. Buff, glauconitic sand ................................ 18.0
9. Cross-bedded, calcareous sandstones ............... 1.0
8. Buff, glauconitic sand, 1 - 2 inches thick
interbedded with gray shales 1 - 2 inches thick .... 31.5
7. Buff sands ............................................. 4.5
6. Gray, interbedded sands and shales with cal-
careous sandstone concretions near the top ......... 15.0
5. Lignite and lignitic shale with jarosite .......... 3.0
4. Medium-gray micaceous sand ....................... 7.0
3. Medium-gray, shaly sandstone .................... 15.0
2. Dark-brown lignite and lignitic shale ............ 2.0
1. Medium-gray shale grading downward
into sandy shale ....................................... 3.0

Total 123.0

Covered by water of Cedar Creek.
### Section 44

NE 1/4 SW 1/4 sec. 21, T. 129 N., R. 89 W., Sioux County, North Dakota

**CAMBONIA FORMATION**

4. Yellowish-brown sands interbedded with grayish-brown shales   &lt;#28;   8.5  

**Total** 4.0

**LUDLOW FORMATION**

3. Medium-gray, brown weathering, lignitic shales   6.0
1. Gray to brown shale with plant fragments   2.5  

**Total** 9.5

---

### Section 45

SE 28, T. 130 N., R. 82 W., Sioux County, North Dakota

**HELL CREEK FORMATION (BUFF MEMBER)**

14. Light-gray sands with shale partings   13.0  

**Total** 13.0

**HELL CREEK FORMATION (PORT RICHEY MEMBER)**

13. Moderate-brown to grayish-brown, lignitic shales, and lignite   12.5
12. Gray sand with limonite streaks, siderite nodules weathering to limonite, highly weathered marcasite concretions, and bentonitic shale partings   12.5
11. Dark-purplish-brown, lignitic shale   3.5
10. Gray, bentonitic shales with siderite nodules weathering to limonite   4.0
9. Gray to buff sand   7.5
8. Gray limonite stained shale with siderite nodules weathering to limonite at the base   3.0
7. Dark-brown lignites and lignitic shales 

Total thickness of Fort Rice Member

BELL CREEK FORMATION (BARTEN MEMBER)

6. Brown, gray weathering sands with plant fragments

5. Medium-gray, bentonitic, lignitic shale with siderite concretions weathering to limonite

4. Greenish-brown sands with greenish glauks

Total thickness of Barten Member

BELL CREEK FORMATION (CROWFOOT MEMBER)

3. Gray shales intertingering with dark-brown lignitic shale and lignites

Covered (measured by Altimeter to Route 24, 1/4 mile to the southeast) (20.0)

2. Dark-brown, lignitic shales and lignites

Total thickness of Crowfoot Member (?) 29.0

Thickness of Bell Creek Formation measured (105.0)

FOX HILLS FORMATION (BULL HEAD MEMBER)

1. Gray, banded silts and shales

Covered

Total 1.04

Section 46

C. sec. 29, T. 130 N., R. 35 W., Sioux County, North Dakota

BELL CREEK FORMATION (PRETTY BUTCH MEMBER)

23. Light-gray, contorted clays, folds ten feet between crats, crets ten feet above trowgs, siderite concretions weathering to limonite at the base

Total 3.0
<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.</td>
<td>Light-greenish-brown, bentonitic shales</td>
<td>2.0</td>
</tr>
<tr>
<td>21.</td>
<td>Light-greenish-brown bentonite</td>
<td>2.5</td>
</tr>
<tr>
<td>20.</td>
<td>Brown, lignitic, limonitic shales</td>
<td>2.5</td>
</tr>
<tr>
<td>19.</td>
<td>Medium-gray bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>18.</td>
<td>Light-brownish-gray silt and fine sand</td>
<td>3.5</td>
</tr>
<tr>
<td>17.</td>
<td>Light-gray shale</td>
<td>3.5</td>
</tr>
<tr>
<td>16.</td>
<td>Dark-purpleish-brown lignite and lignitic shale</td>
<td>0.5</td>
</tr>
<tr>
<td>15.</td>
<td>Medium-gray, bentonitic shale with white calcareous blebs</td>
<td>4.5</td>
</tr>
<tr>
<td>14.</td>
<td>Medium-gray, silty shale with gypsum</td>
<td>3.0</td>
</tr>
<tr>
<td>13.</td>
<td>Slightly bentonitic, lignitic shales</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td><strong>31.5</strong></td>
</tr>
</tbody>
</table>

**HELL CREEK FORMATION (BUFF MEMBER)**

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.</td>
<td>Brownish-gray sand with shale partings, and siderite nodules weathering to limonite in the middle of the bed</td>
<td>20.0</td>
</tr>
<tr>
<td>11.</td>
<td>Brownish-gray silt with light-gray, calcareous sandstone lenses, and siderite nodules weathering to limonite at the base</td>
<td>25.5</td>
</tr>
<tr>
<td>10.</td>
<td>Brown, lignitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>9.</td>
<td>Medium-brownish-gray, bentonitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>8.</td>
<td>Light-brownish-gray, lignitic, silty clay and fine sand</td>
<td>7.0</td>
</tr>
<tr>
<td>7.</td>
<td>Moderate-purpleish-brown, lignitic shale and lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>6.</td>
<td>Medium-brownish-gray, lignitic shales</td>
<td>5.0</td>
</tr>
<tr>
<td>5.</td>
<td>Medium-gray shales somewhat bentonitic with occasional, sandy, sideritic nodules weathering to limonite at the base</td>
<td>9.0</td>
</tr>
</tbody>
</table>
4. Medium-yellowish-gray sands with occasional calcareous sandstone lenses ........................................ 27.0
   Total thickness of Buff Member ................................................................................................................ 107.3

SHELL CREEK FORMATION (PONT RIEUX MEMBER)

3. Siderite nodules with plant fossils grading laterally into a conglomerate of the same composition, all weathering to limonite .................................................... 9.5
2. Dark-brown, lignitic shale, and lignite ...................................................................................................... 1.5
1. Medium- to light-gray, silty clays ............................................................................................................... 5.0

   Total 3.0

Covered

Thickhess of Shell Creek Formation measured ....................................................................................... (147.0)

Section 47

Sec. 22, T. 33 N., R. 51 W., Sioux County, North Dakota

LINLON FORMATION

36. Buff sand interbedded with gray clays .................................................................................................. 6.9

   Total 6.8

SHELL CREEK FORMATION (PRETTY DOTTS MEMBER)

35. Brown, lignitic shale ......................................................................................................................... 1.0
34. Brown, clay-rich sand ......................................................................................................................... 9.9
33. Dark-brown lignite, and lignitic shale .................................................................................................. 1.8
32. Grayish-brown, sandy shale ............................................................................................................... 9.9
31. Grayish-brown, slightly sandy, bentonitic shale with 2 inches of yellowish-green bentonite with
   white calcareous concretions ............................................................................................................. 2.3
30. Moderate-brown, lignitic shale and lignite ......................................................................................... 1.5
29. Gray to buff sands ............................................................................................................................. 4.0
28. Moderate-brown lignite and lignitic shale with 2 inches of grayish-green bentonite on the top .......... 1.0
27. Gray, sandy shale .......................... 6.0
26. Lignite and lignitic shale ......................... 1.0
25. Gray bentonite .................................. 1.0
24. Gray sand with gray shale beds ................. 2.5

Total thickness of Pretty Butte Member ........ 35.5

HELL CREEK FORMATION (BUFF MEMBER)

23. Medium-gray sand with shale partings and siderite nodules weathering to limonite in two zones near the top .......................... 25.5
22. Yellowish-gray sand with gray shale partings, and rolled weathering .............................. 14.0
21. Greenish-gray, coarse, sand with lignite fragments; salt-and-pepper appearance pronounced because of dark chart and hornblende grains ................ 2.0
20. Gray sand with lignitic lenses and gypsum .... 24.5
19. Buff, cross-bedded sand with lignitic lenses .... 29.0
18. Moderate-brown, lignitic shale .................... 2.5
17. Dark-brown lignite and lignitic shale ............. 1.0
16. Gray bentonite .................................. 1.0
15. Greenish- or purplish-brownish-gray, lignitic shales and sands ................................ 8.0
14. Greenish-gray bentonite ............................ 1.0
13. Coarsely bedded, sandy shale, lignitic shale, and silts with bentonitic lenses, gypsum and marcasite concretions .................................. 26.0
12. Gray, fluted weathered sand with marcasite concretions .................................. 14.5
11. Gray to brown, bentonite, bentonitic shale, and lignitic shale with siderite nodules weathering to limonite, and gypsum .................. 9.5
10. Yellowish-gray sands with a few shale partings
and two centrally located zones of siderite
nodules weathering to limonite...........29.5

Total thickness of Buff Member.............198.9

HELL CREEK FORMATION (PORT RICE MEMBER)

9. Black to dark-brown lignite, and
lignite shale................................14.0

8. Gray, bentonitic shale with siderite
concretions weathering to limonite........4.0

7. Gray sand................................1.3

6. Lignite and lignitic shale..............1.0

5. Gray sand with siderite nodules weathering
   to limonite at the base..............2.0

4. Bentonitic, lignitic shale...........11.0

Total 28.3

Covered........................................(29.5)

3. Gray sands with siderite nodules weathering
   to limonite containing a molluscan fauna.....2.9

Total 2.9

Covered........................................(34.3)

HELL CREEK FORMATION (BRIESEN MEMBER)

2. Green to greenish-brown glauconitic sands,
weathering rusty brown with a bed of
Octone gilbura near the top..............14.9

Total 14.9

HELL CREEK FORMATION (CRONGHOST MEMBER)

1. Dark-gray to dark-brown, lignitic shale
and lignite................................17.0

Covered

Thickness of Bell Creek Formation measured........(351.0)
Section 46
Sec. 12, T. 131 N., R. 31 W., Sioux County, North Dakota

HILL CREEK FORMATION (BRIEN MEMBER)

2. Buff sands with Ophiomorpha major and
Ostracum alabre .................. 12.0

Total 12.0

HILL CREEK FORMATION (CROCKHORN MEMBER)

1. Dark to light-brown, lignitic shale, shaly
lignite, and lignite .................. 17.5

Covered

Thickness of Hill Creek Formation measured ....... (29.5)

Section 49
SW 1/4 sec. 13, T. 131 N., R. 32 W., Sioux County, North Dakota

CANNONBALL FORMATION

24. Buff sand .................. 6.5
23. Buff, calcareous sandstone .............. 1.0
22. Buff sand .................. 3.0
21. Moderate-brown, calcareous sandstone ...... 0.5
20. Gray, buff weathering sands with shark's teeth,
and clam-bored wood ................. 20.0
19. Gray sands with gray limy concretions about 3 feet
below the top, and again about 15 feet below the
top. The lower ones are fossiliferous ........... 23.0
18. Brown, limonitic sands ................ 1.0
17. Gray sands .................. 5.0

Total 82.0

Covered .................. (11.5)
<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>16. Medium-gray to brown, fossil shale</td>
<td>11.5</td>
</tr>
<tr>
<td>15. Concretionary limestone</td>
<td>1.0</td>
</tr>
<tr>
<td>14. Gray sand</td>
<td>2.3</td>
</tr>
<tr>
<td>13. Buff sand</td>
<td>4.0</td>
</tr>
<tr>
<td>12. Dark-gray, organic, interbedded sands and shales</td>
<td>11.5</td>
</tr>
<tr>
<td>11. Dark-gray, fossil shale weathering brownish</td>
<td>21.0</td>
</tr>
<tr>
<td>10. Brown sands with carbonaceous shale partings</td>
<td>11.0</td>
</tr>
<tr>
<td>9. Dark-gray shale</td>
<td>3.0</td>
</tr>
<tr>
<td>8. Medium-gray, buff weathering sands with gray, clay concretions at the base</td>
<td>5.5</td>
</tr>
<tr>
<td>7. Medium-gray sand weathering buff</td>
<td>1.5</td>
</tr>
<tr>
<td>6. Buff sand</td>
<td>23.0</td>
</tr>
<tr>
<td>5. Gray sands with shale partings</td>
<td>9.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>108.0</td>
</tr>
<tr>
<td><strong>Covered</strong></td>
<td>31.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>13.0</td>
</tr>
</tbody>
</table>

Continued in galleries by altimeter

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>3. Buff sand</td>
<td>16.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>18.5</td>
</tr>
</tbody>
</table>

Thickness of Cannonball Formation measured (242.0)

**Ludlow Formation**

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Dark-gray to black, lignite and lignitic shale</td>
<td>6.5</td>
</tr>
<tr>
<td>1. Gray shale</td>
<td>19.5</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>16.0</td>
</tr>
</tbody>
</table>

**Covered**
Section 50
NW 1/4 sec. 14, T. 131 N., R. 32 W., Sioux County, North Dakota

CANNONBALL FORMATION

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>26. Brown, gyspiferous sands with gray shale partings</td>
<td>11.0</td>
</tr>
<tr>
<td>25. Gray shale</td>
<td>16.5</td>
</tr>
<tr>
<td>Total</td>
<td>27.5</td>
</tr>
</tbody>
</table>

LUDLOW FORMATION

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>24. Dark-brown lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>23. Light-gray shale</td>
<td>3.0</td>
</tr>
<tr>
<td>22. Greenish-brown sands with lignite fragments</td>
<td>3.0</td>
</tr>
<tr>
<td>21. Gyspiferous, lignitic sands, and lignite</td>
<td>3.0</td>
</tr>
<tr>
<td>20. Brown sands with lignitic lenses, and gypsum</td>
<td>5.0</td>
</tr>
<tr>
<td>19. Gray, lignitic shale, and lignite</td>
<td>9.5</td>
</tr>
<tr>
<td>18. Buff sand with limonite, and gypsum</td>
<td>4.5</td>
</tr>
<tr>
<td>17. Buff to brown weathering lignitic shales, sand, and lignite</td>
<td>6.5</td>
</tr>
<tr>
<td>Total thickness of Ludlow Formation</td>
<td>36.5</td>
</tr>
</tbody>
</table>

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>16. Grayish-brown bentonite with siderite nodules</td>
<td>6.5</td>
</tr>
<tr>
<td>weathering to limonite at the base</td>
<td></td>
</tr>
<tr>
<td>15. Gray shales; brown, lignitic shales; and</td>
<td>20.5</td>
</tr>
<tr>
<td>dark-brown lignite</td>
<td></td>
</tr>
<tr>
<td>14. Gray bentonite</td>
<td>1.3</td>
</tr>
<tr>
<td>13. Gray to brown, somewhat lignitic shale with 1 inch</td>
<td>13.5</td>
</tr>
<tr>
<td>siderite beds weathering to limonite</td>
<td></td>
</tr>
<tr>
<td>Total thickness of Pretty Butte Member</td>
<td>46.5</td>
</tr>
</tbody>
</table>
HELL CREEK FORMATION (BUFF MEMBER)

12. Gray, interbedded shales and sand .................................. 10.0
11. Yellowish-grey sands with shale partings
    and siderite nodules weathering to limonite
    near the base ............................................. 24.0
10. Light-brownish-gray bentonite ................................ .... 1.5
  9. Brownish-gray, bentonitic shale ................................... 9.5
  8. Yellowish-gray sand .......................................... 2.0
  7. Medium-gray shale with siderite nodules
    weathering to limonite at the top .............................. 2.0
  6. Dark-purple-brown lignite, and
    lignitic shales .......................................... 3.5
  5. Light-yellowish-gray shale ..................................... 9.0
  4. Brown, lignite, lignitic shale, and lignitic
    sands, well jointed ....................................... 5.0
  3. Moderate-dark-brown, shale, weathering gray .................... 5.0
  2. Moderate-brown to dark-purple-brown lignite,
    and lignitic shale ........................................ 3.5
  1. Light-gray sands with some lignitic lenses ..................... 32.5

Covered

Thickness of Hell Creek Formation measured ................................ (162.0)

Total 115.5

Section 31

Sec. 16, T. 132 N., R. 62 W., Sioux County, North Dakota

CARSON HALL FORMATION

26. Buff sands with half inch siderite beds
    weathering to limonite ...................................... 5.0

Total 5.0
## LUDLOW FORMATION

| 23. | Dark-brown, lignitic shale                  | 0.3 |
| 24. | Buff sand with siderite partings,          | 2.0 |
|     | weathering to limonite                     |     |
| 25. | Buff, Calcareous sandstone                 | 2.0 |
| 22. | Brown to black lignite, and lignitic shales| 8.3 |
|     | with some gypsum                           |     |
| Total thickness of the Ludlow Formation   | 13.0|

## HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

| 21. | Grayish-brown, lignitic, bentonitic shales | 10.5|
| 20. | Brownish-gray, lignitic sand with bentonitic | 3.5 |
|     | shale partings                             |     |
| 18. | Medium- to dark-bluish-gray bentonite       | 2.5 |
| Total thickness of the Pretty Butte Member | 24.0|

## HELL CREEK FORMATION (BUFF MEMBER)

| 17. | Light-brownish-gray silt and fine sand     | 4.0 |
| 16. | Light-gray sand with lignitic lenses,      | 4.0 |
|     | and shale partings                          |     |
| 15. | Brown, somewhat bentonitic shale with      | 7.5 |
|     | siderite nodules weathering to limonite     |     |
|     | near the top                                |     |
| 14. | Sand with some siderite nodules weathering  | 1.0 |
|     | to limonite                                 |     |
| 13. | Medium-bluish-gray, somewhat bentonitic,    | 15.0|
|     | silty shale                                 |     |
| 12. | Gray siltstone with siderite nodules       | 6.5 |
|     | weathering to limonite near the top, and    |     |
|     | white calcareous                            |     |
|     | concentrations near the base                |     |
| 11. | Light-brownish-gray sand with lignitic     | 24.5|
|     | lenses, and shale partings                  |     |
| Total thickness of Buff Member              | 78.3|

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HELLE CREEK FORMATION (FORT SIOUX MEMBER)

10. Medium-gray, siltstone, sand with siderite nodules at the top weathering to limonite, and a siderite bed near the middle 7.5

9. Gray sand 9.5

8. Light-brown, shaly sand with siderite nodules weathering to limonite near the top 3.5

7. Brown, lignitic sand with siderite nodules weathering to limonite concentrate near the top 9.0

6. Gray, clay-rich sand 10.0

5. Gray sand with large siderite nodules weathering to limonite both at the top and bottom 9.0

4. Brown, lignitic sand 2.5

3. Light-gray, shaly sand 10.0

Section covered but continued near the road

2. Gray, sandy shales with siderite nodules, and siderite pebble conglomerates weathering to limonite 4.5

1. Light-gray clay-rich sands with gray shale partings, and siderite nodules weathering to limonite just above the base of the section 27.0

Total 81.0

Thickness of Hell Creek Formation measured (184.0)

Section 52

Sec. 27, T. 131 N., R. 84 W., Sioux County, North Dakota

CANNONBALL FORMATION

33. Brown to gray shales 5.0

Total 5.0
LUDLOW FORMATION

32. Black lignite ........................................... 1.0

31. Gray shales interbedded with buff sands, and lignite stringers. White, calcareous sandstones lenses near the base, and a siderite bed weathering to limonite about 10 feet above the base ............. 35.0

30. Dark-brown to black, lignite, lignitic shale, and reddish-brown to orangish-brown "scoria" ........ 3.0

Total thickness of Ludlow Formation ............... 43.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

29. Dark-gray, bentonitic shale ................................ 1.0

28. Light-grayish-brown, lignitic sand ......................... 13.0

27. Moderate-grayish-brown, somewhat bentonitic shale ........................................ 9.0

Total thickness of Pretty Butte Member ............... 23.0

HELL, CREEK FORMATION (RUPT MEMBER)

26. Medium-gray, fine sands, shales, and silts with siderite nodules near the top ........ 29.5

25. Dark-brown lignite, and lignitic shale ........ 1.0

24. Medium-gray, somewhat bentonitic shale .................. 4.0

23. Light-gray, fine sand with shale partings and calcaceous sandstones lenses near the base ........ 11.0

22. Siderite nodule bed and conglomerate weathering to limonite ......................... 0.3

21. Dark-purpleish-brown, lignitic shale ...................... 1.5

20. Moderate-grayish-brown, lignitic, bentonitic shale ........................................ 4.0

19. Moderate-brown lignite and lignitic shale ........ 2.5

18. Light-gray silts, shales, and fine sands with siderite nodules weathering to limonite near the base .... 10.3
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>17</td>
<td>Dark-purple-brown lignite, and lignitic shale</td>
<td>1.5</td>
</tr>
<tr>
<td>16</td>
<td>Moderate-brown, lignitic shale</td>
<td>3.5</td>
</tr>
<tr>
<td>15</td>
<td>Light-gray sand with calcareous sandstone lenses</td>
<td>10.5</td>
</tr>
<tr>
<td>14</td>
<td>Moderate-grayish-brown, somewhat bentonitic shales with siderite nodules weathering to limonite near the base</td>
<td>11.5</td>
</tr>
<tr>
<td>13</td>
<td>Light-brownish-gray, silky shale with siderite nodules weathering to limonite in the middle and again at the base</td>
<td>11.5</td>
</tr>
<tr>
<td>12</td>
<td>Light-brownish-gray, somewhat lignitic sand with calcareous sandstone lenses</td>
<td>14.5</td>
</tr>
<tr>
<td></td>
<td>Total thickness of Buff Member</td>
<td>118.0</td>
</tr>
</tbody>
</table>

**HILL CREEK FORMATION (PORT RICH MEMBER)**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Medium-gray, somewhat bentonitic shale</td>
<td>4.9</td>
</tr>
<tr>
<td>10</td>
<td>Light-gray, fine sand</td>
<td>4.9</td>
</tr>
<tr>
<td>9</td>
<td>Light-gray shale</td>
<td>2.5</td>
</tr>
<tr>
<td>8</td>
<td>Moderate-purple-brown, lignitic shale</td>
<td>1.9</td>
</tr>
<tr>
<td>7</td>
<td>Light-gray, somewhat bentonitic shale</td>
<td>3.9</td>
</tr>
<tr>
<td>6</td>
<td>Moderate-brown, lignitic shales, and sands</td>
<td>7.5</td>
</tr>
<tr>
<td>5</td>
<td>Light-gray, somewhat bentonitic shales with sandy lenses</td>
<td>16.0</td>
</tr>
<tr>
<td>4</td>
<td>Light-gray sand</td>
<td>3.9</td>
</tr>
<tr>
<td>3</td>
<td>Moderate-brown, lignitic sand, and sandy lignite</td>
<td>2.9</td>
</tr>
<tr>
<td>2</td>
<td>Light-gray shales with some fine sand beds, and siderite nodules weathering to limonite at the base</td>
<td>10.5</td>
</tr>
<tr>
<td>1</td>
<td>Light-gray shales</td>
<td>2.9</td>
</tr>
</tbody>
</table>

**Total 35.5**

Covered
Thickness of Well Creek Formation measured \( 196.5 \) feet

**Section 53**

Sec. 5, T. 132 N., R. 81 W., Sioux County, North Dakota

**Well Creek Formation (Buff Member)**

10. Buff sands with gray shale partings, white calcareous blebs, (?) concretions around roots, and marcasite concretions \( 17.0 \)

9. Limonite cemented sandstone \( 1.0 \)

8. Medium-gray shale with a few gray sand beds \( 10.0 \)

7. Dark-brown, lignitic shale and shaly lignite \( 1.0 \)

6. Yellowish-gray sands, and shales with plant fossils, and small white calcareous blebs \( 7.0 \)

5. Medium-gray sands grading downward into shaly, and lignitic sands; siderite nodules weathering to limonite 5 feet below top \( 15.0 \)

4. Medium-gray bentonite \( 1.0 \)

3. Medium-gray sands \( 4.0 \)

**Section continued 1/4 mile west**

2. Medium-gray sands \( 3.0 \)

1. Purplish-gray shale with fragments of plant fossils \( 6.0 \)

Covered

Total 63.0

**Section 54**

Sec. 28, T. 132 N., R. 82 W., Sioux County, North Dakota

**Well Creek Formation (Buff Member)**

21. Brown to buff sands with some bentonitic shale partings, siderite nodules weathering to limonite, and limonite sandstone lenses forming ledges \( 46.0 \)
20. Medium-gray bentonite ................................................. 1.0
19. Brown sands with bedded nodular siderite weathering to limonite, and some lignitic lenses ............................................. 31.0
18. Yellowish-gray bentonite ............................................. 1.0
17. Gray sands, and shales, thinly bedded, and with siderite nodules weathering to limonite ............................................. 37.5
16. Conglomerate composed of siderite pebbles weathering to limonite. Cores of Semicol. dacite common ............................................. 1.0
15. Moderate-brown lignite, and lignitic shale ......................... 1.0
14. Gray, bentonitic shale, in places slightly purplish, and containing sand lenses ............................................. 17.5
13. Brown, bentonite ......................................................... 2.0
12. Gray, cross-bedded, lignitic sand exhibiting fluted weathering ............................................. 13.0

Total 132.0

HELL CREEK FORMATION (PORT RICE MEMBER)

11. Light-purplish-brown, lignitic, bentonitic shale ............... 4.5
10. Medium-gray, slightly bentonitic shale, sandy near the base. Contains gypsite and marcasite concretions ............................................. 24.5
9. Gray, bentonitic shale ..................................................... 6.5
8. Gray sand with shale partings. Siderite nodules weathering to limonite near the base ............................................. 3.5
7. Interbedded lignite, lignitic shale, and lignitic sands ......................... 3.0
6. Buff to gray sands, siderite nodules 5 feet above the base containing plant and molluscan fossils, lower 5 feet with shale partings ............................................. 17.0
5. Medium-gray bentonite ..................................................... 1.0
4. Dark-brown lignite, and lignitic shale ................................ 2.5
3. Gray sand and snales ...................................... 2.5

Total 36.5

Covered .......................................................... (26.3)

Section continued one mile north in road cut.

HELL CREEK FORMATION (DREXEL MEMBER)

2. Buff sands with Ophiomorpha major ..................... 4.8

Total 4.8

Covered .......................................................... (1.5)

HELL CREEK FORMATION (CROWFOOT MEMBER)

1. Dark-brown lignite with jarosite .......................... 2.0

Total 2.0

Covered

Thickness of Bell Creek Formation measured ............... (254.0)

Section 55

Nw 1/4 Se 1/4 sec. 20, T. 132 N., R. 83 W., Sioux County, North Dakota

CARBONBALL FORMATION

22. Buff sands with limonitic sandstone lenses ............. 27.0

Total 27.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

21. Brownish-gray, lignitic, bentonitic shales with some sand lenses and siderite nodules weathering to limonite at the base ........................................... 11.0

Total thickness of Pretty Butte Member ................... 11.0

HELL CREEK FORMATION (HUFF MEMBER)

20. Buff sands with some lignitic lenses .................... 31.0

19. Medium-gray, lignitic, somewhat bentonitic, silty shale ......................................................... 9.3
13. Gray, bentonitic shale ........................................ 1.5
17. Limonite stained sands with sandy siderite nodules weathering to limonite at the top ............ 5.8
16. Dark-brown to black lignite, and lignitic shale .......................................................... 1.6
15. Gray, bentonitic shale ........................................... 3.3
14. Light-gray sand with lignitic lenses, bentonitic shale partings, and calcareous sandstone lenses ...... 14.5
13. Dark-purple-gray, bentonitic, lignitic shale .......................................................... 2.5
12. Light-gray sands with bentonitic shale partings ....................................................... 9.6
11. Dark-purple-gray lignitic shale, and lignite ....................................................... 1.6
10. Medium-gray, bentonite .................................................. 4.0
9. Medium-gray sand with bentonitic shale partings ..................................................... 3.5
8. Dark-brown lignite, and lignitic shale .............................................................. 1.6
7. Brownish-gray shales ..................................................... 2.0
6. Medium-bluish-gray bentonite ............................................................ 4.0
5. Brownish-gray bentonite ..................................................... 3.0
4. Light-gray sands with moderate-gray bentonitic shale partings with siderite nodules weathering to limonite near the base ...................................................... 27.0
3. Gray sands ................................................................. 12.0
Total thickness of Eau Fau Members .................................................. 145.0

**HELL CREEK FORMATION (PORT RICK MEMBER)**

2. Moderate-grayish-brown, lignitic shale with siderite nodules weathering to limonite at the base .... 4.5
1. Brown shale with lignite fragments .................................................. 5.5

Covered

Thickness of Hell Creek Formation measured ........................................ (167.9)
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Gray, bentonitic shale with siderite generations weathering to limonite</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>Top of a channel which cuts down to the top of the lignitic shale and lignite in the middle of the Crowfoot Member; channel composed of buff sands and gray shale partings with siderite layers weathering to limonite</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(41.0)</td>
</tr>
<tr>
<td>13</td>
<td>Brown, lignitic sands with gray shale partings</td>
<td>3.0</td>
</tr>
<tr>
<td>14</td>
<td>Greenish-brown shale with plant fragments and siderite nodules at the base weathering to limonite</td>
<td>5.0</td>
</tr>
<tr>
<td>13</td>
<td>Dark-brown lignite and lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td><strong>Total</strong></td>
<td>17.0</td>
</tr>
</tbody>
</table>

**Hill Creek Formation (Bretton Member)**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Buff sands interbedded with thin shales near the top</td>
<td>6.5</td>
</tr>
<tr>
<td>11</td>
<td>Gray bentonite</td>
<td>2.0</td>
</tr>
<tr>
<td>10</td>
<td>Buff sands with Orthocoralla major near the top</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td><strong>Total thickness of Bretton Member</strong></td>
<td>16.0</td>
</tr>
</tbody>
</table>

**Hill Creek Formation (Crowfoot Member)**

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Foot</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Gray, bentonitic, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>8</td>
<td>Buff sands with lignitic lenses</td>
<td>6.5</td>
</tr>
<tr>
<td>7</td>
<td>Brown, lignitic sand</td>
<td>2.5</td>
</tr>
<tr>
<td>6</td>
<td>Dark-brown lignite and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>5</td>
<td>Gray, bentonitic shales</td>
<td>6.0</td>
</tr>
<tr>
<td>4</td>
<td>Dark-brown, weathering moderate-gray, silty, lignitic shale with siderite nodules weathering to limonite near the base</td>
<td>5.0</td>
</tr>
</tbody>
</table>
3. Black, shaly lignite ......................... 6.3

Total thickness of Croughest Member ........ 22.5

Thickness of Hell Creek Formation measured .... (35.5)

FOX HILLS FORMATION (BULL BEAR MEMBER)

2. Dark-gray bentonite ......................... 1.0

1. Gray, bentonitic, banded silts, and shales
   with white calcareous blebs .................. 13.0

Total 16.0

Covered

Section 37

Nw 1/4 sec. 23, T. 133 N., R. 82 W., Sioux County, North Dakota

CANNONBALL FORMATION

14. Buff sand with limonite stains, siderite beds
    weathering to limonite, and calcareous sand-
    stone lenses .................................. 27.0

Total 27.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

13. Dark-purplish-brown lignite, and
    lignitic shale ............................... 4.5

12. Yellowish-gray to gray, bentonitic to non-
    bentonitic, lignitic to non-lignitic shales, 
    where the shales are very lignitic their 
    color changes to a dark-purplish-brown .... 29.5

11. Dark-lavender-brown, lignitic shale .......... 1.6

Total thickness of Pretty Butte Member ........ 35.0

HELL CREEK FORMATION (LUFF MEMBER)

10. Light-gray shales becoming very sandy near the 
    base containing calcareous blebs, gypsum con-
    cretions, and siderite nodules weathering to 
    limonite ...................................... 17.0
9. *Medium-greenish-gray sand with white calcareous pods and siderite concretions weathering to limonite*  
   \[ \text{Total: 3.0} \]

8. *Brown, bentonitic sand with siderite nodules near the center weathering to limonite*  
   \[ \text{Total: 4.5} \]

7. *Dark-brown to black, lignitic shale which is very persistent, and may be followed by the eye through the surrounding exposures*  
   \[ \text{Total: 3.0} \]

6. *Gray, somewhat lignitic sand with bentonitic shale partings*  
   \[ \text{Total: 12.5} \]

5. *Brown, bentonitic, lignitic shale*  
   \[ \text{Total: 3.0} \]

4. *Gray shales and sands with siderite nodules weathering to limonite*  
   \[ \text{Total: 10.0} \]

3. *Brown, bentonitic, lignitic shale*  
   \[ \text{Total: 3.0} \]

2. *Gray sands with some shaly lenses, and siderite nodules weathering to limonite near the base*  
   \[ \text{Total: 3.0} \]

1. *Gray sands with fluted weathering*  
   \[ \text{Total: 18.0} \]

**Covered**

Thickness of Wall Creek Formation measured  
\[ (18.0) \]
Sheridan County, North Dakota

Section 38

NE side of Prospect Mountain, north of Pickardville, Sheridan County, North Dakota

CAMBONBELL FORMATION

20. Brown, silty, clay-rich sand, lignite
   at the base ........................................ 15.0

Total 15.0

LINDLOW FORMATION

Missing - represented by few inches of lignitic sand at the base of the Cambonbell Formation.

HELL CREEK FORMATION (? PRETTY BUTTE MEMBER)

19. Dark-purplish-gray, lignitic shale ............. 1.0
18. Gray, brown weathering, bentonitic shale ....... 4.0
17. Purplish-gray, lignitic sand ................ 1.0
16. Brownish-gray, somewhat bentonitic shale .... 13.5

Total thickness of (?) Pretty Butte Member ........ 16.5

HELL CREEK FORMATION (? HUFF MEMBER)

15. Brownish-gray sand .......................... 13.5
14. Light-gray silt ................................. 2.5
13. Brownish-gray, bentonitic shale ............ 2.5
12. Purplish-brown, lignitic shale ............... 2.3
11. Dark-gray to purplish-gray, bentonitic, lignitic silty shales ................. 10.0
10. Light-gray silt ................................. 10.0
9. Brownish-gray sand ............................ 13.0

Total thickness of (?) Huff Member ............... 56.0
HELL CREEK FORMATION (? FORT RICE MEMBER)

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Gray, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>2.</td>
<td>Gray silt</td>
<td>3.0</td>
</tr>
<tr>
<td>3.</td>
<td>Bentonitic shale and silt</td>
<td>9.5</td>
</tr>
<tr>
<td>4.</td>
<td>Bentonitic shale</td>
<td>1.5</td>
</tr>
<tr>
<td>5.</td>
<td>Gray silt</td>
<td>2.0</td>
</tr>
<tr>
<td>6.</td>
<td>Gray, bentonitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>7.</td>
<td>Medium-gray, interbedded bentonitic shales and silty shales</td>
<td>3.0</td>
</tr>
<tr>
<td>8.</td>
<td>Medium-gray, bentonitic shale</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Total** 35.0

Covered

Thickness of Hell Creek Formation measured 187.5

Section is very badly folded by glacial shoves and therefore thickness of beds may be distorted.)
**Slope County, North Dakota**

**Section 29**

Sec. 22, T. 133 N., R. 104 W., Slope County, North Dakota

(section tied together by altimeter)

**TONGUE RIVER FORMATION**

| 29. White calcareous sandstone | 1.5 |

Total 1.5

**LUGLOW FORMATION**

| 25. Light-gray shale | 3.0 |
| 27. Light-yellowish-gray shale | 1.5 |
| 26. Light-brown shale | 2.0 |
| 23. Light-purplish-brown, lignitic shale | 1.0 |
| 24. Light-brown shale | 3.0 |
| 22. Light-brown shale | 9.0 |
| 21. Light-yellowish-brown sand with occasional calcareous sandstone ledges | 40.0 |

20. Light-purplish-brown lignite, and lignitic shale - Tule bed of area (1928) 7.0

19. Light-greenish-brown shale interbedding with sand elsewhere in the area 20.0

18. Light-yellowish-gray shale 2.5

17. Moderate-grayish-brown, lignitic, bentonitic shale 3.5

16. Buff sands with siderite nodules weathering to limonite near the middle of the bed 4.5

15. Moderate-grayish-brown bentonite 9.5

**Sands 17 - 15, Lobo beds**
<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Dark-brown lignite and lignitic shale (may be burned) - T-Cross bed of Marie (1926)</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>Total thickness of Luleck Formation</td>
<td>134.0</td>
</tr>
</tbody>
</table>

**TULLOCK FORMATION**

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Moderate-brown lignite, and lignitic shale</td>
<td>6.0</td>
</tr>
<tr>
<td>2</td>
<td>Light-grayish-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>Buff sand</td>
<td>4.0</td>
</tr>
<tr>
<td>4</td>
<td>Light-grayish-brown lignitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>5</td>
<td>Dark-brown lignite and lignitic shale (may be burned) - T-Cross bed of Marie (1926)</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td>Total thickness of Luleck Formation</td>
<td>134.0</td>
</tr>
</tbody>
</table>

**Section 60**

East side of Marnearth Bridge, on Little Missouri River, Slope County, North Dakota

**HELL CREEK FORMATION (MARNEARTH MEMBER)**

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Buff to yellowish-gray sands with lignitic and bentonitic lenses</td>
<td>37.5</td>
</tr>
<tr>
<td>6</td>
<td>Medium-gray bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>1. Moderate-grayish-brown bentonitic shale</td>
<td>29.3</td>
<td></td>
</tr>
<tr>
<td>2. Brown to rusty-brown bentonite</td>
<td>7.2</td>
<td></td>
</tr>
<tr>
<td>3. Medium-gray sand with light gray, calcareous</td>
<td>28.8</td>
<td></td>
</tr>
<tr>
<td>4. Moderate-brown, lignitic shale</td>
<td>2.8</td>
<td></td>
</tr>
<tr>
<td>5. Light-brown sand with scattered calcareous</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>6. Black lignite with lignite stains</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>7. Moderate-grayish-brown, slightly bentonitic shale</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>8. Moderate-brown to black lignite, and lignitic shale</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>9. Light-grayish-brown sand</td>
<td>6.5</td>
<td></td>
</tr>
<tr>
<td>10. Light-grayish-brown, slightly bentonitic shale</td>
<td>22.5</td>
<td></td>
</tr>
<tr>
<td>11. Moderate-brown bentonite</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>12. Moderate-brown sand with bentonite partings</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>13. Moderate-brown bentonite with siderite nodules weathering to lignite near the middle of the bed</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>14. Dark-gray bentonite</td>
<td>7.0</td>
<td></td>
</tr>
<tr>
<td>15. Black lignite and lignitic shale</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>16. Light-grayish-brown, bentonitic shale</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

Total: 84.5

Section 61

B 1/2 sec. 4, T. 133 N., R. 105 W., Slope County, North Dakota

TULLIGE FORMATION

<p>| 32. Light-grayish-brown sand | 10.0 |
| 31. Moderate-brown bentonite | 2.0 |
| 30. Light-grayish-brown, bentonitic shale | 3.0 |
| 29. Black lignite and lignitic shale | 0.5 |
| 28. Light-grayish-brown, bentonitic shale | 3.0 |
| 27. Moderate-brown, lignitic shale | 2.3 |
| 26. Light-brown sand with scattered calcareous | 7.0 |
| 25. Black lignite with lignite stains | 1.0 |
| 24. Moderate-grayish-brown, slightly bentonitic shale | 4.0 |
| 23. Moderate-brown to black lignite, and lignitic shale | 1.0 |
| 22. Light-grayish-brown sand | 6.5 |
| 21. Light-grayish-brown, slightly bentonitic shale | 22.5 |
| 20. Moderate-brown bentonite | 3.0 |
| 19. Moderate-brown sand with bentonite partings | 5.0 |
| 18. Moderate-brown bentonite with siderite nodules weathering to lignite near the middle of the bed | 4.5 |
| 17. Dark-gray bentonite | 7.0 |
| 16. Black lignite and lignitic shale | 0.5 |
| 15. Light-grayish-brown, bentonitic shale | 3.0 |</p>
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>27</td>
<td>Dark-brown to black lignite, and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>26</td>
<td>Medium-gray bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>25</td>
<td>Moderate-brown, lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>24</td>
<td>Light-brown sand</td>
<td>1.5</td>
</tr>
<tr>
<td>23</td>
<td>Light-grayish-brown, bentonitic shale</td>
<td>1.5</td>
</tr>
<tr>
<td>22</td>
<td>Light-grayish-brown, lignitic sand</td>
<td>3.0</td>
</tr>
<tr>
<td>21</td>
<td>Moderate-brown, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>20</td>
<td>Black lignite, and lignitic shale</td>
<td>0.3</td>
</tr>
<tr>
<td>19</td>
<td>Moderate-brown, bentonitic sand</td>
<td>6.0</td>
</tr>
<tr>
<td>18</td>
<td>Black lignite, and lignitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>17</td>
<td>Gray, bentonitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>16</td>
<td>Moderate-brown, shaly, lignitic, bentonitic sand</td>
<td>3.0</td>
</tr>
<tr>
<td>15</td>
<td>Medium-gray bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>14</td>
<td>Black lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>13</td>
<td>Brown, lignitic sand</td>
<td>4.0</td>
</tr>
<tr>
<td>12</td>
<td>Black to brown, lignitic shale, and some lignite</td>
<td>11.0</td>
</tr>
<tr>
<td>11</td>
<td>Medium-gray, bentonitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>10</td>
<td>Light-gray sand</td>
<td>3.0</td>
</tr>
<tr>
<td>9</td>
<td>Black lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>8</td>
<td>Medium-gray bentonite with white volcanic ash</td>
<td>2.0</td>
</tr>
<tr>
<td>7</td>
<td>Lense of sandy, bentonitic volcanic ash</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>Dark-gray bentonite with white calcareous stellate concretions near the base</td>
<td>3.0</td>
</tr>
<tr>
<td>5</td>
<td>Medium-gray sand with lignitic lenses and calcareous sandstone lenses</td>
<td>25.5</td>
</tr>
<tr>
<td>4</td>
<td>Black lignite</td>
<td>0.5</td>
</tr>
</tbody>
</table>
3. Muddy-yellowish-gray bentonite . . . . . . . . . . . 6.0

2. Light-grayish-brown, lignitic, bentonitic sand —
"Yellow bed" — weathers very soft. Has siderite
nodules weathering to limonite near the base . . . . . . 2.5

Total 19.0

HELL CREEK FORMATION (PRETTY BUTT MEMBER)

1. Dark-gray bentonite with moderate-brown,
lignitic shale lenses . . . . . . . . . . . . . . . . . . . 6.0

Covered

Total 6.0

Section 62

S 1/2 sec. 4, T. 133 N., R. 105 W., Slope County, North Dakota

TULLOCK FORMATION

36. Light-brown, calcareous sandstone . . . . . . . . . 1.5
35. Light-brown sand, badly slumped . . . . . . . . . . 28.5
34. Dark-brown to black lignite, and lignitic shale . . 2.0
33. Light-brownish-gray, somewhat bentonitic shale . 11.0
32. Buff sand . . . . . . . . . . . . . . . . . . . . . . . . . . . 3.0
31. Light-gray to brownish-gray, bentonitic shale
and bentonite . . . . . . . . . . . . . . . . . . . . . . . . . 15.0
30. Medium-brownish-gray, bentonitic shale, and
bentonite . . . . . . . . . . . . . . . . . . . . . . . . . . . 8.0
29. Medium-gray bentonite . . . . . . . . . . . . . . . . 4.0
28. Light-gray, bentonitic shale . . . . . . . . . . . . . . 5.0
27. Moderate-brown, bentonitic sand with white
calcareous sandstone lenses near the base . . . . . . 7.5
26. Dark-brown to black lignite, and lignitic shale . . 1.5
25. Moderate-grayish-brown bentonite . . . . . . . . . 2.0
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Light-brown sand</td>
<td>3.0</td>
</tr>
<tr>
<td>2</td>
<td>Purplish-brown, lignitic, bentonitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>3</td>
<td>Light-brown, bentonitic sand</td>
<td>3.0</td>
</tr>
<tr>
<td>4</td>
<td>Moderate-grayish-brown bentonite</td>
<td>8.0</td>
</tr>
<tr>
<td>5</td>
<td>Dark-purpleish-brown to black lignite and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>6</td>
<td>Moderate-grayish-brown bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>7</td>
<td>Moderate-brown, bentonitic sand with calcareous sandstone concretions near the top</td>
<td>15.0</td>
</tr>
<tr>
<td>8</td>
<td>Dark-brown lignite, and lignitic shale</td>
<td>8.3</td>
</tr>
<tr>
<td>9</td>
<td>Medium-gray bentonite</td>
<td>2.5</td>
</tr>
<tr>
<td>10</td>
<td>Dark-brown lignite, and lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>11</td>
<td>Medium-gray bentonite</td>
<td>5.5</td>
</tr>
<tr>
<td>12</td>
<td>Medium-gray, limonite stained, bentonitic shale</td>
<td>3.5</td>
</tr>
<tr>
<td>13</td>
<td>Medium-gray bentonite with siderite nodules weathering to limonite at the top, and calcareous stellite concretions near the base</td>
<td>8.0</td>
</tr>
<tr>
<td>14</td>
<td>Dark-brown lignite, and lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>15</td>
<td>Dark-gray, limonite stained bentonite</td>
<td>1.5</td>
</tr>
<tr>
<td>16</td>
<td>Gray, bentonitic shale with siderite beds weathering to limonite</td>
<td>10.5</td>
</tr>
<tr>
<td>17</td>
<td>Dark-brown to black lignite and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>18</td>
<td>Gray sand</td>
<td>1.0</td>
</tr>
<tr>
<td>19</td>
<td>Dark-brown lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>20</td>
<td>Medium-gray to purplish-gray, bentonitic shale</td>
<td>8.0</td>
</tr>
<tr>
<td>21</td>
<td>Light-brown to buff sand - &quot;Yellow bed&quot;</td>
<td>8.0</td>
</tr>
</tbody>
</table>
2. Black lignite - "lowest persistent lignite" ........................................... 2.0

Total 2.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

1. Dark-gray bentonite with brown lignitic shale lenses .................................... 3.0

Total 3.0

Covered

Section 63

Sec. 3, T. 133 N., R. 103 W., Slope County, North Dakota

TULLOCK FORMATION

11. Moderate-grayish-brown bentonite ......................................................... 2.0

10. Moderate-brown to dark-brown lignite, and lignitic shale ................................ 3.5


8. Black lignite ......................................................................................... 1.0

7. Light-brown silt and sand ....................................................................... 4.5

6. Moderate-grayish-brown, bentonitic, lignitic shale ...................................... 2.5

5. Yellowish-brown silt, and sand .................................................................. 15.0

4. Black lignite, and lignitic shale .................................................................. 1.0

3. Medium-gray bentonite ............................................................................ 2.0

2. Dark-brown to black lignite, and lignitic shale ......................................... 2.0

Total 35.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

1. Dark-gray bentonite ............................................................................... 2.0

Total 2.0

Covered
Section 64

C. sec. 8, T. 133 N., R. 103 W., Slope County, North Dakota

TULLOCH FORMATION

26. Fine, yellow to buff sand, bentonitic near the base ("yellow bed") .......................... 10.0
25. Black lignite ........................................... 1.0

Total 11.0

HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

24. Medium-yellowish-gray bentonite ........................................ 3.0
23. Dark-brown to black, lignitic shale, and shaly lignite ................................. 1.5
22. Medium-purplish- and yellowish-gray bentonite ......................................... 3.5

Total thickness of Pretty Butte Member ........................................ 8.0

HELL CREEK FORMATION (HUFF MEMBER)

21. Gray sand with bentonitic shale partings, light-gray calcareous sandstone lenses, and occasional siderite nodules weathering to limonite ........................................ 41.0
20. Medium- to dark-purplish-gray bentonite ........................................ 2.0
19. Dark-brown, lignitic shale ........................................ 1.0
18. Medium-brownish-gray bentonite ........................................ 7.0
17. Medium-yellowish-gray, bentonitic shale ........................................ 2.0
16. Light-yellowish-gray sand, lignitic near the base, with light-gray, calcareous sandstone lenses ........................................ 5.0
15. Moderately-grayish-brown, bentonitic shale ........................................ 7.0
14. Grayish-brown sand with bentonitic shale partings and light-gray, calcareous sandstone lenses ........................................ 11.5
13. Black lignite, and brown, lignitic shale ........................................ 1.0
12. Dark-gray bentonite ........................................ 1.0
1. Medium- to light-gray and greenish-brown bentonite; light-brown, lignitic shale lenses; siderite nodules weathering to limonite .......................... 13.0

Total 109.0

Covered

Thickness of Hall Creek Formation measured .......... (117.0)

Section 65

Sec. 13, T. 133 N., R. 105 W., Slope County, North Dakota

YUCCA FORMATION

46. Light-brown sand with calcareous sandstone lenses, and siderite nodules weathering to limonite near the middle ........................................... 30.0

47. Moderate-brown to black lignitic shale, sandy lignite, and lignite with gypsum crystals ........................................... 25.0

46. Gray shale .................................................. 2.5

45. Dark-gray to purplish-brown, lignitic bentonitic shale .................................................. 4.5

44. Black to dark-purplish-brown lignite, and lignitic shale ............................... 0.5
<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Depth (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>Light-grayish-brown, lignitic, bentonitic shale</td>
<td>4.5</td>
</tr>
<tr>
<td>42</td>
<td>Light-gray sand</td>
<td>0.3</td>
</tr>
<tr>
<td>41</td>
<td>Light-grayish-brown, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>40</td>
<td>Dark-purplish-brown to black lignite and lignitic shale</td>
<td>0.5</td>
</tr>
<tr>
<td>39</td>
<td>Medium-brownish-gray bentonite, and bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>38</td>
<td>Moderate-brown bentonite with siderite nodules weathering to limonite</td>
<td>5.0</td>
</tr>
<tr>
<td>37</td>
<td>Dark-gray bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>36</td>
<td>Moderate-brown to black lignite, and lignitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>35</td>
<td>Moderate-brown, lignitic, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>34</td>
<td>Fine, light-grayish-brown sand with bentonitic partings grading downward into a bentonite</td>
<td>20.0</td>
</tr>
<tr>
<td>33</td>
<td>Dark-gray bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>32</td>
<td>Moderate-brown, bentonitic sand with calcareous sandstone lenses, and siderite nodules weathering to limonite near the top</td>
<td>14.0</td>
</tr>
<tr>
<td>31</td>
<td>Black lignite</td>
<td>2.0</td>
</tr>
<tr>
<td>30</td>
<td>Moderate-grayish-brown, bentonitic sand</td>
<td>6.0</td>
</tr>
<tr>
<td>29</td>
<td>Black lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>28</td>
<td>Moderate-brown bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>27</td>
<td>Medium-brownish-gray bentonite with a siderite bed weathering to limonite at its base</td>
<td>1.0</td>
</tr>
<tr>
<td>26</td>
<td>Dark-gray bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>25</td>
<td>Light-gray sand with calcareous sandstone lenses near the top, and siderite nodules weathering to limonite near the base</td>
<td>15.0</td>
</tr>
<tr>
<td>24</td>
<td>Medium-brownish-gray bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>23</td>
<td>Moderate-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Quantity</td>
</tr>
<tr>
<td>---</td>
<td>------------------------------------------------------------------------------</td>
<td>----------</td>
</tr>
<tr>
<td>22</td>
<td>Medium-brownish-gray bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>21</td>
<td>Moderate-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>20</td>
<td>Moderate-grayish-brown bentonite</td>
<td>6.3</td>
</tr>
<tr>
<td>19</td>
<td>Moderate-brown lignite and lignitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>18</td>
<td>Brownish-gray bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>17</td>
<td>Moderate-brown to black lignite, and lignitic shale</td>
<td>1.5</td>
</tr>
<tr>
<td>16</td>
<td>Brownish-gray bentonite</td>
<td>2.0</td>
</tr>
<tr>
<td>15</td>
<td>Light-gray, bentonitic sand with calcareous sandstone lenses</td>
<td>2.0</td>
</tr>
<tr>
<td>14</td>
<td>Gray bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>13</td>
<td>Dark-gray to almost black bentonite - very malleable</td>
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<td>12</td>
<td>Grayish-brown, bentonitic sands</td>
<td>5.0</td>
</tr>
<tr>
<td>11</td>
<td>Moderate-brown to black lignite, and lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>10</td>
<td>Medium-gray bentonite</td>
<td>2.0</td>
</tr>
<tr>
<td>9</td>
<td>Light-brown, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>8</td>
<td>Black to dark-brown lignite, and lignitic shale</td>
<td>3.3</td>
</tr>
<tr>
<td>7</td>
<td>Gray to brown bentonitic shales with flat-bedded siderite horizons weathering to limonite</td>
<td>10.3</td>
</tr>
<tr>
<td>6</td>
<td>Brown, lignitic shale</td>
<td>0.3</td>
</tr>
<tr>
<td>5</td>
<td>Brown bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>4</td>
<td>Brown to black lignite, and lignitic shale</td>
<td>2.3</td>
</tr>
<tr>
<td>3</td>
<td>Yellow to buff sand - &quot;Yellow bed&quot;</td>
<td>5.3</td>
</tr>
<tr>
<td>2</td>
<td>black lignite - &quot;lowest persistent lignite&quot;</td>
<td>2.3</td>
</tr>
</tbody>
</table>

Total: 242.3
WELL CREEK FORMATION (PRETTY BUTTE MEMBER)

1. Dark-gray bentonite ........................................ 1.3

Covered

TOTAL ...................................................... 1.3

Section 56

Secs. 23 and 24, T. 134 N., R. 105 W., Slope County, North Dakota

TULLOCK FORMATION

31. Tan, gray weathering, salt-and-pepper sand with calcareous sandstone lenses near the top, and siderite nodules weathering to limonite near the base ........................................ 27.3

32. Grayish-brown, bentonitic shale ................................ 2.5

33. Lignite and lignitic shale with gypsum crystals ............ 2.5

34. Brown sand .................................................. 7.5

35. Black lignite .................................................. 0.5

36. Gray bentonite ................................................ 2.0

37. Tan bentonite ................................................ 2.0

38. Grayish-brown, bentonitic shale ................................ 3.5

39. Black lignite .................................................. 1.0

40. Brown sand .................................................. 0.5

41. Grayish-brown, bentonitic shale ................................ 11.0

42. Black lignite .................................................. 0.5

43. Dark-gray bentonite .......................................... 1.0

44. Brown sand with bentonitic shale partings, and siderite nodules weathering to limonite near the base ..................... 14.0

45. Brown lignite, and lignitic shale .............................. 1.0

46. Brown sand with buff, calcareous sandstone lenses near the base ........................................ 6.0
<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>35.</td>
<td>Brown bentonite</td>
<td>3.3</td>
</tr>
<tr>
<td>34.</td>
<td>Black lignite</td>
<td>0.5</td>
</tr>
<tr>
<td>33.</td>
<td>Gray bentonite and bentonitic shale</td>
<td>10.0</td>
</tr>
<tr>
<td>32.</td>
<td>Grayish-brown, bentonitic silts with limonite stains</td>
<td>12.0</td>
</tr>
<tr>
<td>31.</td>
<td>Light-gray bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>30.</td>
<td>Dark-gray bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>29.</td>
<td>Brown, lignitic shale and lignite</td>
<td>0.5</td>
</tr>
<tr>
<td>28.</td>
<td>Brown, bentonitic shale with siderite nodules weathering to limonite</td>
<td>10.5</td>
</tr>
<tr>
<td>27.</td>
<td>Brown lignite, and lignitic shale</td>
<td>7.0</td>
</tr>
<tr>
<td>26.</td>
<td>Moderate-grayish-brown bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>25.</td>
<td>Light-brown to light-gray silt, sand, and bentonitic shale with calcareous,</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>cone-in-cone concentrations at the top</td>
<td></td>
</tr>
<tr>
<td>24.</td>
<td>Lignite</td>
<td>0.5</td>
</tr>
<tr>
<td>23.</td>
<td>Brown bentonite</td>
<td>3.5</td>
</tr>
<tr>
<td>22.</td>
<td>Moderate-brown lignite, and lignitic shale</td>
<td>2.5</td>
</tr>
<tr>
<td>21.</td>
<td>Light-brown, lignitic, fine sand -- &quot;yellow bed&quot;</td>
<td>4.5</td>
</tr>
<tr>
<td>20.</td>
<td>Brown lignite and lignitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>19.</td>
<td>Gray, bentonitic shale</td>
<td>0.5</td>
</tr>
<tr>
<td>18.</td>
<td>Black lignite</td>
<td>2.9</td>
</tr>
</tbody>
</table>

**Total 135.0**

Beds 20, 19, 16 - "lowest persistent lignite"

**HELL CREEK FORMATION (PRETTY BUTTE MEMBER)**

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.</td>
<td>Dark- to medium-gray bentonite</td>
<td>20.0</td>
</tr>
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</table>

**Total thickness of the Pretty Butte Member** | 20.0 |
### HELL CREEK FORMATION (BUFF MEMBER)

<table>
<thead>
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</tr>
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<tbody>
<tr>
<td>16</td>
<td>Gray sand with calcareous sandstone lenses</td>
<td>54.0</td>
</tr>
<tr>
<td>15</td>
<td>Medium-gray bentonite</td>
<td>5.0</td>
</tr>
<tr>
<td>14</td>
<td>Light-grayish-brown sand with calcareous sandstone lenses near the top, and bentonitic shale partings near the base</td>
<td>32.0</td>
</tr>
<tr>
<td>13</td>
<td>Dark- to light-bluish- or greenish-gray bentonites</td>
<td>15.0</td>
</tr>
<tr>
<td>12</td>
<td>Purplish- to reddish-brown bentonite with siderite nodules weathering to limonite</td>
<td>2.0</td>
</tr>
<tr>
<td>11</td>
<td>Greenish- to yellowish-brown bentonite</td>
<td>6.0</td>
</tr>
<tr>
<td>10</td>
<td>Grayish-brown, fine sand</td>
<td>1.5</td>
</tr>
<tr>
<td>9</td>
<td>Dark-gray bentonite</td>
<td>6.5</td>
</tr>
<tr>
<td>8</td>
<td>Brown, lignitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>7</td>
<td>Brown to gray, lignitic sand</td>
<td>5.0</td>
</tr>
</tbody>
</table>

Total thickness of the Buff Member: 151.0

### HELL CREEK FORMATION (BACON CREEK MEMBER)

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Medium-gray bentonite</td>
<td>4.0</td>
</tr>
<tr>
<td>5</td>
<td>Brown sand</td>
<td>2.0</td>
</tr>
<tr>
<td>4</td>
<td>Lignite and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>3</td>
<td>Moderate-brown to gray bentonite</td>
<td>9.5</td>
</tr>
<tr>
<td>2</td>
<td>Lignite and lignitic shale</td>
<td>0.5</td>
</tr>
<tr>
<td>1</td>
<td>Gray to brown sand with calcareous sandstone lenses, and lignitic lenses</td>
<td>34.0</td>
</tr>
</tbody>
</table>

Total: 71.0

Covered

Thickness of Hell Creek Formation measured: (222.0)
## Section 67

Sec. 36, T. 133 N., R. 105 W., Slope County, North Dakota

### TILLOCK FORMATION

<table>
<thead>
<tr>
<th>Depth</th>
<th>Layer Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.</td>
<td>Light-buff sand with calcareous sandstone lenses</td>
</tr>
<tr>
<td>20.</td>
<td>Dark-gray bentonite</td>
</tr>
<tr>
<td>19.</td>
<td>Dark-brown to black lignite, and lignitic shale with gypsum crystals</td>
</tr>
<tr>
<td>18.</td>
<td>Light-brown, lignitic shale</td>
</tr>
<tr>
<td>17.</td>
<td>Black lignite</td>
</tr>
<tr>
<td>16.</td>
<td>Grayish-brown shales with yellow jarosite</td>
</tr>
<tr>
<td>15.</td>
<td>Dark-brown to black lignite</td>
</tr>
<tr>
<td>14.</td>
<td>Gray, bentonitic shale</td>
</tr>
<tr>
<td>13.</td>
<td>Gray silt with siderite nodules weathering to limonite</td>
</tr>
<tr>
<td>12.</td>
<td>Gray bentonite</td>
</tr>
<tr>
<td>11.</td>
<td>Fine sand with bentonitic shale partings, and siderite nodules near the base weathering to limonite</td>
</tr>
<tr>
<td>10.</td>
<td>Brown, bentonitic shale with cane-in-cane, calcareous concretions</td>
</tr>
<tr>
<td>9.</td>
<td>Gray bentonite with silicified tree stumps in place</td>
</tr>
<tr>
<td>8.</td>
<td>Gray, bentonitic shale with limonite stains</td>
</tr>
<tr>
<td>7.</td>
<td>Black lignite</td>
</tr>
<tr>
<td>6.</td>
<td>Dark-gray bentonite</td>
</tr>
<tr>
<td>5.</td>
<td>Brown, lignitic shale</td>
</tr>
<tr>
<td>4.</td>
<td>Medium-gray bentonite</td>
</tr>
<tr>
<td>3.</td>
<td>Bentonitic shale, silt, and fine sand with calcareous sandstone lenses</td>
</tr>
<tr>
<td>Layer Description</td>
<td>Feet</td>
</tr>
<tr>
<td>--------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1. Brown lignite</td>
<td>3.0</td>
</tr>
<tr>
<td>1. Brown, bentonitic shale</td>
<td>3.5</td>
</tr>
<tr>
<td>Covered</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>81.5</td>
</tr>
</tbody>
</table>

**Section 68**

Sec. 1, T. 136 N., R. 106 W., Slope County, North Dakota

**LUBLOW FORMATION**

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>21. Yellow sand</td>
<td>10.0</td>
</tr>
<tr>
<td>20. Black lignite</td>
<td>9.0</td>
</tr>
<tr>
<td>19. Brown, lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>18. Black lignite with gypsum crystals</td>
<td>12.0</td>
</tr>
<tr>
<td>Total</td>
<td>33.0</td>
</tr>
</tbody>
</table>

**TULLOCK FORMATION**

<table>
<thead>
<tr>
<th>Layer Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>17. Light-gray, bentonitic shale</td>
<td>9.5</td>
</tr>
<tr>
<td>16. Buff sand</td>
<td>23.5</td>
</tr>
<tr>
<td>15. Black to brown lignite, and lignitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>14. Gray, somewhat bentonitic shale</td>
<td>10.0</td>
</tr>
<tr>
<td>13. Gray, somewhat bentonitic, cross-beded sand</td>
<td>62.0</td>
</tr>
<tr>
<td>with calcareous sandstone concretions in the lower half, and a few siderite nodules weathering to limonite near the middle</td>
<td></td>
</tr>
<tr>
<td>12. Black, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>11. Grayish-brown, bentonitic shale</td>
<td>6.5</td>
</tr>
<tr>
<td>10. Brown lignite, and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>9. Light-brown, lignitic shale</td>
<td>3.5</td>
</tr>
<tr>
<td>8. Medium-gray, limonite stained bentonite with siderite nodules near the base</td>
<td>12.0</td>
</tr>
<tr>
<td>7. Medium-bluish-gray bentonitic shale</td>
<td>8.0</td>
</tr>
<tr>
<td>6. Black, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>5. Grayish-brown, bentonitic shale</td>
<td>6.5</td>
</tr>
<tr>
<td>4. Brown lignite, and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>3. Light-brown, lignitic shale</td>
<td>3.5</td>
</tr>
<tr>
<td>2. Medium-gray, lignitic shale</td>
<td>12.0</td>
</tr>
<tr>
<td>1. Medium-bluish-gray bentonitic shale</td>
<td>8.0</td>
</tr>
</tbody>
</table>
6. Brownish-gray sand with calcareous sandstone lenses near the top along with siderite nodules weathering to limonite. Sands bentonitic near the base .................................................. 16.0
5. Brown lignite, and lignitic shale ........................................ 3.0
4. Light-brown, soft, lignitic sand ........................................ 6.0
3. Light-gray bentonite ...................................................... 4.0
2. Fine sand and silt ......................................................... 5.0
1. Gray, limonite stained, cross-bedded sand
   with calcareous sandstone lenses .................................... 35.0

Total: 232.0

Covered

**Section 69**

8 1/2 sec. 4, T. 134 N., R. 106 W., Slope County, North Dakota

**TALLOCK FORMATION**

50. Buff sand with white bloom and calcareous, flaggy sandstone lenses and ledges near the middle ........................................... 12.0
49. Gray, interbedded shale, and sand ................................... 6.0
48. Gray to brown, lignitic sand with lignitic shale partings .................. 9.0
47. Brown lignite and lignitic shale with gypsum crystals .................... 7.0
46. Light-brown sand ....................................................... 4.0
45. Buff sand with massecuite flakes ..................................... 12.0
44. Medium-gray, bentonitic shale ........................................ 1.0
43. Light-buff, bentonitic sand with siderite nodules weathering to limonite .................................................. 3.0
42. Medium-gray, bentonitic shale ........................................ 1.0
41. Buff sand ................................................................. 6.0
<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>Black to dark-brown lignite, and lignitic shale</td>
<td>2.5</td>
</tr>
<tr>
<td>22</td>
<td>Light-gray, bentonitic sands, and shales</td>
<td>15.0</td>
</tr>
<tr>
<td>23</td>
<td>Light-grayish-brown sand</td>
<td>1.5</td>
</tr>
<tr>
<td>24</td>
<td>Black lignite, and lignitic shale</td>
<td>5.0</td>
</tr>
<tr>
<td>25</td>
<td>Bright-yellowish-brown silt which is soft and has a white bloom on the surface</td>
<td>12.0</td>
</tr>
<tr>
<td>26</td>
<td>Moderate-brown lignite, and lignitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>27</td>
<td>Light-gray silts and fine sands with tan calcareous concretions, siderite nodules in their centers weathering to limonite near the middle of the bed</td>
<td>12.0</td>
</tr>
<tr>
<td>28</td>
<td>Dark-gray bentonite</td>
<td>1.5</td>
</tr>
<tr>
<td>29</td>
<td>Light-gray bentonitic sands with limonite stains and calcareous sandstone lenses near the base</td>
<td>6.5</td>
</tr>
<tr>
<td>30</td>
<td>Medium-gray bentonite</td>
<td>0.5</td>
</tr>
<tr>
<td>31</td>
<td>Light-gray, bentonitic sand</td>
<td>4.5</td>
</tr>
<tr>
<td>32</td>
<td>Dark-brown lignite, and lignitic shale</td>
<td>10.0</td>
</tr>
<tr>
<td>33</td>
<td>Yellowish-brown bentonitic shale and bentonite with moderate-brown, limy concretions near the base and again near the middle</td>
<td>17.0</td>
</tr>
<tr>
<td>34</td>
<td>Moderate-grayish-brown bentonite and bentonitic shale</td>
<td>13.0</td>
</tr>
<tr>
<td>35</td>
<td>Dark-brown lignite, and lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>36</td>
<td>Light-brown, bentonitic sand with a white bloom</td>
<td>5.0</td>
</tr>
<tr>
<td>37</td>
<td>Light-brown sand</td>
<td>2.0</td>
</tr>
<tr>
<td>38</td>
<td>Black to brown lignite, and lignitic shale with gypceum crystals</td>
<td>1.0</td>
</tr>
<tr>
<td>39</td>
<td>Moderate-brown, lignitic, bentonitic sand</td>
<td>3.0</td>
</tr>
<tr>
<td>40</td>
<td>Medium-gray bentonite</td>
<td>1.0</td>
</tr>
<tr>
<td>Number</td>
<td>Description</td>
<td>Thickness</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------------------------------------------------------------------------------------------</td>
<td>-----------</td>
</tr>
<tr>
<td>20</td>
<td>Medium-brownish-gray, bentonite, and bentonitic shale</td>
<td>15.0</td>
</tr>
<tr>
<td>19</td>
<td>Dark-brown lignite, and lignitic shale</td>
<td>0.5</td>
</tr>
<tr>
<td>18</td>
<td>Medium-gray bentonite</td>
<td>3.5</td>
</tr>
<tr>
<td>17</td>
<td>Medium-gray, limonite stained, bentonitic shale with siderite nodules weathering to limonite</td>
<td>10.0</td>
</tr>
<tr>
<td>16</td>
<td>Light-gray, bentonitic sand with calcareous sandstone lenses</td>
<td>1.0</td>
</tr>
<tr>
<td>15</td>
<td>Medium-gray bentonite</td>
<td>6.0</td>
</tr>
<tr>
<td>14</td>
<td>Dark-brown, lignitic shale</td>
<td>0.5</td>
</tr>
<tr>
<td>13</td>
<td>Medium-gray bentonite</td>
<td>3.5</td>
</tr>
<tr>
<td>12</td>
<td>Medium-gray to brown, bentonitic shale</td>
<td>16.0</td>
</tr>
<tr>
<td>11</td>
<td>Dark-brown to black lignite and lignitic shale - &quot;lowest persistent lignite&quot;</td>
<td>9.3</td>
</tr>
</tbody>
</table>

**Total 245.5**

**Hill Creek Formation (Pretty Butte Member)**

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Dark-gray bentonite</td>
<td>4.5</td>
</tr>
<tr>
<td>9</td>
<td>Medium-gray, bentonitic shale</td>
<td>6.0</td>
</tr>
<tr>
<td>8</td>
<td>Light-brown, lignitic shale</td>
<td>1.5</td>
</tr>
<tr>
<td>7</td>
<td>Medium-gray bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>6</td>
<td>Moderate-brown, lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>5</td>
<td>Medium-gray, bentonitic shale with lignitic shale lenses near the top</td>
<td>19.5</td>
</tr>
</tbody>
</table>

**Total thickness of the Pretty Butte Member** | 28.5 |

**Hill Creek Formation (Huff Member)**

<table>
<thead>
<tr>
<th>Number</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Light-brown, bentonitic sand with siderite nodules weathering to limonite near the top</td>
<td>13.5</td>
</tr>
<tr>
<td>3</td>
<td>Light-brown sand with a calcareous sandstone lens in the middle of the bed</td>
<td>9.5</td>
</tr>
</tbody>
</table>
1. Dark-gray bentonite with siderite nodules
weathering to limonite .......................... 3.0

2. Moderate-yellowish-brown, sandy bentonite .......................... 6.0

Covered

Thickness of Hell Creek Formation measured .......................... (60.1)

**Section 70**

Sec. 25, T. 134 N., R. 106 W., Slope County, North Dakota

**TULLOCK FORMATION**

26. Light-gray bentonite .......................... 0.5

27. Yellowish-brown silt, and fine sand with
siderite nodules weathering to limonite,
and gypsum crystals near the base .................. 8.5

28. Black lignite .......................... 1.5

Total 10.5

**HELL CREEK FORMATION (PRETTY BUTTE MEMBER)**

25. Brownish-gray bentonite .......................... 4.5

24. Gray sand giving way rapidly to bentonites.
Sand contains calcareous sandstone lenses ........ 14.5

23. Brown, lignitic sand .......................... 0.5

22. Grayish-brown, somewhat greenish bentonite with
siderite nodules weathering to limonite ............ 6.0

21. Light-gray silt with bentonitic shale partings .... 4.5

20. Dark-gray bentonite .......................... 3.5

19. Brownish-gray, lignitic, bentonitic shale
with siderite nodules near the base weathering
to limonite ........................................ 3.5

18. Medium-gray bentonite .......................... 2.5
17. Gray to brown, bentonitic shale .............................. 30.0

Total thickness of Pretty Butte Member ........................ 55.0

HELL CREEK FORMATION (HUFF MEMBER)

16. Gray sand with "log" calcareous sandstone lenses  ... 25.0

15. Medium-gray bentonite ........................................ 5.0

14. Light-gray silt with siderite nodules
weathering to limonite at the base ............................ 5.0

13. Dark-gray, brownish near the top, greenish
near the base bentonite ........................................ 11.5

12. Brown lignite and lignitic shale ............................. 1.0

11. Medium-gray bentonitic silt with siderite
nodules weathering to limonite at the base ................. 16.0

10. Medium-gray, bentonitic shale ............................... 18.0

9. Silt and fine sand somewhat bentonitic ................. 19.0

6. Brown, gray weathering sand with light-gray
calcareous sandstone lenses enclosing siderite
nodules weathering to limonite ............................. 14.0

Total thickness of Huff Member ................................ 104.0

HELL CREEK FORMATION (BACON CREEK MEMBER)

7. Moderate-grayish-brown bentonite with siderite
nodules weathering to limonite at the base ............... 6.0

6. Medium-gray bentonite with dark-gray streaks ........ 8.0

5. Slate-blue bentonite grading downward into
gray sand ............................................................. 7.0

4. Gray sand with light gray calcareous sandstone
lenses ("log" concretions) ................................ 10.0

3. Black lignite, and lignitic shale .......................... 1.0

2. Brown, lignitic shale ........................................ 3.0
1. Gray bentonite ........................................ 4.0

Total 67.0

 Thickness of Ball Creek Formation measured ........ (226.0)

Section 71

SW 1/4 sec. 35, T. 134 N., R. 106 W., Pretty Butte, Slope County, North Dakota

LUDLOW FORMATION

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>56.</td>
<td>Sandy &quot;scoria&quot;</td>
<td>10.0</td>
</tr>
<tr>
<td>55.</td>
<td>Shaly &quot;scoria&quot;</td>
<td>20.0</td>
</tr>
<tr>
<td>54.</td>
<td>White ash plus black natural coke</td>
<td>4.5</td>
</tr>
<tr>
<td>53.</td>
<td>Shaly &quot;scoria&quot;</td>
<td>1.0</td>
</tr>
<tr>
<td>52.</td>
<td>White to pale lavender ash</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Total 36.5

Sands 52, 53, and 57 are the T-Cross bed of Hares (1928)

TULLOCK FORMATION

<table>
<thead>
<tr>
<th>No.</th>
<th>Description</th>
<th>Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>56.</td>
<td>Gray shale</td>
<td>2.5</td>
</tr>
<tr>
<td>55.</td>
<td>Light-brown silt</td>
<td>3.5</td>
</tr>
<tr>
<td>54.</td>
<td>Brown sand with small siderite nodules weathering to limonite near the base</td>
<td>14.5</td>
</tr>
<tr>
<td>53.</td>
<td>Light-gray lignitic shale</td>
<td>11.0</td>
</tr>
<tr>
<td>52.</td>
<td>Light-purple-brown, fossil, lignitic shale</td>
<td>7.0</td>
</tr>
<tr>
<td>51.</td>
<td>Brown lignite with gypsum, and jarosite</td>
<td>1.0</td>
</tr>
<tr>
<td>50.</td>
<td>Brown, fossil, lignitic shale</td>
<td>2.5</td>
</tr>
<tr>
<td>49.</td>
<td>Brown, soft sand</td>
<td>0.5</td>
</tr>
<tr>
<td>48.</td>
<td>Light-brown, fine sand interbedded with silt and shale</td>
<td>7.0</td>
</tr>
<tr>
<td></td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>---</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>47</td>
<td>Gray, bentonitic shale</td>
<td>9.9</td>
</tr>
<tr>
<td>46</td>
<td>Moderate-brown lignite, and lignitic shale</td>
<td>1.8</td>
</tr>
<tr>
<td>45</td>
<td>Buff sand and silt</td>
<td>8.9</td>
</tr>
<tr>
<td>44</td>
<td>Grayish-brown, bentonitic shale</td>
<td>10.0</td>
</tr>
<tr>
<td>43</td>
<td>Grayish-brown shale</td>
<td>6.5</td>
</tr>
<tr>
<td>42</td>
<td>Brown, interbedded silts and shales with white calcareous concretions,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>lignitic shale lenses, lignite lenses, siderite beds weathering to</td>
<td></td>
</tr>
<tr>
<td></td>
<td>limonite</td>
<td>24.5</td>
</tr>
<tr>
<td>41</td>
<td>Brown, bentonitic shale</td>
<td>13.0</td>
</tr>
<tr>
<td>40</td>
<td>Grayish-brown bentonite with limonite stains</td>
<td>4.5</td>
</tr>
<tr>
<td>39</td>
<td>Brown, hard silt and clay</td>
<td>2.5</td>
</tr>
<tr>
<td>38</td>
<td>Gray, limonite stained, interbedded bentonite, and bentonitic shale with</td>
<td></td>
</tr>
<tr>
<td></td>
<td>white, calcareous concretions in the central portions</td>
<td>19.5</td>
</tr>
<tr>
<td>37</td>
<td>Purplish-brown, bentonitic shale</td>
<td>0.3</td>
</tr>
<tr>
<td>36</td>
<td>Grayish-brown bentonite</td>
<td>7.5</td>
</tr>
<tr>
<td>35</td>
<td>Brown, bentonitic silt</td>
<td>5.5</td>
</tr>
<tr>
<td>34</td>
<td>Lignitic shale</td>
<td>1.0</td>
</tr>
<tr>
<td>33</td>
<td>Tan, bentonitic shale</td>
<td>3.0</td>
</tr>
<tr>
<td>32</td>
<td>Black lignite</td>
<td>1.0</td>
</tr>
<tr>
<td>31</td>
<td>Gray bentonite</td>
<td>2.8</td>
</tr>
<tr>
<td>30</td>
<td>Fine, gray, bentonitic sand with calcareous, cone-in-cone concretions</td>
<td></td>
</tr>
<tr>
<td></td>
<td>near the top</td>
<td>6.3</td>
</tr>
<tr>
<td>29</td>
<td>Brown lignite, and lignitic shale</td>
<td>0.5</td>
</tr>
<tr>
<td>28</td>
<td>Gray, bentonitic shale</td>
<td>1.8</td>
</tr>
<tr>
<td>27</td>
<td>Light-brown sand with calcareous sandstone</td>
<td></td>
</tr>
<tr>
<td></td>
<td>lenses near the top often limonite stained</td>
<td>15.0</td>
</tr>
<tr>
<td>26</td>
<td>Gray bentonite</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td></td>
</tr>
<tr>
<td>25.</td>
<td>Brown to black lignite, and lignitic shale</td>
<td>11.0</td>
</tr>
<tr>
<td>24.</td>
<td>Bluish- to greenish-gray bentonite with siderite nodules weathering to limonite in the middle portions</td>
<td>11.0</td>
</tr>
<tr>
<td>23.</td>
<td>Gray, bentonitic shale with calcareous penetrations near the top and siderite nodules weathering to limonite throughout</td>
<td>20.9</td>
</tr>
<tr>
<td>22.</td>
<td>Brown lignite and lignitic shales</td>
<td>5.3</td>
</tr>
<tr>
<td>21.</td>
<td>Yellowish- to brownish-gray bentonite</td>
<td>6.2</td>
</tr>
<tr>
<td>20.</td>
<td>Brownish-gray, bentonitic shale, silty near the base</td>
<td>7.3</td>
</tr>
</tbody>
</table>

Codes 24 through 19 are replaced laterally by a thick sand.

18. Light-yellowish-brown silt - "Yellow bed" | 13.0 |
17. Brown to black lignite, and lignitic shale - "lowest persistent lignite" | 2.8 |

**Total thickness of the Tullock Formation** | 268.3

**HILL CREEK FORMATION (PRETTY BUTTE MEMBER)**

16. Medium-gray bentonite | 8.0 |
15. Gray sand with siderite nodules weathering to limonite near the middle and the base, and calcareous sandstone lenses above the base | 16.5 |
14. Medium-gray bentonite with siderite nodules weathering to limonite at the base | 12.5 |
13. Gray, bentonitic shales | 17.0 |

**Total thickness of the Pretty Butte Member** | 51.0

**HILL CREEK FORMATION (BUFF MEMBER)**

12. Buff sand | 1.5 |
11. Gray, limonite stained, badly slumped, interbedded shales and silts | 67.5
10. Gray, bentonitic silt and sand .......................... 6.5  
9. Gray, bentonitic silt ....................................... 22.5  
Total thickness of the Ruff Member ........................ 99.0  

HELL CREEK FORMATION (BACON CREEK MEMBER)  
8. Medium-gray bentonite with siderite nodules  
weathering to limonite below the top ..................... 6.5  
7. Dark-gray bentonite ....................................... 1.5  
6. Medium-gray bentonite .................................... 5.5  
5. Brown, bentonitic sand with lignitic lenses,  
calcareous sandstone lenses, and siderite  
nodules weathering to limonite at the base .............. 35.0  
4. Brownish-gray bentonite .................................. 3.5  
3. Dark-gray bentonite ....................................... 2.5  
2. Brownish-gray, lignitic shale ............................ 1.0  
1. Gray, bentonitic shale .................................... 4.5  
Total 55.0  

Covered  
Total thickness of Hell Creek Formation measured .......... (285.0)  

Section 72  
Sec. 10, T. 135 N., R. 103 W., Slope County, North Dakota  

TONGUE RIVER FORMATION  
23. Soft, yellow-brown sands, bentonitic near the  
top, and containing light-gray, calcareous  
sandstone lenses ............................................ 40.0  

LUDLOW FORMATION (Undifferentiated)  
22. Slack to brown, lignitic shale, and lignite  
containing gypsum crystals ................................. 3.6  
21. Moderate-brown, lignitic sands ........................ 3.0  
20. Light-brown, lignitic shale .............................. 3.0
### LUDLOW FORMATION (LABO MEMBER)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.</td>
<td>Dark-brown, lignitic shale</td>
<td>7.5</td>
</tr>
<tr>
<td>10.</td>
<td>Light-brown, lignitic sand</td>
<td>1.0</td>
</tr>
<tr>
<td>11.</td>
<td>Moderate-brown, lignitic shale with gypsum crystals</td>
<td>4.0</td>
</tr>
<tr>
<td>12.</td>
<td>Light-brown, lignitic sand</td>
<td>1.0</td>
</tr>
<tr>
<td>13.</td>
<td>Black lignite and lignitic shale</td>
<td>4.0</td>
</tr>
<tr>
<td>14.</td>
<td>Moderate- to dark-brown, lignitic shale</td>
<td>26.0</td>
</tr>
<tr>
<td>15.</td>
<td>Thinly bedded, lignitic sands with limonite and jasomite</td>
<td>6.0</td>
</tr>
<tr>
<td>16.</td>
<td>Moderate-brown, lignitic shale with gypsum crystals</td>
<td>2.0</td>
</tr>
<tr>
<td>17.</td>
<td>Black lignite, and lignitic shale</td>
<td>6.0</td>
</tr>
<tr>
<td>18.</td>
<td>Light-brown, lignitic sands</td>
<td>3.0</td>
</tr>
<tr>
<td>19.</td>
<td>Lignite and lignitic shale with yellow jasemit near the base</td>
<td>11.3</td>
</tr>
</tbody>
</table>

Total thickness of Labo Member = 92.3

### LUDLOW FORMATION (Undifferentiated)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.</td>
<td>Black lignite and lignitic shale - T-Cross bed of Barnes (1926)</td>
<td>6.3</td>
</tr>
</tbody>
</table>

Total thickness of Ludge Formation = (123.0)
## TULLOCK FORMATION

### Section 73

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 and 26</td>
<td>Sandy &quot;scoria&quot;</td>
<td>12.0</td>
</tr>
<tr>
<td>23</td>
<td>Shaly &quot;scoria&quot;</td>
<td>39.0</td>
</tr>
<tr>
<td>25</td>
<td>White ash - T-Cross bed of Horns (1928)</td>
<td>1.3</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>52.5</td>
</tr>
</tbody>
</table>

## TULLOCK FORMATION

<table>
<thead>
<tr>
<th>Section</th>
<th>Description</th>
<th>Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>Buff sands with a buff, calcareous sandstone ledge in the middle</td>
<td>46.0</td>
</tr>
<tr>
<td>29</td>
<td>Brown to black lignite, and lignitic shale with gypsum</td>
<td>1.5</td>
</tr>
<tr>
<td>30</td>
<td>Buff sands with calcareous sandstone lenses - &quot;log&quot; concentrations near the base</td>
<td>22.0</td>
</tr>
<tr>
<td>27</td>
<td>Gray, bentonitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>28</td>
<td>Brown lignite, and lignitic shale</td>
<td>2.0</td>
</tr>
<tr>
<td>25</td>
<td>Brownish-gray bentonite</td>
<td>3.0</td>
</tr>
<tr>
<td>24</td>
<td>Brownish-gray, bentonitic sand with siderite nodules baking to limonite near the top and the bottom</td>
<td>12.0</td>
</tr>
<tr>
<td>23</td>
<td>Brown lignite, and lignitic shale with gypsum crystals</td>
<td>1.3</td>
</tr>
<tr>
<td>22</td>
<td>Buff sand with calcareous sandstone lenses</td>
<td>27.5</td>
</tr>
</tbody>
</table>
21. Brown, bentonitic sand with a white bloom       14.0
20. Brown to black lignite, and lignitic shale   8.0
19. Buff sand                                       2.0
18. Light-brown to yellowish-brown, bentonitic sand with white bloom 7.0
17. Black to brown lignite, and lignitic shale with gypsum crystals 9.0
16. Buff to light-brown sand                       3.0
15. Yellowish-brown to grayish-brown, bentonitic sand with a white bloom 11.0
14. Black lignite                                    2.0
13. Dark-gray bentonite becoming lighter-gray at the base 6.5
12. Brown to grayish-brown lignite, and lignitic shale 2.5
11. Light-grayish-brown sand                        1.0
10. Light-gray, bentonitic sand                      5.0
9. Light-gray sand with calcareous sandstone lenses, and siderite nodules weathering to limonite near the base 13.0
8. Medium-gray to brown, bentonitic sands, and shale with siderite nodules weathering to limonite 3.0
7. Light-gray bentonite with siderite nodules weathering to limonite near the top 5.5
6. Moderate-brown lignite, and lignitic shale with jarosite 1.0
5. Medium-gray bentonite, and bentonitic shale 18.3
4. Black lignite, and lignitic shale - "lewed persistent lignite" 7.0

Total thickness of Tullock Formation              238.3
HELL CREEK FORMATION (PRETTY BUTTE MEMBER)

1. Dark-gray bentonite ........................................... 5.0
2. Medium-brownish-gray sands interbedded with
   bentonitic shales ........................................... 13.0

Total thickness of Pretty Butte Member ........................ 18.0

HELL CREEK FORMATION (BUFF MEMBER)

1. Light-brownish-gray sand with calcareous
   sandstone lenses ........................................... 34.0

Total 34.0

Thickness of Hell Creek Formation measured ............... (32.0)
APPENDIX E

FAUNAL LOCATION LISTS FOR FOX HILLS, HELL CREEK, TULLOCK,
AND LUDLOW FORMATIONS*

<table>
<thead>
<tr>
<th>Formation</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fox Hills Formation</td>
<td>353</td>
</tr>
<tr>
<td>Hell Creek Formation</td>
<td>354</td>
</tr>
<tr>
<td>Little Beaver Creek Member</td>
<td>354</td>
</tr>
<tr>
<td>Marmarth Member</td>
<td>355</td>
</tr>
<tr>
<td>Bacon Creek Member</td>
<td>356</td>
</tr>
<tr>
<td>Croggnot Member</td>
<td>357</td>
</tr>
<tr>
<td>Stroed Member</td>
<td>359</td>
</tr>
<tr>
<td>Fort Rice Member</td>
<td>364</td>
</tr>
<tr>
<td>Buff Member</td>
<td>370</td>
</tr>
<tr>
<td>Pretty Butts Member</td>
<td>379</td>
</tr>
<tr>
<td>Tullock Formation</td>
<td>386</td>
</tr>
<tr>
<td>Ludlow Formation</td>
<td>382</td>
</tr>
</tbody>
</table>

*For locations of sites see Plate 8 in folder.
Fox Hills Formation

Location #18

Sec 1/4 sec. 9, T. 136 N., R. 79 W., Morton County, North Dakota
Plants
Species: *Ptilosicyclus perisilicatatus* Cockerell

Location #19

Sec 1/4 sec. 18, T. 131 N., R. 76 W., Ransom County, North Dakota
Plants
Species: *Sphenopteris (Bannemeadia) burlingi* Well

?Equisetaceae

Unidentified leaves

Cf. *Pityophyllum subfalsatum* Lesquereux

Cf. *Vitala stramenti* (Kawitzke) Brown

Cf. *Dembrogenis celastrensis* Brown
Bell Creek Formation

Little Beaver Creek Member

Location #127

C. sec. 1, T. 129 N., R. 126 W., Bowman County, North Dakota
Plants

Lepidactylotus daktotensis Brown
Location #125
Sec. 25, T. 129 N., R. 187 W., Bowman County, North Dakota
Vertebrates
Cf. Typhosaurus sp. Coshorn

Location #126
S 1/2 sec. 20, T. 133 N., R. 106 W., Slope County, North Dakota
Plants
Gleape laricifolia Ward
Strychnos subtilegatum Lesquereux
Ficus praetereformis Brown
Myophaeteae atria (Brown)
Corpus praetereformis Knowlton

Location #124
Sec. 26, T. 133 N., R. 106 W., Slope County, North Dakota
Vertebrates
Cf. Anamosaurus sp.
Unidentified reptile bone
Bacco Creek Member

Location #65

SE 1/4 sec. 32, T. 134 N., R. 106 W., Slope County, North Dakota

Vertebrates

Triconodon sp.
Croughost Member

Location #115
SE 1/4 sec. 19, T. 133 N., R. 78 W., Emmens County, North Dakota
Plants
Sequoia dakeotensis Brown
Invertebrates
Cf. Amphiscomus. Meek and Hayden

Location #123
SW 1/4 sec. 13, T. 135 N., R. 78 W., Emmens County, North Dakota
Plants
Ginkgo laripinnata Maidenhair
Abies concolor Lassen (Lassen)
Dysoxylum subfalcum Lassen (Lassen)
Invertebrates
Notobelus angustipennis (Meek and Hayden)

Location #111
SW 1/4 sec. 21, T. 134 N., R. 80 W., Morton County, North Dakota
Vertebrates
Cf. Amphiscomus sp.

Location #118
SW 1/4 sec. 30, T. 133 N., R. 80 W., Sioux County, North Dakota
Plants
Vitis grandifolia (Leaner) Brown

Location #116
Sec. 26, T. 134 N., R. 81 W., Sioux County, North Dakota
Plants
Sequoia dakeotensis Brown
Seed

Location #117
C. sec. 33, T. 134 N., R. 81 W., Croughost Cemetery, Sioux County, North Dakota
Plants
Wood

Location #122
C. sec. 31, T. 134 N., R. 82 W., Sioux County, North Dakota
Plants
Wood

Location #120
SW 1/4 sec. 33, T. 14 N., R. 19 E., Iron Lightning Railroads, South Dakota
Vertebrates
Lamiaunium silesiense Bates
Polyodon spathula Cove
Lamiaunium accidentalis (Loisy)
Fish vertebra
Turtle fragments
*Leidyesuchus sternbergi* Gilmore
*Brachyclemmys montana* Gilmore
*Cf. Dryptosaurus* sp.
*Triceratops* sp.
Unidentified reptile bones

Location 5119
Bump Creek, 1 mile south of South Dakota 65, South Dakota

Vertebrates
*Leidyesuchus sternbergi* Gilmore
Breton Member

Location #104
SE 1/4 sec. 12, T. 131 N., R. 78 W., Eddy County, North Dakota
Plants
Concretions around roots (fossil?)

Location #106
SE 1/4 sec. 35, T. 135 N., R. 78 W., Eddy County, North Dakota
Invertebrates
Nectria glabra Neek and Hayden
Ophiocorpha major Lasqueux

Location #104
NW 1/4 sec. 28, T. 136 N., R. 78 W., Eddy County, North Dakota
Invertebrates
?Discombobulus comradii (Norton)
Ophiocorpha major Lasqueux

Location #102
SE 1/4 sec. 8, T. 136 N., R. 78 W., Eddy County, North Dakota
Invertebrates
Ophiocorpha major Lasqueux

Location #114
C. sec. 17, T. 136 N., R. 78 W., Eddy County, North Dakota
Invertebrates
Nectria glabra Neek and Hayden
Lipocorona ranacolorata (Neek and Hayden)
Cf. Ophiocorpha major Lasqueux

Location #109
NE 1/4 SE 1/4 sec. 10, T. 133 N., R. 82 W., Morton County, North Dakota
Plants
Concretions around roots
Invertebrates
Corbicula sp., cf. C. cytheriformis (Neek and Hayden)
Ophiocorpha major Lasqueux

Location #113
SE 1/4 sec. 17, T. 133 N., R. 82 W., Morton County, North Dakota
Invertebrates
Corbicula cytheriformis (Neek and Hayden)
Nectria glabra Neek and Hayden
Thoracic tubes

Location #110
SE 1/4 SE 1/4 sec. 17, T. 133 N., R. 82 W., Morton County, North Dakota
Invertebrates
A poorly preserved class
?Corbicula cytheriformis (Neek and Hayden)
Catera glabra Meek and Hayden
Tubora tubes

Location 691
SE 1/4 sec. 21, T. 134 N., R. 89 W., Morton County, North Dakota
Plants
Sesalia dakotensis Brown
Carpelithes sp.
Invertebrates
Catera glabra Meek and Hayden
An unidentified Bryoidea
Ophiomorpha major Lasquereux
Tubora burrows
Vertebrates
Cf. Lamos cuspidenta Agassiz
Cf. Orduna obliquus Agassiz
Hylaeus bisplittus Cope
Fish vertebrae
Turtle fragments
Leiocraneus sternbergi Gilmore
Cf. Tetragonactes rex Osborn
Cf. Triceratops sp.
Unidentified reptile bones
Nemicyctes robustus (Marsh)

Location 998
SE 1/4 sec. 17, T. 134 N., R. 81 W., Morton County, North Dakota
Invertebrates
Catera glabra Meek and Hayden
Catera sp. cf. C. haydeni White
?Vallisa (Brachioceras) multilinearis Meek
Cobichula cytheriformis (Meek and Hayden)
Cf. Trigonoceras obtusum (Meek and Hayden)
"Heloria" wyomingensis (Meek)
Ophiomorpha major Lasquereux
?Burrows

Location 991
NE 1/4 sec. 8, T. 135 N., R. 79 W., Morton County, North Dakota
Invertebrates
Catera glabra Meek and Hayden
A poorly preserved clam
Ophiomorpha major Lasquereux

Location 993
NE 1/4 sec. 18, T. 135 N., R. 79 W., Morton County, North Dakota
Plants
?Plant stems
Invertebrates
Catera glabra Meek and Hayden
Cobichula sp. cf. C. cytheriformis (Meek and Hayden)
Cobichula pyriformis Meek
Vertebrates
Coprolites
Location #97  
C. sec. 18, T. 133 N., R. 79 W., Morton County, North Dakota  
**Invertebrates**  
*Planerida americana* (Haast and Hayden)  
*Ostrea glabra* Haast and Hayden  
*Ophiomorpha* *major* Linsqueaux

Location #95  
SE 1/4 sec. 6, T. 136 N., R. 79 W., Morton County, North Dakota  
**Invertebrates**  
*Planerida americana* Haast and Hayden  
*Ostrea glabra* Haast and Hayden  
*Ophiomorpha* *major* Linsqueaux

**Vertebrates**  
Cf. *Campsosaurus* sp.

Location #109  
Sec. 1, T. 136 N., R. 80 W., Morton County, North Dakota  
**Plants**  
Asper  
**Invertebrates**  
*Sphaeria* sp. cf. *S. hankethense* Warren  
A poorly preserved unidentified gastropod  
?Several species of worm tubes  
**Vertebrates**  
*Nylaeaphus bipartitus* Cope  
*Leidyosaurus sternbergi* Gilmore  
*Brachyochampsa montana* Gilmore  
Cf. *Draspoposaurus* sp.

Location #96  
NE 1/4 sec. 3, T. 129 N., R. 81 W., Sioux County, North Dakota  
**Invertebrates**  
*Ostrea glabra* Haast and Hayden  
*Ophiomorpha* *major* Linsqueaux  
*Ostrea* sp. cf. *O. glabra* Haast and Hayden  
Burrows

Location #111  
NE 1/4 sec. 1, T. 133 N., R. 82 W., Sioux County, North Dakota  
**Invertebrates**  
*Planeridae wyomingensis* (Haast)

Location #106  
Sec. 18, T. 133 N., R. 82 W., Sioux County, North Dakota  
**Invertebrates**  
*Planeridae wyomingensis* (Haast)  
*Ophiomorpha* *major* Linsqueaux  
Cf. *Ophiomorpha* *major* Linsqueaux
Location #103
Sec. 28, T. 134 N., R. 81 W., Sioux County, North Dakota
Plants
Concretions around plant roots
Invertebrates
Ostrea glabra Meek and Hayden
Cf. "Melania" wyomingensis (Meek)
Horn burrows
Ophiomorpha major Lasqueux
Vertebrates
Turtle fragments
Chaussaurus sp. cf. C. natator Parks

Location #107
Sec. 29, T. 134 N., R. 81 W., Sioux County, North Dakota
Invertebrates
"Melania" wyomingensis (Meek)

Location #103
SW 1/4 sec. 32, T. 134 N., R. 81 W., Sioux County, North Dakota
Invertebrates
Ostrea glabra Meek and Hayden

Location #92
C. sec. 33, T. 134 N., R. 81 W., Crowghost Cemetery, Sioux County,
North Dakota
Plants
Concretions around roots
Invertebrates
Ostrea glabra Meek and Hayden
Cf. Trigonocollis nebrascensis Meek and Hayden
Cf. "Melania" wyomingensis (Meek)
Horn tubes
Ophiomorpha major Lasqueux
Vertebrates
Nylestes bipartitus Cope

Location #112
Sec. 34, T. 134 N., R. 81 W., (1 mile east of Crowghost Cemetery)
Sioux County, North Dakota
Invertebrates
Corbicula cytheriformis (Meek and Hayden)
"Melania" wyomingensis (Meek)

Location #99
C. sec. 35, T. 134 N., R. 81 W., Sioux County, North Dakota
Invertebrates
Ostrea glabra Meek and Hayden
Ostrea sp. cf. O. haydeni White
Piasis nebrascensis Meek
Oesquilla sp. cf. O. (Pachydiplax) multilocularis Meek
Corbicula cytheriformis (Meek and Hayden)
Cf. Trigonocollis nebrascensis (Meek and Hayden)
Holling scutule Meek and Hayden
Carabidae subtrigonalis Meek and Hayden
Cf. Phoromorpha sp.
Ophiomorpha major Basquesaux
Squatness
Regular unidentified forms
Fossil Beds Member

Location 973
SW 1/4 sec. 27, T. 135 N., R. 78 W., Benson County, North Dakota
Plants
Sequoia dakotensis Brown
Invertebrates
Untie sp., cf. S. praetexta White
Sphenarium sp. (Undescribed species)
Sphenarium sp., cf. S. baskathenses Warren
Viviparus sp., cf. V. westoni Tozer
Campeloma sp., cf. C. chumashensis Tozer
Lioplatodes tenuicarinata (Neck and Hayden)

Location 967
SE 1/4 sec. 26, T. 135 N., R. 78 W., Benson County, North Dakota
Plants
Sequoia dakotensis Brown
Amber
Wood
Invertebrates
Sphenarium sp., cf. S. baskathenses Warren
Viviparus sp., cf. V. praetexta praetexta White
Viviparus sp., cf. V. praetexta praetexta White
Viviparus sp., cf. V. planulata Russell
Viviparus sp., cf. V. tenuis Dyer
Viviparus sp.
Campeloma sp., cf. C. nebrascensis nebrascensis (Neck and Hayden)
Campeloma sp., cf. C. nebrascensis Tozer
Lioplatodes tenuicarinata (Neck and Hayden)
Lioplatodes tenuicarinata (Neck and Hayden)
Vertebrates
Cf. Triceratops sp.

Location 978
SE 1/4 sec. 29, T. 136 N., R. 78 W., Benson County, North Dakota
Invertebrates
One poorly preserved fragment of a snail
Vertebrates
Campeloma sp.

Location 976
SW 1/4 sec. 32, T. 136 N., R. 78 W., Benson County, North Dakota
Plants
Caroas sp.
Unidentified seed
Invertebrates
A poorly preserved flea
Location #60
Dawes County, North Dakota

Invertebrates

One poorly preserved clam
Campaloea sp. cf. C. admontomensis Toser
Cytherea sp. cf. C. canadensis White
A poorly preserved small fragment

Location #66
S 1/4 sec. 9, sec. 10, T. 129 N., R. 61 W., Sioux County, North Dakota

Plants

Sequoia dawesiana Brown
?Ceratodytes schrenkianus (Beek and Hayden)
Campolithus sp.

Invertebrates

Several poorly preserved specimens of Family Unionidae
?Ceratodytes sp.
Sphaerium sp. (Undescribed species)
Sphaerium sp. cf. C. humboldtense Warren
Sphaerium sp. cf. S. sequoia Russell
Viviparinae sp. (Beek and Hayden)
Viviparinae sp. cf. V. prouti White
Viviparinae sp. cf. V. prouti (Beek and Hayden, immature specimen)
Viviparinae sp. cf. V. lasi (Beek and Hayden)
Viviparinae sp. cf. V. planolaria Russell
Viviparinae sp. cf. V. costata Toser
Campaloea admontomensis Toser
Campaloea sobralensis sobralensis (Beek and Hayden)
Liphielodiscus sp. cf. L. lineatostrobus (Beek and Hayden)
Liphielodiscus tumilicarinata (Beek and Hayden)
Liphielodiscus sp. cf. L. stami (White)
Liphielodiscus sp.
Physa bullatula White

Location #74
S 1/2 sec. 10, T. 129 N., R. 61 W., Sioux County, North Dakota

Plants

Campolithus sp. cf. C. (Cranidioceramus?) carnegyi (Knowlton)
?Campolithus sp.

Invertebrates

Eisenia macconnelli Russell
One poorly preserved clam
Sphaerium sp. (Undescribed species)
Sphaerium sp. cf. S. fowleri Russell
Viviparinae sp. (Undescribed species)
Viviparinae sp. cf. V. planolaria Russell
Viviparinae sp. cf. V. planolaria Toser
Viviparinae sp.
Campaloea sp. cf. C. admontomensis Toser
Liphielodiscus tumilicarinata (Beek and Hayden)
Scomberella sp. cf. S. proteus (Ten)
Vertebrates
  Fish vertebra
  ?Fish vertebra

Location #69
  Sec. 22, T. 131 N., R. 81 W., Sioux County, North Dakota
  Plants
    *Sorbus* denticulata Brown
  Invertebrates
    ?Harrakia usalifornia Russell
    A poorly preserved class of Family Unionidae
    *Sphaerium* denticulata n. sp.
    *Harrakia* sp. cf. *S. sorbus* Russell
    *Viviparus* sp. cf. *V. prodentus willowensis* Towner
    *Limnolochus limnocharis* (Steb and Hayden)
    *Liplocodes puncticarinata* (Steb and Hayden)
  Vertebrates
    Cf. *Hystricognathus* sp.

Location #66
  Sec. 3, T. 132 N., R. 82 W., Sioux County, North Dakota
  Plants
    *Mima* gibba (Newberry) Bollick
    *Chukko larameensis* Ward
    *Sorbus* denticulata Brown
    *Vicia stenopetra* (Knovitom) Brown
    Leaf fragments

Location #77
  Sec. 27, T. 132 N., R. 82 W., Sioux County, North Dakota
  Invertebrates
    *Campiglossa* sp. cf. *C. adenontonensis* Towner
    ?Macrtria sp.
    One poorly preserved small

Location #65
  NE 1/4 sec. 29, T. 132 N., R. 82 W., Sioux County, North Dakota
  Plants
    *Sorbus* denticulata Brown
    *Aranarites longifolia* (Lasqueaux) Dorf
    *Campiglossa* sp.
    Sand
  Invertebrates
    *Campiglossa* sp. cf. *C. adenontonensis* Towner

Location #63
  NW 1/4 sec. 35, T. 133 N., R. 80 W., Sioux County, North Dakota
  Plants
    ?Concretions around roots
Location #84
NE 1/4 sec. 1, T. 133 N., R. 62 W., Sioux County, North Dakota
Plants
Tepidium albidum (Heath) Brown
Datisa occidentalis (Newberry) Chamney
Tamarix sp.
Sycamorus pubiflorus Leopold
Tamariscidens sp.
Viscar crassifolii (Knowlton) Brown

Location #82
Sec. 36, T. 133 N., R. 62 W., Sioux County, North Dakota
Plants
Sequoia dawsonensis Brown

Location #73
Sec. 28, T. 134 N., R. 61 W., Sioux County, North Dakota
Plants
Amor
Unidentified seed

Location #67
Sec. 29, T. 134 N., R. 61 W., Sioux County, North Dakota
Vertebrates
Turtle fragments
Cf. Chelydra sp.
Cf. Trionyx sp.
Unidentified reptile bones

Location #72
C. sec. 11, T. 134 N., R. 61 W., Crowfoot Cemetery, Sioux County, North Dakota
Plants
Carpophilus megalops Bell
Wood
Seed pod
Black

Vertebrates
Cf. Dentalium sp. ?78. (Lavendalium) pauperculum Heek and Hayden
Planocellina sp. (Undescribed species)
Cf. Sphairina sp. (Undescribed species)
Cf. Sphairina sp. cf. S. hessehoesa Warren
Cf. Sphairina sp. cf. S. fowleri Russell
Cf. Sphairina sp. (Undescribed species)
Cf. Sphairina sp. cf. S. praurantium willemenis Tamer
Cf. Sphairina sp. cf. S. reinners (Heek and Hayden)
Cf. Sphairina sp. cf. S. westeri Tamer
Cf. Sphairina sp. cf. C. meridionalis Tamer
Cf. Sphairina sp. (Undescribed species)
Cf. Sphairina sp. cf. E. lamacarinata (Heek and Hayden)
Physea sp. cf. P. khambonoi White
Physea montanensis Van
Physea sp. cf. P. ballum White
Toment tubes

Vertebrates
Fish vertebrae
Turtle fragments
Cheirolepis sp. cf. C. natator Parks
Leptocrocutus sternbergi Gilmore
Pachycephalosaurus sp.
Unidentified reptile bones

Location #66
Sec. 17, T. 133 N., R. 82 W., Morton County, North Dakota

Plants
Dicerandra nebrascensis (Newberry) Hall
Carpolithus sp.
?Carpolithus sp.

Invertebrates
Dipto sp. cf. D. campylosporum Warren
?Diplodictyos sp.
Ephesurus sp. cf. E. pictus Tisser
Ephesurus sp. cf. E. hassenan White
Viviparus prunatus prunatus White
Viviparus sp. (Undescribed species)
Viviparus sp. cf. V. westoni Tisser
?Viviparus sp.
Campeloma sp. cf. C. nebrascensis nebrascensis (Meech and Hayden)
Campeloma sp. cf. C. edmontoniensis Tisser
?Campeloma sp.
Lioleades sp. cf. L. limbataforms (Meech and Hayden)
Lioleades tenuicarinata (Meech and Hayden)
?Diseoceras sp.

Location #68
81 1/4 sec. 17, T. 134 N., R. 81 W., Morton County, North Dakota

Plants
Sequoia dawsoniana Brown
Amber
Wood

Invertebrates
A poorly preserved elasm.
Viviparus sp. (Undescribed species)
Viviparus trochoformes (Meech and Hayden)
Viviparus sp. cf. V. prunatus (Meech and Hayden)
Viviparus sp. cf. V. prunatus prunatus White
Viviparus sp. cf. V. westoni Tisser
?Campeloma edmontoniensis Tisser
Lioleades tenuicarinata (Meech and Hayden)
Location 879
Sec. 6, T. 136 N., R. 79 W., Morton County, North Dakota
Plants
Wood
Invertebrates
Viviparus sp., cf. V. westoni Toser
Campeloma nebrascensiae nebrascensiae (West and Hayden)
Campeloma sp., cf. C. edmontonicus Toser
Vertebrates
Coprolites

Location 881
Sec. 1, T. 136 N., R. 80 W., Morton County, North Dakota
Plants
Wood
Prurus sp., cf. P. carunculatus Brown
Vertebrates
Campaesaurus sp., cf. C. nataor Parts
Turtle fragments
Leidyacanthus sternbergi Gilmore
Cf. Triauratops sp.

Location 871
Jet. Routes 13 and 18, Morton County, North Dakota
Plants
Qesidium dactylale Brown
Ceratiphyllum sp., cf. C. exsulans (Haer) Brown
Invertebrates
A questionable fragment of a clam
Sphaerium sp., cf. S. hankthorae Warren
Campeloma sp., cf. C. edmontonicus Toser
Vertebrates
Coprolites
Buff Member

Location #51
Sioux County, North Dakota
Plants
Amber

Location #54
Sec. 26, T. 131 N., R. 82 W., Sioux County, North Dakota
Plants
_Sequoia dawsonica_ Brewer
_Cryptodinia_ sp., cf. _C. eratina_ (Lees) Brewer

Location #55
Sec. 27, T. 131 N., R. 84 W., Sioux County, North Dakota
Plants
Stem or root
Invertebrates
_Viviparidae_ sp., cf. _V. nebrascensis_ Tosser
_Viviparidae_ sp., cf. _V. westoni_ Tosser

Location #56
Sec. 5, T. 132 N., R. 81 W., Sioux County, North Dakota
Plants
Concretions around roots (fossil)

Location #57
3/14 3S 1/4 sec. 2C, T. 131 N., R. 83 W., Sioux County, North Dakota
Invertebrates
_Sphaerium_ sp., cf. _S. fowleri_ Russell
_Viviparidae_ sp.,
_Complectia_ sp., cf. _C. nebrascensis nebrascensis_ (Wack and Hayden)

Location #58
3/14 sec. 11, T. 130 N., R. 86 W., Grant County, North Dakota
Vertebrates
_Dinosaur tooth_

Location #59
3/4 1/4 sec. 35, T. 130 N., R. 88 W., Grant County, North Dakota
Plants
Seed? Fruit?
Invertebrates
_Poorly preserved specimen of Family Unionidae_
_Viviparidae_ sp., cf. _V. westoni_ Tosser

Location #60
Sec. 1, T. 129 N., R. 105 W., Bowman County, North Dakota
Vertebrates
_Turtle remains_
_Archeoglossojugosaurus potator_ Parks
_cf. Anatosaurinae annectans_ (Marsh)
Location #47
Sec. 2, T. 129 N., R. 105 W., Bowman County, North Dakota
Plants
Vitis australis (Kewlton) Brown
Tobacco
Carpolithus sp.
Invertebrates
†Umbellosomus White
†Plagioplicata sp., cf. P. priamus (Neck and Hayden)
Two poorly preserved species of Unionidae
Two unidentified species of class
Viviparus sp., cf. V. quasatus Zosher
Viviparus sp., cf. V. planisulcatus Russell
Viviparus sp., cf. V. terebriforme (Neck and Hayden)
One internal mold of a gastropod
Vertebrates
Cf. Protosperm sp.
Lepisosteus occidentalis (Laidy)
Several species of turtle
Leidyosuchus sternbergi Gilmore
Cf. Anatosaurus angustatus (Marsh)
Cf. Anatosaurus sp.
†Phalanga of hadrosaurid dinosaur
†Ankylosaurus sp.
†Triceratops sp.

Location #48
Sec. 35, T. 130 N., R. 105 W., Bowman County, North Dakota
Plants
Carpolithus sp.
Invertebrates
†Campeloma sp.
Cf. Schisometra major Leaquareux
Several broken interior molds of Family Unionidae
Vertebrates
Lepisosteus occidentalis (Laidy)
Several species of turtles
Leidyosuchus sternbergi Gilmore
Hadrosaurus foulkii Laidy
Anatosaurus sp., cf. A. angustatus (Marsh)
Cf. ? Anklylosaurus sp.
Cf. Mammalosaurus recurvicaudus Cope
Triceratops sp., cf. T. brevicornis Hatcher
Triceratops sp.
Cf. Pterosaurus sp.
Unidentified reptile bones

Location #49
Sec. 22, T. 131 N., R. 105 W., Bowman County, North Dakota
Vertebrates
Three species of corollita
Location #36
Sec. 27, T. 131 N., R. 105 W., Bowman County, North Dakota
Invertebrates
\textit{Serpulid worm tubes}
Vertebrates
\textit{Turtle remains}
\textit{Leidyosuchus sternbergi} Gilmore

Location #38
Sec. 34, T. 132 N., R. 105 W., Bowman County, North Dakota
Plants
\textit{Ellividium} sp. cf. \textit{S. pachycorpus} Cockerell
Invertebrates
\textit{Turtle burrows in bone}
Vertebrates
\textit{Leidyosuchus occidentalis} (Leidy)
Several species of turtles
\textit{Leidyosuchus sternbergi} Gilmore
\textit{Cf. Apatosaurus annectens} (Marsh)
\textit{Triceratops} sp.
Coprolites
Unidentified reptile remains including ribe, claw, and vertebrae

Location #36
T. 132 N., R. 105 W., Bowman County, North Dakota
Plants
Monospermous leaves

Location #41
Sec. 2, T. 132 N., R. 105 W., Bowman County, North Dakota
Vertebrates
\textit{Cf. Apatosaurus} sp.

Location #42
Sec. 7, T. 132 N., R. 105 W., Bowman County, North Dakota
Invertebrates
\textit{Unio} sp. cf. \textit{U. amarillima} Stanton
\textit{Planerellia} sp.

Location #60
C., sec. 9, T. 132 N., R. 105 W., Bowman County, North Dakota
Plants
\textit{Caryolobus} sp.
Seeds which might be seeds
Vertebrates
\textit{Fish vertebrae}
\textit{Turtle} fragments

Location #57
Sec. 12, T. 132 N., R. 105 W., Bowman County, North Dakota
Vertebrates
\textit{Cf. Apatosaurus} sp.
Location #63
East edge of sec. 16, T. 132 N., R. 103 W., Bowman County, North Dakota

Plants
Corilgynium sp. cf. C. arcticum (Beer) Broun
Molinia sp.

Invertebrates
Unio sp. cf. U. stantoni White
Tail to a crawfish-like animal

Vertebrates
Leptocyonus occidentalis (Leidy)
Fish vertebra
Turtle fragments
Champsaurus sp. cf. C. natator Parks
Leidyosuchus sternbergi Gilmore
Unidentified reptile bones

Location #29
Sec. 17, T. 132 N., R. 103 W., Bowman County, North Dakota

Invertebrates
Vivinus sp.
Bianellonia sp. Stanton
Shell fragments

Vertebrates
Beloneoide longirostris (Last)
Leptocyonus occidentalis (Leidy)
?Platanodon unnamed Marsh
Several species of fish vertebra
?Urostyla of ?Family Palaeostegidae
Ophiactris var. Auffenberg
?Vertebrae of an Amphibian
Several species of turtles
Cf. Glyptosaurus aigantua Gilmore
Champsaurus sp. cf. C. natator Parks
Cf. Epictysis longicordia Gilmore
Leidyosuchus sternbergi Gilmore
Brachysauraus montana Gilmore
Cf. Tyranosaurus rex Osborn
Triceratops sp.
Assorted reptile bones unidentified

Location #46
Sec. 20, T. 132 N., R. 103 W., Bowman County, North Dakota

Vertebrates
Cf. Tyranosaurus rex Osborn
Cf. Anteosaurus annoskopa (Marsh)
Triceratops sp. cf. T. fishallatus Marsh

Location #43
Sec. 30, T. 132 N., R. 103 W., Bowman County, North Dakota

Vertebrates
Champsaurus sp. cf. C. natator Parks
Leidyosuchus sternbergi Gilmore
Location #31
Sec. 21, T. 133 N., R. 105 W., Bowman County, North Dakota
Vertebrates
Champsaurosaurus sp. cf. C. nodatus Parks
Reptile claw
Unidentified reptile bones

Location #32
Sec. 18, T. 133 N., R. 105 W., Bowman County, North Dakota
Vertebrates
Turtle fragments
Leidyvocamus sternbergi Gilmore
Unidentified reptile bones

Location #40
Sec. 4, T. 134 N., R. 105 W., Slope County, North Dakota
Vertebrates
Rib fragments of a reptile

Location #25
G, sec. 4, T. 134 N., R. 105 W., Slope County, North Dakota
Plants
?Potamogeton fruticosus Berry
?Viburnum xiloides Hard
?Carpelitum sp.
Invertebrates
Clams - Unionidae
?Unio holocentrus White
?Pleciaformia sp.
?Tetragallina subapiculata (Week and Hayden)
?Sphaerium sp. cf. S. aequale Russell
?Vivianites op. cf. V. prudentius willowensis Touse
?Vivianites prudentius prudentius White
?Vivianites sp. cf. V. planulata Russell
?Vivianites sp. (Undescribed species)
Carpalina sp. cf. C. harlottomensis (Stanton)
?Liplocudes fanningiata (Week and Hayden)
?Liplocodes sp.
Beetle remains (questionably fossil)
Vertebrates
Lepidostoma eulophus Estes
?Acipenser americanus Estes
?Cf. Lepidostoma avronica Estes
?Nelsonichthys bipartitus Cope
?Cf. Kinnearia fragosa Jordan
?Holosteium longirostris (Lambe)
?Lepidostoma occidentalis (Laidy)
?Cf. Protomiasus fibularis (Cope)
Unidentified genera and species of Elopidae
Unidentified genera and species of Albulidae
Many unidentified fish bones (many species)
Several unidentified turtles
Carnosaaurus sp. cf. C. abductor Parks
Chamae sauris Marsh
Lambeosaurus dentrinasus (Gilmore)
Eotitanus leosacra Gilmore
Cf. Parasaurolophus wyomingensis Gilmore
Cf. Parasaurolophus leosacra Eaton
Palaeosaurus manadensis Gilmore
Leidyosaurus sternbergi Gilmore
Brachylophosaurus canadenis Gilmore
Teeth of ?Family Caudalidae
Cf. Brontosaurus sp.
Stegosaurus sp.
Anatosaurus sp. cf. A. manna Marsh
Several species of Triceratops
Undeclared bones, vertebrae, and other bones of widely
separated taxonomic groups
Coprolites
Theropods sp.
Facies Papillicollis Gilmore
Nasal tooth fragment

Location #39
Sec. 18, T. 134 N., R. 106 W., Slope County, North Dakota
Vertebrates
Cf. Anatosaurus sp.
Cf. Triceratops sp.

Location #62
Sec. 16, T. 134 N., R. 106 W., Slope County, North Dakota
Plants
?Amma sp. cf. A. roberti Berry
Carpolithus sp.
Invertebrates
Planocera (Undescribed species)
?Corallus sp.
Viviparus sp. cf. V. planulatus Russell
Lepidoceras tommatiforme (Buck and Hayden)
Lepidoceras sp. cf. L. limaniforme (Buck and Hayden)
Phryn sp. cf. P. pleurostomis White
A poorly preserved unidentified gastropod

Location #30
Sec. 25, T. 134 N., R. 106 W., Slope county, North Dakota
Plants
Seysea dakotensis Brown
Corethunderium sp. cf. C. arcticum (Bate) Brown
Carpolithus sp.
Imprint of bark or seeds
Invertebrates
Sphaerium sp.
Vertebrates
Cf. Pachycephala sp.
Several species of turtles
Location #25
NE 1/4 sec. 15, T. 134 N., R. 106 W., Slope County, North Dakota
Vertebrates
Cf. Plesiosaurus sp.
Several species of turtles
Cf. Champsosaurus sp.
?Leidyosuchus sternbergi Gilmore

Location #27
Sec. 30, T. 135 N., R. 106 W., Slope County, North Dakota
Plants
?Phacocarya hispida Brown
Corinna sp. cf. C. insignis Bear
?Viburnum ellicoides Ward
Carpolithus sp.
?Carpolithus sp.
Invertebrates
Basil sp. cf. B. stantoni White
Unioidea
?Placozoa sp.
Vivipara sp. cf. V. bamekare Russell
Cephaloma sp. cf. C. amarilla Gilmore
Vertebrates
Cf. Lasloe sp.
Cf. Kindsfaden fragna Jordan
Cf. Pteranodon sp.
Leguminosae occidentalis (Leidy)
Several species of fish vertebra
Several species of turtles
Leidyosuchus sternbergi Gilmore
Brachyacanthosaurus montana Gilmore
Cf. Tyrannosaurus rex Osborn
Cf. Triceratops sp.
Cf. Anatosaurus sp.
Triceratops sp.

Location #26
Sec. 12, T. 135 N., R. 106 W., Slope County, North Dakota
Plants
Amber
Carrisphylloides sp. cf. C. australis (Beard) Brown
Carpolithus sp.
?Carpolithus sp.
Invertebrates

*a. helvetica* White

*Interior molds of class of Family Unionidae

*Planelliptio* sp.

*Viviparus* sp. cf. *V. tasmania* Dyer

Vertebrates

*Nykephos bipartitus* Cope

*Trichiura frigida* Jordan

*Lepiscapha occidentalis* (Laidy)

*Unidentified genus and species of Family Albulidae

*Fish vertebra

*Osphobranch keyi* Auffenberg

*Champsaaurus* sp. cf. *C. natter* Parks

*Cf. Eostopus lanceolatus* Gilmore

*Lapidosaurus sternbergi* Gilmore

*Brachychampsa montana* Gilmore

*Cf. *Dryptosaurus* sp.

*Triceratops* sp.

Reptile bones including class and vertebra

Location #28

Sec. 33, T. 135 N., R. 106 W., Slope County, North Dakota

Plants

*Pterophyllum subfalcatum* Lamoureux

*Ceratophyllum* sp. cf. *C. articulatum* (Nees) Brown

*Carpolitius lanceolatus* Hall

*Carpolitius* sp.

*Seed pod

*Twig impression

Vertebrates

*Nykephos bipartitus* Cope

*Lepiscapha occidentalis* (Laidy)

*Several species of fish vertebra

*Turtle fragments

*Champsaaurus* sp. cf. *C. natter* Parks

*Lapidosaurus sternbergi* Gilmore

*Cf. *Eostopus* sp.

*Cf. *Anatosaurus* sp.

*Triceratops* sp.

Location #59

Sec. 33, T. 135 N., R. 106 W., Slope County, North Dakota

Plants

*Carpolitius* sp. cf. *C. (Cynodinacarpus) saratoga* (Snowdon)

*Carpolitius* sp. cf. *C. (Cynodinacarpus) faultoni* Hall

*Carpolitius* sp.

Invertebrates

*Several poorly preserved specimens of Family Unionidae

*Planelliptio* sp.

Vertebrates

*Several unidentified reptile bone fragments.*
Location #44
Sec. 34, T. 133 N., R. 106 W., Slope County, North Dakota
Vertebrates
Anatosaurus sp. cf. A. amnsecta (Marsh)

Location #31
SE 1/4 sec. 35, T. 135 N., R. 106 W., Slope County, North Dakota
Plants
Sequoia dakotensis Brown
Amber
Ceratidium sp. cf. J. arcticum (Meer) Brown
Carpolthis sp.
?Carpolthis sp.
?Actinidia sp.
Invertebrates
Unio sp. cf. U. stantonii White
Suberium sp. cf. E. bowiei Russell
Sphaerium sp. cf. J. hasekianum Warren
Copelea sp.
?Pealeielliptio sp.
?Glyptostrea sp. cf. G. potamophila (Russell)

Location #64
Sec. 26, T. 21 N., R. 37 E., Garfield County, Montana
Type section for the Bell Creek Formation
Invertebrates
Unio stantonii White
Unio pyramidaloides Whitfield
Unio hasekianus White
Planelliptio sp. cf. P. brachyopisthmus (White)
Planelliptio sp. (Undescribed species)
Planelliptio sp. cf. P. ptychae (Meek and Hayden)
Planelliptio sp.
Pedallon sp. (Undescribed species)
Sphaerium sp. cf. J. hasekianum Warren
Viviparus sp. cf. V. prudentius prudentius White
Copelea amarillensis Stanton
Lipolacoda keminsinarata (Meek and Hayden)
Lipolacoda mariana Yen
Lipolacoda etichii (White)
Lipolacoda sp.
Coneites virginiae (Osolin)
Osolinix camptidentis (White)
Pretty Butte Member

Location #20
Sec. 13, T. 130 N., R. 105 W., Bowman County, North Dakota
Vertebrates
Triceratops sp.

Location #22
Sec. 9, T. 132 N., R. 105 W., Bowman County, North Dakota
Plants
Cretionella speciosa Lesquereux

Location #23
Sec. 1/4 sec. 16, T. 132 N., R. 105 W., Bowman County, North Dakota
Plants
Cardiophyllum sp. cf. C. arcticum (Kear) Brown

Invertebrates
Unio sp. cf. U. ostenfeldi White
Pleuromamma sp. cf. P. subspatulatus (Neal and Hayden)
Viviparus sp. cf. V. westoni Tuzer

Vertebrates
?Palaeostoma longirostris (Lambe)
Lepidosteoidea occidentalis (Leidy)
Cf. Champsosaurus sp.
Leidychelys sternbergi Gilmore
Reptile bone fragments
Cimolodon nitidus Marsh

Location #24
Sec. 15, T. 134 N., R. 106 W., Slope County, North Dakota
Vertebrates
Turtle fragments

Location #21
Sec. 32, T. 135 N., R. 106 W., Slope County, North Dakota
Plants
Carnoites sp.

Invertebrates
Clam fragments

Vertebrates
Lepidosteoidea occidentalis (Leidy)
?Platacoelenus name Marsh
?Haplochelys dilatata Gilmore
?Ophiactites keri Auffenberg
Champsosaurus sp. cf. C. spatator Parke
Turtle fragments
Leidychelys sternbergi Gilmore
Cf. Kritosaurus sp.
Unidentified dinosaur teeth
Coptosites
Dulcak Formation

Location #17
Sec. 4, T. 133 N., R. 105 W., Slope County, North Dakota
Plants
Ulmus americana Ward
Ficus arctocarpoides Lasqueuce
Ficus plicatula Lasquezue
Ficus subvesicata Lasquezue
Horsetamentana Brown
Platanus ramuloides Newberry
Persea brasiliensis Lasquezue
Cercidiphyllum arctium (Bear) Brown
Magnolia liliiflora Knowlton
Eucommia aurata (Newberry) Brown
Prunus cerasiferae Brown
Prunus sp.
Ipsapinae americana (Newberry) Brown
Viburnum sp.

Location #18
Sec. 13, T. 134 N., R. 106 W., Slope County, North Dakota
Vertebrates
Cheiropusurus sp.

Location #19
Sec. 16, T. 134 N., R. 106 W., Slope County, North Dakota
Vertebrates
Cheiropusurus sp.
Lovelyomus osterhargi Gilmore
Turtle fragments

Location #20
Sec. 27, T. 135 N., R. 106 W., Slope County, North Dakota
Plants
Cercidiphyllum arctium (Bear) Brown
?Carpelition sp.
Invertebrates
Scheurum sp., cf. S. baskethamus Harron
Vivipaxa sp., cf. V. primitiva willosensis Toner
Camelina suberescens suberescens (Weck and Hayden)
Vertebrates
Cf. Protasia sp.
Turtle fragments

Location #21
SE 1/4 sec. 33, T. 135 N., R. 106 W., Slope County, North Dakota
Plants
?Hypophytris esmena (Bear) Bantke
H松asencledonous Leaves
Leaf fragments
Root fragments
Invertebrates

P. sp., cf. V. tagging Dyer

?Ferrissia alata (Skec and Hayden)

Location #14

T. 135 N., R. 106 W., Slope County, North Dakota
Plants
Monocotyledonous leaves

Location #13

Sec. 2, T. 129 N., R. 108 W., Bowman County, North Dakota
Plants
Wood

Location #12

Sec. 35, T. 130 N., R. 105 W., Bowman County, North Dakota
Plants
Wood
Ludlow Formation

Location #1
Sec. 17, T. 133 N., R. 82 W., Morton County, North Dakota
Plants

?Equisetum sp.
Flave caroten (Knowlton)
?Carpolarites sp.

Location #3
Sec. 1, T. 134 N., R. 82 W., Morton County, North Dakota
Vertebrates
Lainreausius sternbergi Gilmore

Location #7
Sec. 11, T. 134 N., R. 82 W., Morton County, North Dakota
Vertebrates
CF. Lepta sp., Apus apus

Location #5
SW 1/4 sec. 17, T. 134 N., R. 82 W., Morton County, North Dakota
Plants

?Glyptostrobus nordenskioldi (Bee) Brown
?Tamarix argyrolepis (Lesch.) Knowlton
Takal perwallii Newberry
Platanus raymondii Newberry

Location #9
SW 1/4 sec. 11, T. 134 N., R. 82 W., Morton County, North Dakota
Plants

Isotetes horridus (Dawson) Brown
Metasequoia occidentalis (Newberry) Chaney
?Podocarpus tarrii (Dawson) Brown
Hydroxystria angusta (Bee) Manke

Beds
?Carbon sp.

Platanus raymondii Newberry
Cephalanthus occidentalis (Newberry) Berry
Cephalanthus ericoides (Bee) Brown

Cephalanthus marginata (Lesch.) Brown

Location #3
Sec. 22, T. 131 N., R. 81 W., Sioux County, North Dakota
Plants
Melanoptites montanae Brown
Location #6
50 1/4 sec. 11, T. 131 N., R. 32 W., Sioux County, North Dakota
Vertebrates
Cf. Lamna cuspidata Agassiz

Location #4
Sec. 22, T. 132 N., R. 105 W., Bowman County, North Dakota
Plants
Glyptostrobus p. nordenskioldi (Beers) Brown
Metasequoia occidentalis (Newberry) Chanev

Location #2
88 1/4 sec. 33, T. 133 N., R. 106 W., Bowman County, North Dakota
Plants
?Papax sp.
APPENDIX C

SYNOPSIS OF HEAVY MINERAL STUDY

The following is a synopsis of the heavy mineral study of the upper Cretaceous and lower Paleocene beds of eastern Montana, western North Dakota, and central North Dakota. The mineral species are arranged alphabetically in two groups because of the large set of samples.

Sample numbers are those used in the field note books. The first number is the location and the second number is the number of the sample number collected at that location. The following is a key to the locations:

Location #59 (Sections #1 and 2).

Sec. 26, T. 21 N., R. 37 E., Bell Creek State Park, Garfield County, Montana

Sec. 14, T. 21 N., R. 37 E., Bell Creek State Park, Garfield County, Montana

Location #52 (Section #19).

NE 1/4 sec. 35, T. 132 N., R. 105 W., Bamman County, North Dakota

Location #25 (Section #22).

NE 1/4 sec. 16, T. 131 N., R. 78 W., Bammona County, North Dakota

Location #22 (Section #25).

SE 1/4 sec. 8, T. 136 N., R. 78 W., Bammon County, North Dakota

-184-
Location #54 (Section #71).

SW 1/4 sec. 35, T. 134 N., R. 106 W., south end of Pretty Butte, Slope County, North Dakota

Location #6 (Section #6).

G. sec. 33, T. 134 N., R. 81 W., Crowghost Cemetery, Sioux County, North Dakota

Location #32 (Section #30).

SW 1/4 sec. 14, T. 131 N., R. 82 W., Sioux County, North Dakota

Locations #62 and #63 (Section #20).

Sec. 1, T. 15 N., R. 55 W., Hakeshika State Park, Dawson County, Montana

Location #20 (Section #26).

SW 1/4 sec. 32, T. 136 N., R. 73 W., Dawson County, North Dakota

The following symbols are used in the succeeding pages:

P = present - An opaque mineral which was noted to be present in the sample but no calculations were made as to the amount except that it is included in the percent of opaque minerals found in the sample.

t = trace - A trace is defined as occurring in a quantity of less than 1% of the heavy mineral fraction but occurring at least in a frequency of 1 grain in 300.

r = rare - Rare is defined as occurring in a given collected sample of heavy minerals but in less frequency than 1 grain in 300.
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<th>(paragenetic)</th>
<th>(clinozoisite)</th>
<th>Apatite (clear)</th>
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</table>

- **Evanite**
- **Limonite**
- **Magnetite**
- **Muscovite**
- **Fusible**
- **Sphene**
  - (clear)
  - (honey)
  - (red orange)
  - (deep red)
- **Siderite**
- **Kilimanjaro**
- **Staurolite**
- **Tourmaline**
  - (metallic blue)
  - (amethyst brown)
APPENDIX D

COLOR AND MATRIX OF SANDSTONES IN FOX HILLS, HILL CREEK, TULLOCK, LUDLOW, AND CANNONBALL FORMATIONS
<table>
<thead>
<tr>
<th>Location</th>
<th>Sample Number</th>
<th>Mix</th>
<th>Grain Size</th>
<th>Color</th>
<th>Matrix and Cement</th>
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<td>Dawson Co., N. Dak.</td>
<td>62-1</td>
<td>Tt</td>
<td>coarse sand</td>
<td>5 Y 6/4 dusky yellow</td>
<td>clay, limonite</td>
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<td>Dawson Co., N. Dak.</td>
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<td>5 Y 6/1 light olive gray</td>
<td>clay, limonite</td>
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<tr>
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<td>5 Y 5/2 light olive gray</td>
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<td>10 YR 6/2 pale yellowish brown</td>
<td>clay, jarosite</td>
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<td>24-3</td>
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<td>clay</td>
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<td>No.</td>
<td>Grain Size</td>
<td>Color</td>
<td>Matrix and Cement</td>
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<td>Slope Co.,</td>
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<td>clay</td>
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<td>clay</td>
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<td>Kha</td>
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<td>5 Y 6/1 light olive gray</td>
<td>clay</td>
</tr>
<tr>
<td></td>
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<td>Kha</td>
<td>coarse sand</td>
<td>5 Y 6/1 light olive gray</td>
<td>clay</td>
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<tr>
<td></td>
<td>12-4</td>
<td>Kha</td>
<td>medium sand</td>
<td>10 YR 6/2 pale yellowish brown</td>
<td>calcite, limonite</td>
</tr>
<tr>
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<td>12-5</td>
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<td>clay</td>
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<td>12-7</td>
<td>Kha</td>
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<td>5 Y 5/1 olive gray</td>
<td>trace of clay</td>
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<td>Kha</td>
<td>coarse sand</td>
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<td>trace of clay</td>
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FENCE DIAGRAM OF LOWER TERTIARY AND UPPER CRETACEOUS FORMATIONS
FROM EASTERN MONTANA TO CENTRAL NORTH DAKOTA
FENCE DIAGRAM OF THE HELL CREEK FORMATION AND ITS MEMBERS
FROM EASTERN MONTANA TO CENTRAL NORTH DAKOTA

LEGEND

- Khcb  Pretty Butte Member
- Khch  Huf Member
- Khcbc  Bocoon Creek Member
- Kcbr  Fort Riel Member
- Khcb  Brien Member
- Khcc  Crowfoot Member
- Khcm  Mornaruh Member
- Khcbc  Little Beaver Creek Member
- lsb  lower sandstone beds

Scales:
horizontal: 1 inch = 15 miles
vertical: 1 inch = 100 feet
Datum Plane: top of Pretty Butte Member

Contact
Contact inferred
Unconformity

Plate IV
FENCE DIAGRAM OF THE BENTONITES IN THE LOWER TERTIARY AND UPPER CRETACEOUS FORMATIONS FROM EASTERN MONTANA TO CENTRAL NORTH DAKOTA

LEGEND

Tt  Tongue River Formation
Ti  Lobe Shale
Ts  Cenozoic
Tl  Latlow Formation
Tc  Toadstool Formation
Kh  Hell Creek Formation
    Khcb  Pretty Butte Member
    Khch  Hell Member
    Khcc  Bear Creek Member
    Khec  Ft. Rice Member
    Khcb  Brown Member
    Khcc  Crowfoot Member
    Khm  Marmarth Member
    Khbo  Little Bemidjo Member
    lb  Lower Sandstone beds

SCALE:

Formation contact
Member contact
inferred contact
unconformity
bentonite found at all locations
intermittent bentonite

Horizontal: 1 inch = 5 miles
Vertical: 1 inch = 30 feet
Deluxe Plane = top of Hell Creek Formation
GEOLOGIC MAP OF SOUTHWESTERN NORTH DAKOTA

SOURCES OF DATA
Lloyd, 1914; Calvert, and others, 1914; Hancock, 1921; Hones, 1926; Fisher, 1952; Hansen, 1956; Kume and Hansen, 1965; and field work by the writer.

LEGEND

- Twr White River
- Tgv Golden Valley
- Tfr Tongue River
- Tc Cannonball
- Tl Ludlow
- Tt Tullock
- Khc Hell Creek
- Kfh Fox Hills
- Kp Pierre

CENOZOIC

CRETAEOUS

SCALE IN MILES

0 5 10 15 20 25