UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Text to Accompany:

COAL RESOURCE OCCURRENCE MAP AND COAL DEVELOPMENT POTENTIAL MAP OF THE EMERSON QUADRANGLE, DUNN COUNTY, NORTH DAKOTA

[Report includes 13 plates]

By

WOODWARD-CLYDE CONSULTANTS

Open-File Report 78-069
1978

This report has not been edited for conformity with U.S. Geological Survey editorial standards or stratigraphic nomenclature.

TABLE OF CONTENTS

APPENDIX A - PROXIMATE AND ELEMENTAL ANALYSES

PLATES

PLATE 1 - COAL DATA MAP

PLATE 2 - BOUNDARY AND COAL DATA MAP

PLATE 3 - COAL DATA SHEET

PLATE 4 - STRUCTURE CONTOUR AND OVERBURDEN MAP OF THE HT BUTTE COAL BED

PLATE 5 - ISOPACH AND MINING RATIO MAP OF THE HT BUTTE COAL BED

PLATE 6 - AREAL DISTRIBUTION AND IDENTIFIED AND HYPOTHETICAL RESOURCES OF THE HT BUTTE COAL BED

PLATE 7 - STRUCTURE CONTOUR AND OVERBURDEN MAP OF THE HAZEN COAL BED

PLATE 8 - ISOPACH AND MINING RATIO MAP OF THE HAZEN COAL BED

PLATE 9 - AREAL DISTRIBUTION AND IDENTIFIED AND HYPOTHETICAL RESOURCES OF THE HAZEN COAL BED

PLATE 10 - STRUCTURE CONTOUR AND OVERBURDEN MAP OF THE BEULAH-ZAP COAL BED

PLATE 11 - ISOPACH AND MINING RATIO MAP OF THE BEULAH-ZAP COAL BED

PLATE 12 - AREAL DISTRIBUTION AND IDENTIFIED AND HYPOTHETICAL RESOURCES OF THE BEULAH-ZAP COAL BED

PLATE 13 - COAL DEVELOPMENT POTENTIAL MAP FOR SURFACE MINING METHODS

INTRODUCTION

The occurrence, extent, and preliminary geologic evaluation of coal beds in the Emerson quadrangle in west-central North Dakota are described in this report. Subsurface data, consisting of oil and gas well and exploration drill hole logs, and surface data comprised of measured sections, are presented on the Coal Data Map and Coal Data Sheet, Plates 1 and 3, respectively. Federal ownership of coal, total Reserve Base, and Hypothetical resources of coal by section are presented in the Boundary and Coal Data Map, Plate 2. Derivative maps, which consist of coal isopachs, structure contours, overburden, mining ratios, reserve categories, and Reserves and Reserve Base have been compiled for each coal seam of reserve base thickness underlying the quadrangle and are presented on Plates 4 through 12, respectively. A Coal Development Potential map for surface mining is presented on Plate 13.

This work has been performed under contract with the Conservation Division of the U.S. Geological Survey (Contract No. 14-08-0001-17118).

The resource information gathered in this program is in response to the Federal Coal Leasing Amendments Act of 1975 and is part of the U.S. Geological Survey's coal program. This

information is intended to provide basic data on coal resources for land-use planning purposes by the Bureau of Land Management, state and local governments, and the public.

LOCATION

The Emerson 7 1/2 minute quadrangle is located in Dunn County, North Dakota, about 1.3 miles (2.1 km) east of Manning and 11 miles (17.7 km) west of Hirschville.

ACCESSIBILITY

The area is accessible by a county road which leaves State Highway 22, 1.3 miles (2.1 km) to the east of the eastern quadrangle boundary. State Highway 22 goes through Manning and connects with Interstate 94 at Dickinson, 23 miles (37.0 km) to the south.

The Burlington Northern Railroad operates and maintains an east-west route, which extends through Halliday, Dunn Center and Killdeer, about 10 miles (16.1 km) north of the quadrangle. No railroad routes currently pass through or closer to the quadrangle than the existing Burlington Northern route to the north.

PHYSIOGRAPHY

The quadrangle lies in the central portion of a large topographic high known as the Missouri Plateau, which is being dissected by the Knife, Heart, Cannonball and Cedar Creek

Rivers. In the eastern portion of the plateau the topography is generally hilly and along the Missouri River there are bluffs 500-600 feet high (152-183 m). The western part of the Missouri Plateau is characterized by more irregular topography than that which is prevalent throughout the remainder of the plateau. This area, which is known collectively as "the Badlands", comprises an intricate maze of narrow ravines, sharp crested ridges and pinnacles.

The topography of the Emerson quadrangle is controlled primarily by the Knife River, which meanders from west to east across the central sector of the quadrangle, and its numerous shallow tributaries. Generally, the topography may be characterized as gently rolling to hilly, with a maximum relief across the quadrangle of 400 feet (122 m).

The vegetation is mixed prairie grasses, and some of the land is cultivated.

CLIMATE

North Dakota's climate may be characterized as semi-arid; the average annual precipitation is 17 inches (43.2 cm) at Dunn Center, which is located 9 miles (14.5 km) north of the quadrangle.

Maximum precipitation occurs during the late spring and early summer with slightly over half the total annual precipitation occurring during May, June and July. Although

the mean annual temperature is about 40°F (4.4°C), temperatures as recorded at the Dunn Center weather station by the U.S. Department of Commerce can range from 102°F (38.9°C) in summer months to -25°F (-31.7°C) in winter months. The prevailing northerly winds increase in velocity during the colder months of November through March.

LAND STATUS

The quadrangle lies in the western one-half of the Knife River Coal Resource Area (KRCRA). The Federal Government owns the coal rights to approximately 35 percent of the quadrangle. In addition, the Federal Government has restricted coal rights on less than one percent of the area incorporated in the quadrangle.

PREVIOUS WORK

This report has drawn on a number of basic data reports on the coal occurrences in the Knife River KRCRA, including: Law (1977), Benson (1953), and United States Geological Survey (USGS) and North Dakota Geological Survey (NDGS) (1976, 1977). Ground water data reports in the Knife River area were also used, including: Croft (1970) and Klausing (1971, 1974, 1976).

METHOD OF STUDY

Lithologic and geophysical logs from seven drill holes and two measured sections provided the basic data for this study.

The most important sources of data were Klausing (1976), Law (1977), and USGS and NDGS (1976). The quality of the available coal information is variable. Lithologic and geophysical logs from exploration holes drilled by the North Dakota Geological Survey, North Dakota State Water Commission, and private coal companies generally provide the most detailed and reliable subsurface data. Lithologic logs of private water wells are less detailed and less reliable, but they provide usable information in some cases. Where the data for a specific coal bed appeared to be inaccurate or inconsistent with surrounding drill hole data, it was not included in the data base that was used for construction of derivative maps for that coal bed. For instance, in some drill holes, where coal intervals were not noted and the data appeared anomalous in relation to data from adjacent drill holes, rather than plot a zero coal thickness, the coal bed was assumed to be laterally extensive. Many coal splits were not mapped because of inconsistent data that did not allow projection of split thicknesses with reasonable reliability or accuracy.

Drill hole data and projected coal outcrop-traces from previous investigations (Law, 1977) were plotted on the Coal Data Map, Plate 1. These outcrop data were then modified in accordance with structural trends in the present mapping. It was assumed that all beds extended to the surface although it

is known that thick alluvial, colluvial, and glacial materials are sometimes present. Subsurface information was used to construct correlation diagrams of coal beds (Coal Data Sheet, Plate 3). Correlation diagrams for the Emerson quadrangle and the adjoining Lake Ilo, and Ziner Butte quadrangles were then integrated and coal structure contours, coal thickness isopachs, overburden isopachs, and mining ratio maps were constructed for coal beds of reserve base thickness (5 feet minimum) (Plates 4 through 12).

GEOLOGY

STRATIGRAPHY

The oldest rocks present in the uppermost 500 feet (152 m) of the stratigraphic section in the Emerson quadrangle are the coal bearing Tongue River and Sentinel Butte members of the Paleocene age Fort Union Formation (Rehbein, 1977). Sandstones, siltstones and shales of this formation are locally mantled by erosional remnants of the Upper Paleocene-Lower Eocene Golden Valley Formation, and by Quaternary glacial, eolian, and alluvial deposits.

Fort Union Formation - Paleocene.

Tongue River member - this member ranges in thickness from 350 to 900 feet (107 to 274 m) and consists of an alternating sequences of fluvially deposited sandstone, siltstone, shale,

and lignite. It conformably overlies the marine Cannonball member and the time equivalent, nonmarine Ludlow member. The Tongue River member is similar to the overlying Sentinel Butte member and in places cannot be distinguished from it. The contact between the Tongue River and Sentinel Butte members, which has been arbitrarily set at the top of the HT Butte lignite, is conformable.

Sentinel Butte member - this member averages 500 feet (152 m) in thickness and consists of alternating sequences of fluvially deposited sandstone, siltstone, shale, carbonaceous shale, and lignite. In general, the sandstones are fine grained and poorly cemented. Shales range from soft, plastic clay to moderately indurated claystone. Locally, there are thin, calcareous or silicious concretions. Shales and siltstones readily break down and form gentle slopes beneath the sandstone ledges.

Golden Valley Formation - Eocene.

This formation consists of about 200 feet (61 m) of alternating shales, siltstones, and crossbedded sandstones. These sediments, which comformably overlie the Sentinel Butte member, have been eroded away in much of the study area.

Channel Deposits - Pleistocene.

Sand and gravel channel deposits of indeterminate thickness lie beneath alluvial deposits. These deposits

underlie early Wisconsinan glacial till and Quaternary alluvium in the area.

Glacial Till - Pleistocene.

The glacial till is a heterogeneous mixture of clay, silt, sand, gravel, cobbles, and boulders which was deposited during Wisconsinan episodes of continental glaciation.

Eolian Deposits - Pleistocene and Recent.

Unconsolidated dune and loess-like deposits, from several inches to more than five feet thick, mantle most of the study area. The loess-like deposits consist of silty clays, clayey silt, and silty to clayey sands, and are probably of late Pleistocene to Recent age. Recent dunes, consisting of silts and very fine-grained sand, have been deposited on the lee side of knobs and ridges.

Alluvium - Recent.

Alluvium consisting of clay, silt, sand, and gravel mantles valley floors in the study area.

DEPOSITIONAL ENVIRONMENTS OF THE LIGNITES

The Tongue River lignites are relatively thick and laterally extensive. The HT Butte bed, at the top of the Tongue River Formation, can be traced over thousands of square miles. The lignite beds of the Tongue River member were formed in large swamps adjacent to fluvial channels (Rehbein, 1977).

The Sentinel Butte lignites, though fewer in number, are almost as continuous as the Tongue River lignites and had a similar depositional environment.

STRUCTURE

Regionally, the Knife River KRCRA is located on the southeastern flank of the Williston Basin, approximately 60 miles (97 km) from the basin center. Generally, the sedimentary units are flat lying or gently undulating, with a northward to northeastward regional dip ranging from less than 10 feet per mile (1.9 m per km) to 180 feet per mile (34 m per km). Upper strata have been warped into a gentle syncline with a northeast to southwest trending axis located approximately 10 miles (16 km) east of the town of Dodge. The dips on the flanks of the syncline are approximately 18 feet per mile (3.4 m per km).

The coal beds, as mapped within this quadrangle, show minor structural variations from the regional structural framework. More definitive descriptions of the structural aspects of the coal seams may be found in the "Coal Geology" section which follows. Major faulting has not been observed in the area (Menge, 1977). Surficial materials generally mask most of the older stratigraphic units, making it difficult to assess the importance of minor faulting.

COAL GEOLOGY

Four major coal beds and several local coal beds are either mapped at the surface or identified in the subsurface in this quadrangle (composite section, Plate 3). The HT Butte coal bed is stratigraphically the lowest recognized coal bed. It is successively overlain by a sequence of rocks approximately 185 feet (56 m) thick containing two local coal beds (a local coal bed, and Local 4, a local bed correlatable between several quadrangles); the Hazen coal bed; a non-coal bearing rock interval approximately 25 feet (7.6 m) thick; Local 3, a local bed correlatable between several quadrangles; non-coal bearing rocks varying from approximately 15 to 35 feet (4.6 to 10.7 m) thick; the Beulah-Zap coal bed; a sequence of rocks approximately 25 feet (7.6 m) thick containing one local coal bed and the Schoolhouse coal bed, which is overlain by non-coal bearing rock. Table 1 shows the coal bed names and their stratigraphic position.

The coal beds of the Fort Union Formation in the Knife River area are lignite in rank containing 0.4 to 1.2 percent sulphur, less than 10 percent ash and between 5910 and 7330 BTU/lb (Table A-1). Coal analyses indicate that these coals have less than or about the same amount of trace elements as coal beds in other areas of the northern Great Plains coal province (Tables A-2 through A-5).

Table 1 -- Coal Bed Names and Stratigraphic Position

Bed Name	Stratigraphic Equivalent
Schoolhouse	Otter Creek
↑ 25 feet ↓	
Beulah-zap	Dunn Center, Herman
↑ 15-35 feet ↓	
Local 3	
↑ 25 feet ↓	
Hazen	Spear, Hazen "B", Kruckenberg, Red Butte
↑ 35 feet ↓	
Local 4	
↑ 150 feet ↓	
HT Butte	Hazen "A", Garrison Creek, Yeager, Hagel, Berg, Keuther, Stanton

HT BUTTE COAL BED

The lowest mapped coal bed, the HT Butte, does not crop out in the Emerson quadrangle and was only found in one drill hole in this quadrangle. Based upon data from this drill hole and projections from adjacent quadrangles, it is assumed that the HT Butte dips west at 15 feet per mile (2.8 m per km) as shown on Plate 4.

The thickness of the bed ranges from 4 feet (1.2 m) to 12 feet (3.7 m), and the bed increases in thickness from north to south as shown on Plate 5. The overburden ranges in thickness from 200 feet (61.0 m) to 400 feet (121.9 m) as shown on Plate 4.

Chemical Analyses of the HT Butte Coal Bed - Proximate (as received) and elemental analyses of the HT Butte coal bed are presented in Tables A-1 and A-2, respectively, and indicate that the HT Butte coal is lignite in rank. No coal analyses are available from this quadrangle, but analyses of coal samples from the Center quadrangle indicate the following: Ash, 5.9%; Sulfur 0.7% and BTU/lb, 7024.

HAZEN COAL BED

The Hazen coal bed overlies the HT Butte coal bed. It is separated from the HT Butte coal bed by approximately 185 feet

(56 m) of rock containing two local coal beds. The Hazen coal bed underlies approximately 90 percent of the quadrangle; in the remainder of the quadrangle, the Hazen coal bed has been removed by erosion or has pinched out. The Hazen coal bed dips southeast at approximately 5 feet per mile (0.9 m per km) as shown on Plate 7.

The Hazen coal bed ranges from 0 feet (0.0 m) to 10 feet (3 m) thick with the thickness increasing from southeast to northwest as shown on Plate 8. The overburden ranges from 0 feet (0.0 m) to 200 feet (61.0 m) thick, as shown on Plate 7.

Chemical Analyses of the Hazen Coal - Proximate (as received) and elemental analyses of the Hazen coal bed are presented in Tables A-1 and A-3, respectively, and indicate that the Hazen coal is lignite in rank. No coal analyses are available from this quadrangle, but analyses of samples from the Hazen coal bed in the Red Butte quadrangle indicate the following: Ash, 4.2%; Sulfur, 0.5%; and BTU/lb, 6290.

BEULAH-ZAP COAL BED

The Beulah-Zap coal bed is the uppermost coal bed of reserve base thickness in the quadrangle. It is separated from the underlying Hazen coal bed by approximately 60 feet (18 m) of rock. One to two local coal beds are found in this rock interval. The Beulah-Zap coal bed underlies approximately 45 percent of the quadrangle. In the remainder of the quadrangle,

the Beulah-Zap coal bed has been removed by erosion. The Beulah-Zap coal bed dips east at approximately 23 feet per mile (4.4 m per km) as shown on Plate 10.

The bed ranges in thickness from 4 feet (1 m) to 10 feet (3 m). The thickness increases to the east and west away from the northeast quadrant of the quadrangle, as shown on Plate 10, and the unit has up to 2 partings which total up to 8 feet (2.4 m) thick. The overburden ranges in thickness from 0 feet (0.0 m) to 200 feet (61.0 m) as shown on Plate 10.

Chemical Analyses of the Beulah-Zap Coal Bed - Proximate and elemental analyses of the Beulah Zap coal bed are presented in Tables A-1 and A-4 and indicate that the coal is of lignite rank.

No coal analyses are available from this quadrangle, but analyses of samples from the Beulah-Zap coal bed in the Dunn Center quadrangle indicate the following: Ash, 8.0%; Sulfur 0.8%; and BTU/lb, 6800.

SCHOOLHOUSE COAL BED

The Schoolhouse coal bed is the uppermost coal bed in the quadrangle. It is separated from the underlying Beulah-Zap coal bed by approximately 25 feet (7.6 m) of rock. Although no drill hole intersects the Schoolhouse coal seam in the Emerson quadrangle, drill hole data from the adjacent Lake Ilo quadrangle to the north indicate the generalized stratigraphic

relationships shown on the composite section. This relationship was used to project the approximate location of the outcrop of the Schoolhouse coal bed (Plate 1).

Due to the lack of detailed information, reserves for the Schoolhouse coal bed were not calculated.

LOCAL COAL BEDS

In the Emerson quadrangle, four local coal beds, varying in thickness from 1 to 8 feet (.3 to 2 m), occur in the Sentinel Butte member of the Fort Union Formation. The thickest coal bed is Local 3, a local bed that is correlatable between several quadrangles. Generally, the coal beds are thin, usually less than 5 feet thick, and of limited areal extent. Derivative maps were not constructed and coal resources and reserves were not calculated for the local coal beds because of insufficient data.

COAL RESOURCES

Coal resource classification, as used in this report, is based on the degree of geological assurance of the existence of the coal bed and the feasibility of recovery. The criteria for resource classification are based on the distance from the data point. The resource categories are:

Identified

measured - within 1/4 mile radius of data point

indicated - between 1/4 and 3/4 mile radius of data point

inferred - between 3/4 and 3 mile radius of data point

Hypothetical - beyond 3 mile radius of data point

Coal resource/reserve calculations are made using data presented on isopach and overburden contour maps for all Federal Government coal lands in the quadrangle. Where Federal coal ownership is restricted, the Reserve Base/Reserve tonnage was multiplied by the appropriate ownership percentage.

In areas suitable for surface mining, Reserve Base and Reserve tonnages are calculated for identified coal resources. Reserves are not calculated for Hypothetical coal resources.

In areas suitable for underground mining (coal bed thickness of 5 feet or greater and overburden from 200 to 1000 feet), Reserve Base and Hypothetical coal resource tonnages are calculated.

The resource tonnages are estimated by a computer algorithm which is interactive with an automated planimeter-digitizer. Each area is traced with a magnifying cursor and when a section is completed, a check is made to see that partial areas stored on diskettes sum to the area of the whole section.

The areas measured are converted by the algorithm using given parameters (lignite = 1750 tons per acre foot (1750 tons per acre foot - 12871 metric tons per hectare meter); recovery factor for strippable coal = 0.85) to yield Reserve Base and Reserves in millions of short tons per section for each class. Coal resource values for the HT Butte, Hazen, and Beulah-Zap beds are shown on Plates 6, 9 and 12, respectively. Reserve and Reserve Base values are rounded off to the hundredth of one million short tons.

Total Reserve Base and Hypothetical resource data for the three coal beds mapped in this quadrangle are shown on Plate 2.

COAL DEVELOPMENT POTENTIAL

Areas considered to have strip mining potential are assigned a high, moderate, or low development potential based on the mining ratio (cubic yards of overburden per ton of recoverable coal).

Coal outcrop traces were projected from structure contour maps and checked against previously projected outcrops (Law, 1977). An overlay of the structure contour and topographic maps provides data for computation of overburden thickness. The coal isopach map was overlain by the overburden isopach map and a mining ratio was calculated using the following the formula:

$$MR = \frac{To\ (.922)}{Tc\ (.85)}$$

where:

MR = cubic yards of overburden per ton of recoverable coal

To = thickness of overburden

Tc = thickness of coal

0.922 = factor to convert thickness of overburden and thickness of coal to cubic yards per ton

0.85 = coal recovery factor (85%)

The Coal Development Potential (CDP) map is compiled by overlaying each mining ratio map for the quadrangle on the property base and noting, for all Federal coal land, whether each 40-acre tract contains Reserve Base coal in any of the mining ratio categories (Plate 13). Areas of high, moderate, and low development potential for surface mining methods are here defined as areas underlain by coal beds having respective mining-ratio values of 0 to 10, 10 to 15, and greater than 15. The highest rating for each tract is plotted on the CDP map. Areas beyond the outcrop are designated "not applicable" and areas of less than 5 feet coal thickness are designated "0" development potential. Mining ratios are not calculated where the coal thickness is less than 5 feet or overburden thickness exceeds 200 feet.

DEVELOPMENT POTENTIAL FOR SURFACE MINING METHODS

The coal development potential for surface mining methods (less than 200 feet (61 m) of overburden) is shown on Plate 13 and coal tonnages are summarized in Table 2.

The Beulah-Zap, Hazen, and the HT Butte coal beds contain strippable coal reserves. The Beulah-Zap coal bed contains the most substantial quantities of strippable coal reserves (Table 2).

The area of high development potential in the southern quarter of the Emerson quadrangle is due mostly to the effect of the Beulah-Zap coal bed which reaches thicknesses of up to 8 feet (2.4 m). There are scattered areas of high development potential in the north central portion which are also due to the presence of shallow Beulah-Zap coal.

Both the Hazen and HT Butte coal seams contain less significant totals of strippable coal reserves (Table 2). Distribution of strippable coal reserves for the HT Butte and Hazen coal beds are shown on Plates 6 and 9, respectively.

The Hazen bed is too thin in most of this quadrangle to have much effect on the coal development potential. Throughout the center of the quadrangle, an area where ratings are not applicable, the Hazen coal is thinner than 5 feet (1.5 m), the HT Butte bed is deeply buried and much of the Beulah-Zap coal has been removed by erosion.

Table 2 - Strippable coal reserve base for Federal Coal Lands (in millions of short tons) in the Emerson Quadrangle, Dunn County, North Dakota

Development potentials are based on mining ratios (cubic yards of overburden/ton of underlying coal). To convert short tons to metric tonnes, multiply by 0.0972; to convert mining ratios in yd^3/ton to m^3/t, multiply by 0.842.

Coal Bed	High development potential (0-10 mining ratio)	Moderate development potential (10-15 mining ratio)	Low development potential (>15 mining ratio)	Total
Beulah-Zap	65.60	12.53	4.77	82.90
Hazen	0.26	0.11	3.66	4.03
HT Butte	0.00	0.00	6.53	6.53
	65.86	12.64	14.96	93.46

DEVELOPMENT POTENTIAL FOR UNDERGROUND MINING METHODS AND IN SITU GASIFICATION

The HT Butte coal bed, which is the lowest identified coal bed in the quadrangle, and the Hazen coal bed have substantial quantities of non-strippable (greater than 200 feet of overburden) coal resources as shown in Tables 2 and 3. The areal distribution of the coal resources is shown on Plates 6, 9 and 12, respectively.

The development potential for underground mining methods is considered low in this quadrangle because there are no active or planned underground mines in the quadrangle and no criteria for its classification have been established.

No criteria have been established for rating the development potential by in situ gasification of coal methods in this area.

Table 3 - Coal Reserve Base for Non-Strippable Coal for Federal Coal Lands (in millions of short tons) in the Emerson Quadrangle, Dunn County, North Dakota.

To convert short tons to metric tons, multiply by 0.9072.

	High development potential	Moderate development potential	Low development potential	Total
Beulah-Zap	0.00	0.00	0.08	0.08
Hazen	0.00	0.00	0.96	0.96
HT Butte	0.00	0.00	88.16	88.16
	0.00	0.00	89.20	89.20

REFERENCES

Bauer, C.M., and Herald, F.A., 1921, Lignite in the western part of the Fort Berthold Indian Reservation south of Missouri River, North Dakota: U.S. Geological Survey Bulletin 726-D, 77 p.

Bensen, W.E., 1951, Geologic map of North Dakota southwest of the Missouri River: U.S. Geological Survey Preliminary Map, Scale 1:500,000.

_____, 1953, Geology of the Knife River area, North Dakota: U.S. Geological Survey Open-File Report 1953, 323 p.

Bluemle, J.P., 1971, Geology of McLean County, North Dakota: North Dakota Geological Survey, Bulletin 60, Part I, 65 p.

Brant, R.A., 1953, Lignite resources of North Dakota: U.S. Geological Survey Circular 226, 78 p.

Carlson, C.G., 1972, Stratigraphic position of lignite beds in Tertiary rocks of Mercer and Oliver Counties, North Dakota, in Ting, T.T.C. (Ed), Depositional environments of the lignite-bearing strata in western North Dakota: North Dakota Geological Survey Guidebook No. 3, Miscellaneous Series No. 50, p 95-104.

_____, 1973, Geology of Mercer and Oliver Counties, North Dakota: North Dakota Geological Survey Bulletin 56, Part I, 72 p.

Clayton, Lee, 1969, Geologic map of Dunn County, North Dakota: North Dakota Geological Survey Miscellaneous Map 11, Scale 1:2 miles.

Colton, R.B., Lemke, R.W., and Lindvall, R.M., 1963, Preliminary glacial map of North Dakota: U.S. Geological Survey Miscellaneous Geological Investigations Map I-331, Scale 1:500,000.

Croft, M.G., 1970, Ground water basic data, Mercer and Oliver Counties, North Dakota: North Dakota State Water Commission County Ground Water Studies 15, Part II, 268 p.

Electric Log Services, Inc., 1977, Electrical, radioactivity and hydrocarbon survey: Rocky Mountain Well Log Service Index to Northern Rockies, 1702 p.

REFERENCES (Continued)

Hainer, J.L., 1956, The geology of North Dakota: North Dakota Geological Survey Bulletin 31, 52 p.

Hancock, E.T., 1921, The New Salem lignite field, Morton County, North Dakota: U.S. Geological Survey Bulletin 726-A, 39 p.

Johnson, W.D., and Kunkel, R.P., 1959, The Square Buttes coal field, Oliver and Mercer Counties, North Dakota: U.S. Geological Survey Bulletin 1076, 91 p.

Klausing, R.L., 1971, Ground water basic data, McLean County North Dakota: North Dakota State Water Commission County Ground Water Studies 19, Part II, 468 p.

_____, 1974, Ground water resources of McLean County North Dakota: North Dakota State Water Commission County Ground Water Studies 19, Part III, 73 p.

_____, 1976, Ground water basic data for Dunn County, North Dakota: North Dakota State Water Commission County Ground Water Studies 25, Part II, 501 p.

Law, R., 1977, Preliminary report on the geology of the near-surface coal beds in the Knife River area, North Dakota: U.S. Geological Survey Open File Report 77-481, 12 p.

Leonard, A.G. Babcock, E.J., and Dove, L.P., 1925, The lignite deposits of North Dakota: North Dakota Geological Survey Bulletin No. 4, 240 p.

Menge, M., 1977, A preliminary report on the near-surface Federal Coal Reserve Base underlying the south half of the Dunn Center Lignite Field, Dunn County, North Dakota: U.S. Geological Survey Open-File Report, in preparation, 127 p.

North Dakota Geological Survey, 1973, Mineral and water resources of North Dakota: North Dakota Geological Survey Bulletin 63, 252 p.

_____, 1977, Unpublished Summary of 1977 Drilling, 19 p.

Pollard, B.C., Smith, J.E., and Knox, C.C., 1972, Strippable lignite reserves of North Dakota, location, tonnage, and characteristics of lignite and overburden: U.S. Bureau of Mines Information Circular 8537, 37 p.

REFERENCES (Continued)

Rehbein, E.A., 1977, Preliminary report on stratigraphy and depositional environments of the lignites in the Fort Union Formation, west-central North Dakota: U.S. Geological Survey Open-File Report 77-69, 23 p.

Royse, C.F. & Jr., 1967, Tongue River-Sentinel Butte contact in western North Dakota: North Dakota Geological Survey Report of Investigation No. 45, 53 p.

_____, 1971, A sedimentologic analysis of the Tongue River-Sentinel Butte interval (Paleocene) of the Williston Basin, western North Dakota: North Dakota Geological Survey Miscellaneous Series No. 43, 80 p.

_____, 1972, the Tongue River and Sentinel Butte Formations (Paleocene) of western North Dakota, In Ting, T.T.C. (Ed), Depositional environments of the lignite-bearing strata in western North Dakota: North Dakota Geological Survey Guidebook No. 3, Miscellaneous Series No. 50. p 31-42.

Sondreal, E.A., Kube, W.R., and Elder, J.L., 1968, Analysis of the Northern Great Plains province lignite and their ash -- A study of variability: U.S. Bureau of Mines Report Inv. 7158, 94 p.

Swanson, Vernon E. et.al., 1976, Collection, chemical analysis and evaluation of coal samples in 1975, U.S. Geological Survey Open-File Report 76-468, 503 p.

United States Department of Interior, 1977, Resource and potential reclamation evaluation of Horse Nose Butte study area. Dunn Center lignite field: U.S. Department of Interior EMRIA Report No. 9, 83 p.

United States Geological Survey and Montana Bureau of Mines and Geology, 1976, Preliminary report of coal beds in Campbell and Sheridan Counties, Wyoming: Custer, Praire, Garfield Counties, Montana; and Mercer County, North Dakota: U.S. Geological Survey Open-file Report 76-319, 377 p.

United States Geological Survey and North Dakota Geological Survey, 1976, Preliminary report on 1975 drilling of lignites in western North Dakota: Adams, Bowman, Dunn, Hettinger, McLean, Mercer, Oliver, Slope, and Williams Counties: U.S. Geological Survey Open-File Report 76-869, 144 p.

REFERENCES (Continued)

_____, 1977, Preliminary report of 1976 drilling of lignites in western North Dakota: Adams, Billings, Dunn, Hettinger, McKenzie, Mercer, Morton, Oliver, Slope, and Stark Counties: U.S. Geological Survey Open-File Report 77-857, 336 p.

Zubovic, Peter, Stadnichanko, Taisia, and Shaffey, N.B., 1961, Geochemistry of minor elements in coals of the Northern Great Plains coal province: U.S. Geological Survey Bulletin 117-A, 58 p.

APPENDIX A

PROXIMATE AND ELEMENTAL ANALYSES

Table A-1 Proximate Analyses (as received)

Bed Name	No. of Samples	Moisture %	Volatile Matter %	Fixed Carbon %	Ash %	Sulphur (Ultimate) %	Btu/lb*	Data Source
HT Butte	2	36.6	27.9	29.5	5.9	0.7	6970	Pollard et al., 1972
HT Butte	2	32.4	31.6	30.3	5.9	0.7	7024	Brant, 1953
HT Butte	3	35.5	28.6	31.1	4.9	0.5	7150	Johnson & Kunkel, 1959
Hazen	1	41.0	25.9	28.9	4.2	0.5	6290	Johnson & Kunkel 1959
Beulah-Zap	15	36.1	26.9	30.7	6.2	0.73	6890	Sondreal, Kube Elder, 1968
Beulah-Zap	3	34.0	29.0	29.0	8.0	0.8	6800	Pollard, et al., 1972
Beulah-Zap	1	39.5	28.3	25.3	6.9	0.4	5910	Johnson & Kunkel, 1959
Beulah-Zap	2	35.7	28.5	30.8	4.9	0.6	7018	Brant, 1953
Beulah-Zap	2	35.88	27.66	30.18	6.27	1.00	6566	Leonard, et al., 1925
Beulah-Zap	4	36.3	28.1	29.6	6.0	1.16	7028	USGS & Mont.Bur. of Mines & Geol. 1976
Beulah-Zap	10	29.6	29.6	34.2	6.7	0.5	7330	Swanson et al., 1976
Schoolhouse	1	35.8	26.9	31.7	6.6	1.0	6910	Pollard, et al., 1972
Schoolhouse	3	38.1	27.5	28.7	5.7	1.2	6720	Johnson & Kunkel 1959
Ave. Dunn Co.	-	40.6	-	-	7.0	0.6	6310	USDI, 1977
Ave. N.D.	-	36.0	28.0	29.0	6.0	0.7	6600	Leonard, et al., 1925

* To convert Btu/lb to Kilojoules/Kilogram, multiply by 2.326

Table A-2 -- Elemental Analysis of HT Butte Coal Bed

Element	Concentration in % Sample No.* D-80824	Sample No.* D-80825	Sample No.* D-80823
Sulphur	0.6	0.4	0.4
Hydrogen	6.8	6.9	6.9
Carbon	41.5	43.1	42.3
Nitrogen	0.7	0.6	0.7
Oxygen	44.0	45.0	45.5

*Johnson and Kunkel, 1959.

Table A-3 -- Elemental Analysis of Hazen Coal Bed

Element	Concentration-in % Sample No.* D-55178	Sample No.* 49875
Sulphur	0.5	
Hydrogen	7.0	
Carbon	38.0	
Nitrogen	0.6	
Oxygen	49.7	
U		0.0001
Ge**		ND
Ga**		0.002
V**		0.005
Cu**		0.004
Cr**		0.002
Zn**		0.01
Ni**		0.005
Co**		0.002
Be**		0.0003
Y**		0.01
La**		0.02
Mo**		ND

* Johnson and Kunkel, 1959
** Results in percent of ash

Table A-4 -- Elemental Analysis of Beulah-Zap Coal Bed

Element	Concentration in % Sample No.* 49879	Sample No.*** ND-KR-Bu	Sample No.**** ND-TT-DS	Sample No.***** D175930 to D17539
Sulphur				0.5
Hydrogen				6.2
Carbon				44.6
Nitrogen				0.7
Oxygen				41.3
U	0.0003			0.00005
Ge**	ND	0.001	ND	ND
Ga**	0.002	0.002	0.004	0.0015
V**	0.008	0.005	0.007	0.0035
Cu**	0.005	0.007	0.02	0.0055
Cr**	0.006	0.005	0.004	0.0025
Zn**	ND	ND	ND	0.0025
Ni**	0.005	0.003	0.006	0.0020
Co**	0.002	0.001	0.002	0.0010
Be**	0.0002	0.0008	0.0008	0.0003
Y**	0.01	0.004	ND	0.0025
La**	0.01	0.004	ND	0.01
Mo**	ND	0.002	0.004	0.0010
B**		0.24		0.110
Ti**		0.2		0.70******
Sn**		ND		---

* Johnson and Kunkel, 1959
** Results in percent of ash
*** Zubovic et al., 1961, average of 4 samples
**** Zubovic et al., 1961, average of 2 samples
***** Swanson et al., 1976
****** as TiO_2

Table A-5 - Elemental Analaysis of Schoolhouse Coal Bed

	Concentrations in %				
Element	Sample No.* D-55179	Sample No.* D-55176	Sample No.* D-55175	Sample No.* 49874	Sample No.* 49880
Sulphur	0.9	0.5	2.1		
Hydrogen	7.1	6.9	6.7		
Carbon	39.9	40.4	39.2		
Nitrogen	0.6	0.6	0.6		
Oxygen	46.4	47.4	43.6		
U				0.0001	0.0001
Ge**				ND	ND
Ga**				0.002	0.002
V**				0.01	0.006
Cu**				0.02	0.004
Cr**				0.007	0.005
Zn**				0.7	0.06
Ni**				0.002	0.003
Co**				0.001	0.001
Be**				0.001	0.0007
Y**				0.01	ND
La**				0.02	ND
Mo**				ND	ND

* Johnson and Kunkel, 1959
** Results in percent of ash