NORTH DAKOTA GEOLOGICAL SURVEY

WILSON M. LAIRD, *Director*
Bulletin 19

Heavy Mineral Correlation of the Fox Hills, Hell Creek and Cannonball Sediments, Morton and Sioux Counties, North Dakota

By
MARIE LOUISE LINDBERG

Reprinted from
Journal of Sedimentary Petrology
Vol. 14, No. 3, pp. 131-143, 1944

Grand Forks, North Dakota, 1945

FORWARD

The field work for this paper prepared by Mrs. Lindberg was done for the North Dakota Geological Survey in the summer of 1942. It was primarily a labor of love for her, as her salary was very small. It does add, however, substantially to the geological information of the State. While it is primarily a scientific study that will be read mainly by geologists, it will be of interest to many non-geologists in North Dakota. It does prove that heavy minerals can be used to a certain extent for correlation purposes which was the main reason for the study.

WILSON M. LAIRD
State Geologist

JOURNAL OF SEDIMENTARY PETROLOGY, VOL 14, NO. 3, PP. 131–143, FIGS. 1–4, TABLES 1–3, DECEMBER, 1944

HEAVY MINERAL CORRELATION OF THE FOX HILLS, HELL CREEK, AND CANNONBALL SEDIMENTS, MORTON AND SIOUX COUNTIES, NORTH DAKOTA

MARIE LOUISE LINDBERG
Geological Survey[1]
U. S. Department of Interior, Washington, D. C.

ABSTRACT

The heavy minerals from surface exposures in the Fox Hills, Hell Creek, Ludlow, and Cannonball formations, Morton and Sioux Counties, North Dakota, are studied. Nine mineral zones are established on the basis of heavy mineral frequencies. The first three correspond to lithologic units in the Fox Hills, the third extending to the base of the Breien marine member of the Hell Creek. Zone 4, in the Cannonball River sections, is the lower bed of brown sands in the Breien. Zones 5 and 8 are local. Zone 6 begins in a bentonitic sand in the Breien and extends above the Breien. Zone 7 is in the upper Hell Creek and Ludlow. Zone 9 corresponds to the Cannonball.

The Fox Hills and the Cannonball are characterized by a high percentage of green amphibole. The Hell Creek is differentiated by its epidote, garnet, and sphene content.

INTRODUCTION

Much of North Dakota, South Dakota, Montana, and Wyoming are covered with continental and marine sediments of Upper Cretaceous and Tertiary age. The present work was undertaken in an effort to correlate a restricted portion of these sediments by their heavy mineral content.

The area covered in this report extends south and southwest of Bismarck and Mandan, North Dakota, along the Missouri and Cannonball Rivers. River bluffs and isolated buttes furnished excellent exposures.

STRATIGRAPHY

Upper Cretaceous

Fox Hills

The Fox Hills is the lowermost formation which crops out in the area studied. It consists of (1) a lower horizon of thick-bedded yellowish brown sandstone, with brown concretions and Halymenites; (2) an intermediate horizon of yellow to olive colored sandy, banded shale, in part equivalent to (3); and (3) an upper horizon of gray-white sandstone with concretions.

Hell Creek

The Hell Creek formation consists of buff or gray sand with shale partings, bentonite, and brown and black lignitic shale. The shale partings occur in zones four to eight inches wide and are separated by massive sands two to four feet thick. The individual partings are one-sixteenth to one-eighth inch wide. The Hell Creek contains concretions of marcasite, limonite, and of a black ferruginous, manganese-bearing material. The Breien marine member of the Hell Creek occurs close to the base of the Hell Creek.

Paleocene

Ludlow

The Ludlow formation resembles lithologically the Hell Creek formation but differs from it in containing more persistent lignite beds. In the area studied, the Ludlow consists of chocolate brown

[1] Published by permission of the State Geologist of North Dakota. Extract from an Essay submitted to the Board of University Studies of The Johns Hopkins University in conformity with the requirements for the degree of Master of Arts.

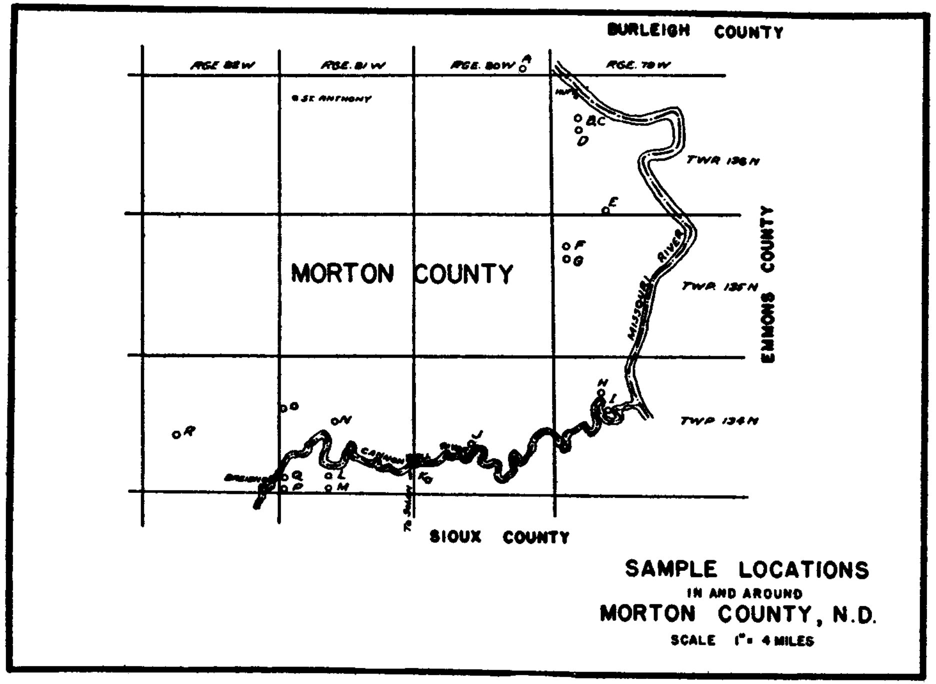

FIG. 1.

lignitic shales, with some black lignite. Charcoal was found in some exposures.

Cannonball

The Cannonball formation consists of buff, yellow, or greenish yellow sandstones and dark gray shales. Its marine character is indicated by the presence of Halymenites. It interfingers with and overlies the Ludlow.

STRUCTURES

In the individual exposures the strata appear to be horizontal, or are cross-bedded, or irregularly bedded, or they fill channels. Hancock (1921, p. 11) and Calvert (1914), in the course of a study of the neighboring lignite fields, determined a dip of a few feet per mile to the northwest. Laird (1942) reports a dip of 15 feet per mile to the northwest. This dip is evident from the mineral zones along the Cannonball and Missouri Rivers, since equivalent zones occur lower in the section to the west and north.

Filled stream channels are narrow, shallow, and mark an erosional unconformity. They may have sharp, steep sides, or may be marked only by an irregular lower level. Channeling is typically developed at locality F. Slump and joint blocks dip into the sides of the channel. The channel filling is irregularly bedded, with rapid variations horizontally and vertically from clay to medium-grained sands. In the middle portion the strata dip from the side toward the center and are cross-bedded. Higher up the initial dip flattens, and the sediments are laid in a shallow spoon-shaped deposit.

Slump along bedding planes occurred while the sediments were being deposited at Section B. At various horizons chunky clay is broken into pieces one to four inches long and one inch thick. These pieces are lying at all angles, in the position of small folds, occurring in a single bedding plane. In a zone where buff sands alternate with brown shale partings, folds and drag folds are easily visible. The axial plane is horizontal, but the axis is not constant in direction.

FIELD STUDIES[2]

Section B

S.W. ¼, Sec. 8, T. 136 N., R. 79 W. The section begins on the south side of the bluff at its base.

Hell Creek

1. Sand, fine-grained, and silty clay, buff, fluted, with shale partings. Five samples at 5′ intervals. 24.0′
2. Sand, bentonitic, gray. One sample.
3. Sand, fine-grained, buff, speckled, and gray clay, with shale partings, cross-bedding, and contemporaneous slump. Seven samples at approximate 5′ intervals. 53.0′
4. Shale, brown, bentonite, gray, clay and silty sand, gray. The lower portion contains interbedded bentonitic clay and buff sand; the upper portion is a gray bentonite. One sample. 18.5′

Total thickness Hell Creek 95.5′

Ludlow

5. Brown lignitic shale and loose gray clay with plant remains. Grades into a coaly shale, 11″ thick and 32″ above the base. Gypsum. 14.4′
6. Sand, fine-grained, yellow, with brown shaly partings at the bottom of the bed, gray, concretionary sand in the middle portion of the bed, and yellow sand at the top. One sample. 6.5′

Total thickness Ludlow 20.9′

Cannonball

7. Cover (?) 20.0′
8. Sand, green gray, with brown lignitic partings, marcasite and limonitic concretions, and thin styolitic veinlets and nodules of coarse-grained white gypsum. Four samples. 12.0′
9. Shale, brown, and sandy clay with limonitic stains. Two samples 5′ apart. 20.6′
10. Sand, fine-grained, yellow gray, speckled, with rust stains, and brown to black shaly partings weathering reddish brown on the surface. Fissile black shale. Marcasite nodules and limonitic zones. Halymenites small at base and larger higher in the section. Cross-bedding in middle portion. Topped by a hard concretionary jointed layer with irregular top and bottom. Five samples at 5′ intervals. 29.0′
11. Clay, flaky, shale, gray, cover, and sandy brown or black shale with marcasite concretions. One sample. 43.6′

Total thickness Cannonball 125.2′

Section J

S.E. ¼, Sec. 21, T. 134 N., R. 80 W. Section begins at the edge of the Cannonball River.

Fox Hills

1. Sand, fine- to medium-grained, green to brown, with limonite concretions and staining. Cross-bedded. Halymenites. Four samples at 10′ intervals. 55.0′
2. Sand, fine-grained, brown, with bands of gray clay and some shale. Limonite concretions less abundant. Top of member a cross-bedded and jointed concretionary sand. Three samples at 10′ intervals. 33.0′
3. Sand with clay, bentonitic, gray. Gypsum. 22.0′
4. Sand fine-grained, and interbedded silt, flaky clay, and shale, gray; some brown shale partings; iron-stained; cross-bedded. Concretions cross bedded and jointed. Three samples. 61.3′
5. Clay, silty, gray. 2.2′

Total thickness Fox Hills 173.5′

[2] Five of the 17 localities samples are described. Clay refers to grain size.

Hell Creek

6. Shale, brown lignitic, with some sand and clay. 5.5′
7. Sand, fine-grained, light yellow gray. One sample. 6.0′
8. Clay, gray, silty, with limonitic staining. 4.6′
9. Shale, brown to black lignitic, with sandy clay. 16.2′
10. Sand, fine-grained, silt, clay, buff, with gypsum. Two samples 15′ apart. 26.3′
11. Shale, brown lignitic, with gray silty clay. 6.0′

Total thickness Hell Creek 64.6′

Section L

N.W. ¼, Sec. 33, T. 134 N., R. 81 W. Section begins where the bluffs rise above the floodplane.

Fox Hills

1. Shale, gray, flaky, silty, with sand. Slumped. Base not exposed. A thin band of flaky limonite at top. 8.0′
2. Sand, fine-grained, light gray, with some interbedded bentonitic shale, fluted. Abundant, large coarse-grained concretionary layers. Six samples at 5′ intervals. 32.0′

Total thickness Fox Hills 40.0′

Hell Creek

3. Shale, chocolate, very sandy, and concretionary at bottom; lignitic, fissile toward the top. Channel deposit. Thickness and position variable. Two samples. 3.0′
4. Bentonite, gray, with silicified tree stumps. 2.0′
5. Shale, silty, gray green, with thin ledges of concretions of limonite and marcasite. Toward the top is a black shale with plant remains. 6.0′
6. Sand, very fine-grained, with silt, buff-yellow, marcasitic. Two samples 5′ apart. 8.3′

Breien Marine Member of the Hell Creek

7. Sand, fine-grained, brown, with limonitic chips and with small concretions of limonite. Slumped. Weathered. 2.6′
8. Sand, fine-grained to silt, buff, with marcasite. Two samples.
9. Shale, dark yellow-gray, limonitic, and sandy shale.
10. Sand, fine-grained to silt, gray green. Two samples. } 14.8′
11. Bentonite. 1.8′
12. Sand, fine-grained, bentonitic. One sample. 3.3′

Total thickness Hell Creek 41.8′

Section M

Laterally displaced south of L. Section begins on the east side of the butte.

Breien Marine Member of the Hell Creek

1. Sand, very fine-grained, brown, limonitic, weathered, loose. Halymenites abundant on surface. One sample. 6.0′
2. Sand, slightly bentonitic, gray. One sample. 2.0′
3. Bentonite, gray. 2.2′
4. Sand, fine-grained, buff, with gray clay. 4.4′

Undifferentiated Hell Creek

5. Shale, brown lignitic. 2.2′
6. Silty clay, gray, flaky, bentonitic toward top, with limonitic concretions. One sample. 15.3′
6. Shale, brown lignitic. 4.2′
7. Sand, fine-grained, pale yellow or buff, fluted. Three samples at 5′ intervals. 13.8′
8. Shale and silt interbedded. 9.4′
9. Sand, fine-grained, buff, fluted, with flaky shale, buff clay, and brown shale partings. Three samples 5′ apart. 14.1′

Total thickness Hell Creek 73.6′

Section R

Center section 20, T. 134 N., R. 82 W. Section begins on the east side of the butte at the base.

Hell Creek

1. Sand, fine-grained, gray or buff, with silty clay and shale partings, fluted, compact, with limonitic concretions. Three samples at 5′ intervals. 16.0′
2. Sand, very fine-grained, silt, clay, bentonite, shale. 5.0′
3. Bentonitic clay, sandy toward top. 18.0′

Total thickness Hell Creek 39.0′

Ludlow

4. Shale, chocolate brown, flaky or fissile, with some buff sand, dark gray clay, and black lignitic shale interbedded. Marcasitic concretions. One sample in sand. 27.0′

Total thickness of Ludlow 27.0′

Cannonball

5. Sand, medium-grained, yellow, cross-bedded, topped by a layer of indurated yellow sand three feet thick. Four samples at 5′ intervals. 17.0′

Total thickness of Cannonball 17.0′

LABORATORY STUDIES

A preliminary examination of the samples showed that they are well sorted, with a fine- to very fine-grained texture, and contain silt and clay. The silt and clay were decanted until the water remained clear after one minute in a 400 cc. beaker. The dried sand was sieved on a 150 mesh Tyler screen, opening .104 mm., and the portion retained on the sieve was separated by tetrabromoethane, sp. gr. 2.9. The heavy fraction was boiled with a weak solution of hydrochloric acid to destroy the calcite and limonite that act as a cement in some of the samples.

Two hundred and fifty non-opaque minerals were counted, and the ratio between opaque iron ores and the non-opaque minerals was determined, making a total of 500 grains counted when the ratio is 1:1. Tables were computed showing the relative percentages of platy minerals, and opaque and non-opaque minerals, and the non-opaque ones were recomputed to 100%. The mineral frequencies of the non-opaque minerals, especially green amphibole, epidote, and garnet, formed the basis for formulating nine mineral zones. Table 1, "Average and Range of Mineral Frequencies" shows the number of samples examined in each zone at each section, the average percentage of each mineral present, and the range over which it occurs in a given zone, at that section. Table 2, "Representative Mineral Frequencies" shows the average percentage of each mineral in a zone and the typical proportions between the varietal forms.

DESCRIPTION OF THE MINERAL SUITE

The heavy mineral fraction may be divided into three groups, the platy minerals, the non-opaque ones, and the opaque iron ores. Selective sorting, rather than provenance, causes a change in proportions of each group, since platy minerals will be floated beyond the non-opaque ones, which, in turn, are carried farther than the heavier opaque minerals.

The platy minerals are biotite, chlorite, and muscovite. They are widespread in small percentages, but, exceptionally, are found in appreciable quantities in shales and rotten sandstones. Biotite occurs as brown or green pseudohexagonal or irregular basal sections; chlorite, as well rounded, light green basal plates; and muscovite, as splendent pseudohexagonal basal plates.

The opaque iron ores consist of magnetite, ilmenite, and leucoxene intergrown with ilmenite. The grains are equidimensional and subangular.

The non-opaque heavy minerals form the basis for heavy mineral correlation. The characteristics of the various minerals are listed below. The mineral frequency may be found in Tables 2 and 3.

Andalusite occurs in rounded-irregular, and elongated-subangular grains. Pleochroic and non-pleochroic varieties are equally dominant. The former is always fresh, but the latter is occasionally sericitized.

Amphibole is diagnostic for purposes of correlation. It occurs in acicular prisms. There are three types: (1) color-

TABLE 1. *Average and Range of Mineral Frequencies (First figure indicates average, second minimum count, third maximum count on an observed specimen)*

	No. of Specimens in each zone	Platy Minerals: Mica	Platy Minerals: Chlorite	Opaque Minerals	Non-opaque Minerals	Non-opaque mineral recomputed to 100%: Andalusite	Amphibole	Clinozoisite	Corundum	Epidote
Section A										
Zone 7	6	1(tr–4)	1(0–1)	44(23–67)	54(32–75)	1(0–2)	2(1–5)	9(5–15)	0	55(48–64)
Zone 6	1	1/2	1/2	52(—)	47(—)	1(—)	11(—)	8(—)	tr(—)	40(—)
Zone 4	5	1(—)	1(0–1)	53(33–70)	45(30–65)	tr(0–2)	18(6–35)	5(1–6)	0	37(26–44)
Section B										
Zone 9	12	3(0–11)	tr(0–2)	26(23–41)	71(59–91)	1(0–3)	49(33–65)	6(3–8)	tr(0–tr)	25(19–32)
Zone 7	10	4(1–10)	2(0–3)	45(33–50)	49(39–63)	1(0–2)	1(0–2)	10(3–18)	tr(0–1)	61(37–68)
Zone 6	3	8(1–18)	1(0–1)	40(28–60)	51(39–62)	1(1–2)	5(3–6)	5(4–6)	0	45(40–48)
Zone 4	2	7(3–11)	2(1–3)	29(—)	62(58–67)	1(0–1)	15(12–17)	4(4–4)	0	48(45–51)
Section D										
Zone 9	4	8(tr–30)	6(tr–11)	25(23–33)	63(25–77)	1(0–3)	54(32–71)	6(1–12)	0	20(14–29)
Zone 7	9	3(1–6)	1(tr–3)	45(33–63)	51(33–65)	tr(0–1)	3(0–6)	12(3–24)	tr(0–1)	46(34–61)
Section E										
Zone 7	2	2(1–2)	tr(0–tr)	53(47–60)	45(39–51)	2(1–2)	8(6–12)	7(5–7)	tr(0–tr)	49(44–54)
Zone 6	2	0	tr(0–tr)	61(55–68)	39(32–45)	1(0–1)	7(6–7)	3(1–5)	0	38(32–43)
Zone 4	6	2(tr–3)	1(0–3)	30(23–37)	67(58–72)	tr(0–1)	39(21–56)	7(4–10)	0	33(19–44)
Section F										
Zone 7	3	4(1–5)	tr(0–1)	40(28–47)	56(47–71)	tr(0–tr)	5(3–6)	6(5–8)	0	54(52–55)
Zone 6	2	5(1–9)	1(—)	29(—)	65(61–71)	tr(0–tr)	8(6–9)	8(6–9)	0	47(45–49)
Zone 4	5	4(tr–12)	4(1–13)	37(29–47)	54(46–74)	tr(0–1)	15(4–28)	10(3–16)	tr(0–tr)	47(40–59)
Section G										
Zone 7	4	2(1–3)	1(—)	39(29–50)	58(46–69)	tr(0–1)	2(tr–8)	6(2–13)	tr(0–tr)	60(55–63)
Zone 6	4	4(1–5)	1(tr–2)	37(9–50)	58(44–85)	tr(0–tr)	2(1–5)	9(6–11)	0	49(45–52)
Transition	4	2(tr–3)	1(tr–2)	43(33–50)	54(45–63)	0	4(1–8)	8(5–10)	0	52(43–62)
Zone 4	7	2(tr–5)	1(tr–3)	27(16–37)	70(59–78)	1(0–2)	14(1–38)	10(4–14)	0	43(22–52)
Section H										
Zone 2	1	tr(—)	tr(—)	49(—)	51(—)	0(—)	23(—)	10(—)	0	32(—)
Zone 1	6	1(0–3)	tr	36(17–50)	63(47–83)	1(tr–2)	43(32–51)	7(5–12)	tr(0–tr)	29(27–32)
Section J										
Zone 4	2	6(2–10)	3(1–4)	30(17–44)	61(42–80)	1(tr–1)	18(15–21)	10(5–14)	0	40(34–47)
Zone 3	4	5(4–6)	1(tr–2)	24(17–34)	70(59–77)	tr(0–1)	63(59–71)	5(4–7)	0	23(16–29)
Zone 2	3	tr(tr–1)	tr(0–tr)	54(43–61)	46(39–56)	1(0–2)	24(20–29)	9(6–12)	0	29(28–31)
Zone 1	4	3(1–6)	tr(0–1)	48(41–50)	49(47–52)	1(0–2)	39(35–43)	10(7–13)	0	18(14–20)
Section K										
Zone 2	4	1(tr–2)	0(—)	63(55–68)	36(32–44)	1(0–1)	17(15–20)	10(5–15)	tr(0–tr)	33(25–34)
Section L										
Zone 6	3	6(5–7)	tr(—)	58(58–59)	36(35–36)	1(0–1)	6(5–7)	17(12–21)	0	28(20–34)
Zone 4	2	2(tr–4)	tr(—)	38(—)	60(58–62)	1(0–1)	24(—)	8(4–11)	0	32(26–38)
Zone 3	10	5(1–15)	1(0–3)	17(5–34)	77(60–91)	tr(—)	72(45–87)	3(1–8)	0	12(5–24)
Section M										
Zone 7	5	9(1–25)	5(1–17)	33(29–41)	53(34–59)	1(0–1)	4(2–6)	10(5–16)	0	47(40–51)
Zone 6	3	2(—)	2(1–2)	50(—)	46(46–47)	1(0–2)	5(4–7)	8(3–11)	1(0–1)	39(37–40)
Zone 4	1	19(—)	0	50(—)	31(—)	0	37(—)	7(—)	0	22(—)
Section N										
Zone 6	2	4(1–7)	1(—)	51(42–60)	44(32–56)	0	9(8–10)	6(5–6)	0	34(26–42)
Zone 3	2	2(1–2)	1(0–3)	30(23–37)	67(59–75)	tr(—)	60(—)	3(—)	0	14(13–16)
Section PQ										
Zone 8	3	2(0–5)	0	29(28–29)	69(66–71)	1(0–1)	25(19–32)	6(5–6)	0	31(30–31)
Zone 7	4	4(1–7)	tr(0–tr)	40(34–47)	56(47–65)	tr(0–tr)	10(5–14)	17(10–22)	0	44(41–53)
Zone 5	4	4(0–7)	1(0–1)	33(23–44)	62(48–69)	1(0–2)	53(44–60)	5(3–7)	0	20(18–26)
Zone 4	4	9(4–13)	1(tr–2)	56(53–63)	34(32–36)	tr(0–1)	13(5–20)	7(6–9)	0	44(33–50)
Zone 3	5	8(0–29)	1(0–2)	20(9–44)	71(48–91)	tr(0–1)	71(56–88)	5(2–9)	0	13(6–17)
Section O										
Zone 9	3	2(—)	tr	23(—)	75(—)	tr(tr–1)	65(64–68)	5(4–6)	0	14(13–16)
Zone 7	8	5(1–9)	1(0–3)	42(23–50)	52(47–67)	1(0–4)	2(0–6)	14(7–17)	0	44(36–50)
Section R										
Zone 9	4	3(1–6)	tr(0–1)	28(23–33)	69(66–72)	1(tr–1)	54(38–70)	2(0–5)	0	24(18–30)
Zone 7	4	6(3–14)	6(2–11)	48(45–50)	41(34–50)	tr(0–tr)	1(0–3)	19(17–21)	0	50(40–57)

	Non-opaque minerals recomputed to 100%: Garnet	Glaucophane	Kyanite	Rutile	Sillimanite	Sphene	Staurolite	Tourmaline	Zircon	Zoisite	Ratio Opaque to Non-opaque Mines
Section A											
Zone 7	13(8–20)	tr(0–1)	1(0–1)	1(0–1)	tr(0–tr)	10(7–12)	1(0–2)	1(tr–2)	4(tr–9)	1(0–2)	.82
Zone 6	22(—)	0	tr(—)	1(—)	0	8(—)	3(—)	1(—)	2(—)	0	1.11
Zone 4	16(12–22)	0	tr(0–1)	tr(0–1)	0	16(8–25)	1(tr–2)	1(1–3)	4(0–11)	0	1.18
Section B											
Zone 9	8(4–14)	0(0–tr)	tr(0–1)	0(0–1)	tr(0–tr)	7(4–12)	1(0–3)	1(0–2)	1(0–4)	tr(0–2)	.37
Zone 7	11(4–26)	tr(0–1)	tr(0–1)	1(0–1)	tr(0–1)	12(5–20)	1(0–2)	1(0–3)	1(0–3)	tr(0–1)	.92
Zone 6	19(16–23)	0	1(0–1)	1(0–1)	tr(0–1)	19(14–23)	1(1–2)	tr(tr–1)	2(tr–6)	1(—)	.78
Zone 4	15(13–16)	0	tr(0–tr)	1(0–1)	tr(0–tr)	12(10–13)	1(tr–1)	1(0–1)	2(1–2)	0	.47
Section D											
Zone 9	6(2–9)	tr(0–tr)	1(0–3)	1(0–3)	0	7(5–12)	tr(0–tr)	1(0–3)	2(1–3)	0	.40
Zone 7	15(8–22)	0	1(0–2)	tr(0–2)	tr(0–tr)	14(7–19)	1(0–2)	2(tr–2)	3(0–10)	2(0–4)	.88
Section E											
Zone 7	16(14–17)	tr(0–tr)	tr(0–1)	tr(0–tr)	0	10(8–11)	2(—)	1(—)	4(2–6)	tr(0–tr)	1.18
Zone 6	32(24–40)	0	tr(0–tr)	1(1–2)	tr(0–1)	7(4–9)	1(1–2)	tr(0–tr)	10(8–12)	0	1.56
Zone 4	10(7–15)	0	tr(0–1)	1(0–1)	tr(0–tr)	7(4–11)	1(0–1)	1(0–2)	1(—)	tr(0–1)	.45
Section F											
Zone 7	16(15–17)	0	tr(0–tr)	1(tr–2)	tr(0–tr)	14(11–17)	1(0–2)	1(tr–2)	1(tr–2)	1(tr–1)	.71
Zone 6	22(—)	0	tr(0–tr)	tr(0–tr)	0	12(10–14)	1(—)	0	1(0–1)	tr(—)	.45
Zone 4	12(9–15)	tr(0–1)	tr(0–1)	1(0–3)	0	10(5–12)	1(0–2)	1(tr–4)	1(0–4)	1(0–1)	.69
Section G											
Zone 7	15(7–22)	0	tr(0–1)	1(0–1)	0	12(10–14)	0	1(tr–2)	2(tr–1)	1(0–2)	.67
Zone 6	24(20–30)	0	tr(0–1)	tr(tr–1)	0	11(9–13)	1(0–2)	1(0–2)	3(2–4)	tr(0–1)	.64
Transition	16(12–19)	0	tr(0–1)	1(0–2)	0	15(10–19)	1(0–2)	1(0–2)	2(0–2)	tr(0–tr)	.80
Zone 4	15(7–27)	tr(0–1)	tr(0–1)	1(0–1)	tr(0–tr)	14(10–23)	1(0–2)	1(0–3)	1(0–4)	tr(0–1)	.39
Section H											
Zone 2	19(—)	0	0	1(—)	0	12(—)	1(—)	tr(—)	1(—)	1(—)	.96
Zone 1	11(8–15)	0	tr(0–tr)	1(tr–1)	tr(0–tr)	5(3–8)	1(tr–2)	1(tr–2)	1(tr–2)	tr(0–2)	.57
Section J											
Zone 4	14(9–18)	0	1(0–1)	1(—)	tr(0–tr)	11(7–16)	1(—)	1(0–1)	1(—)	1(—)	.49
Zone 3	6(4–7)	tr(0–tr)	tr(0–1)	tr(0–tr)	0	3(2–6)	tr(0–tr)	tr(0–tr)	tr(0–1)	tr(0–1)	.34
Zone 2	14(10–18)	0	1(1–2)	tr(0–tr)	0	17(14–20)	1(tr–1)	3(1–5)	tr(0–1)	1(tr–1)	1.17
Zone 1	12(10–14)	0	1(tr–2)	1(tr–1)	0	13(9–16)	1(tr–2)	2(2–3)	tr(0–tr)	1(tr–1)	.98
Section K											
Zone 2	17(15–20)	tr(0–1)	1(0–1)	tr(0–1)	0	15(11–19)	1(tr–1)	2(tr–3)	3(1–4)	tr(tr–1)	1.75
Section L											
Zone 6	20(15–22)	1(0–2)	2(0–3)	tr(0–1)	0	20(13–27)	1(0–2)	2(1–3)	1(0–4)	2(1–3)	1.60
Zone 4	20(18–24)	tr(0–tr)	1(0–1)	2(tr–5)	0	9(6–11)	1(tr–1)	tr(—)	2(tr–3)	tr(tr–1)	.63
Zone 3	5(1–17)	tr(0–tr)	tr(0–1)	tr(0–1)	0	5(2–14)	1(0–2)	tr(0–tr)	1(0–4)	tr(0–1)	.22
Section M											
Zone 7	17(13–20)	tr(0–tr)	1(0–1)	1(0–1)	0	15(12–18)	2(0–2)	2(tr–4)	2(tr–2)	1(—)	.62
Zone 6	22(21–24)	0	tr(0–1)	1(—)	tr(0–1)	12(11–15)	2(1–3)	2(1–3)	5(2–9)	tr(0–1)	1.11
Zone 4	22(—)	0	0	0	0	7(—)	0	2(—)	2(—)	0	1.61
Section N											
Zone 6	24(—)	0	1(0–1)	tr(—)	0	19(17–22)	1(0–2)	1(tr–2)	5(tr–10)	0	1.16
Zone 3	11(—)	0	tr(0–tr)	tr(—)	0	9(7–10)	1(0–2)	1(—)	1(0–2)	tr(0–tr)	.45
Section PQ											
Zone 8	23(19–28)	0	1(tr–1)	tr(—)	0	8(7–11)	2(1–3)	1(1–2)	2(tr–4)	tr(0–tr)	.42
Zone 7	13(11–14)	1(0–1)	tr(tr–1)	tr(tr–1)	0	11(7–14)	1(tr–1)	1(0–2)	1(0–2)	1(0–2)	.71
Zone 5	9(7–11)	0	1(—)	0	0	8(7–9)	1(0–2)	1(0–3)	1(0–3)	tr(0–2)	.53
Zone 4	18(11–24)	0	tr(0–1)	1(0–1)	tr(0–tr)	11(8–15)	1(0–1)	1(0–2)	5(tr–12)	tr(0–2)	1.65
Zone 3	5(1–9)	tr(0–tr)	tr(0–tr)	tr(0–tr)	0	5(2–9)	tr(0–1)	1(0–1)	tr(0–1)	tr(0–1)	.29
Section O											
Zone 9	10(7–13)	0	0	tr(0–1)	0	4(3–6)	1(tr–1)	tr(0–tr)	tr(0–1)	0	.31
Zone 7	16(11–19)	tr(0–tr)	1(1–2)	tr(tr–1)	0	17(13–23)	1(0–3)	1(0–2)	2(1–2)	tr(0–1)	.81
Section R											
Zone 9	10(8–12)	0	tr(0–1)	tr(0–1)	0	5(3–7)	2(0–4)	1(0–2)	tr(tr–1)	0	.41
Zone 7	14(11–22)	tr(0–1)	tr(0–tr)	tr(0–1)	tr(0–1)	12(11–13)	1(0–1)	2(0–3)	1(0–2)	0	1.17

less; (2) brown, absorption Z > Y > X, Z = greenish brown to brown, Y = brown, X = straw; (3) green, absorption Z > Y > X, Z = dark bluish green, Y = green, X = green, extinction angle Z∧c = 18°. Colorless amphibole occurs sparingly throughout the area. The brown amphibole is characteristically associated with weathered bentonitic sands. In section P, in the bentonitic sands above the ash beds, brown amphibole forms up to 90% of the non-opaque minerals. In other environments it is a sparse constituent. The green amphiboles are dominant wherever else amphiboles are reported.

Clinozoisite (see Epidote).

Corundum occurs as fragments, basal plates, and twinned crystals. Fragments and twinned crystals appear mottled yellow due to an uneven depth of color. The basal plates are colorless or pale blue. Most of these are uniaxial, but some give an anomalous biaxial figure with a moderate 2V.

Epidote occurs in euhedral, in angular, and in rounded grains. The pleochroism is: X = Z = colorless to pale yellow, Y = bottle green. The euhedral grains are very transparent, but the rounded ones are often dusky. Clinozoisite resembles epidote, but is colorless and positive, and zoisite is differentiated by anomalous blue interference colors.

The garnet has various shapes and colors. Yellow oblong garnets with hackly surface occur only in zone 1. Brown trapezahedron-dodecahedrons occur sparingly, but especially in zone 6, where they are associated with other colored garnets. Clear pink, angular to subangular garnets with conchoidal fracture are the common type in many zones, but are subordinate to the colorless garnets in zones 4 and 5. In zones 6, 8 and 9 some of the pink

TABLE 2. *Representative Mineral Frequencies*

Zones	1	2	3	4	5	6	7	8	9
Andalusite	1	1	tr	1	1	1	1	1	1
Colorless	R	R	R	R	R	R	R	R	R
Pleochroic	R	R	R	R		R	R		R
Amphibole	41	22	66	21	53	7	4	25	55
Green; greenish brown	C	C	C	C	C	S	S	C	C
Colorless	R	R	R	R	R	R	R		R
Clinozoisite	8	10	4	8	5	8	11	6	5
Corundum	0	0	0	0	0	tr	tr	0	tr
Epidote	24	32	15	38	20	40	51	31	21
Detrital	C	C	C	C	C	C	C	nd	C
Authigenic	S	S	C	S	S	S	C	nd	S
Garnet	12	17	8	16	9	23	15	23	9
Colorless	R	S	C	C	R	S	S	S	S
Yellow	R								
Pink	C	C	R	S	C	C	C	C	S
Salmon, brown	S	S	R	R	S	S	S	S	R
Glaucophane	0	tr	tr	tr	0	tr	tr	0	tr
Kyanite	tr	1	tr	tr	1	1	1	1	tr
Rutile	1	tr	tr	1	tr	tr	tr	tr	tr
Sillimanite	0	0	0	tr	0	tr	tr	0	tr
Sphene	9	11	5	11	8	12	13	8	6
Colorless round	R	S	R	R	R	R	R	R	R
Colorless euhedral	R	R	R	S	R	S	S	R	R
Brown round	R	S	R	S	S	S	S	S	S
Honey	C	C	S	S	S	C	R	S	S
Brown pleochroic	S	R	R	R	R	R	R	R	R
Staurolite	1	1	1	1	1	1	1	2	1
Tourmaline	2	2	1	1	1	1	1	1	1
Brown	R	R		R		R	R		S
Blue	R	R		R		R	R		R
Greenish brown	S	S	S	S	R	S	S	R	R
Pinkish brown	R	S	R	S	R	R	R	R	S
Colorless, Incl.	R	R		R		R	R		S
Zircon	1	1	1	2	1	2	2	2	1
Colorless	S	S	S	S	S	S	S	S	S
Red pleochroic	R	R	R	R	R	R	R	R	R
Zoisite	tr	1	tr	tr	tr	tr	1	tr	tr

C = common, above 8%; S = sparse, 1 to 8%; R = rare, 0–1%; C/S or S/R, the first mineral more abundant than the second; C/R the first mineral very much more abundant than the second.

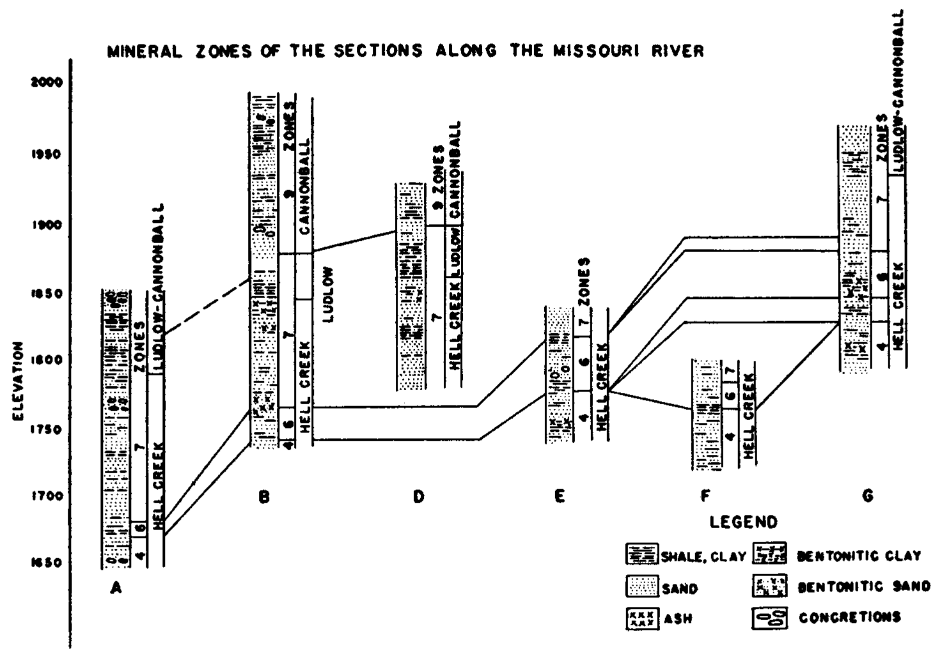

FIG. 2.

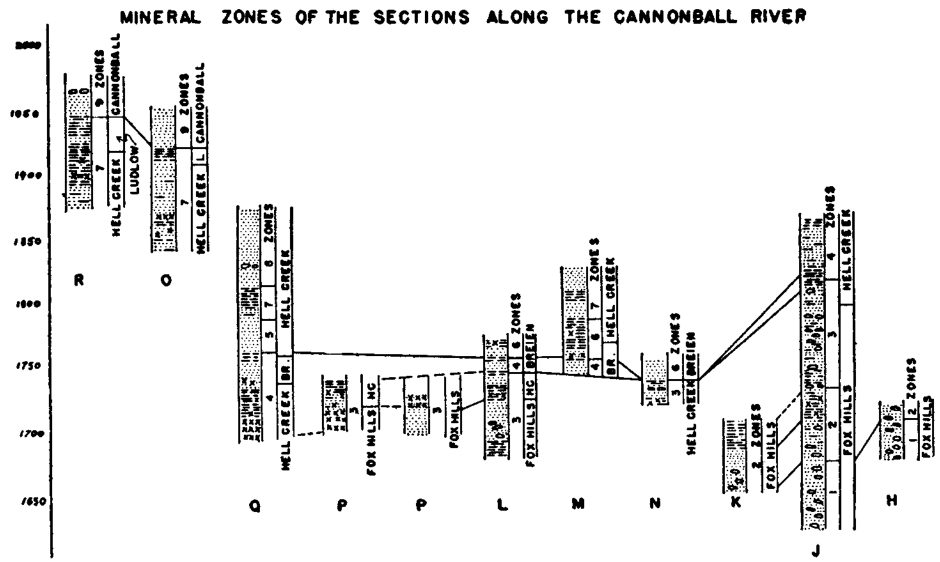

FIG. 3.

garnets are well rounded and dusky. Salmon and brown garnets are found in greater numbers with pink than with colorless garnets. Inclusions are commonly present.

Glaucophane occurs in prismatic grains with vertical striations (110 cleavage). Pleochroism: Z = blue, Y = violet, X = pale blue.

Kyanite occurs in subangular prisms showing (010) and sometimes (001) cleavage.

Rutile occurs in brown and yellow-brown prisms and twins, and, less frequently, in dark red platy grains.

Sillimanite is characterized by parallel and interlacing fibers.

Sphene has several crystal habits and colors. Most common is a honey-colored, slightly pleochroic type, which is oblong or irregular in shape. Locally common are dull dark brown irregular, rounded, or diamond-shaped grains; transparent, round, colorless grains; and transparent, colorless to straw-colored ones. Least common is the strongly pleochroic brown to yellow sphene.

Staurolite is oblong or irregularly shaped, and has either a hackly or a conchoidal fracture. Pleochroism is in shades of yellow, or rarely, chestnut brown. Inclusions are commonly present in the prismatic form.

Tourmaline is varied in crystal habit and color.

Epsilon	*Omega*	*Habit*
brown	black	prismatic, round
blue, gray	blue, gray	basal fragments
greenish brown	brown to black	prismatic, round
pinkish brown	green, brown, black	prismatic, round
colorless, pale green	brown	prismatic, contains small opaque inclusions

Zircon occurs predominantly in colorless, doubly terminated prisms, and in colorless, well rounded grains. Rarely are round red, slightly pleochroic rounded grains.

Zoisite (see Epidote).

CORRELATION

On the basis of heavy mineral frequencies of green and brown amphiboles, epidote, and garnet, nine mineral zones are proposed. Table 3 gives the relative percentages of these minerals, in terms of total non-opaque heavy minerals, and the localities and beds sampled, while figures 2, 3, and 4 give schematic correlation between sections and zones.

In the Fox Hills formation, three lithologic units were noted. These coincide with three heavy mineral zones: (1) The lowermost horizon of thick bedded, yellowish brown sandstone with brown concretions and Halymenites corresponds to zone 1 (cf. p. 133, section J, bed 1). The average amphibole content for this zone is 41%. (2) The intermediate horizon of yellow to olive colored sandy, banded shale is represented by zone 2 (cf. p. 133, section J, bed 2), in which the average amphibole content has fallen from 41% to 22%. (3) The upper horizon of gray white sandstone with concretions corresponds to most of zone 3 (cf. p. 133, section J, beds 4–7). There is a decided increase in the amount of amphibole, from 22% to 66%, and a decrease in the other heavy minerals.

The high amphibole count of the Fox Hills continues into the Hell Creek, above the lignitic shale marking the boundary, to the base of the Breien (cf. p. 133, section L, bed 2; p. 134, section L, beds 3–6).

The Hell Creek is divided into a series of alternating beds of brown lignitic shale, weathered bentonite, and massive sands with zones of shale partings. Along the Missouri River, the Fox Hills is not exposed. Zone 4 occurs in the sands and shales below the first bentonitic bed (cf. p. 133, section B, bed 1). Along the Cannonball River, zone 3 extends to the base of the Breien. The lowermost bed in the Breien is a fine-grained, brown, badly weathered sand, with limonitic concretions and Halymenites (cf. p. 134, section

TABLE 3. *Correlation*

Zone	Locality	Bed[1]		Amphibole	Epidote	Garnet
1	H			43	29	11
1	J	(1)		39	18	12
			Average	41	24	12
2	H			23	32	19
2	J	(2)		24	29	14
2	K			17	33	17
			Average	22	32	17
3	J	(4–7)		63	23	6
3	L	(2–6)		72	12	5
3	N			60	14	11
3	P			71	13	5
			Average	66	15	8
4	A			18	37	16
4	B	(1)		15	48	15
4	E			39	33	10
4	F			15	47	12
4	G			14	43	15
4	J	(10)		18	40	14
4	L	(8)		24	32	20
4	M	(1)		37	22	22
4	Q			13	44	18
			Average	21	38	16
5	PQ			53	20	9
			Average	53	20	9
6	A			11	40	22
6	B	(1)		5	45	19
6	E			7	38	32
6	F			8	47	22
6	G			2	49	24
6	L	(8)		6	28	20
6	M	(1–7)		5	39	22
6	N			9	34	24
			Average	7	40	23
7	A			2	55	13
7	B	(2–6)		1	61	11
7	D			3	46	15
7	E			8	49	16
7	F			5	54	16
7	G			2	60	15
7	M	(7–9)		4	47	17
7	O			10	44	13
7	O			2	44	16
7	R	(1–4)		1	50	14
			Average	4	51	15
8	Q			25	31	23
			Average	25	31	23
9	B	(8–11)		49	25	8
	D			54	20	6
	O			65	14	10
	R	(5)		54	24	10
			Average	55	21	9

[1] In sections described in the text, the numbers after the locality refer to the beds from which the samples were collected.

L, beds 7 and 8). This corresponds to zone 4. There is a decrease in amphibole count from 66% in zone III to 21% in zone 4.

Above zone 4 is a dark gray limonitic shale followed by a fine-grained to silty, gray-green sand and bentonite which mark the beginning of zone 6 (cf. p. 134, section L, beds 9–12).

Zone 6 is differentiated from zone 4 by a decrease in amphiboles from 21% to 7%, and by a change in the character of garnets, from predominantly colorless to predominantly colored. Zone 6 extends above the Breien member.

Zones 6 and 7 are differentiated particularly on the basis of their epidote and garnet count. Zone 7 extends through most of upper Hell Creek, and to the top of the Ludlow. In zone 6, garnet is above 20%. The average amount of epidote is 40%, with the count slightly above average in the sections along the Missouri River and below average along the Cannonball River (cf. p. 133, section B, bed 1 and p. 134, section M, beds 2–7). It may be expected that sections closer together, will be more like each other.

Zone 7 shows a decrease in the amount of garnet, from 23% to 15%, and an increase in epidote from 40% to 51%. Again the sections along the Missouri River contain more epidote than the sections along the Cannonball River, but the trend is to increase in epidote in zone 7.

The Ludlow consists almost entirely of lignitic shales. Narrow sand beds could not be differentiated from the Hell Creek beds in zone 7.

Zones 5 and 8 are local at Q.

There is a marked change in heavy mineral content at the base of the Cannonball formation. The amphibole content increases from an average of 4% in zone 7 to 55% in zone 9, with greater quantities of amphibole nearer the contact than higher up.

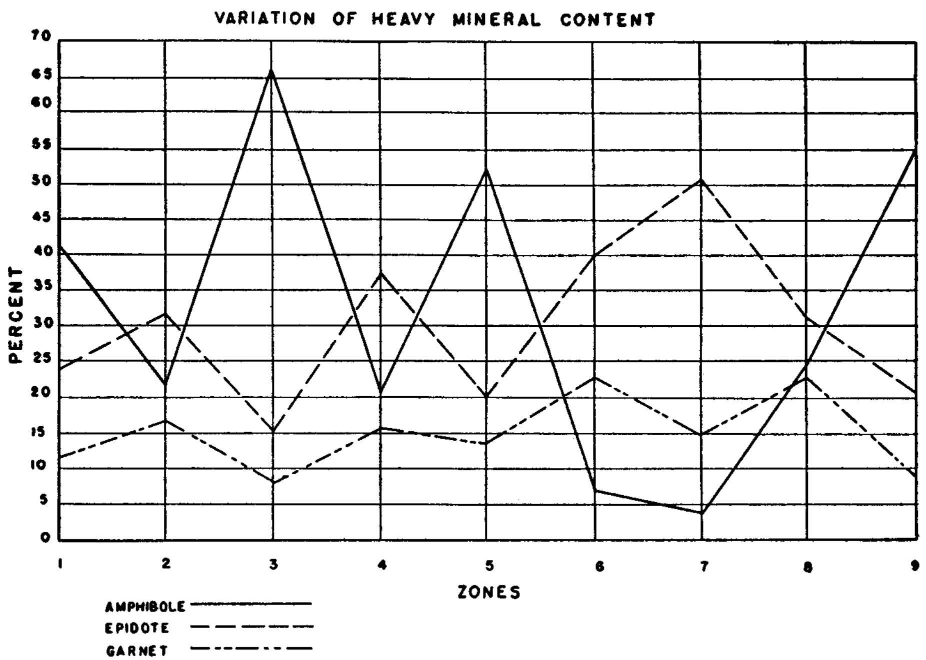

FIG. 4.

SUMMARY

A study of a restricted area in Morton and Sioux Counties, North Dakota, was made to correlate various exposures of Fox Hills, Hell Creek, Ludlow, and Cannonball sediments. Nine mineral zones were established. In the marine Fox Hills and marine Cannonball sediments, the zones were characterized by a large quantity of amphibole. The amphibole diminishes in amount in the lower Hell Creek, and, except at one locality, Q, amphibole is insignificant in upper Hell Creek. Epidote, sphene and garnet are the significant minerals in the Hell Creek and Ludlow sediments.

ACKNOWLEDGMENTS

The author is indebted to the North Dakota Geological Survey for providing for field expenses, without which this work could not have been undertaken. Dr. Wilson Laird, State Geologist, directed the field work and contributed valuable information of the stratigraphy and areal geology. To Miss A. Swineford of the Kansas Geological Survey special thanks are due for accompanying the author in the field.

Dr. J. L. Anderson of the Department of Geology of the Johns Hopkins University gave material direction in the laboratory studies and in the preparation of the mineral charts. The Geological Laboratory of the Johns Hopkins University furnished the materials used in making the heavy mineral analyses.

Field and laboratory studies were carried on during the summer of 1942.

The paper was critically read by Dr. Paul Krynine, Pennsylvania State College, and Dr. C. S. Ross and Dr. H. D. Miser, United States Geological Survey.

BIBLIOGRAPHY

BAUER, CLYDE, and HERALD, FRANK A., *1921*, Lignite in the western part of Fort Berthold Indian Reservation south of the Missouri River, North Dakota, *U. S. Geol. Surv. Bull.* 726, pp. 109–172.

CALVERT, W. R., *1914*, Geology of the Standing Rock and Cheyenne River Indian Reservations, North and South Dakota, *U. S. Geol. Surv. Bull.* 575, pp. 1–49.

DOBBIN, C. E., and REESIDE, J. B., JR., *1929*, The contact of the Fox Hills and Lance formations, *U. S. Geol. Surv. Prof. Paper* 158, pp. 9–25.

HANCOCK, E. T., *1921*, The New Salem Lignite field, Morton County, North Dakota, *U. S. Geol. Surv. Bull.* 726, pp. 1–41.

PISHEL, M. A., *1910*, Lignite in the Fort Berthold Indian Reservation, North Dakota, north of the Missouri River, *U. S. Geol. Surv. Bull.* 471, pp. 170–187.

SEAGER, O. A. et al., *1942*, Stratigraphy of North Dakota, Am. Assoc. Pet. Geol., *Bull.*, vol. 26, No. 8, pp. 1414–1418.

STANTON, T. W., *1910*, Fox Hills sandstone and Lance formation ("Ceratops beds") in South Dakota, North Dakota, and eastern Wyoming, *Am. Jour. Sci.*, 4th ser., vol. 30, pp. 172–188.

THOM, W. T., JR., and DOBBIN, C. E., *1924*, Stratigraphy of Cretaceous-Eocene transition beds in eastern Montana and the Dakotas, *Geol. Soc. Am. Bull.*, vol. 35, pp. 481–506.

TISDALE, ERNEST E., *1941*, The geology of the heart Butte Quadrangle, *North Dakota Geological Survey Bull.* 13, 32 pp.

WARD, FREEMAN, *1924*, The Lance problem in South Dakota, *Am. Jour. Sci.*, 5th ser., vol. 7, No. 37, p. 66.

WILSON and WARD, *1923*, The possibilities of oil in northern Ziebach County, *South Dakota Geol. and Nat. Hist. Surv. Circ.* 13, pp. 6–7, 1923.