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An investigation of the Bakken and Englewood formations (Kinderhookian) of North Dakota and northwestern South Dakota

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AN INVESTIGATION OF THE BAKKEN AND ENGLEWOOD FORMATIONS (KINDERHOOKIAN) OF NORTH DAKOTA AND NORTHWESTERN SOUTH DAKOTA

by

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This thesis submitted by Jack Kume in partial fulfillment of the requirements for the Degree of Master of Science in the University of North Dakota, is hereby approved by the Committee under whom the work has been done.

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ABSTRACT

Lower Mississippian rocks of the Williston Basin and the Black Hills include the Bakken and Englewood formations of Kinderhookian age. The Englewood formation crops out in the northern Black Hills and can be traced with difficulty into the subsurface. The Bakken formation does not crop out in the area of this study. This study is based upon well sample and mechanical log information and measured surface sections.

The Englewood in the outcrops consists of a lower shale unit, a middle argillaceous and shaly limestone unit, and an upper dolomitic limestone unit. A type section, NW¼SE¼ sec. 31, T. 4 N., R. 3 E., two miles southwest of Englewood, South Dakota, is proposed.

About ten miles north of the outcrop area, the Englewood consists of a lower calcareous siltstone unit, a middle silty limestone unit, and an upper calcareous siltstone unit. In northern Butte County, South Dakota, the formation consists of an argillaceous limestone which overlies the Bakken.

The Bakken formation consists of a lower black shale unit, a middle sandstone, silty limestone, or limestone unit, and an upper black shale unit. The Bakken can be easily defined and traced where the three units are present. This area of occurrence is designated the Central Area. Around the Central Area the stratigraphic units converge and become thin, and the lower shale is not present. This area of occurrence is designated the Marginal Shelf.

The Bakken sea probably originated in the Cordilleran region, was initially restricted in circulation, later became a normal marine sea, and was then again restricted in circulation. The seaway probably occupied the Central Area with its marginal area defined by the Marginal Shelf.

ACKNOWLEDGMENTS

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INTRODUCTION

General Statement

Since 1951, when oil was discovered in North Dakota, renewed interest and added information has resulted in the undertaking of many investigations of the subsurface of the Williston Basin. The Mississippian system has especially been widely studied because most of the oil production comes from rocks of this system. Widespread black shales of the Bakken formation in the Williston Basin represent the initial deposits of the Mississippian seas. The relationship of the subsurface Bakken formation and the Englewood formation of nearly equivalent age which crops out in the Black Hills and also occurs in the subsurface, has not been entirely understood.

Purpose

The purpose of this paper is to present stratigraphic descriptions of the Englewood and Bakken formations, and with the use of cross sections and isopach maps to present information which might be of value in understanding their relationship.

Area of Study

The area of this regional study consists of approximately 50,000 square miles in west and central North Dakota, northwestern South Dakota, and a minor amount of northeastern Montana (Figure 1). This area includes

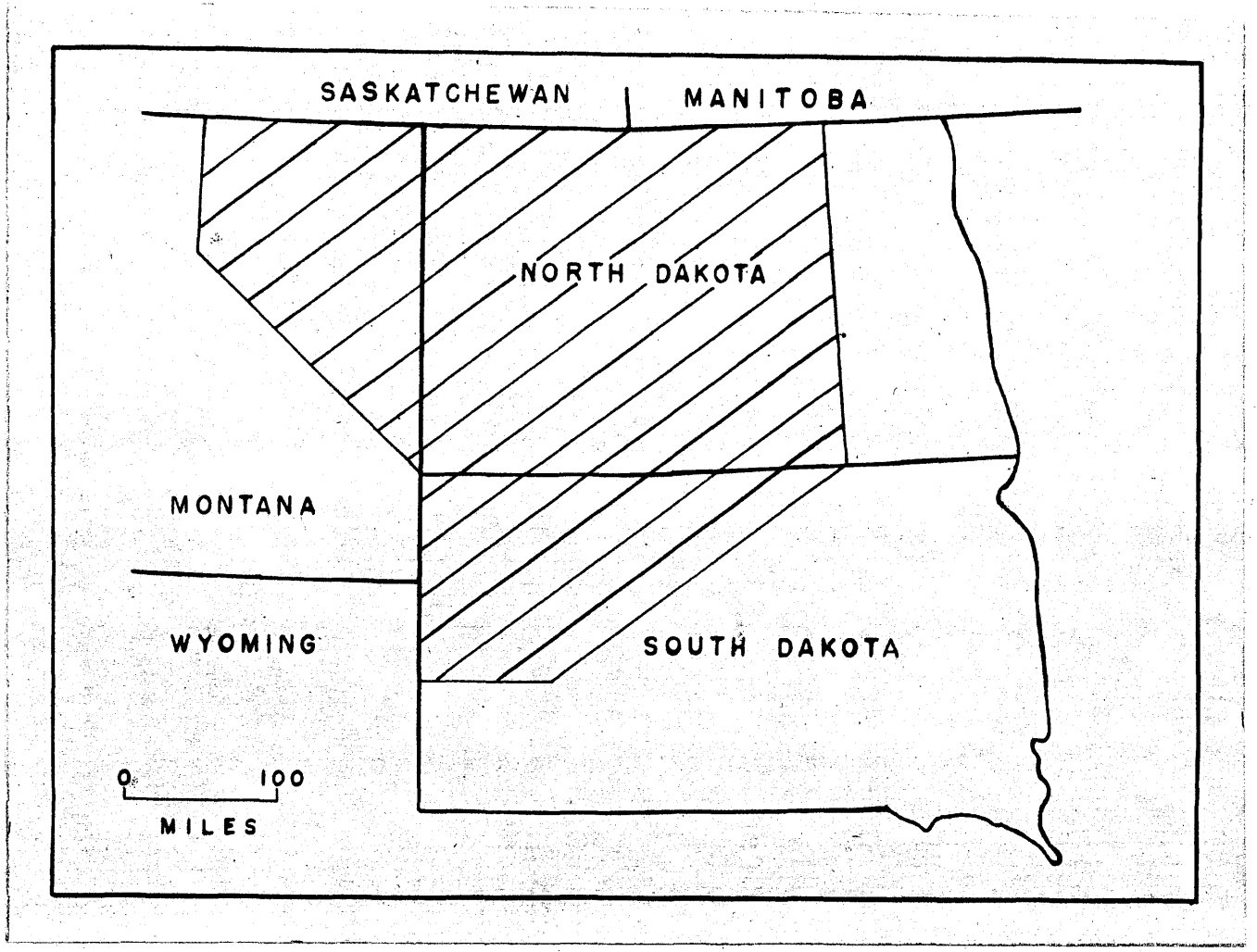

Fig. 1. -- Index map showing the area of this study.

a large portion of the Williston Basin and part of the Black Hills.

Sections of the Englewood which crop out in the northern Black Hills were studied. North of this area, the Englewood passes into the subsurface where it was studied by the use of well samples and mechanical logs from several wells drilled in northwestern South Dakota.

The Bakken formation was named from the subsurface and does not crop out in the area of this study. It was studied by the use of well cuttings and cores from selected wells drilled in North Dakota and South Dakota. Mechanical logs were studied in conjunction with the lithologic studies, and in some instances, mechanical logs were studied without the aid of samples. The type section of the Bakken formation occurs in the Amerada Petroleum Corporation - H. O. Bakken No. 1 well, SW¼NW¼ sec. 12, T. 157 N., R. 95 W., Williams County, North Dakota. The type section was restudied and redefined.

A list of wells studied and lithologic descriptions of the samples studied appear in the appendices of this report.

Method of Study

Field Methods

During the summer of 1959 the writer made two trips in the field, one during the first week of August and the other during the first week of September. Two sections of the Englewood formation were studied and described in detail. One of the sections occurs in the type area as designated by Darton (1901), near Englewood, South Dakota, and the other section occurs near Deadwood, South Dakota. The latter section is herein referred to as the Deadwood junkyard section since the section was measured behind

a junkyard near the Deadwood city dump. These sections were measured with a six-foot steel tape, hand level, and Brunton compass. The color names used in the lithologic descriptions are those given in the Rock Color Chart (Goddard, and others, 1951). Hand samples and fossils were collected and studied in the laboratory.

Laboratory Methods

During the summer of 1959 the writer examined samples of well cuttings and cores from wells drilled in North Dakota. The samples and cores were made available from the depository in the North Dakota Geological Survey. The samples were studied under a binocular microscope in conjunction with mechanical well logs. The mechanical logs were especially useful in determining exact footage of the samples. The black shales of the Bakken formation which contain a high concentration of radioactive elements, were easily defined by the use of the gamma ray well log. Lithologic descriptions were made of the well samples studied. The size of the medium grained material was determined by comparison with sized sand grains mounted in an accurately sieved sand size comparison chart prepared by the writer.

Several attempts were made to "break down" or disaggregate the black shale for the purpose of concentrating conodonts which are present. Some of the methods tried, but with little or no success included: (1) dissolving in acetic acid, (2) boiling in sodium hydroxide (maximum time tried was 12 hours), (3) boiling in potassium hydroxide, (4) soaking in Stoddard solution for 12 hours, drying the sample in an oven at 170 degrees centigrade for one hour, and boiling the sample in sodium hydroxide for 8 hours.

Lithologic studies of the Englewood and Bakken in several South Dakota wells were conducted by the writer in October, 1959, at the South Dakota Geological Survey at Vermillion, South Dakota.

Regional Geologic Setting

Structure

The structure contour map (Figure 2) shows the present configuration of the upper surface of the Bakken formation. The maximum depth to the top of the Bakken found by the writer was attained in eastern McKenzie County, North Dakota, in The California Company - Rough Creek Unit No. 1 well, NW¼NE¼ sec. 13, T. 148 N., R. 98 W. The Bakken occurs at a depth of 8739 feet below sea level or at a depth of 11,200 feet in this drilled hole.

The Williston Basin is clearly shown by this structural contour map, and the center of the Basin is located near the mutual boundaries of McKenzie and Dunn Counties. The difference in elevation of the upper surface of the Bakken formation from central North Dakota to west central North Dakota is 5800 feet. Kay (1951, p. 23) reported that an autogeosyncline or a basin isolated from highland source areas, developed in this area during the Mississippian.

The Nesson Anticline is roughly shown on the structure contour map. It trends north-south and extends for about 66 miles through Williams, McKenzie, Mountrail, and Dunn Counties.

The Cedar Creek Anticline does not show on the structure contour map, but it occurs mainly in southeastern Montana, trending in a northwest-southeast direction. The southern end of the Cedar Creek Anticline occurs near the southwest corner of North Dakota.

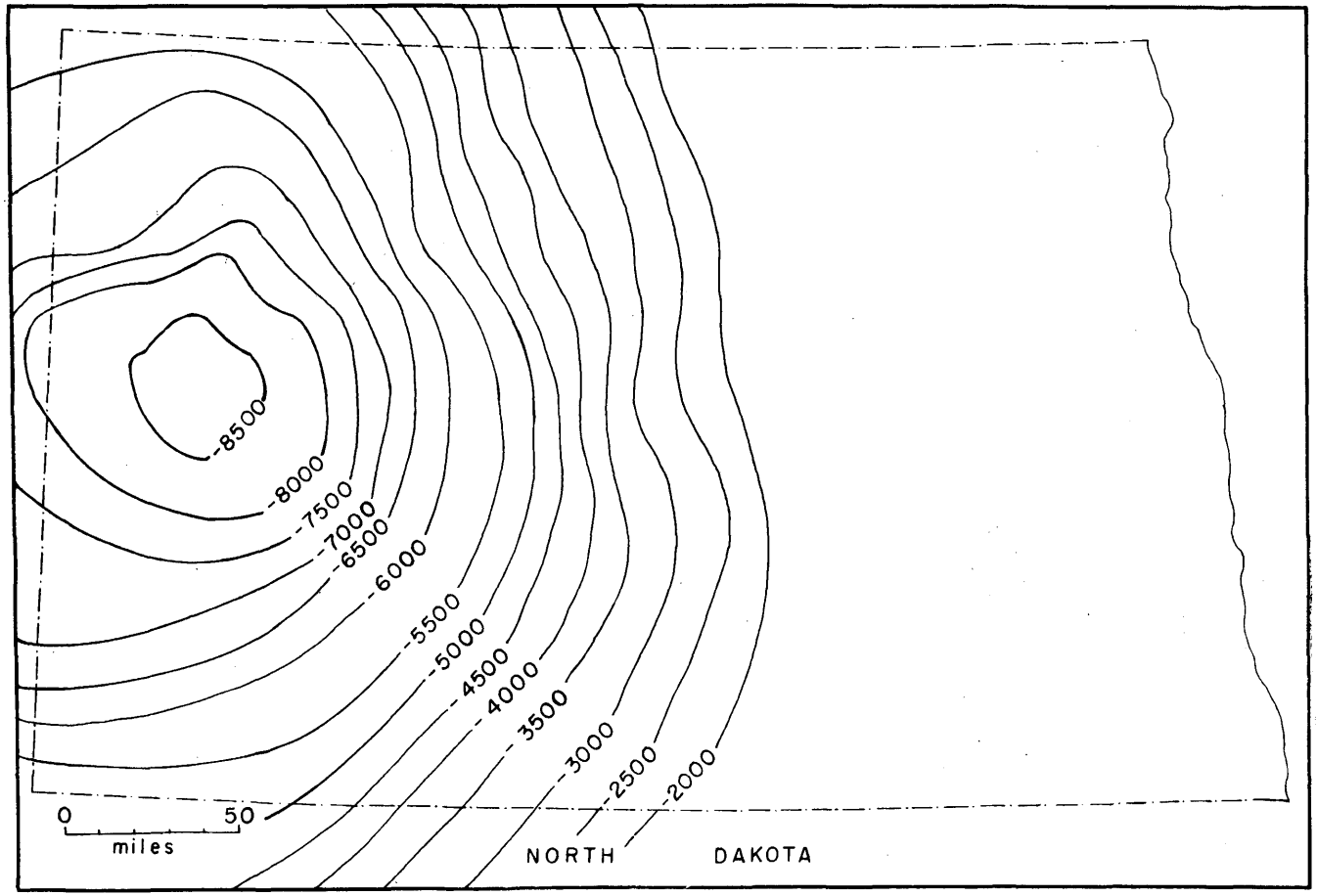

Fig. 2. -- Structure contour map on the top of the Bakken formation. Contour interval = 500 feet. Datum = Sea level.

Hardley (1951, p. 42, and Plates 4 and 5) pointed out some of the regional structures that influenced sedimentation during the Devonian and Mississippian time in the area of study. During the Devonian, the Cambridge Arch, trending in a northwest-southeast direction, was located in southeastern Montana and western South Dakota. The Continental Arch, trending in a southwest-northeast direction, was located in eastern South Dakota and in most of Minnesota. The Alberta Shelf was present in Canada, northwest of the area of this study. During the Mississippian the Big Snowy Basin extended from central Montana into the western half of North Dakota. Borden (1956, p. 157) reported that near the northwestern boundary of the Williston Basin in southeastern Alberta, the Sweetgrass Arch was uplifted in late Devonian to early Mississippian time.

Sandberg and Hammond (1958, p. 2350) reported that renewed uplift of the Cedar Creek platform and the "ancestral" Cedar Creek Anticline took place near the end of Bakken deposition.

Stratigraphy

Devonian-Mississippian stratigraphic names associated with the systemic boundary which have been used in the area of this study and adjoining areas are shown in Figure 3. The systemic boundary has been placed at the base of the black shales by many workers, some of whom are listed. Black or gray shales, which have been considered by these workers as Mississippian in age, occur in the Bakken formation, the Englewood formation, the Sappington sandstone of Montana and the Exshaw shale of Alberta. The Little Chief Canyon member of the Lodgepole formation in Montana, although not listed in Figure 3, consists of black shale which

is considered by Knechtel, and others, (1954) as Kinderhookian in age. Sandstones and siltstones are commonly found overlying or underlying these black to gray shales as shown by the middle clastic-carbonate unit of the Bakken, the sandstone unit of the Sappington, and the lower silty shale or siltstone of the Englewood.

	BLACK HILLS SOUTH DAKOTA DARTON AND PAIGE 1925	WILLISTON BASIN NORTH DAKOTA NORDQUIST, 1953 (MODIFIED)	SOUTHWESTERN MONTANA HOLLAND, 1952	SOUTHERN ALBERTA PENNER, 1958	WESTERN ALBERTA CRICKMAY, 1952
MISSISSIPPIAN	PAHASAPA	MADISON: MISSION CANYON / LODGEPOLE	MADISON: MISSION CANYON / LODGEPOLE	PEKISO / BANFF	BANFF
MISSISSIPPIAN	ENGLEWOOD	BAKKEN	SAPPINGTON	BAKKEN	EXSHAW
DEVONIAN		THREE FORKS	THREE FORKS	BIG VALLEY	PALLISER
DEVONIAN		BIRDBEAR (NISKU)	JEFFERSON		
ORD.	WHITEWOOD				
ORD.	WINNIPEG				

Fig. 3.--List of stratigraphic names associated with the Devonian-Mississippian boundary in the area of this study and adjoining areas.

PREVIOUS WORK

Black shales associated with the Devonian-Mississippian contact have been reported in the Williston Basin and adjoining areas in Montana and Canada by many workers.

Various names have been applied to these black shales in this area such as "Kinderhookian", Exshaw, "Englewood", Little Chief Canyon member of the Lodgepole, Sappington, and Bakken formations. "Kinderhookian" has been used informally by some workers as a formation name for the black shales of the Williston Basin, but this usage should be abandoned, as the term conflicts with the standard time-stratigraphic (series) designation and also, because adequate lithostratigraphic terminology has been introduced for these shales.

In western Alberta, Warren (1937) named 35 feet of black shale underlying the Banff shale and overlying the eroded surface of the Palliser formation, the Exshaw shale. Initially a Devonian age was ascribed to the Exshaw based on a small collection of ammonites. However, Crickmay (1952) challenged the identification of the ammonites and suggested that the Devonian-Mississippian boundary be placed at the base of the Exshaw shale. Paleontologic evidence was the basis for this placement of the systemic boundary. He also believed that the lithology of the Exshaw shale was in variance with Devonian deposits, and it initiated the mode of sedimentation of the Mississippian.

Knechtel and Hass (1958) studied conodonts from a black shale of the Little Rocky Mountains in Montana, and ascribed a Devonian age to the conodonts. Another study of conodonts was conducted in 1943 by Cooper and Sloss. They found Lower Mississippian conodonts in a black shale in Montana and Alberta.

Sloss and Laird (1945, 1947) studied the Devonian system in central and northwestern Montana, and they reported that black shale underlies the Lodgepole limestone of the Madison group of Mississippian age and overlies the Three Forks formation at Logan, Montana. They stated (1947, p. 1420) that the, ". . . lithogenetic and cartographic top of the Devonian units is the base of the black shale."

Holland (1952) also studied the Lower Mississippian rocks in the Three Forks area near Logan, Montana, and agreed with Berry (1943) in assigning a Mississippian age to the Sappington sandstone. In addition to paleontological evidence, Holland recognized an unconformity below the black shale which underlies the sandstone unit of the Sappington. He therefore extended the Sappington formation downward to include the black shale and placed the Devonian-Mississippian boundary at the base of the black shale.

Knechtel, and others, (1954) proposed the name, Little Chief Canyon member of the Lodgepole formation for a thin, conodont-bearing black shale at the base of the Lodgepole which crops out in the Little Rocky Mountains. The shale contains a Kinderhookian conodont fauna.

Sandberg and Hammond (1958) conducted an extensive study of the Devonian in the Williston Basin. They believed that the age of the Bakken is Devonian (?) and Early Mississippian. They reported that intense

erosion thinned Upper Devonian and Lower Mississippian rocks on the basin edges, the Central Montana platform, and the "ancestral" Cedar Creek Anticline. They believed that the subsurface equivalent of the Sappington is the Bakken formation.

Due to the lack of agreement of many workers in the Williston Basin and the resulting confused terminology, the term "Bakken formation" was introduced by the Williston Basin Nomenclature Committee of the Saskatchewan Society of Petroleum Geologists and of the Rocky Mountain Section of the American Association of Petroleum Geologists in 1953. The term was proposed for the occurrence of two black "organic shales" separated by a dark, very fine grained, calcareous sandstone in the Amerada Petroleum Corporation - H. O. Bakken No. 1 well near Tioga, North Dakota. The term, however, was not formally defined, but it appeared in Regional Cross Sections published by the North Dakota Geological Society (1953).

Nordquist (1953, p. 72) noticed that the Bakken formation had never been formally defined or described. He, therefore, proposed the term for the strata occurring between the depths of 9615-9720 feet in the Amerada Petroleum Corporation - H. O. Bakken No. 1 well, SW¼NW¼ sec. 12, T. 157 N., R. 95 W., Williams County, North Dakota. He assigned a Kinderhookian age to the Bakken on the basis of a pronounced lithogenetic break between the basal shale unit of the Bakken and the underlying Devonian. Nordquist thought that the Bakken is equivalent to the Exshaw shale to which Crickmay (1952) assigned a Kinderhookian age.

Fuller (1956) studied the Bakken formation in southeastern Saskatchewan. He divided the area into three regions based on the occurence of the shale units of the Bakken. He recognized an erosional surface, marked

by a pebble bed, between the Bakken and the Three Forks formation.

Reasoner and Hunt (1954, p. 1539) introduced the term "Coleville sand" for the middle sandstone unit of the Bakken formation. According to Kents (1959, p. 18) the term had been previously used by Berg (1953) in a master's thesis at the University of Saskatchewan. Reasoner and Hunt also referred to the lower shale unit of the Bakken as the Exshaw shale member.

Penner (1958, p. 263-270) studied the Bakken formation in southern Alberta and recognized four lithologic units of the Bakken. He stated (p. 264-265) that, "In view of the obvious and exact correlation of this unit with the Bakken of North Dakota it is proposed to adopt the use of this name in southeastern Alberta."

Kents (1959) reported that in west central Saskatchewan the Bakken consists of three members: Exshaw shale member, Coleville sandstone, and upper shale.

Disagreement still existed among some workers as to the correct terminology, and as late as 1958, Anderson (p. 8) reported that:

> . . . in the opinion of the North Dakota Geological Survey, the Englewood of North Dakota correlates reasonably closely with the Englewood of the Black Hills. Therefore, there is no apparent need to use the term "Bakken" unless further study indicates the need.

Folsom, Carlson, and Anderson (1959, p. 5) however, reported that the term "Bakken formation" was accepted by the North Dakota Geological Survey who had previously used "Englewood formation" for the same interval.

The term "Englewood limestone" was introduced by Darton (1901, p. 509) for the occurrence of a "thin-bedded, pale pinkish-buff limestone" exposed near Englewood, South Dakota, in the central Black Hills. In

1925 additional studies were made by Darton and Paige who conducted extensive studies of the central Black Hills.

Paleontological investigations of the Englewood formation by Girty (1925) suggested a Kinderhookian age. Huedemann and Lockman (1942) reported the finding of three new species of Dictyonema from the basal shale of the Englewood. They reported that this was the second known occurrence of graptolites in Mississippian rocks of North America. Weller, and others, (1948) assigned a Kinderhookian age to the Englewood as shown by the association of Paraphorhynchus and Productus s. l. They also reported that the basal shale may correspond to black Kinderhookian shales in other areas of the interior of North America.

		NORTH DAKOTA				SOUTH DAKOTA
		NORDQUIST, 1953	ANDERSON, 1958	FOLSOM, AND OTHERS, 1959	THIS STUDY	
MISSISSIPPIAN	MADISON	LODGEPOLE	LODGEPOLE	LODGEPOLE	LODGEPOLE	PAHASAPA
		BAKKEN	ENGLEWOOD	BAKKEN	BAKKEN	ENGLEWOOD
DEVONIAN		THREE FORKS	LYLETON	"SANISH" QU'APPELLE	"SANISH" THREE FORKS	
		"NISKU"	"NISKU"	BIRDBEAR ("NISKU")	BIRDBEAR	

Fig. 4.--A comparison of stratigraphic terminology in the area of this study.

Gries (1952, p. 70-71) pointed out that the division of the Englewood and the Pahasapa formations on the basis of the obvious color change which may not coincide with a change in insoluble residue content. He observed, ". . . a steady decrease in red clay residue as the top of the section is approached. The residue drops suddenly to a trace near the Pahasapa-Englewood contact."

STRATIGRAPHY

Englewood Formation

Name and Definition

Darton (1901, p. 509) in his original description of the Englewood formation stated:

> In the southern Black Hills the Deadwood formation is overlain by a series of thin bedded pale pinkish-buff limestones. On the suggestion of Mr. Jagger it is proposed to designate this formation the Englewood limestone from a locality in the northern Black Hills where it is extensively exposed.

Darton and Paige (1925, p. 7) subsequently reported that:

> On Whitewood Creek above Englewood station the limestone has a deep pinkish purple tint. Its upper part is thin bedded, but it is more massive below . . . In this region the Englewood lies on greenish-gray shale at the top of the Deadwood formation.

The greenish-gray shale has been referred to as the Winnipeg formation of Ordovician age by Carlson (1959). Overlying the Englewood formation is the Pahasapa formation of Mississippian age. The Englewood formation is Kinderhookian in age.

Type Section

<u>Location</u>

Darton did not designate any specific location as a type section for the Englewood formation. He had, however, designated a type locality which was near Englewood, South Dakota.

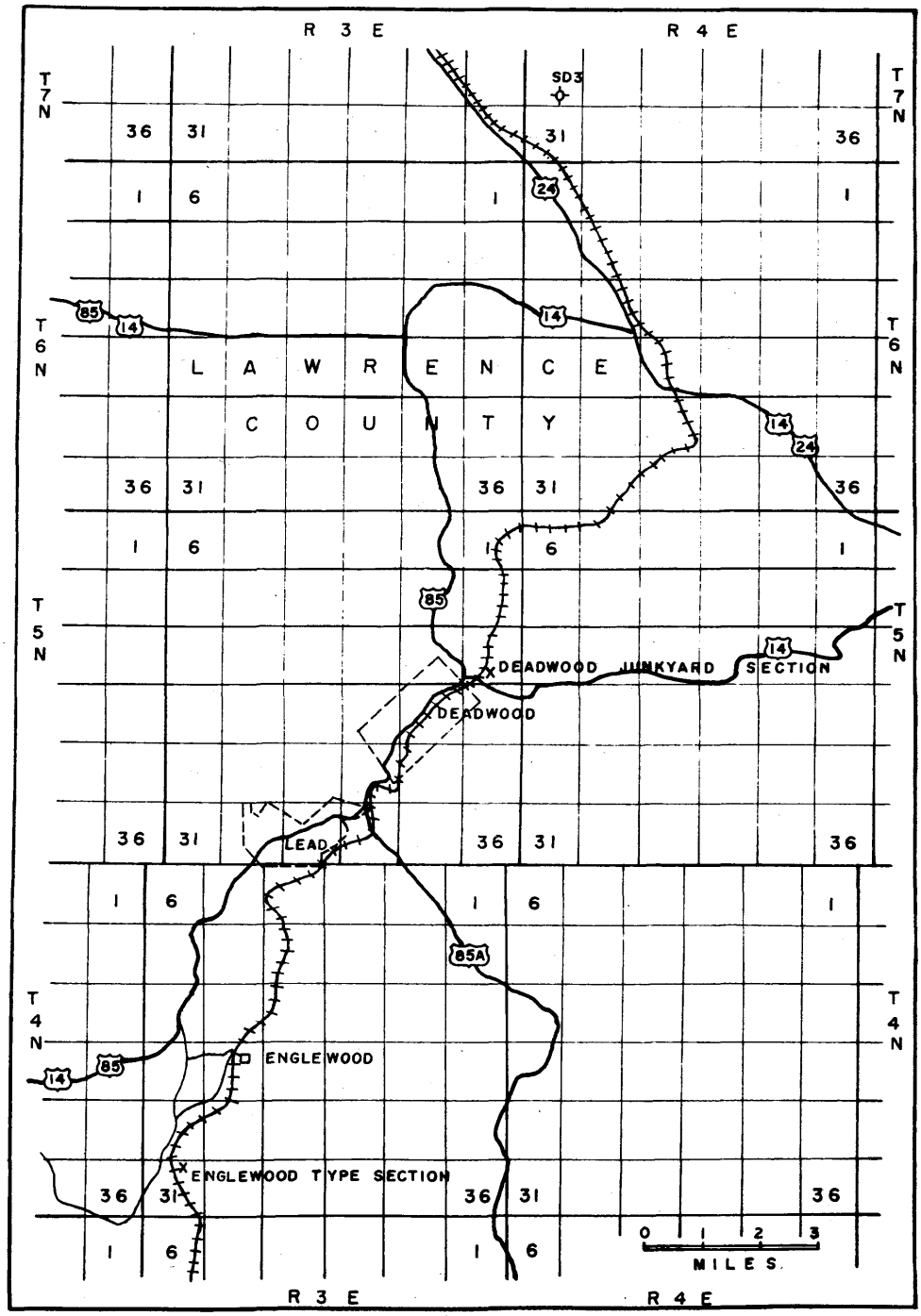

Fig. 5.—Index map showing location of the proposed Englewood type section and standard reference section. Location of the Weller Bush - Weisman No. 1 well is shown (SD 3).

The writer visited the area near Englewood, South Dakota, in August, 1959, and again in September, 1959. Three exposures of the Englewood formation were found in a Chicago, Burlington, and Quincy Railway cut. The locations of these exposures are NW¼NE¼ sec. 31, T. 4 N., R. 3 E.; NW¼SE¼ sec. 31, T. 4 N., R. 3 E.; and SE¼NE¼ sec. 30, T. 4 N., R. 3 E., respectively, Lawrence County, South Dakota. Of these three exposures, the Englewood formation is best exposed and most complete at the first listed location. Although the lower contact of the Englewood is covered, and although there has been some slumping in this area, this outcrop is the best type exposure available, so it is herein proposed as the type section for the Englewood formation.

It might be argued by some workers that this proposed type section is not characteristic since the lower contact is covered and since the lower shale unit as seen in other distant areas, may be missing. If the lower siltstone which is exposed at the proposed type section can be demonstrated as not being part of the Englewood formation as it is exposed in other areas to the north, then only the middle limestone and upper dolomitic limestone unit are present.

The siltstone which is thought by the writer to be the lower unit of the Englewood formation in the proposed type section may, however, be the Roughlock member of the Winnipeg formation (Carlson, 1959, personal communication in the field). The use of the term "Winnipeg" is used as suggested by Carlson (1959) who has traced the Winnipeg formation from its type locality in Canada, across the Williston Basin, to the Black Hills. Due to the covered interval immediately above and below the exposed siltstone unit, the direct relationship with the Winnipeg formation could

not be established. Samples of the siltstone were digested in hydrochloric acid, and a grayish red purple clay residue was present in the insoluble residue. The color compares perfectly with the argillaceous material found in the insoluble residues of the overlying limestone unit of the Englewood. On the basis of the clay residue and the gray color of the siltstone, it was concluded by the writer that the siltstone is probably a physical facies equivalent of the lower shale unit of the Englewood as observed at the more complete exposure near the Deadwood city dump.

It is the writer's opinion that since the original describer (Darton, 1901) gave the Englewood area as the type area, the type section should be designated in that general vicinity, even though the formation may be better exposed elsewhere.

Dunbar and Rodgers (1957, p. 269) stated that there are two extreme points of view concerning type sections: (1) a formation is independent of any one section or locality, though it may be typically displayed by one or by several sections; and (2) a type section defines the formation, especially to its time span and nothing can be admitted to the formation that cannot be correlated with beds in the type section. They further stated (1957, p. 270) that:

> We hold that formation is primarily based on a concept in the mind of the describer, and that the type section is a device for obtaining at least one objective tiepoint for that concept.

Darton (1901) originally described the Englewood, but it appears that he was referring only to the "thin bedded, pale pinkish-buff limestones." It was later that the shale unit was included in the Englewood formation, based mainly on evidence taken from areas other than

near Englewood, South Dakota. Hence, the concept of the original description and the present concept of the formation differ somewhat.

Lithology

The lower unit of the Englewood formation at the proposed type section consists of 5 feet 11 inches of yellowish gray (5Y 8/1) and medium gray (N5), argillaceous, slightly calcareous, compact siltstone. The bedding is massive.

Fig. 6.--Englewood proposed type section exposed in a railroad cut approximately two miles southwest of Englewood, South Dakota. The siltstone which underlies the limestone is not shown in this view. (View, looking toward the east.) Exposed at NW¼NE¼ sec. 31, T. 4 N., R. 3 E., Lawrence County. The upper strata are beds of the Pahasapa formation.

The siltstone is overlain by 24 feet 2 inches of grayish red purple (5RP 4/2), argillaceous limestone. The bedding ranges from thin (1 inch to 1 foot) with occasional shale partings to medium (1 to 2 feet). About

21 feet above the base of the measured section a fossiliferous layer is present. A yellow gray mottling in a grayish red purple limestone is present about 30 feet above the base of the measured section.

The upper unit is composed of 1 foot 9 inches of yellowish gray (5Y 7/2) limestone, dolomitic. Dark reddish brown (10R 3/4) blotches are dispersed in the lower portion of this unit. The bedding is medium (1 to 3 feet), whereas, the yellow gray dolomite of the overlying Pahasapa is thick (3 to 6 feet) to massively bedded (greater than 6 feet).

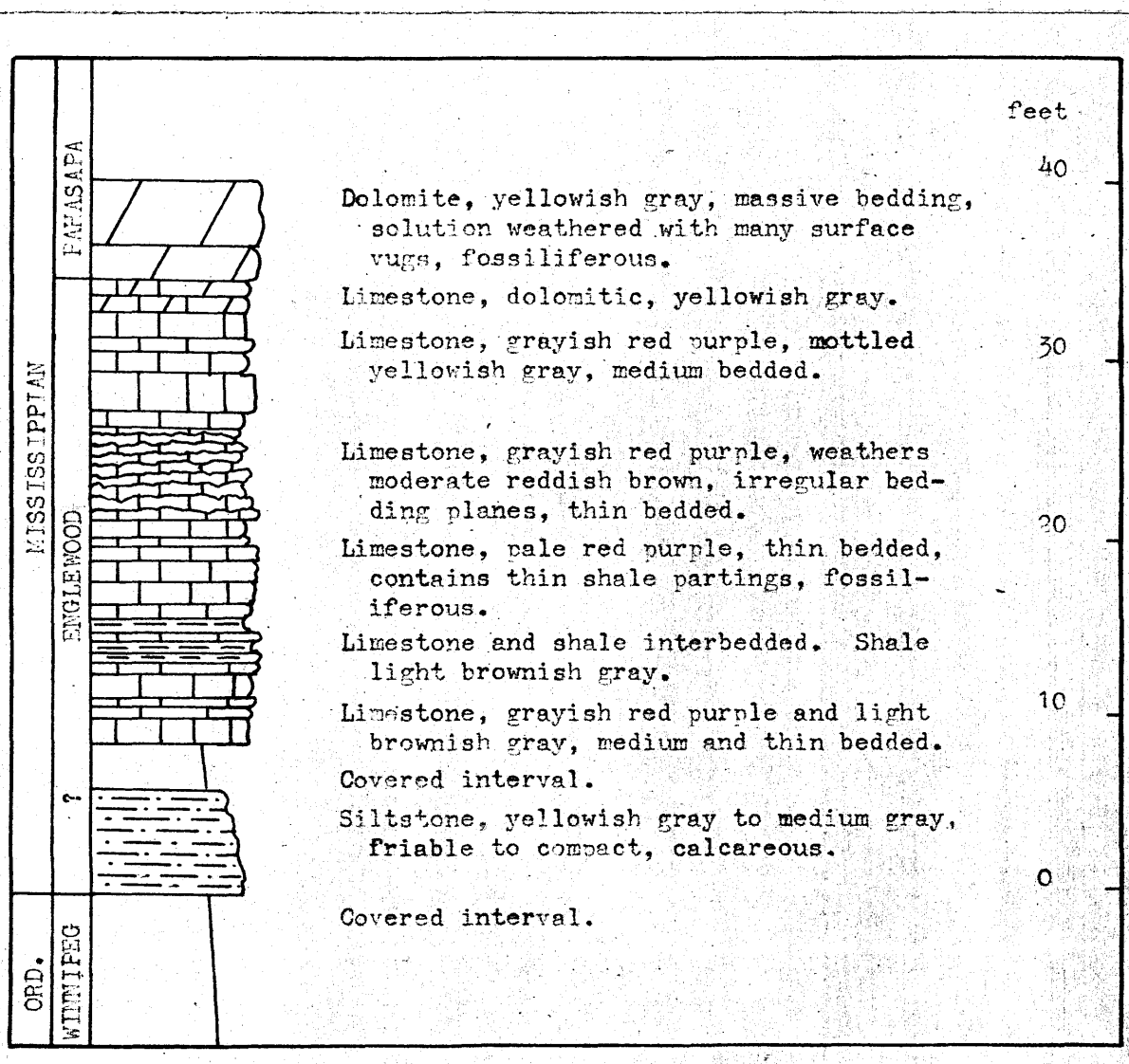

Fig. 7.—Type section (proposed) of Englewood formation.

Thickness

The thickness of the Englewood formation at the proposed type section is 34 feet 5 inches. This is 23 feet 2 inches less than the thickness of the Englewood at the Deadwood junkyard section. However, the discrepancy can be accounted for by four feet six inches of depositional thinning of the middle and upper units, and the lack of exposure of the complete lower unit.

Fauna

Poorly preserved fossils were collected in a dense limestone about 21 feet above the base of the measured section. The fossils consisted mainly of brachiopods, Leptaena sp., Productella ? sp., and Schuchertella ? sp., and many crinoid stems.

Standard Reference Section

Location

A complete section of the Englewood formation is located on the east side of Whitewood Creek along the Chicago and Northwestern Railway tracks across from the Deadwood city dump north of U. S. Highway 14 near its junction with U. S. Highway 85. This section, the Deadwood junkyard section, located at NE¼SW¼ sec. 15, T. 5 N., R. 3 E., Lawrence County, South Dakota, is here proposed as a standard reference section for the Englewood formation. All three units of the Englewood are well exposed, as well as the overlying Pahasapa formation of Mississippian age and the underlying Whitewood dolomite of Ordovician age.

Lithology

At the Deadwood junkyard section the lower unit of the Englewood consists of 27 feet 8 inches of silty shale which lies paraconformably

Fig. 8.--Deadwood junkyard section near Deadwood, South Dakota, showing the paraconformity between the Whitewood dolomite (Ordovician) and the Englewood formation (Mississippian). Overlying the Englewood is the Pahasapa formation, and underlying the Whitewood dolomite is the Roughlock member of the Winnipeg formation. (View looking toward the north.) O_{wt} = Whitewood dolomite, M_e = Englewood formation, M_p = Pahasapa formation.

Fig. 9.--Deadwood junkyard section showing a close-up view of the lower silty shale unit of the Englewood formation. The Englewood formation is a slope-former occurring between the resistant Pahasapa and Whitewood dolomite. (View looking toward the southeast.)

upon the Whitewood dolomite. A thin grayish orange (10YR 7/4), slightly calcareous, silty shale is present immediately above the contact. Overlying this basal shale are dark gray (N3), greenish black (5G 2/1), and medium gray (N5) shales.

Overlying the shale unit is 24 feet 8 inches of grayish purple (5P 4/2), grayish red purple (5RP 4/2), and pale red purple (5RP 6/2), dense, medium bedded to laminated limestone. About four feet above the base of the limestone unit, interbedded limestone and shale are present through a three foot interval. The interbedded grayish green (10GY 5/2), fissile shale occurs in layers from 1/8 to 2 inches in thickness (Figure 10). The limestone overlying this shale unit, has a varve-like appearance.

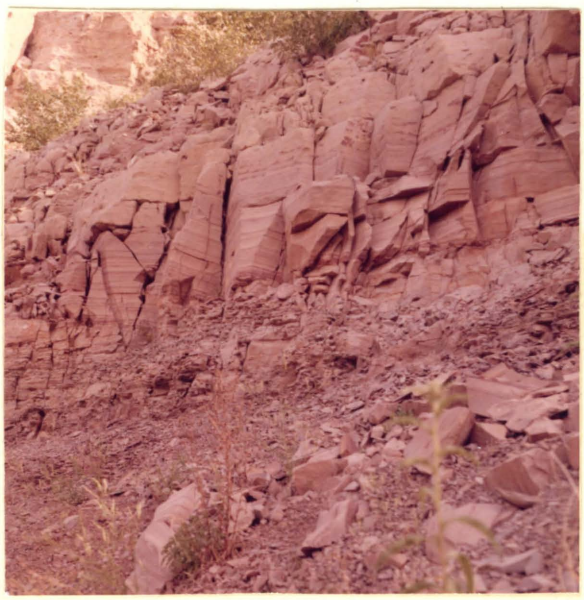

Fig. 10.--Interbedded limestone and shale of the Englewood formation at the Deadwood junkyard section. Note the varve-like appearance of the limestone.

The upper unit of the Englewood which overlies the limestone unit consists of 5 feet 3 inches of yellowish gray (5YR 7/2), medium bedded,

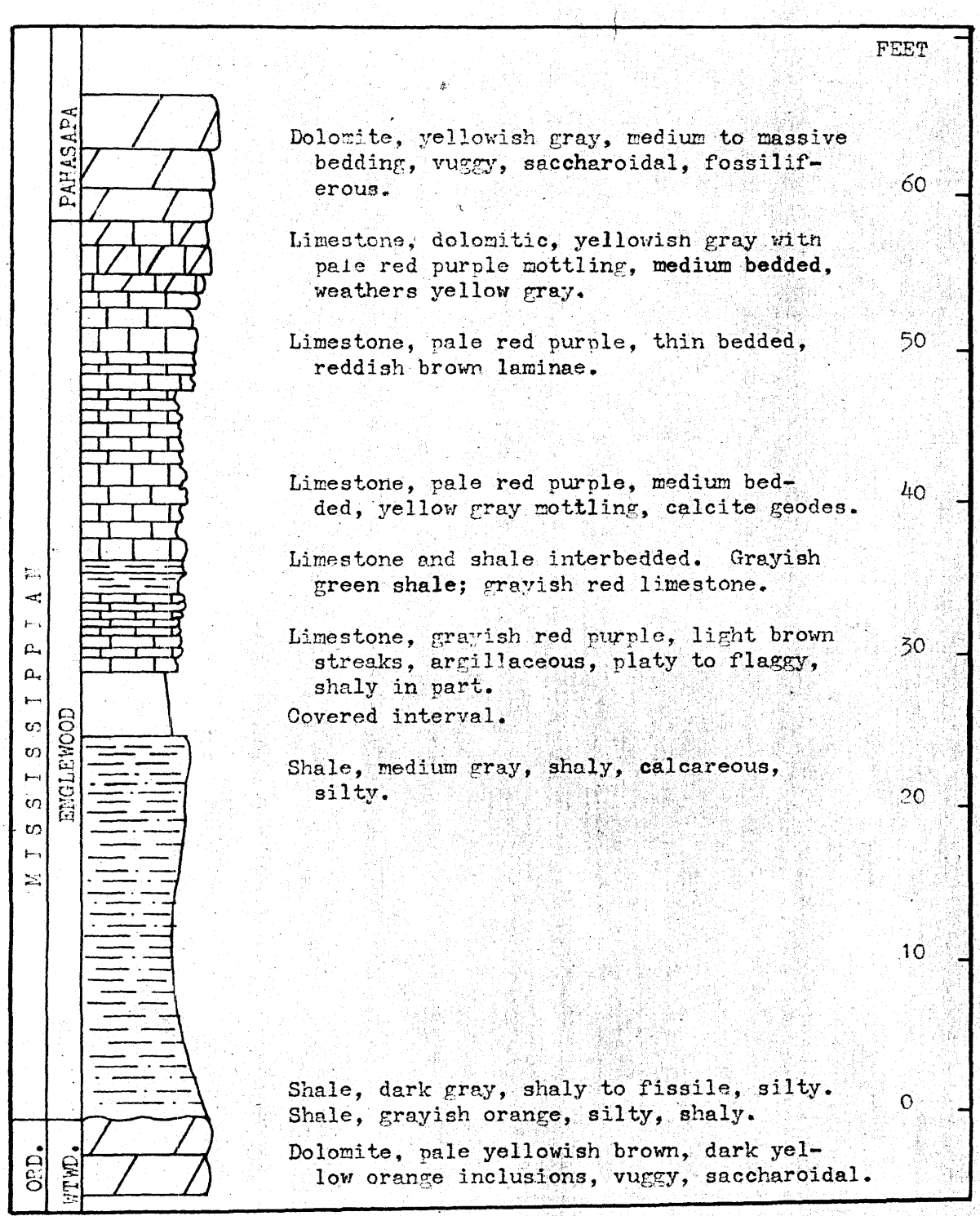

Fig. 11.—Standard reference section (proposed) of the Englewood formation. Located at NE¼SW¼ sec. 13, T. 5 N., R. 3 E., Lawrence County, South Dakota.

dolomitic limestone. Pale red purple mottling occurs in this unit. The upper contact of this unit is transitional with the Pahasapa.

Thickness

The thickness of the Englewood at the Deadwood junkyard section is 57 feet 7 inches.

Lithology

The Englewood formation consists of three subdivisions: a lower gray silty shale; a middle grayish red purple, argillaceous, and partly shaly, limestone; and an upper yellowish gray, dolomitic limestone.

Approximately 10 miles north of the Deadwood junkyard section, 50 feet of Englewood are present in the Weller Bush - Weisman No. 1 well at NW¼SW¼SE¼ sec. 30, T. 7 N., R. 4 E., Lawrence County, South Dakota. The lithology of the Englewood formation in the subsurface differs from that observed in the outcrop. As observed in cuttings from this well, the lower unit consists of 10 feet of medium grey (N6), calcareous siltstone overlying the Whitewood dolomite. Overlying the siltstone are 25 feet of grayish red purple (5RP 4/2) silty limestone. The upper unit consists of a grayish red purple, calcareous, argillaceous siltstone which is overlain by limestone of the Madison group. The limestone is moderate orange (5YR 8/4) to grayish orange pink (5YR 7/2), and saccharoidal to fragmental. The Bakken formation was not found to be present in this well.

In Butte County, South Dakota, the Englewood formation consists of very dark red (5R 2/6), dusky red (5R 3/4), and pinkish gray (5YR 8/1) argillaceous limestone.

Thickness

The Englewood formation in northwestern South Dakota ranges in thickness from a maximum measured thickness of 57 feet 7 inches at the

outcrop near Deadwood to a knife edge in the subsurface near the northern part of Harding County. The Englewood formation, although very distinctive in the outcrop, becomes very difficult to trace as a subsurface unit. This difficulty may be due partly to changes in lithology, changes in color, and poor sample recovery during drilling.

Relation to Adjacent Formations

The Englewood formation at the proposed type locality rests unconformably on the Winnipeg formation of Ordovician age, whereas, approximately seven miles to the northwest of Englewood, South Dakota, at the Deadwood junkyard section, the Englewood formation rests paraconformably upon the Whitewood dolomite of Ordovician age.

The relationship of the Englewood formation and the Winnipeg formation seems to be indicated in a railway cut at NW¼NE¼ sec. 30, T. 4 N., R. 3 E., Lawrence County. Although this is a poor exposure of the Englewood, the dark green shales of the Winnipeg are well exposed, and these shales underlie a badly weathered limestone unit of the Englewood. The siltstone unit is not present at this particular outcrop.

Pre-Mississippian erosion might account for the disappearance of the Whitewood dolomite which is over 60 feet thick at the Deadwood junkyard section, but which is not present at the proposed Englewood type section. Erosion may also have occurred in early Englewood time as suggested by the missing siltstone unit.

The upper contact of the Englewood formation is transitional with the overlying Pahasapa formation of Mississippian age. The transition from a yellowish gray, dolomitic limestone to a yellowish gray dolomite

is evident through an interval of about two feet in the type locality to five feet in the Deadwood junkyard section.

Several samples of the upper grayish red purple limestone and yellowish gray dolomitic limestone of the Englewood, and several samples of the yellowish gray dolomite of the Pahasapa were digested in hydrochloric acid. Each sample digested showed that some argillaceous material was present. The color of these insoluble residues coincided very closely with the color of the sample digested. Therefore, the color of the clay residue was not the distinguishing criterion for establishing the contact between the Pahasapa and the Englewood. The relative amounts of the argillaceous material decreased near the contact between the dolomitic limestone and the dolomite. It was upon this decrease in clay residue and the change in lithology and bedding characteristics, that the Englewood and Pahasapa formations were distinguished.

In northwestern South Dakota the Englewood formation may overlie the Bakken formation. In the Amerada Petroleum Corporation - State No. 1 well, NW¼NW¼ sec. 4, T. 14 N., R. 4 E., Butte County, South Dakota, 26 feet of dark gray (N3) to black (N1), fissile shale (Bakken) is overlain by 17 feet of very dark red (5R 2/6), dusky red (5R 3/4), and pinkish gray (5YR 8/1) argillaceous limestone. This relationship seems to suggest that if the limestone which overlies the shale is a lithologic equivalent of the Englewood formation, then the relationship of the Bakken and Englewood formations is established. The limestone is considered by the writer as being a lithologic equivalent to the Englewood, hence, the Englewood is considered as overlying the Bakken in this area. However, since the Englewood formation is difficult to trace in the subsurface,

as previously stated, this relationship, suggested by the writer, may be open to question.

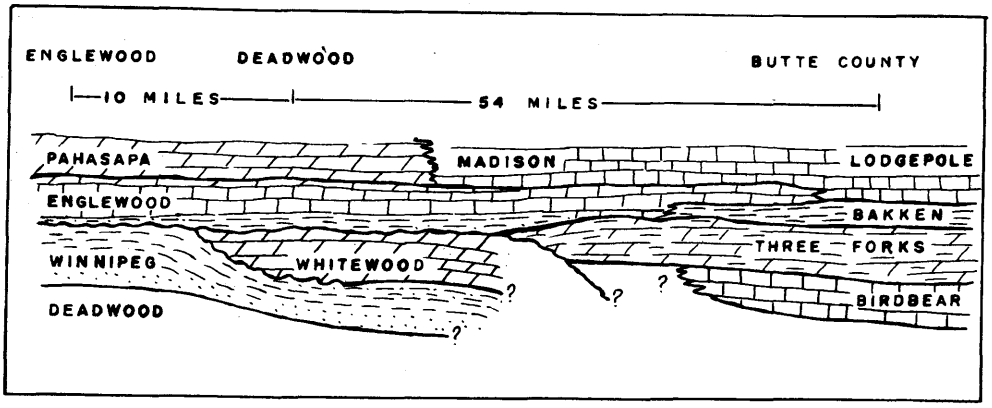

Fig. 12.--Generalized diagrammatic cross-section showing the stratigraphic relationship of the Englewood and Bakken formations in South Dakota.

Underlying the dark gray to black shale is a moderate reddish brown (10R 4/6) shale, pale purple limestone, and light olive gray (5Y 6/1) siltstone. This seems to suggest that the Three Forks formation underlies the Bakken in the Amerada Petroleum Corporation - State No. 1 well.

The Bakken formation was also found to be present in the Youngblood and Youngblood - Galvin No. 1 well, SW¼SE¼ sec. 25, T. 16 N., R. 22 E., Dewey County, South Dakota and the Shell Oil Company - Veal No. 1 well, SE¼SE¼ sec. 7, T. 17 N., R. 15 E., Perkins County, South Dakota. In both of these wells the Bakken formation was overlain by the Lodgepole formation and underlain by the Three Forks formation. The Englewood formation was missing in both wells.

Bakken Formation

Name and Definition

The term "Bakken formation" was introduced by the Williston Basin Nomenclature Committee of the Saskatchewan Society of Petroleum Geologists and of the Rocky Mountain Section of the American Association of Petroleum Geologists in 1953. However, since the term was not formally defined, Nordquist (1953, p. 72) proposed the term for the strata occurring between the depth of 9615-9720 feet in the Amerada Petroleum Corporation - H. O. Bakken No. 1 well, SE¼NW¼ sec. 12, T. 157 N., R. 95 W., Williams County, North Dakota.

Underlying the Bakken formation is the Three Forks Formation of Devonian age. Overlying the Bakken is the Lodgepole formation which is the lowest formation of the Madison group of Mississippian age. The Bakken formation has been assigned a Kinderhookian age.

Type Section

Location

The type section as designated by Nordquist (1953, p. 72) is located between the depths of 9615-9720 feet in the Amerada Petroleum Corporation - H. O. Bakken No. 1 well or the Tioga - Madison Unit G 123, SE¼NW¼ sec. 12, T. 157 N., R. 95 W., Williams County, North Dakota.

Lithology

The type section as proposed by Nordquist (1953, p. 72) is as follows:

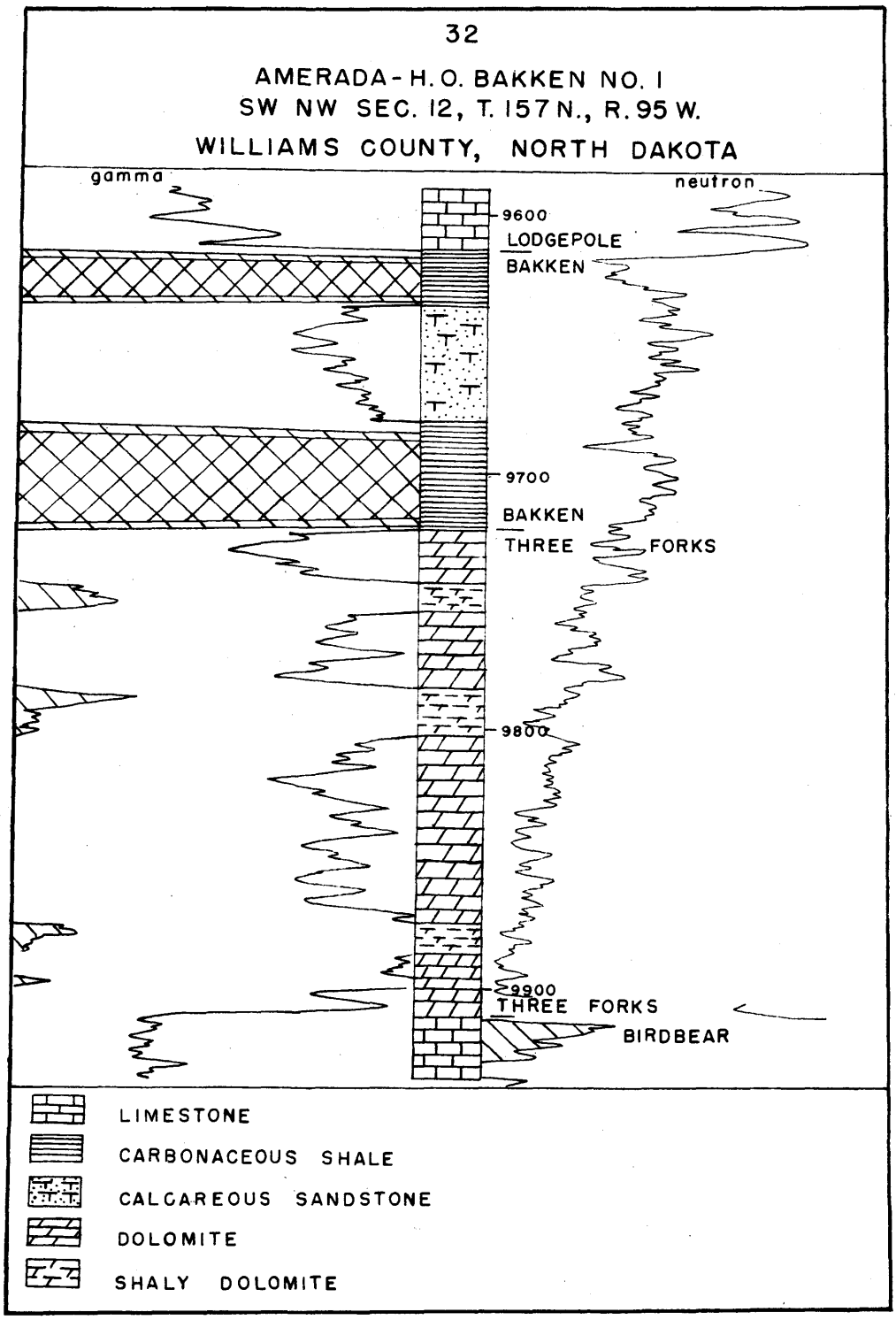

Fig. 13.--Type section of the Bakken formation in the Amerada Petroleum Corporation - H. O. Bakken No. 1 well.

Bakken formation

	Thickness	Depth
Shale, black, fissile, very slightly calcareous.	20 feet	9615 - 9635
Sandstone, light gray to gray brown, very-fine grained, calcareous, interbedded with minor amounts of gray-brown cryptocrystalline limestone.	60 feet	9635 - 9695
Shale, black, fissile, very slightly calcareous.	25 feet	9695 - 9720

The writer studied the well cuttings from this well and found that the upper unit of the Bakken formation consisted of 20 feet of dark gray (N3), slightly calcareous, fissile, pyritic shale. The shale is underlain by 45 feet of brownish gray (5YR 4/1) to light gray (N7), very fine grained, calcareous sandstone. Rounded to subrounded quartz grains are present. Approximately 15 per cent of the sample in the 9650 - 9680 foot interval consisted of yellow gray (5Y 7/2) anhydrite. The lower unit consisted of 40 feet of dark gray, slightly calcareous, fissile, pyritic shale.

Thickness

The thickness of the Bakken formation at the type section is 105 feet. The writer disagrees with the thickness of the lower and middle units as proposed by Nordquist (1953, p. 72). He reported that the thickness as 25 feet, 60 feet, and 20 feet for the lower shale unit, middle sandstone unit, and the upper shale unit, respectively. As logged by the writer, the three units are 40 feet, 45 feet, and 20 feet thick for the lower, middle, and upper units, respectively. After a close examination of the gamma-ray log and the well samples, the boundaries of the three units were picked on the basis of their radioactivity pro-

perties. The shale units can be easily distinguished due to their exceptionally high gamma-ray intensity. The middle unit composed of clastic and carbonate material has a lesser amount of natural radioactivity, hence, a minor deflection is recorded on the gamma-ray log. The boundaries of the three units were sharply defined by this method.

Lithology

The Bakken formation of northwestern to central southeastern North Dakota consists of three subdivisions: a lower shale unit, a middle clastic-carbonate unit, and an upper shale unit. These three units can be easily recognized in the subsurface by the use of radioactivity logs. The relatively strong radioactivity of the black shales causes a large deflection on the gamma-ray log. Due to this prominent feature the Bakken formation is a very reliable "marker" unit of the lower part of the Mississippian system in the Williston Basin.

The lower and upper shale units appear identical lithologically and they consist of black to dark gray, fissile, slightly calcareous, and pyritic shale. The lithology of the middle unit of the Bakken varies from a brownish gray to light gray, calcareous sandstone, siltstone, silty limestone, or limestone in the area of this study.

Relation to Adjacent Formations

Underlying the Bakken formation is the Three Forks formation of Devonian age. The Three Forks formation consists of greenish gray shale, brownish gray dolomite, quartzose sandstone, yellow-gray dolomite, reddish brown shale, and light gray siltstone.

The contact between the Bakken and Three Forks shows little evidence of being unconformable in the deeper portions of the Williston Basin. However, McCabe (1954, p. 2004) reported that the unconformity at the base of the Mississippian is the most pronounced of the regional unconformities in the Williston Basin. The contact, as observed by the present writer in cores, shows an abrupt lithologic change from a sandstone or a dolomite, or greenish gray shale to a black shale, which implies a change in regimen, but which may not mean an unconformity or a break in deposition.

The Three Forks formation shows some interesting features in a core taken from the Amerada Petroleum Corporation - C. C. Mogen Tract 1, No. 1 well, SE¼SW¼ sec. 10, T. 153 N., R. 96 W., McKenzie County. Here the formation consists mainly of interbedded brownish gray dolomite and greenish gray shale. The bedding occurs as 1/8 to 3/8 inch layers and small scale intertonguing. Disrupted bedding with "microfaults" were observed at a depth 10,014 - 10,017 feet. A breccia of brownish gray dolomite and greenish gray shale occurs at a depth of 10,047 - 10,050 feet which may be analogous to the breccias reported in the Three Forks formation by Sloss and Laird (1947, p. 1421).

Locally, a quartzose sandstone informally referred to by the workers in the Williston Basin as the "Sanish sand", but properly included in the Three Forks formation, underlies the Bakken. This sandstone was observed in a core from The Texas Company - J. M. Donahue No. 1 well, SW¼NE¼ sec. 23, T. 154 N., R. 100 W., Williams County. Five feet of fine-grained sandstone occurs at the depth of 11,010 - 10,015 feet and shows a slight fluorescence. The sandstone was found to be present in

scattered wells in Williams, McKenzie, Mountrail, and Bottineau Counties, but its occurrence was erratic and not continuous for any great distance. Such an occurrence is suggestive of beach sand deposits or concentrations of sand such as sand bars in shallow water.

Overlying the Bakken formation is the Lodgepole formation which is the lowest formation of the Madison group. The lodgepole formation consists of medium dark gray to light gray, microcrystalline and dense limestone with minor amounts of chert and anhydrite.

Locally, a black shale is present in the lower portion of the Lodgepole formation (Figure 14), and it is usually separated from the upper shale unit of the Bakken formation by a thin bed of limestone which is similar to that of the Lodgepole. Fuller (1956, p. 26) reported a gray to black "marker" shale in the Madison of southeastern Saskatchewan. He found it to be present about 10 to 13 feet above the Bakken and overlying a red-stained, brecciated limestone. A similar black shale is present in several wells in McKenzie, Dunn, and Mountrail Counties. Commonly, the shale is separated from the Bakken by a medium gray, dense limestone. However, in the Socony Vacuum Oil Company - C. Dvorak No. 1 well, SE¼NE¼ sec. 6, T. 141 N., R. 96 W., Dunn County, seven feet of black shaly limestone is separated from the Bakken by one foot of brownish gray, fragmental and crystalline limestone, and seven feet of light olive gray, dense limestone (Figure 14).

Stanton (1956, p. 79) proposed the term Scallion member for the lowermost carbonate member of the Lodgepole formation in southwestern Manitoba. He described this member as consisting of white to pinkish limestones, microcrystalline, cherty or chalky, and locally oolitic and

crinoidal. He also proposed the term "Routledge shale" for a locally distributed black shale which overlies the Bakken. Stanton (1958, p. 381) reported that the Routledge attains a maximum thickness of 90 feet; the contact of this shale with the Bakken is conformable, and the lithology electric log trace at the Routledge and Bakken are similar. He stated that the difference between the Routledge and Bakken is that:

> It [Routledge] lies beneath typical Scallion member lithology and above the stratigraphic horizon selected elsewhere as marking the top of the Bakken formation.

The writer did not use this terminology as these units appear to be local in extent and not traceable throughout the area of this study. The writer agrees with Stanton (1958, p. 382) in questioning the lithology found in the Bakken interval in the Routledge type section well. Stanton reported that the well cuttings consisted of dark brown shale, light greenish gray siltstone and sandstone, and a trace of red shale. Except for the brown shale, the lithology did not seem typical or consistent with that of the Bakken as seen from other localities by the writer. The local black shale found in the lower portion of the Lodgepole formation may be equivalent to the Routledge shale; however, the writer could not demonstrate this relationship.

Thickness

In North Dakota the Bakken formation ranges in thickness from a maximum of 115 feet in western Divide County to a knife edge in the eastern third of the state where it is truncated by the pre-Jurassic erosional unconformity. The Bakken formation thickens from the southeast to northwest portion of North Dakota. It is thin in a narrow,

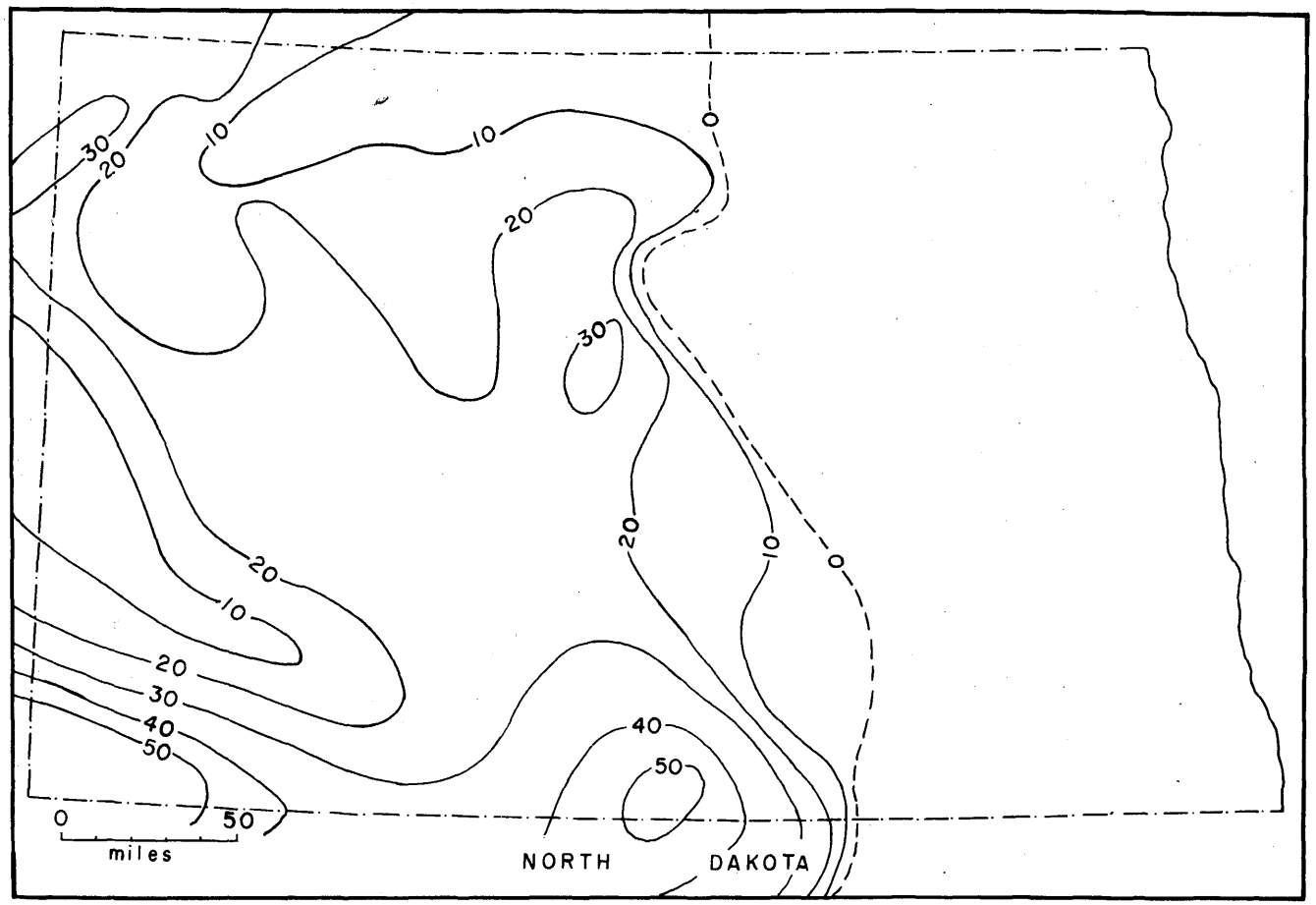

Fig. 14. -- Isopach map of the upper shale unit of the Bakken formation. Contour interval = 10 feet.

elongate area trending northwest to southeast in the southwestern portion of North Dakota. The Bakken appears to be missing in central Golden Valley County. To the south of this area where the Bakken is thin, the shale becomes thicker, and it is about 50 feet thick near the Slope-Bowman County boundary.

In northwestern South Dakota the Bakken formation ranges in thickness from a maximum of 42 feet in Perkins County to a knife edge in the vicinity of northern Butte and Meade Counties. It is thought by the writer that the Bakken is overlain by the Englewood formation in Butte County.

Cross sections of the Bakken and the underlying Three Forks formation show that the sedimentary units converge or wedge out in an easterly direction across the area of study (Plate II, III). The upper shale unit of the Bakken seems to extend over a greater area than the lower shale unit (Figure 15). However, the lower shale of the Bakken is generally thicker than the upper shale, especially in the western half of the area of this study (Figure 16). The thinning (possibly convergence) of the sedimentary units of the Three Forks formation may be due to pre-Bakken erosion or depositional thinning. The writer did not attempt to divide the Three Forks formation into lithogenetic units as the lithology was found to be quite variable. This variability made it difficult to trace the various lithologic units for any great distance. Fuller (1956, p. 23) recognized truncation of the "Qu'Appelle group" (Three Forks formation) in eastern Saskatchewan. He reported that erosion is indicated by a pebble bed or "basal conglomerate" at the base of the Bakken shale.

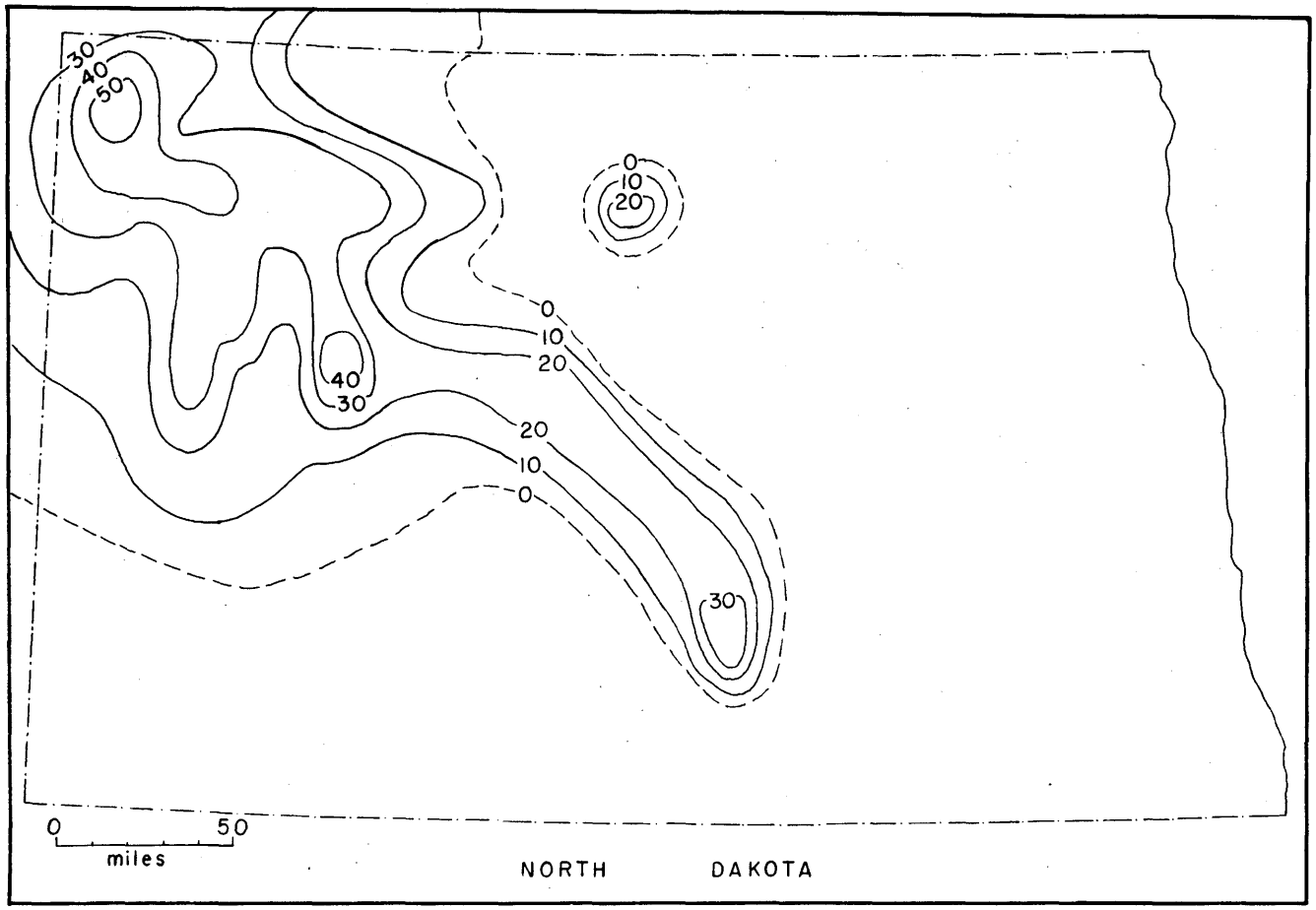

Fig. 15. -- Isopach map of the lower shale unit of the Bakken formation. Contour interval = 10 feet.

Fuller (1956, p. 18) divided southeastern Saskatchewan into three regions: (1) Central Area or the area in which the three units of the Bakken formation are present, (2) Eastern Shelf Area or the are in which the lower shale unit is missing, (3) Northwestern Area or the area where the lower shale unit is missing, but its position is "occupied by pale green and ochreous varigated shales, which closely resemble those of the Qu'Appelle group [Three Forks]."

On the basis of Fuller's division, the Central Area and the Eastern Shelf Area could be extended southward into the area of this study. However, as this "shelf" area extends around the Central Area in southern North Dakota and eastern Montana, it might appear appropriate to designate this area the southern and western shelf areas. The boundary between the southern and eastern shelf areas could be arbitrarily drawn near the mutual county boundaries of Emmon and McIntosh Counties which is near the southern most limit of the Central Area. Rather than having a division based mainly upon geographic location and arbitrary boundaries, a better means of designating this area seem appropriate. The writer proposes that the "shelf" area around the Central Area in this area of study be designated the Marginal Shelf. The terms "eastern, southern, and western shelf areas" could be used for discussion purposes in pointing out geographic locations of features within the Marginal Shelf.

The middle clastic-carbonate unit of the Bakken formation occurs mainly in the Central Area where it is easily defined, since it is underlain be the lower shale unit. One exception to this generalization occurs in McHenry County which is located in the northeastern portion of the Marginal Shelf. In this area an isolated occurrence of all three

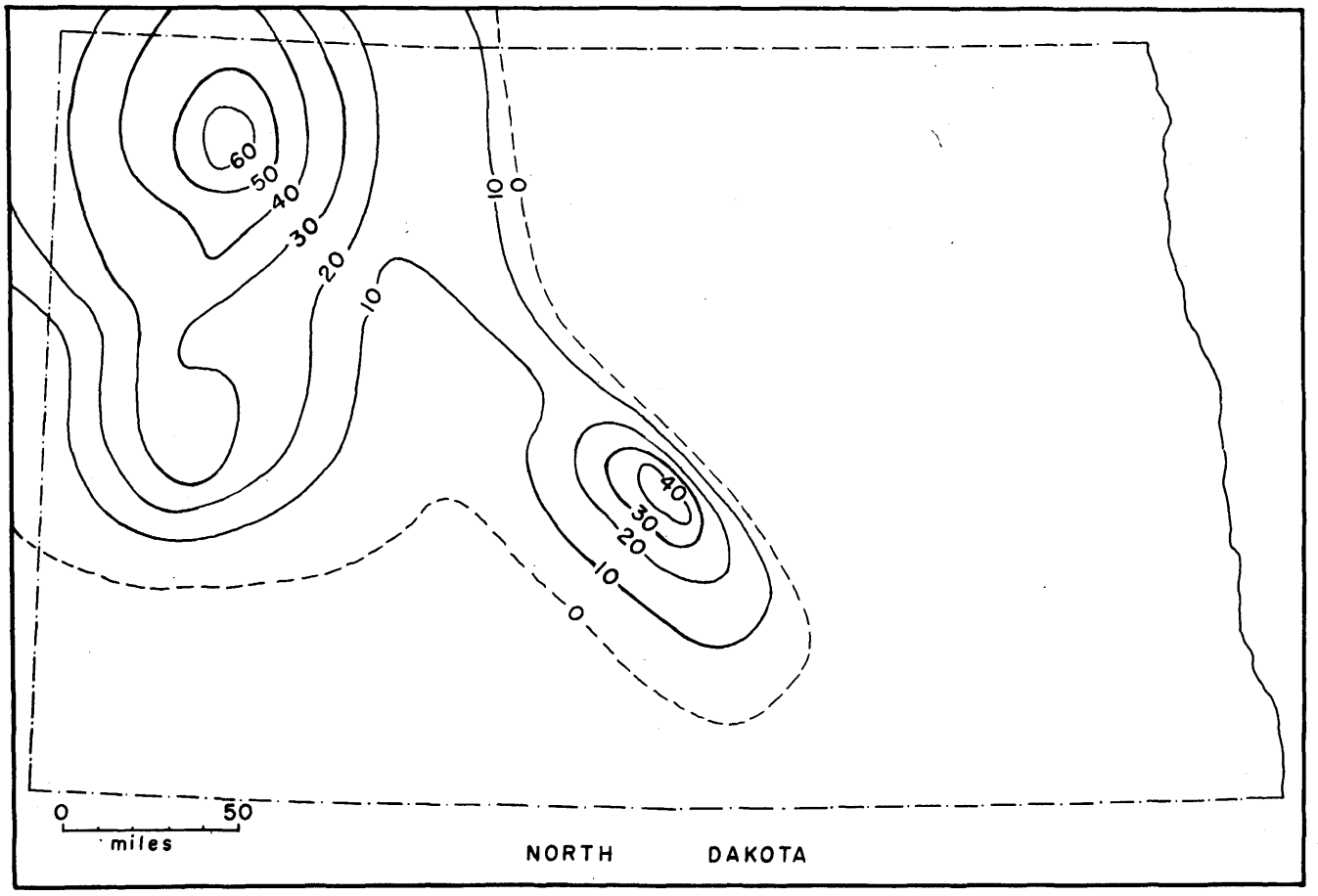

Fig. 16. -- Isopach map of the middle clastic-carbonate unit of the Bakken formation. Contour interval = 10 feet.

units of the Bakken are present. This occurrence possibly can be attributed to a local depression in which the complete Bakken was deposited and protected from erosion which probably occurred during the lower Mississippian in different parts of the Marginal Shelf.

The middle unit reaches a maximum thickness of 60 feet in northwestern Mountrail County in the Amerada Petroleum Corporation - Tioga Unit K. 143, SW¼NW¼ sec. 18, T. 158 N., R. 94 W., (Figure 17). The thickness of the middle unit in this area of study is quite variable, therefore, definite trends of sedimentation were difficult to establish. Generally, the unit is thicker toward the northwest corner of the area of this study, and thinner toward the Marginal Shelf, but exceptions to this trend are common. Nordquist (1953, p. 74) reported that, "the clastic ratio of the formation [Bakken] increases northward into southern Canada and a source in that direction is indicated." Reasoner and Hunt (1954, p. 1539) introduced the term "Coleville sand" for the middle "sand" of the Bakken formation. The writer does not agree with their usage of the term "sand". Its usage should be restricted to the unconsolidated sand size material rather than to designate sandstone, especially in formal nomenclature. The lithology of the middle unit of the Bakken varies from a calcareous sandstone and siltstone to a silty limestone in the area of this study, and, as reported by Reasoner and Hunt, the lithology consists of shale, limestone, and "sand" in the Coleville region. It, therefore, seems necessary to drop the term "sand" or sandstone from the term "Coleville sand" and rename the middle unit of the Bakken, the Coleville member. A type section should be designated since the mere suggestion of a region (the Coleville region, Saskatche-

wan, which was designated as the region for which the term "Coleville" was proposed and applied) does not seem adequate. Although this term has been used quite extensively in the literature by workers north of the international boundary, it is the writer's opinion that the term should be reproposed in accordance with the standards of the Stratigraphic Code. Therefore, the term "Coleville sand" should be abandoned. It is not utilized in this work.

Standard Reference Section

The Socony Vacuum Oil Company - C. Dvorak No. 1 well, SE¼NE¼ sec. 6, T. 141 N., R. 94 W., Dunn County, was continuously cored from the lower part of the Lodgepole formation, through the Bakken and Three Forks formations and into the Birdbear formation. The gamma ray and lateral log trace of these formations are very characteristic, and they can be easily used to define the boundaries of the various lithologic units.

It is, therefore, proposed by the writer that the Bakken interval at a depth of 10,035 - 10,095 feet in this well be designated as a standard subsurface reference section in the area of this study.

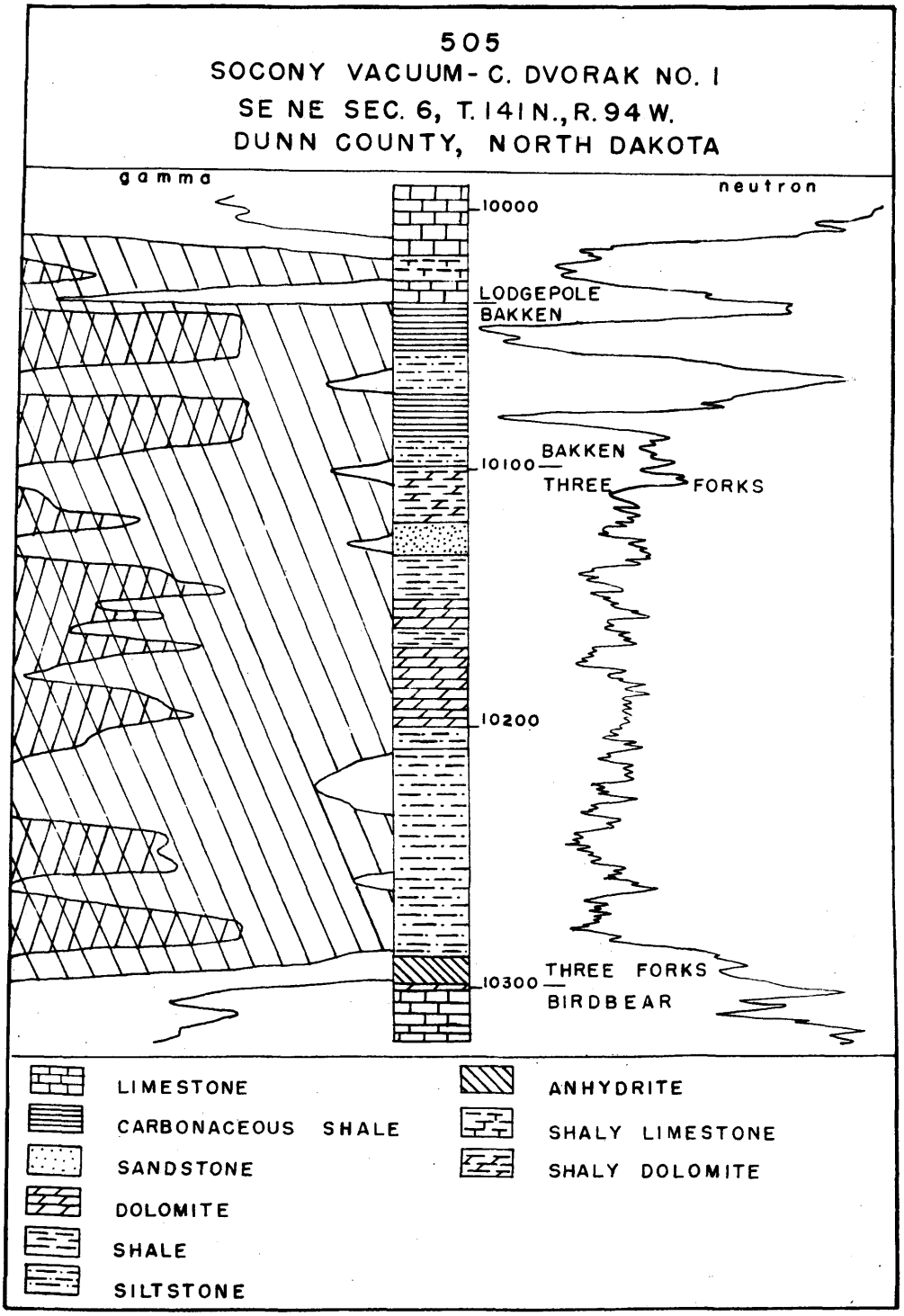

Fig. 17.—Proposed standard subsurface reference section of the Bakken formation located in the Socony Vacuum Oil Company - C. Dvorak No. 1 well at a depth of 10,035 - 10,095 feet in the drilled well.

ENVIRONMENT OF DEPOSITION

The isopach map of the Bakken formation in North Dakota shows a marked thickening of sediments toward the northwest corner of the state with a maximum thickness in Divide County (Plate I). The sediments appear to have been deposited in a subsiding trough which extended into the area of this study from Canada. The Central Area of North Dakota, Montana, and Saskatchewan in which the three units of the Bakken formation are present, is thought by the writer to be the general area occupied by the seaway. The Bakken sea probably transgressed from the Cordilleran region across Canada and into the Central Area. This sea was initially restricted in circulation, later became a normal marine sea, and was then again restricted in circulation. The black shales were deposited during times of a restricted sea, and the clastic-carbonates were deposited during times of a normal marine sea.

The Marginal Shelf is thought to be the general marginal area of the Bakken sea. Toward the marginal area, the stratigraphic units of the Bakken converge and depositional thinning occurs. Within the marginal areas the lower unit of the Bakken is missing, probably because of non-deposition in some areas and erosion in other areas. For this reason in the marginal areas the Bakken formation is very difficult to trace either with mechanical logs or samples.

Borden (1956, p. 137) reported that during Late Devonian time the Cordilleran sea transgressed southeastward across southern Alberta,

western Saskatchewan, and into northwestern North Dakota. He also pointed out that in Late Devonian - Early Mississippian time there was uplift in central Saskatchewan, and in southern Alberta the Sweetgrass Arch was uplifted. Borden (1956, p. 137) also believed that:

> With the advent of the Mississippian there was a small break, and then a shallow stagnant sea from the Cordilleran invaded western Canada. The sea became deeper and more open in the latter part of the Mississippian.

The cyclical deposition of the Bakken formation from a lower black shale to a silty-sandy limestone, and an upper black shale, probably can be attributed to the control of circulation of this early Mississippian sea by tectonic activity in southern Alberta and south-central Saskatchewan. During times of tectonic activity, a threshold, shelf or some other submarine barrier could have existed and restricted the free circulation of the sea. Although this could hardly have been the sole cause for the restricted sea during Bakken time, it might have been one of the contributing factors in the area of this study. Contemporaneous widespread environmental conditions favorable to the deposition of black shales existed during the Upper Devonian and Lower Mississippian. Black shales such as the Chattanooga, New Albany, Grassy Creek, Antrim, Sudbury, and Ohio were deposited throughout various sections of the interior of North America.

It was during times of poor circulation and aeration in quiet waters that the black shales were deposited. The shales are very fine grained, finely laminated, and fissile which suggests an environment probably below the influence of any wave action and deposition mainly by settling of suspended material. The environment below wave base is called fondo

environment (Rich, 1951, p. 2019). According to Rich, the depositional environment of shales may be indicated by the type of stratification, nature of the materials, speed of deposition, and nature of the fauna and flora.

The dark color of the shales is usually due to the high content of organic material much of which is probably allochthonous. Twenhofel (1939, p. 1181) pointed out that the lack of oxygen and the accumulation of toxic products will eliminate scavengers and certain bacteria which are necessary for decomposition of organic material. This allows the organic material to be preserved and later deposited.

Fossils are rare in the Bakken black shales except for an abundant conodont fauna. Although conodonts are commonly found in black shales, they are also found in many types of sedimentary deposits, hence, they have been associated with various environments. One specimen of Conularia was found in a core taken from a depth of 4199 - 4202 feet in the Continental Oil Company - Lueth No. 1 well in Wells County, North Dakota. Since conularids are found in deposits representing a wide range of environmental conditions, their mere presence does not suggest a particular environment. Fish scales (?) were observed in a core taken from the depth of 11,258 - 11,261 feet in The California Company - Rough Creek No. 1 well in McKenzie County. These fish scales (?) indicate that an environment probably existed at the time of deposition which allowed the organic material to become preserved and not decomposed. This black shale fauna seems to be an assemblage of nektonic or planktonic organisms which could have survived near the surface of the water. After death, remains of the organisms settled to the bottom, and became preserved because of the absence of scavengers.

Fossils are more abundant in the middle clastic-carbonate unit of the Bakken formation. The fossils consisted mainly of brachiopods which included Orbiculoidea sp., Cyrtospirifer (?) sp., and Camarotoechia sp. This fauna indicated that a "normal" marine environment existed during the deposition of the middle clastic-carbonate unit of the Bakken. Brachiopods are marine sessile benthonic organisms, and their presence is suggestive of an environment capable of sustaining bottom life.

Sandberg and Hammon (1958, p. 2331) reported that, "renewed uplift of the Central Montana Platform and the 'ancestral' Cedar Creek Anticline marked the close of black shale deposition." This was followed by a short period of erosion of the Upper Devonian and Lower Mississippian rocks which were exposed on the uplifted areas.

The thinning of the Bakken formation in Golden Valley and Hettinger Counties probably occurred at this time due to local uplift associated with the major uplift of the Central Montana and "ancestral" Cedar Creek Anticline. The thinning of the Bakken occurs very rapidly from 60 feet in southern Dunn County to less than 10 feet in Hettinger County. This rapid thinning could possibly be partly due to truncation at the time of the uplift, and also, because the lower shale and the middle clastic-carbonate units are missing either because of non-deposition or erosion.

Reasoner and Hunt (1954, p. 1540) reported that the middle unit of the Bakken formation is a typical sand bar-type deposit in the Coleville region of Saskatchewan due to its variable thickness in short distances.

Sandberg and Hammond (1958, p. 2330) pointed out that the Englewood formation probably was deposited over the submerged Black Hills Arch about the same time as the Central Montana Platform and "ancestral" Cedar Creek Anticline were being uplifted and eroded.

Fig. 18.--Core of the middle clastic-carbonate unit of the Bakken formation in The Texas Company - J. M. Donahue No. 1 well at a depth of 11,000 feet.

Fig. 19.--Core of the lower shale unit of the Bakken formation in The Texas Company - J. M. Donahue No. 1 well at a depth of 11,008 feet.

The Englewood probably was deposited about the same time as the Bakken. However, Englewood deposition probably continued after the end of Bakken black shale deposition. This relationship of deposition is suggested from the stratigraphic relationship of the Bakken and Englewood formations in northwestern South Dakota. The Englewood formation seems to have been deposited near the outer edges of the marginal Bakken sea. However, the environment of Englewood deposition seems to be quite different than that of the Bakken. The presence of a lower silty shale of the Englewood suggests that the initial deposition took place in a sea that was less restricted than the initial Bakken sea. Fluctuating sea conditions followed, as shown by the interbedded shales and limestones. The sea then became open and continued as such for a long period of deposition as indicated by the continuous sequence of limestone and dolomite of the Englewood and Pahasapa formations. The contact between these two formations is transitional, and no break in sedimentation is indicated in the rocks.

CORRELATION AND STRATIGRAPHIC COMPARISONS

The placement of the Devonian-Mississipian boundary in the area of this study is beyond the scope of this report, therefore, the writer relied heavily on the opinions of other workers who have conducted paleontological studies. Many workers agree that the systemic boundary occurs at the base of the black to gray shales of the Exshaw formation, the Little Chief Canyon member of the Lodgepole formation, the Sappington sandstone, the Englewood formation, and the Bakken formation. Generally, conodonts have been used to date the black shales, and the overlying strata usually contain Mississippian fossils and the underlying strata contain Devonian fossils.

It had been hoped that a study of the conodonts present in the black shales of the Bakken formation could be conducted. However, difficulty of extracting complete specimens was encountered, and the study was not pursued.

For the sake of convenience and lack of evidence to the contrary, the writer agrees with the placement of the Devonian-Mississippian boundary at the base of the black to gray shales. The boundary coincides with the lithogenetic break between Devonian-type sedimentation and Mississippian-type sedimentation in the area of this report. The systemic boundary could, however, conceivably occur within the black shales. An example of such an occurrence takes place within the Chattanooga shale in Tennessee and the New Albany shale of Illinois and Kentucky.

Harker and McLaren (1958, p. 253) state that:

> The two lower members of the Bakken formation of the subsurface corresponds lithologically with the Exshaw formation. Similar correspondance exists between the Exshaw and the Sappington formation of southwestern Montana, if the Sappington is interpreted as including the black shale below the sandstone.

Kent (1959, p. 16) in west-central Saskatchewan divided the Bakken into three members which are the Exshaw shale member, the Coleville snadstone member, and the upper shale member. Penner (1958, p. 266) correlated the lower shale unit of the Bakken with the black shale of southern Alberta which is correlated with the Exshaw shale. He further stated (p. 267) that:

> Inasmuch as the term "Exshaw" is used exclusively by the industry (with some justification) no change in terminology is proposed in this paper. However, if the basal black shale of the Bakken is named in a future paper then that name would be applicable.

The writer hesitates at this time in designating the lower unit of the Bakken formation in the area of this study, the Exshaw shale member. However, there seems to be some evidence as shown by the workers north of the international boundary that this relationship exists. Further work seems necessary in the way of regional correlation from the area of this study to the outcrop area of the Exshaw shale.

The Bakken formation does not extend to the Black Hills, however, the lower shale unit of the Englewood formation is thought by the writer as being equivalent or nearly equivalent to the Bakken lower shale. This relationship is suggested by the stratigraphic position of the Bakken and Englewood in Butte County, South Dakota.

CONCLUSIONS

1. The Englewood formation of Mississippian age crops out in the northern Black Hills, and it is difficult to trace in the subsurface for any great distance.
2. Difficulty in tracing the Englewood in the subsurface may be due to changes in lithology, changes in color, and poor sample recovery.
3. A type section occuring two miles southwest of Englewood, South Dakota, NW¼NE¼ sec. 31, T. 4 N., R. 3 E., is proposed for the Englewood formation.
4. The Englewood formation in the outcrops consists of a lower shale unit, a middle argillaceous and shaly limestone unit, and an upper dolomitic limestone.
5. The Englewood formation appears to overlie the Bakken formation in Butte County, South Dakota.
6. A standard reference section (the Deadwood junkyard section) occuring at NE¼SW¼ 13, T. 5 N., R. 3 E., is proposed for the Englewood formation.
7. The lower shale unit of the Englewood formation is considered to be equivalent or nearly equivalent to the Bakken shale.
8. The Bakken formation does not crop out in the area of this study, however, it occurs throughout the Williston Basin.
9. A lower black shale unit, a middle sandstone, siltstone, silty limestone, or limestone, and an upper black shale unit make up the Bakken formation.

10. The Bakken can be easily traced and defined in the area where the three units are present; this area is designated the Central Area.

11. Around the Central Area, the Bakken lithologic units converge and become thin, and the lower shale is missing; this area of occurrence is designated the Marginal Shelf.

12. For the sake of convenience and having found no evidence to the contrary, the writer agrees with the placement of the Devonian-Mississippian boundary at the base of the Bakken formation.

13. The Bakken sea probably had its origin in the Cordilleran region, was initially restricted in circulation, later became a normal marine sea, and was then again restricted in circulation.

14. The Bakken sea probably occupied the Central Area with its general marginal area defined by the Marginal Shelf.

15. The Englewood formation probably was deposited about the same time as the Bakken, but Englewood deposition probably continued after Bakken deposition.

16. The term "Coleville sand" which was introduced by Reasoner and Hunt (1954) is herein rejected.

17. At this time, the writer hesitates to call the lower black shale unit of the Bakken the Exshaw shale member as suggested by workers north of the international boundary.

18. A standard reference section (Socony Vacuum - C. Dvorak No. 1 well) for the Bakken formation occurring at SE¼SE¼ sec. 6, T. 141 N., R. 94 W., Dunn County, North Dakota, is proposed for the Bakken formation.

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APPENDICES

Appendix I. List of Well Locations

North Dakota - Sample Study

Numbers are those used by the North Dakota Geological Survey.

Well No.

27. Union Oil Company of California - Chris Skjervheim No. 1 well, NW¼NE¼ sec. 28, T. 159 N., R. 65 W., Cavalier County.

32. Amerada Petroleum Corporation - H. O. Bakken No. 1 well or Tioga Madison Unit G. 123, SW¼NW¼ sec. 12, T. 157 N., R. 95 W., Williams County.

39. Hunt Oil Company - W. B. Shoemaker No. 1 well, NE¼SW¼ sec. 3, T. 157 N., R. 78 W., McHenry County.

151. Hunt Oil Company - Emma Kleven No. 1 well, SW¼SW¼ sec. 18, T. 140 N., R. 80 W., Burleigh County.

207. Continental Oil Company - Lueth No. 1 well, NE¼NW¼ sec. 27, T. 146 N., R. 95 W., Wells County.

232. Youngblood and Youngblood - Lester Kelstrom No. 1 well, SW¼SW¼ sec. 26, T. 133 N., R. 83 W., Grant County.

291. Amerada Petroleum Corporation - Herman May No. 1 well, NW¼NE¼ sec. 9, T. 139 N., R. 100 W., Billings County.

392. Sam J. Harrison - J. H. Anderson, and others, No. 1 well, SW¼SW¼ sec. 21, T. 157 N., R. 85 W., Ward County.

405. Pure Oil Company - J. M. Carr No. 1 well, NE¼NE¼ sec. 15, T. 146 N., R. 66 W., Foster County.

410. Gulf Oil Company - Dorough Federal No. 1 well, NE¼SE¼ sec. 24, T. 143 N., R. 103 W., Golden Valley County.

505. Socony Vacuum Oil Company, Inc. - C. Dvorak No. 1 well, SE¼NE¼ sec. 6, T. 141 N., R. 94 W., Dunn County.

516. Western Natural Gas Company - Traux Traer No. 1 well, NW¼SW¼ sec. 13, T. 132 N., R. 102 W., Bowman County.

527. The California Company - Rough Creek Unit No. 1 well, NW¼NE¼ sec. 13, T. 148 N., R. 98 W., McKenzie County.

528. W. H. Hunt - L. C. Andersen No. 1 well, NW¼NE¼ sec. 25, T. 157 N., R. 89 W., Mountrail County.

644. Gordon Butterfield - Rudolf Trautman No. 1 well, SE¼SE¼ sec. 5, T. 139 N., R. 68 W., Stutsman County.

665. Caroline Hunt Trust Estate - John Waltz, Jr., No. 1 well, NE¼NE¼ sec. 15, T. 148 N., R. 76 W., Sheridan County.

706. Shell Oil Company - Gifford Marchus No. 1 well, SE¼SE¼ sec. 23, T. 157 N., R. 70 W., Pierce County.

763. Caroline Hunt Trust Estate - Anton Novy No. 1 well, SE¼SE¼ sec. 14, T. 144 N., R. 77 W., Burleigh County.

769. Calvert Exploration Company - Fred and Signa Wright No. 1 well, NW¼NW¼ sec. 14, T. 154 N., R. 78 W., McHenry County.

793. Socony Vacuum Oil Company - Solomon Birdbear No. 1 well, SE¼NW¼ sec. 22, T. 149 N., R. 91 W., Dunn County.

895. Lion Oil Company - Wallace Hall, and others, No. 1 well, NW¼NW¼ sec. 14, T. 162 N., R. 76 W., Bottineau County.

956. Gulf Oil Company - B. Pierre Federal No. 1 well, NW¼SW¼ sec. 28, T. 148 N., R. 104 W., McKenzie County.

999. The Texas Company - J. M. Donahue No. 1 well, SW¼NE¼ sec. 23, T. 154 N., R. 100 W., Williams County.

1069. Cardinal Drilling Company - B. M. Keeler No. 1 well, NW¼NW¼ sec. 1, T. 159 N., R. 82 W., Bottineau County.

1405. Amerada Petroleum Corporation - C. Penck Tract 1, No. 2 well, NW¼NE¼ sec. 27, T. 150 N., R. 96 W., McKenzie County.

1575. The Carter Company - L. L. Johnson and Ellen Johnson No. 1 well, NW¼SW¼ sec. 9, T. 129 N., R. 106 W., Bowman County.

1620. Pan American Petroleum Corporation - Raymond Vetter No. 1 well, NE¼SW¼ sec. 27, T. 139 N., R. 90 W., Morton County.

1679. Amerada Petroleum Corporation - C. C. Mogen Tract 1, No. 1 well, SE¼SW¼ sec. 10, T. 153 N., R. 96 W., McKenzie County.

North Dakota - Mechanical Log Study

Numbers are those used by the North Dakota Geological Survey.

Well No.

25. Roesser and Pendleton, Inc. - J. J. Weber No. 1 well, SE¼ sec. 35, T. 133 N., R. 76 W., Emmons County.

33. Amerada Petroleum Corporation - B. H. Risser No. 1 well, SW¼SE¼ sec. 12, T. 149 N., R. 96 W., McKenzie County.

49. Stanolind Oil and Gas Company - McLean County No. 1 well, SW¼SW¼ sec. 28, T. 150 N., R. 80 W., McLean County.

91. Stanolind Oil and Gas Company - J. Brusich No. 1 well, SE¼SE¼ sec. 8, T. 135 N., R. 98 W., Slope County.

105. Stanolind Oil and Gas Company - Walter and Ingeberg Naswick No. 1 well, SW¼NE¼ sec. 2, T. 153 N., R. 85 W., Ward County.

174. Continental - Gueneland No. 1 well, NW¼NW¼ sec. 3, T. 140 N., R. 77 W., Burleigh County.

355. Amerada Petroleum Corporation - Tioga Madison Unit K. 143 well, SW¼NW¼ sec. 18, T. 158 N., R. 94 W., Mountrail County.

548. Pure Oil Company - Ole Gunderson No. 1 well, SW¼NW¼ sec. 11, T. 160 N., R. 98 W., Divide County.

590. Caroline Hunt Trust Estate - F. M. Fuller No. 1 well, SW¼SE¼ sec. 6, T. 136 N., R. 73 W., Logan County.

607. Socony Vacuum Oil Company - Angus Kennedy F-32-24-P well, SW¼NE¼ sec. 24, T. 149 N., R. 93 W., Dunn County.

631. Ohio Oil Company - Standing Rock Sioux Tribal No. 1 well, NE¼SW¼ sec. 29, T. 131 N., R. 80 W., Sioux County.

656. W. H. Hunt - Guy Almy No. 1 well, NW¼NE¼ sec. 13, T. 155 N., R. 82 W., Ward County.

1231. Amerada Petroleum Corporation - Iverson Nelson Unit No. 1 well, NE¼ sec. 2, T. 155 N., R. 96 W., Williams County.

1443. Dakamont Exploration Corporation - H. E. Jacobson No. 1 well, SW¼NE¼ sec. 6, T. 162 N., R. 96 W., Divide County.

1446. James H. Snowden, and others - M. A. Morrison No. 1 well, SE¼SW¼ sec. 34, T. 130 N., R. 105 W., Bowman County.

1534. Amerada Petroleum Corporation - Herfindahl Kvam Unit No. 1 well, NE¼ sec. 26, T. 156 N., R. 96 W., Williams County.

1546. Kerr McGee Oil Industry, Inc. - Arlot Johnson No. 1 well, NE¼NW¼ sec. 34, T. 162 N., R. 101 W., Divide County.

2010. The Carter Oil Company - D. Moore No. 1 well, NW¼NE¼ sec. 7, T. 163 N., R. 102 W., Divide County.

South Dakota - Sample Study

Numbers are those of the writer.

Well No.

SD 1. Amerada Petroleum Corporation - State No. 1 well, NW¼NW¼ sec. 4, T. 14 N., R. 4 E., Butte County.

SD 2. Shell Oil Company - State of South Dakota No. 1 (5409) well, C SW¼SE¼ sec. 9, T. 21 N., R. 4 E., Harding County.

SD 3. Weller Bush - Weisman No. 1 well, NW¼SW¼SE¼ sec. 30, T. 7 N., R. 4 E., Lawrence County.

SD 4. Youngblood and Youngblood - No. 1 Galvin well, C SE¼SE¼ sec. 25, T. 16 N., R. 22 E., Dewey County.

SD 5. Shell Oil Company - Veal No. 1 well, SE¼SE¼ sec. 7, T. 17 N., R. 15 E., Perkins County.

South Dakota - Mechanical Log Study

Number is that of the writer.

Well No.

SD 7. Shell Oil Company - Minter No. 1 well, NW¼SW¼ sec. 11, T. 22 N., R. 19 E., Corson County.

Montana - Sample Study

Number is that of the writer.

Well No.

M 1. Shell - No. 43 - 22A Unit well, C NE¼SE¼ sec. 22, T. 11 N., R. 57 E., Wibaux County.

Montana - Mechanical Log Study

Numbers are those of the writer.

Well No.

M 2. Amerada Petroleum Corporation - No. 1 Loucks well, C NE¼SW¼ sec. 35, T. 36 N., R. 52 E., Sheridan County.

M 3. Union Oil Company of California - Muhring No. 1 well, NW¼NE¼ sec. 32, T. 35 N., R. 47 E., Daniels County.

M 4. Murphy, and others - E. Poplar No. 1 well, C SW¼NE¼ sec. 2, T. 28 N., R. 51 E., Roosevelt County.

M 5. Richfield - Madoc No. 1 well, NW¼SW¼ sec. 31, T. 37 N., R. 49 E., Daniels County.

M 6. Phillips, Brown, and Rock - No. 1 Harmon well, NW¼NW¼ sec. 29, T. 27 N., R. 58 E., Roosevelt County.

M 7. Mobile - No. F-33-23-P Damm well, NW¼SE¼ sec. 23, T. 29 N., R. 54 E., Roosevelt County.

Appendix II. Lithologic Descriptions

North Dakota

Well No.

27. Union Oil Company of California - Chia Skjervheim No. 1 well, NW¼NE¼ sec. 28, T. 159 N., R. 63 W., Cavalier County.

Lodgepole formation
1575 - 1589 Limestone, light gray (N7), crystalline.

Devonian (?) Birdbear formation (?)
1589 - 1628 Limestone, grayish orange pink (5YR 7/2), coarsely crystalline, and vuggy.

(Bakken formation not present)

32. Amerada Petroleum Corporation - H. O. Bakken No. 1 well, or Tioga - Madison Unit G. 125, SW¼NW¼ sec. 12, T. 157 N., R. 95 W., Williams County.

Lodgepole formation

9470 - 80 Limestone, medium gray (N6) to light gray (N7), fine grained, dense; anhydrite, white, about 1 percent of the sample; minor amount of sandstone, moderate reddish orange (10R 6/6), fine-grained.

9480 - 9510 Limestone as above.

9510 - 20 Limestone as above; limestone, medium gray (N4), dense.

9520 - 9600 Limestone as above; minor amount of anhydrite, white.

9600 - 10 Limestone, medium dark gray (N4) to light gray (N7), dense; shale, dark gray (N3), fissile, calcareous.

Bakken formation 9613

9610 - 20 Limestone and shale, as above; crinoid stems.

9620 - 50 Shale, dark gray (N3), slightly calcareous, fissile, pyritic, carbonaceous.

9650 - 90 Sandstone, brownish gray (5YR 4/1) to light gray (N7), very fine grained, calcareous, rounded quartz grains; anhydrite, yellow gray (5Y 7/2), about 15 percent of the sample; brachiopod fragments.

9690 - 9720 Shale, dark gray (N3), slightly calcareous, fissile, pyritic.

Three Forks formation 9720

9720 - 30 Shale, as above; dolomite, light greenish gray (5G 8/1), microcrystalline.

9730 - 40 Dolomite, yellowish gray (5Y 7/2); dolomite, light greenish gray; shale as above.

9740 - 50 Dolomite, yellowish gray (5Y 7/2), saccharoidal to cryptocrystalline.

9750 - 60 Dolomite, yellowish gray to grayish orange pink (5YR 7/2), cryptocrystalline.

9760 - 90 Dolomite, as above; anhydrite, white and yellow gray.

9790 - 9800 Dolomite, as above; limestone, grayish orange pink, cryptocrystalline; anhydrite, white.

9800 - 9900 Dolomite, as above; shale, moderate reddish brown (10R 4/6), fissile; pyrite crystals; dolomite, light gray, microcrystalline; minor chert, white; minor gypsum crystals.

Well No.

Birdbear formation 9905
9900 - 20 Shale, moderate reddish brown (10R 4/6), fissile, calcareous; dolomite, yellowish gray and light greenish gray (5G 8/1), microcrystalline; anhydrite.

9920 - 60 Limestone, brownish gray (5YR 4/1), dense; limestone, very light gray (N8), crystalline; anhydrite, light brownish gray (5Y 6/1).

39. Hunt Oil Company - W. B. Shoemaker No. 1 well, NE¼SW¼ sec. 3, T. 157 N., R. 78 W., McHenry County.

Lodgepole formation
4560 - 4650 Limestone, medium light gray (N6) and light gray (N7), fragmental and finely crystalline.

Bakken formation 4650
4650 -4670 Shale, dark gray (N3) to black (N1), fissile to platy.

4670 - 4680 Shale, as above; siltstone, medium gray (N5), calcareous.

4680 - 4690 Siltstone, dark gray; shale, as above.

4690 - 4710 Shale, as above; shale, reddish brown (10R 5/4); siltstone, light gray, calcareous.

Three Forks formation 4710
4710 - 4730 Shale, reddish brown, calcareous.

151. Hunt Oil Company - Emma Kleven No. 1 well, SW¼SW¼ sec. 18, T. 140 N., R. 80 W., Burleigh County.

Lodgepole formation
5800 - 10 Limestone, medium light gray (N6), very fine grained, microcrystalline.

Bakken formation 5810
5810 - 50 Shale, black (N1) fissile to compact.

Three Forks formation 5850
5850 - 90 Dolomite, light brownish gray, crystalline, microsaccharoidal; limestone, medium gray (N5), dense.

5890 - 5900 Limestone, greenish gray (GY 6/1), dense, microcrystalline.

5900 - 10 Siltstone, pinkish gray (5YR 8/1); limestone, as above.

Well No.

207. Continental Oil Company - Lueth No. 1 well, NE¼NE¼ sec. 27, T. 146 N., R. 95 W., Wells County.

Core Study
Lodgepole formation (?) 4193
4193 - 95 Dolomite, grayish orange pink (5YR 7/2), crystalline, saccharoidal.

Bakken formation 4195
4195 - 4205 Shale, medium gray (N5) to dark gray (N3), fissile.

Birdbear formation (?) 4205
4205 - 06 Dolomite, grayish orange (10YR 7/4), saccharoidal, vuggy.

232. Youngblood and Youngblood - Lester Kelstrom No. 1 well, SW¼SW¼ sec. 26, T. 133 N., R. 83 W., Grant County.

Lodgepole formation
5520 - 45 Limestone, light gray (N7), dense to microcrystalline; shale (cavings?), medium gray (N4), fissile, very slightly calcareous; minor dolomite, greenish gray (5GY 6/1), dense, (cavings?).

5545 - 70 Limestone, light gray, dense to microcrystalline; chert, white; sandstone, light brown (5YR 6/1), quartz grains well rounded, fine grained.

5570 - 85 Limestone, very light gray (N8), dense to microcrystalline, some fragmental; limestone, medium light gray (N6), dense.

Bakken formation 5585
5585 - 95 Shale, dark gray (N4), fissile.

5595 - 5620 Shale, black (N1), fissile to platy with anhydrite inclusions, calcareous; minor amount of shale greenish gray (5G 6/1).

Three Forks formation 5620
5620 - 35 Limestone, light brownish gray (5YR 6/1), dense, fragmental; siltstone, very light gray (N8), calcareous; rounded quartz grains.

5635 - 50 Limestone, as above; siltstone, greenish gray (5G 6/1), slightly calcareous; dolomite, greenish gray; siltstone, pinkish gray (5YR 8/1), calcareous.

Well No.

5650 - 80 Limestone, light brown (5YR 6/4), oolitic fossiliferous, dense; limestone, light gray, fragmental and crystalline.

291. Amerada Petroleum Corporation - Herman May No. 1 well, NW¼NE¼ sec. 9, T. 139 N., R. 100 W., Billings County.

Lodgepole formation
10,340 - 465 Limestone, medium gray (N5) to medium light gray (N6), dense, cryptocrystalline.

10,465 - 470 Limestone, light gray (N7) to medium gray, dense.

Bakken formation 10,470
10,470 - 480 Shale, dark gray (N3) to black N1), fissile to platy, slightly calcareous; minor limestone, as above.

Three Forks formation 10,480
10,480 - 490 Shale, dark greenish gray (5G 4/1), fissile to platy; minor sandstone, brownish gray (5YR 4/1), slightly calcareous, very fine grained.

10,490 - 500 Shale, as above; dolomite, dusky yellow (5Y 6/4), microcrystalline.

392. Sam G. Harrison - J. H. Anderson, and others, No. 1 well, SW¼SW¼ sec. 21, T. 157 N., R. 85 W., Ward County.

Lodgepole formation
6880 - 6920 Limestone, light gray (N7) to medium light gray (N6), fragmental, dense, very fine grained.

6920 - 50 Limestone, medium gray (N5), argillaceous, very fine grained.

6950 - 60 Limestone, as above; limestone, light gray, very fine grained, dense, fragmental; crinoid stems.

Bakken formation 6960
6960 - 80 Shale, black (N1), fissile, flaky, calcareous.

6980 - 90 Siltstone, light gray, calcareous, micaceous, rounded grains; limestone, light gray, very fine grained, fragmental.

6090 - 7000 Shale, black, fissile, flaky, calcareous.

Three Forks formation 7000
7000 - 20 Dolomite, grayish orange pink (10YR 7/2), fine grained.

Well No.

7020 - 70 Dolomite, as above; brachiopod shells; minor shale, moderate reddish brown (10R 4/6).

7050 - 70 Dolomite, moderate orange pink (10R 7/4), fine grained, microsucrosic.

7070 - 90 Shale, reddish brown (10R 5/4), calcareous, soft.

403. Pure Oil Company - J. M. Carr No. 1 well, NE¼NE¼ sec. 15, T. 146 N., R. 66W., Foster County.

Core Study
This interval is listed as Englewood formation by the North Dakota Geological Survey in a list of Cores Available for Study. The lithology may be that of the Three Forks formation.

Three Forks formation(?)
2390 - 96 Shale, pale red gray (5R 6/2), spotted light green.

2396 - 99 Shale, as above, with no spots.

2399 - 2408 Shale, as above, with light green spots.

2308 - 15 Shale, as above, with red ferruginous banding.

2315 - 18 Shale, as above.

(Bakken formation not present)

410. Gulf Oil Company - Dorough Federal No. 1 well, NE¼SE¼ sec. 24, T. 143 N., R. 103 W., Golden Valley County.

Lodgepole formation
10,400 - 500 Limestone, medium gray (N5), dense.

Bakken formation 10,495
10,500 - 520 Shale, dark gray (N3), fissile; limestone, light gray (N7), dense; pyrite.

Three Forks formation 10,525
10,520 - 550 Limestone, medium light gray (N6), dense, cryptocrystalline; dolomite, medium gray to yellowish gray (5Y 8/1), dense, microsucrosic.

505. Socony Vacuum Oil Company, Inc. - C. Dvorak No. 1 well, SE¼NE¼ sec. 6, T. 141 N., R. 94 W., Dunn County.

Core (chips) Study
Lodgepole formation
9995 - 10,000 Limestone, medium dark gray (N4), dense.

10,000 - 010 Limestone, dark gray (N4), dense.

10,010 - 020 As above, very argillaceous.

10,020 - 027 Shaly limestone, black (N1), fossiliferous (brachiopod and crinoid fragments).

10,027 - 028 Limestone, brownish gray (5YR 4/1), fragmental and crystalline, fossiliferous, dark greenish gray (5G 4/1) material, probably glauconite.

10,028 - 035 Limestone, light olive gray (5Y 6/1), dense, partly crystalline with scattered calcite crystals.

Bakken formation 10,035
10,035 - 038 Shale, medium gray (N5), and limestone, light olive gray (5Y 6/1); bedding occure as small scale intertonguing; limestone, fragmental and recrystalline; pyrite.

10,038 - 045 Shale, black (N1), fissile, abundant conodonts.

10,045 - 050 Shale, black, compact.

10,050 - 053 Silty limestone, medium dark gray, dense, argillaceous.

10,053 - 056 Siltstone, medium gray, calcareous, very fine grained, argillaceous.

10,056 - 058 Sandstone, medium gray, very fine grained, calcareous.

10,058 - 071 Siltstone, medium light gray, calcareous.

10,071 - 075 Shale, black, fissile, pyritic.

10,075 - 095 Siltstone, medium gray, compact, silty, very slightly calcareous.

Three Forks formation 10,095
10,095 - 123 Siltstone, greenish gray (5G 6/1), fissile, and dolomite, light olive gray (5Y 6/1), silty. Interbedded and small scale intertonguing, pyritic. Bedding usually varies from 1/8 to 1/2 inch in thickness.

10,123 - 132 Sandstone, grayish orange pink (5YR 7/2) and shale, grayish brown (5YR 3/2), dolomitic. Minor shale, greenish gray, interbedded.

Well No.

10,132 - 148 Shale, pale brown (5YR 5/2), slightly calcareous.

10,148 - 151 Dolomite, pale yellow brown (10YR 6/2) and shale, greenish gray, interbedded.

10,151 - 160 As above, and shale, grayish brown; siltstone, grayish orange pink (5YR 7/2).

10,160 - 164 Shale, greenish gray, and dolomite, pale yellow brown.

10,164 - 169 Shale, pale brown, breccia of greenish gray shale dolomitized.

10,169 - 176 As above, with a breccia of pale yellow brown dolomite.

10,176 - 180 Dolomite, light greenish gray (5G 8/1), very finely crystalline.

10,180 - 197 Dolomite, brownish gray (5YR 4/1), dense.

10,197 - 206 Siltstone, greenish gray, calcareous, white anhydrite.

10,206 - 243 Siltstone, pale brown, calcareous, white anhydrite.

10,243 - 249 Siltstone, greenish gray, calcareous.

10,249 - 291 Siltstone, pale brown and greenish gray, calcareous.

10,291 - 299 Anhydrite, dusky brown (5YR 2/2), minor amount of siltstone, pale yellow brown; minor amount of limestone, dusky brown.

Birdbear formation 10,300.

10,299 - 304 Dolomite, pale yellowish brown, dense; anhydrite, crystalline, white and dusky brown.

10,304 - 313 Limestone, brownish gray, dense.

316. Western Natural Gas Company - Traux Traer No. 1 well, NW¼SW¼ sec. 13, T. 132 N., R. 102 W., Bowman County.

Lodgepole formation

9200 - 9210 Limestone, medium gray (N5), microcrystalline, very fine grained.

9210 - 9310 Limestone, light gray (N7) to medium dark gray (N4), very fine grained, microcrystalline.

Well No.

Bakken formation 9505
9510 - 60 Limestone, brownish gray (5YR 4/1), very fine grained, microcrystalline; limestone, light gray (N7); minor amount of sandstone, light brownish gray, calcareous, angular grains. Very fine grained.

527. The California Company - Rough Creek Unit No. 1 well, NW¼NE¼ sec. 13, T. 148 N., R. 98 W., McKenzie County.

Lodgepole formation
11,175 - 180 Limestone, medium dark gray (N4), dense, argillaceous.

11,180 - 195 Samples missing.

11,195 - 200 Limestone, medium dark gray, dense, argillaceous.

Bakken formation 11,200.
11,200 - 205 Samples missing.

11,205 - 225 Shale, black (N1), fissile.

Core Study
11,225 - 228 Sandstone, brownish gray (5YR 4/1), calcareous, rounded grains, very fine grained, silty and dolomitic.

11,228 - 249 Siltstone, brownish gray, calcareous.

11,249 - 258 Shale, medium gray (N5) to black, fissile, calcareous.

11,258 - 261 Shale, black, fissile, fossiliferous (fish scales ?).

11,261 - 274 Shale, black, fissile, fossiliferous (conodonts).

11,274 - 288 Shale, as above.

Three Forks formation 11,288
11,288 - 292 Limestone, dark gray (N3), very fossiliferous (brachiopods), mesocrystalline to microcrystalline.

11,292 - 295 Interbedded dolomite and shale. Dolomite, medium gray (N5), microcrystalline, laminae bedding usually occurring in streaks and layers from 1/8 to 3/8 inch in thickness; shale greenish gray (5GY 6/1), calcareous, fissile, laminae bedding similar to that of the dolomite.

528. W. H. Hunt - L. C. Anderson No. 1 well, NW¼NE¼ sec. 25, T. 157 N., R. 89 W., Mountrail County.

Lodgepole formation

8330 - 45 Limestone, medium light gray (N6) to very light gray (N8), dense, cryptocrystalline to microcrystalline; chert, light olive gray (5Y 6/1).

8345 - 75 Limestone, as above; chert, as above; minor amount of shale, dark gray (N3) to black (N1), fissile.

8375 - 8405 Limestone and shale, as above; trace of light olive gray shale, slightly silty; few shell fragments.

Bakken formation 8405

8405 - 25 Shale, black, fissile, very slightly calcareous.

8425 - 45 Siltstone, medium dark gray, calcareous, angular grains, minor amount of rounded quartz grains; chert, light olive gray (5Y 6/1).

8445 - 65 Shale, black, fissile, slightly calcareous.

Three Forks formation 8465

8465 - 70 Sandstone, light gray (N7), calcareous, fine grained; rounded quartz grains, scattered; siltstone, medium dark gray; minor amount of shale, greenish gray, fissile.

8470 - 8540 Dolomite, silty and argillaceous, yellowish gray (5Y 7/2), microsucrosic; siltstone, light gray, calcareous; limestone, light olive gray, dense, microcrystalline.

8540 - 90 Shale and siltstone, light gray to dark gray, calcareous; dolomite, as above.

8590 - 8635 Dolomite and dolomitic limestone, pale reddish brown (10R 5/4), microsucrosic, very fine grained; dolomite, moderate orange pink (10R 7/4); siltstone, dark greenish gray, calcareous, micaceous, argillaceous; shale, as above; trace of pyrite.

8635 - 45 Dolomite and dolomitic limestone, as above; shale, greenish gray, calcareous; chert, white.

8645 - 80 Shale, greenish gray, as above; limestone, dark reddish brown (10R 3/4), argillaceous; siltstone, greenish gray, friable, calcareous, scattered rounded quartz grains.

Birdbear formation 8680

8680 - 8700 Limestone, reddish brown, and light brown (5YR 6/4), fragmental, microcrystalline; chert.

Well No.

644. Gordon Butterfield - Rudolph Trautman No. 1 well, SE¼SE¼ sec. 5, T. 139 N., R. 68 W., Stutsman County.

Lodgepole formation
2950 - 90 Limestone, grayish orange pink, dense; chalk, white, soft.

2990 - 3060 Limestone, light brownish gray (5YR 6/1), crystalline, oolitic, subsucrosic.

Bakken formation 3059
3060 - 80 Limestone, as above; much shale, black to medium dark gray, fissile.

3080 - 3100 Shale, as above; light gray shale.

Duperow formation 3100
3100 - 3190 Dolomite, grayish orange pink (5YR 7/2), sucrosic; dolomite, moderate orange pink (10R 7/4), sucrosic.

3190 - 3215 Limestone, pinkish gray (5YR 8/1) and very pale orange (10YR 8/2), dense.

665. Caroline Hunt Trust Estate - John Waltz, Jr., No. 1 well, NE¼NE¼ sec. 15, T. 148 N., R. 76 W., Sheridan County.

Lodgepole formation
4720 - 30 Limestone, light gray (N7) to medium gray (N5), microcrystalline, argillaceous.

4730 - 50 Shale, dark gray (N3) to gray black (N2), soft, fissile; limestone, as above.

4750 - 80 Limestone, light gray, fragmental, microcrystalline; minor shale, as above.

Bakken formation 4785
4780 - 4800 Shale, dark gray to gray black, fissile.

Three Forks formation 4800
4800 - 10 Limestone, light gray, dense, very fine grained; few scattered quartz grains; anhydrite, white.

4810 - 20 Shale, moderate reddish orange (10R 4/6), soft calcareous, lumpy; limestone as above.

Well No.

4820 - 30 Dolomite, light red (5R 6/6), fine grained, microcrystalline; dolomite, light gray, fine grained, microcrystalline.

706. Shell Oil Company - Gifford Marchus No. 1 well, SE¼SE¼ sec. 23, T. 157 N., R. 70 W., Pierce County.

Lodgepole formation
2895 - 2915 Limestone, moderate orange pink (10R 7/4), dense to microcrystalline; chert, pinkish gray (5YR 8/1) and white.

2915 - 50 Limestone, as above; limestone, grayish orange pink (5YR 7/2), fine grained, crystalline, microvuggular; chert, as above.

Bakken formation 2950
2950 - 82 Shale, black (N1), fissile, very slightly calcareous; minor amount of shale, medium gray (N5).

Three Forks formation 2982
2950 - 90 Dolomitic limestone, brownish gray (5YR 4/1), crystalline; limestone, grayish orange pink (5YR 7/2); siltstone, very pale orange (10YR 8/4).

763. Caroline Hunt Trust Estate - Anton Novy No. 1 well, SE¼SE¼ sec. 14, T. 144 N., R. 77 W., Burleigh County.

Lodgepole formation
4930 - 80 Limestone, medium light gray (N6), dense, microcrystalline, crinoidal, scattered rounded quartz grains.

Bakken formation 4980
4980 - 95 Shale, black (N1), fissile to platy; shale, greenish gray (5G 4/1).

4695 - 5140 Dolomitic siltstone, grayish orange pink (5YR 7/2); shale, as above.

5140 - 49 Dolomite and siltstone, as above; shale, black fissile to platy.

Three Forks formation 5149
5149 - 80 Dolomite, grayish orange pink; anhydrite, white.

Well No.

769. Calvert Exploration Company - Fred and Sigma Wright No. 1 well, NW¼NW¼ sec. 14, T. 154 N., R. 78 W., McHenry County.

Lodgepole formation
4660 - 70 Limestone, light gray (N7), very fine grained, microcrystalline.

4670 - 80 Limestone, as above; shale, medium dark gray (N4) to grayish black (N2), fissile, cavings (?).

4680 - 4760 Limestone, light gray (N7), very fine grained, microcrystalline; minor shale, as above.

4760 - 4810 Limestone, as above; anhydrite, white; minor shale, as above.

Bakken formation 4815
4810 - 40 Shale, black (N1), fissile, minor limestone, as above.

Three Forks formation 4842
4840 - 4900 Shale and limestone, as above.

4900 - 30 Shale, moderate reddish brown (10R 6/6), calcareous; siltstone, greenish gray.

793. Socony Vacuum Oil Company - Solomon Birdbear No. 1 well, SE¼NW¼ sec. 22, T. 149 N., R. 91 W., Dunn County.

Lodgepole formation
9950 - 60 Limestone, medium gray (N5), very fine grained, dense, argillaceous.

9960 - 75 Limestone, as above; fossiliferous; limestone, medium gray, fractured, anhdrite, fills fractures.

9975 - 85 Shale, medium gray (N5), fissile, calcareous.

9985 - 90 Limestone, medium gray, very fine grained, dense, argillaceous.

Bakken formation 9990
9990 - 10,015 Shale, black (N1), fissile.

10,015 - 030 Siltstone, dolomitic, medium light gray (N6), fine grained.

10,030 - 040 Siltstone, as above, with pyrite streaks; shale, greenish gray (5GY 6/1) streaks in siltstone.

Well No.

10,040 - 045 Siltstone, dolomitic, medium gray, fine grained.

10,045 - 060 Samples missing.

10,060 - 085 Shale, black, fissile.

Three Forks formation 10,085
10,085 - 090 Siltstone, light gray, calcareous, dolomitic, very fine grained.

10,090 - 140 Dolomite, grayish orange pink (5YR 7/2), microsucrosic; shale, grayish green (5G 5/2), interbedded with dolomite.

895. Lion - Wallace Hall, and others, No. 1 well, NW¼NW¼ sec. 14, T. 162 N., R. 76 W., Bottineau County.

Lodgepole formation
3705 - 35 Limestone, medium gray (N6) to light gray (N7), dense, microcrystalline; chert, light gray.

3735 - 40 Shale, medium gray (N6), fissile, cavings (?); limestone, as above.

3740 - 70 Limestone, as above.

3770 - 95 Limestone, light gray (N8), dense, microcrystalline; shale, medium gray, fissile, cavings (?).

Bakken formation 3795
3795 - 3801 Shale, medium gray to dark gray (N5), fissile.

Three Forks formation 3801
3801 - 70 Shale, variecolored; greenish gray (5G 6/1), brownish gray (5YR 4/1), moderate reddish brown (10R 4/6); pyrite; anhydrite, crystalline, white.

3870 - 95 Limestone, dark greenish gray, dense, cryptocrystalline; limestone, light brownish gray, fragmental.

956. Gulf Oil Company - E. Pierre Federal No. 1 well, NW¼SW¼ sec. 28, T. 148 N., R. 104 W., McKenzie County.

Lodgepole formation
10,550 - 10,620 Limestone, medium light gray (N7) to medium dark gray (N4), very fine grained to dense, fragmental.

Well No.

Bakken formation 10,610
10,620 - 643 Shale, black (N1), fissile to platy, calcareous; limestone, as above; minor amount of light gray, calcareous siltstone.

Three Forks formation 10,640
10,645 - 650 Shale and limestone, as above; limestone, oolitic, dark gray (N3), oolids in a light olive gray (5Y 6/1) limestone, fragmental; pyrite crystals; siltstone, light brownish gray (5YR 6/1).

10,650 - 680 Dolomite, pale brown (5YR 5/2), crystalline, silty, fine grained; shale, limestone, and silstone, as above.

10,680 - 700 Siltstone, dolomitic, light gray (N7); scattered quartz grains, well rounded; interbedded shale, light green (5G 7/4), and dolomite, brownish gray (5YR 4/1); streaks of pyrite.

999. The Texas Company - J. M. Donahue No. 1 well, SW¼NE¼ sec. 23, T. 154 N., R. 100 W., Williams County.

Lodgepole formation
10,920 - 925 Limestone, medium dark gray (N4) to medium gray (N5), dense, microcrystalline.

Bakken formation 10,925
10,925 - 940 Shale, black (N1) to grayish black (N2), fissile.

10,940 - 980 Shale, as above; siltstone, medium dark gray, very calcareous.

Core Study
Depths adjusted to well log.
10,980 - 986 Limestone, silty, medium dark gray, fossiliferous (brachiopods).

10,986 - 11,010 Shale, black, fissile, pyritic, fossiliferous (conodonts).

Three Forks formation 11,010
11,010 - 015 Sandstone, colorless, fine grained, rounded quarts grains, slightly calcareous, well cemented; contains dark yellowish brown (10YR 4/2) argillaceous material, slightly fluorescent (oil show).

Well No.

11,015 - 026 Dolomite and shale, interbedded. Shale, greenish gray (5G 6/1), fissile, pyritic, slightly calcareous; dolomite, brownish gray (5YR 4/1), microcrystalline, laminae bedding: streaks and layers of dolomite varying from 1/8 to 3/8 inch in thickness.

1069. Cardinal Drilling Company - S. M. Keeler No. 1 well, NE¼NW¼ sec. 1, T. 159 N., R. 82 W., Bottineau County.

Lodgepole formation
5150 - 70 Limestone, medium gray (N5) to light gray (N7), microcrystalline; shale, medium gray, cavings(?).

5170 - 5210 Shale, medium dark gray (N4) to dark gray (N3), fissile; shale, brownish gray (5YR 4/1), fissile; limestone, as above; limestone, light gray, fragmental.

5210 - 20 Limestone, very light gray (N8) to light gray, fragmental, dense, fossiliferous (brachiopods, crinoid stems).

5220 - 30 Shale, medium dark gray to dark gray, fissile.

5230 - 40 Samples missing.

Bakken formation 5240
5240 - 60 Shale, as above.

Three Forks formation 5260
5260 - 70 Sandstone, light gray (N6), calcareous, very fine grained, angular to subrounded grains.

5270 - 80 Sandstone, light brown (5YR 6/4), calcareous, angular, very fine grained.

5280 - 5300 Sandstone, as above.

5300 - 10 Samples missing.

5310 - 40 Shale, moderate reddish brown (10R 4/6), platy; sandstone, light brown, calcareous, very fine grained, angular to subangular.

5340 - 50 Shale, moderate reddish brown (10R 4/6), platy; shale, medium dark gray (N4), fissile.

5350 - 60 Shale, medium dark gray, fissile; siltstone, pale olive (10Y 6/2), micaceous.

Birdbear formation 5370
5360 - 80 Limestone, light brown (5YR 6/4) to very light gray (N*), microsucrosic to dense.

5380 - 5400 Limestone, dolomitic, light brown, microcrystalline to dense.

1405. Amerada Petroleum Corporation - C. Penck Tract 1, No. 2 well, NW¼NE¼ sec. 27, T. 150 N., R. 96 W., McKenzie County.

Core Study
Bakken formation 10,737
10,798 - 801 Shale, black (N1), fissile, pyrite streaks.

10,801 - 803 Shale, black, fissile, pyrite nodules.

10,803 - 806 Shale, as above.

10,806 - 808 Shale, as above; much disseminated pyrite; fossiliferous.

10,808 - 818 Shale, as above.

Three Forks formation 10,818
10,818 - 820 Dolomite, medium gray (N5) to light greenish gray (5G 8/1), microcrystalline, dense, pyritic.

10,820 - 823 Dolomite, as above; anhydrite, white (N9), crystalline.

10,823 - 825 Core missing.

10,825 - 858 Interbedded shale and dolomite. Shale, greenish gray; dolomite, medium gray, pyrite streaks.

10,858 - 862 Dolomite, pinkish gray (5YR 8/1) and medium gray, microcrystalline; minor shale, greenish gray.

10,862 - 865 Dolomite, greenish gray, dense, microcrystalline.

1575. The Carter Company - L. L. Johnson and Ellen Johnson No. 1 well, NW¼SW¼ sec. 9, T. 129 N., R. 106 W., Bowman County.

Ledgepole formation
7640 - 57 Dolomite, limy, grayish orange pink (5YR 7/2), crystalline, subsucrosic; much chert, white; limestone, pale yellow brown (10YR 6/2), crystalline, very fine grained.

Well No.

Bakken formation 7657
7657 - 95 Shale, black (N1), fissile; shale, greenish gray (5G 6/1), fissile; siltstone, greenish gray.

Three Forks formation 7695
7695 - 7715 Dolomite, pale red (5R 6/2), crystalline, subsucrosic; anhydrite, white.

7715 - 40 Dolomite, as above; trace of shale, greenish gray, fissile; siltstone, greenish gray.

Birdbear formation 7740
7740 - 50 Dolomite, pale red, crystalline, very fine grained; dolomite, very pale orange (10YR 8/2).

1620. Pan American - Raymond Vetter No. 1 well, NE¼SW¼ sec. 27, T. 139 N., R. 90 W., Morton County.

Lodgepole formation
8400 - 45 Limestone, light gray (n7), argillaceous, microcrystalline, abundant fossil fragments; pyrite; anhydrite.

8445 - 95 Limestone, as above; trace of shale, black (N1) to grayish black (N2), fissile, slightly calcareous.

8495 - 8590 Limestone, medium dark gray (4), dense, microcrystalline.

8590 -95 Limestone, very light gray (N8), dense.

Bakken formation 8595
8595 - 8620 Shale, black, fissile, calcareous.

Three Forks formation 8620
8620 - 25 Siltstone, medium light gray (N6), calcareous; dolomite, greenish gray (5GY 6/1), dense; limestone, medium gray.

8625 - 35 Siltstone, very light gray, slightly calcareous; siltstone, grayish orange pink (5YR 7/2), calcareous.

8635 - 60 Shale, dark reddish brown (10R 3/4), platy; limestone, light gray; siltstone, as above.

Birdbear formation 8800
8800 - 10 Dolomite, grayish orange pink, subsucrosic; dolomite, moderate reddish brown (10R 4/6), subsucrosic; anhydrite, white.

Well No.

1679. Amerada Petroleum Corporation - C. C. Mogen Trust 1, No. 1 well, SE¼SW¼ sec. 10, T. 153 N., R. 96 W., McKenzie County.

Core Study
Bakken formation (lower shale unit)
10,003 - 011 Shale, black (N1), fissile, disseminated pyrite crystals; fossiliferous (conodonts, fish scales?).

Three Forks formation 10,011
10,011 - 014 Interbedded dolomite and shale. Dolomite, brownish gray (5YR 4/1), microcrystalline; shale, greenish gray (5G 6/1), fissile, waxy, slightly calcareous, bedding: 1/8 to 3/8 inch layers and small scale intertonguing disseminated pyrite crystals.

10,014 - 017 Dolomite and shale, as above; disrupted bedding with microfaults.

10,017 - 022 Dolomite and shale, as above.

10,022 - 047 Dolomite, as above; shale, as above.

10,047 - 050 Dolomite and shale, as above, breccia, pyritic.

10,050 - 055 Dolomite, medium gray (N5), microcrystalline.

End of Core

South Dakota

Well No.

SD 1. Amerada Petroleum Corporation - State No. 1 well, NW¼NW¼ sec. 4, T. 14 N., R. 4 E., Butte County.

Lodgepole formation
6395 - 6410 Limestone, pinkish gray (5YR 8/1) and light gray (N7), fragmental, sucrosic to dense.

6410 -35 Limestone, light gray to medium gray (N5), sucrosic. very fine grained, fossiliferous.

6435 - 40 Limestone, very light gray to white (N9), chalky, lithographic; limestone, pinkish gray (5YR 8/1), fragmental.

6440 - 6500 Limestone, pinkish gray, fragmental, microvuggy, subsucrosic.

Well No.

Englewood formation 6500
6500 - 15 Limestone, very dark red (5R 2/6), argillaceous; limestone, dusky red (5R 3/4), argillaceous; some limestone, chalky, white.

Bakken formation 6517
6515 - 40 Shale, dark gray (N3) to black (N1), fissile.

Three Forks formation 6545
6540 - 45 Shale, as above; minor limestone, pale purple (5P 6/2); siltstone, light olive gray (5Y 6/1).

6545 -55 Shale, moderate reddish brown (10R 4/6); limestone, as above.

6555 - 6610 Shale, as above; varicolored shales (light green, yellow, red, reddish brown).

6610 - 15 Shale, as above; sandstone, white, calcareous, rounded quartz grains, very fine grained.

6615 - 20 Limestone, light gray to pinkish gray, fragmental sucrosic; minor siltstone, light gray.

SD 2. Shell Oil Company - State of South Dakota No. 1 or 3409 well, SW¼SE¼ sec. 9, T. 21 N., R. 4 E., Harding County.

Lodgepole formation
7800 - 75 Limestone, light gray (N7) to medium gray (N5), dense; chert, white.

7875 - 7900 Limestone, as above.

Three Forks formation ? 7900
7900 - 07 Dolomite, brownish gray (5YR 4/1), glauconitic, sucrosic, fragmental.

7907 - 09 Dolomite, light olive gray (5Y 6/1), sucrosic.

7909 - 35 Samples missing.

7935 - 55 Shale, moderate red (5R 5/4), calcareous, fissile.

7955 - 65 Dolomite, moderate orange pink (10R 7/1), coarsely crystalline, sucrosic; shale, as above.

7975 - 80 Dolomite, grayish orange pink (10R 8/2), microcrystalline.

Well No.

SD 3. Weller Bush - Weisman No. 1 well, NW¼SW¼SE¼ sec. 30, T. 7 N., R. 4 E., Lawrence County.

Madison group
2635 - 50 Limestone, moderate orange (5YR 8/4) to grayish orange pink (5YR 7/2), sucrosic to fragmental, microvuggy.

Englewood formation 2650
2650 - 55 Siltstone, grayish red purple (5RP 4/2), calcareous, argillaceous; limestone, as above.

2655 - 80 Limestone, grayish red purple, silty, fragmental; siltstone, as above.

2680 - 2700 Siltstone, medium gray (N6), calcareous; limestone and siltstone, as above.

Whitewood dolomite 2700
2700 - 10 Dolomite, very pale orange (10YR 8/2) to grayish orange pink (5YR 7/2), microvuggy, sucrosic, very fine grained.

SD 4. Youngblood and Youngblood - Galvin No. 1 well, SE¼SE¼ sec. 25, T. 16 N., R. 22 E., Dewey County.

Lodgepole formation
4850 - 65 Limestone, very light gray (N8) to pinkish gray (5YR 8/1), fragmental, dense, sucrosic.

4865 - 70 Limestone, light gray (N7), sucrosic, fragmental; minor limestone, as above.

Bakken formation 4870
4870 - 90 Shale, black (N1), fissile, calcareous; limestone, as above.

Three Forks formation 4870
4890 - 4900 Siltstone, light brown (5YR 6/4), calcareous; limestone, light brown (5YR 6/4), fragmental, sucrosic; rare oolitic limestone, light brown.

4900 - 55 Siltstone, moderate reddish brown (10R 4/6), very slightly calcareous, argillaceous; anhydrite, white; minor shale, pale red (5R 8/2), calcareous.

4965 - 70 Limestone, grayish orange pink (5YR 7/2), fragmental and sucrosic.

Well No.

30 S. Shell Oil Company - Veal No. 1 well, SE¼SE¼ sec. 7, T. 17 N., R. 15 E., Perkins County.

Lodgepole formation
6420 - 95 Limestone, light gray (N7) to medium gray (N5), dense, sucrosic; limestone, light brownish gray (5YR 6/1), fragmental, microcrystalline.

Bakken formation 6495
6495 - 6537 Shale, medium dark gray (N4) to dark gray (N3), fissile, calcareous.

Three Forks formation 6537
6537 - 45 Shale, greenish gray (5G 6/1), calcareous, silty; siltstone, brownish gray (5YR 6/1); shale, very light gray (N8).

Core Chip Study
6545 - 46 Shale, dark reddish brown (10R 3/4), calcareous, silty.

6546 - 48 Dolomite, grayish green (10GY 5/2), argillaceous.

6548 - 49 Anhydrite, moderate pink (5YR 8/4).

6549 - 53 Anhydrite, as above; shale, dark reddish brown (10R 3/4), silty; scattered quartz grains, rounded.

6553 - 55 Anhydrite, white; shale, grayish green calcareous.

Type Section
Englewood formation

East of Whitewood Creek and the Chicago, Burlington, and Quincy Railway tracks, located in a railcut, approximately two miles southwest of Englewood, South Dakota, at NW¼NE¼ sec. 31, T. 4 N., R. 3 E., Lawrence County.

Overlying unit: Pahasapa formation of Mississippian age.

Dolomite, yellowish gray, massive bedding (greater than 6 ft.), solution weathered resulting in a very irregular surface, vuggy, fossiliferous.

Mississippian - Englewood formation		Thickness
UNIT 8.	Limestone, dolomitic, yellowish gray, contains reddish brown blotches or iron stains.	1 ft. 9 in.

		Thickness
UNIT 7.	Limestone, grayish red purple, mottled yellowish gray (5Y 7/2), medium bedded.	6 ft. 8 in.
UNIT 6.	Limestone, grayish red purple, weathers moderate reddish brown (10R 4/6), irregular or wavy bedding planes, thin bedded	4 ft. 9 in.
UNIT 5.	Limestone, pale red purple (5RP 6/2), thin bedded, contains thin shale partings (less than one inch in thickness), fossiliferous near the upper portion of the unit.	5 ft. 0 in.
UNIT 4.	Interbedded limestone and shale. Limestone grayish red purple, and shale, light brownish gray, usually in layers less then two inches thick.	2 ft. 9 in.
UNIT 3.	Limestone, grayish red purple (5RP 4/2) and light brownish gray (5YR 6/1), medium bedded (1 to 3 ft.) and thin bedded (2 in. to 1 ft.).	5 ft. 0 in.
UNIT 2.	Covered.	2 ft. 7 in.
UNIT 1.	Siltstone, yellowish gray (5Y 8/1) and medium gray (N5), compact, argillaceous, slightly calcareous.	5 ft. 11 in.
	Total Thickness = 34 ft. 5 in.	

Underlying unit: Covered (Winnipeg formation of Ordovician age).

Standard Reference Section
Englewood formation

East side of Whitewood Creek along the Chicago, Northwestern Railway tracks across from the Deadwood city dump (junkyard). North of U. S. Highway 14 near its junction with U. S. Highway 85, located at NE¼SW¼ sec. 13, T. 5 N., R. 3 E., Lawrence County.

Measured upward from the top of the Whitewood dolomite with a six foot steel tape, hand level, and Brunton compass.

Overlying unit: Pahasapa formation of Mississippian age.

UNIT 16. Dolomite, yellowish gray, weathers to a very pale orange (10YR 8/2), massive to medium bedded, solution weathered, vuggy, saccharoidal, fossiliferous.

Mississippian - Englewood formation

		Thickness
UNIT 15.	Limestone, dolomitic, yellowish gray (5Y 7/2), with pale red purple mottling, weathers yellow gray (5Y 8/1), medium bedded.	5 ft. 3 in.
UNIT 14.	Limestone, pale red purple, with pale reddish brown (10R 5/4) laminae, thin bedded.	8 ft. 3 in.
UNIT 13.	Limestone, pale red purple, yellow gray (5Y 7/2) mottling which weathers pale olive (10Y 6/2) and dusky yellow (5Y 6/4), contains calcite geodes, medium bedded.	4 ft. 7 in.
UNIT 12.	Limestone, pale red purple (5RP 6/2) with pale reddish brown laminae, bedding medium (1 to 3 ft.), contains calcite geodes.	4 ft. 7 in.
UNIT 11.	Interbedded shale and limestone. Shale, grayish green, fissile; limestone, grayish red purple, flaggy bedding (4 to 5 inches in thickness).	2 ft. 7 in.
UNIT 10.	Shale, grayish green (10GY 5/2), fissile.	0 ft. 2 in.
UNIT 9.	Limestone, grayish red purple (5RP 4/2), laminae bedding (less than 1 inch), argillaceous, shaly in part.	2 ft. 10 in.
UNIT 8.	Limestone, grayish purple (5P 4/2), light brown (5 YR 6/4) streaks, argillaceous, dense, platy to flaggy (3/8 to 3 inches in thickness).	1 ft. 8 in.
UNIT 7.	Covered.	4 ft. 9 in.
UNIT 6.	Shale, medium gray (N5), shaly, silty.	19 ft. 0 in.
UNIT 5.	Shale, greenish black (5G 2/1), shaly, silty.	0 ft. 11 in.
UNIT 4.	Covered.	0 ft. 10 in.
UNIT 3.	Shale, dark gray (N3), shaly to fissile, silty.	1 ft. 4 in.
UNIT 2.	Shale, grayish orange (10YR 7/4), soft, shaly (1/8 to 3/8 inch in thickness), slightly calcareous, silty.	0 ft. 10 in.
	Total Thickness =	57 ft. 7 in.

Underlying unit: Whitewood dolomite of Ordovician age.

UNIT 1. Dolomite, pale yellowish brown (10YR 6/2) with dark yellowish orange (10YR 6/6), inclusions, saccharoidal, vuggy (1 to 2 mm), contains calcite crystals, weathers to a rather smooth surface which is covered by an occasional nobby surface texture, massively bedded (greater than 6 ft.).

Railcut Section No. 1 at NW¼SE¼ sec. 31, T. 4 N., R. 3 E., Lawrence County.

Mississippian - Englewood formation

		Thickness
UNIT 4.	Limestone, grayish orange pink, badly weathered, upper portion of the unit eroded off.	4 ft. 0 in.
UNIT 3.	Limestone, grayish orange pink (5YR 7/2), thin bedded (1 to 4 inches).	9 ft. 7 in.
UNIT 2.	Limestone, pale red purple, dark reddish brown concretions, thin bedded (2 to 4 inches), calcite geodes.	1 ft. 0 in.
UNIT 1.	Limestone, pale red purple (5RP 6/2) with pale reddish brown (10R 5/4) blotches or iron stains, thin to medium bedded (1½ to ½ ft. in thickness).	3 ft. 6 in.
	Total Thickness =	18 ft. 1 in.

Underlying unit: Deadwood formation of Cambrian age, contact covered.

Railcut Section No. 2 at NW¼NE¼ sec. 30, T. 4 N., R. 3 E., Lawrence County.

Mississippian - Englewood formation

UNIT 2.	Limestone, pale red purple (5RP 6/2), badly weathered, upper portion of the unit eroded off.	1 ft. 0 in.

Underlying unit: Winnipeg formation of Ordovician age.

UNIT 1.	Shale, dark greenish gray (5G 4/1), fissile to shaly, waxy, rusty.	10 ft. 0 in.

Montana

Well No.

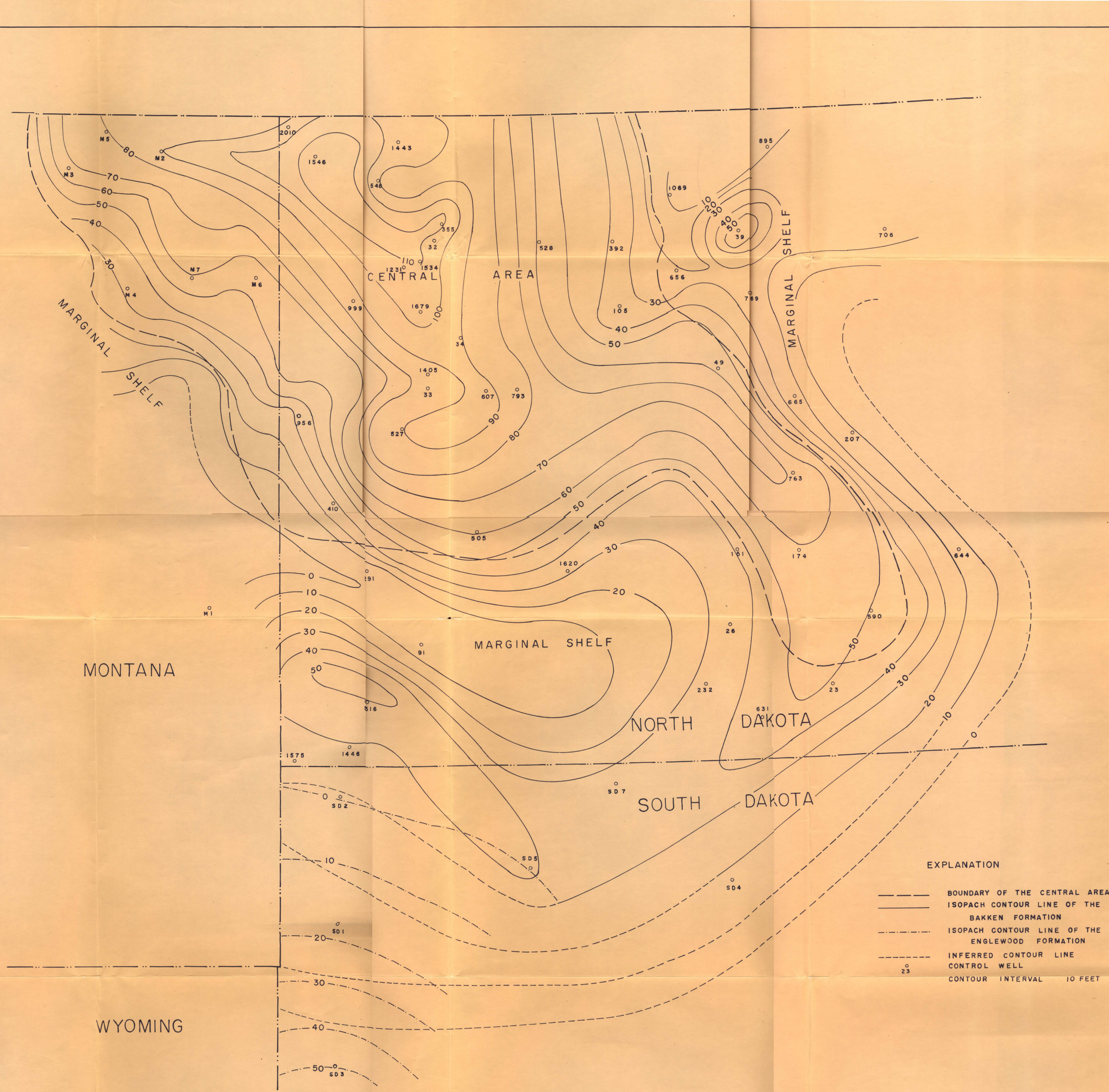
M 1. Shell Oil Company - 45-22A Unit well, NE¼SE¼ sec. 22, T. 11 N., R. 57 E., Wibaux County.

Ledgepole formation
8320 - 30 Limestone, light gray (N7), dense and crystalline; limestone, medium gray (N5) dense; anhydrite white.

Bakken formation (?) 8330
8330 - 35 Limestone, as above; shale, black (N1), fissile, calcareous.

8335 - 45 Limestone, pinkish gray (5YR 8/1) crystalline; as above.

Silurian (?)
8345 - 85 Limestone, pinkish gray, crystalline; limestone, light brownish gray, crystalline.



ISOPACH MAP OF THE BAKKEN AND ENGLEWOOD FORMATIONS IN NORTHWESTERN SOUTH DAKOTA, NORTHEASTERN MONTANA, AND NORTH DAKOTA

Plate I

895
LION-WALLACE HALL NO. 1
NW NW SEC. 14, T. 162 N., R. 76 W.
BOTTINEAU CO., N. DAK.

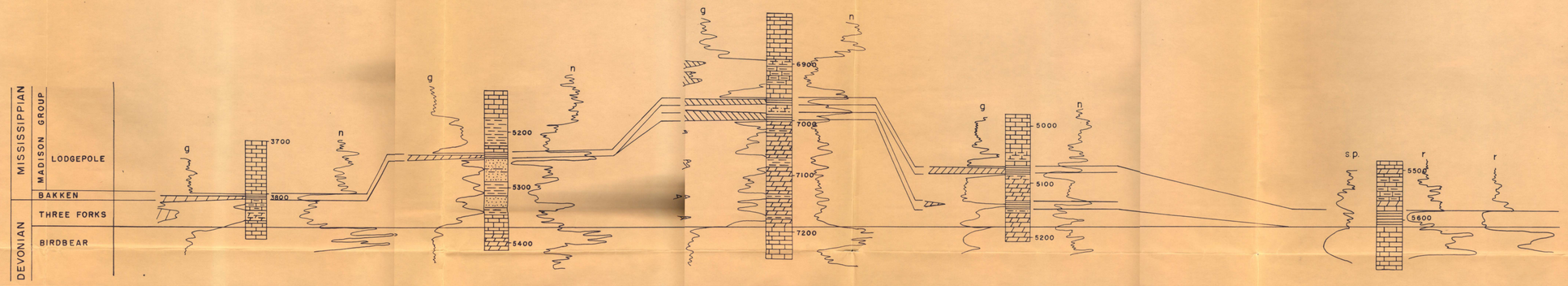
1069
CARDINAL-B. M. KEELER NO. 1
NW NW SEC. 1, T. 159 N., R. 82 W.
BOTTINEAU CO., N. DAK.

392
HARRISON-J. H. ANDERSON NO. 1
SW SW SEC. 21, T. 157 N., R. 85 W.
WARD CO., N. DAK.

763
CARLOLINE HUNT-A. NOVY NO. 1
SE SE SEC. 14, T. 144 N., R. 77 W.
BURLEIGH CO., N. DAK.

232
YOUNGBLOOD-L. KELSTROM NO. 1
SW SW SEC. 26, T. 133 N., R. 83 W.
GRANT CO., N. DAK.

37 MILES | 25 MILES | 98 MILES | 78 MILES



32
AMERADA-H. O. BAKKEN NO. 1
SW SW SEC. 12, T. 157 N., R. 95 W.
WILLIAMS CO., N. DAK.

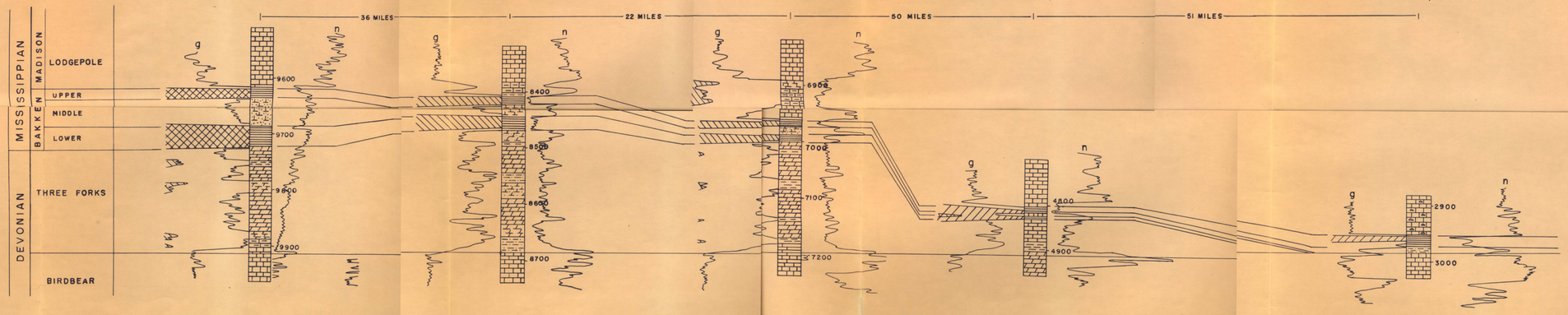
528
W. H. HUNT-L. C. ANDERSON NO. 1
NW NE SEC. 25, T. 157 N., R. 89 W.
MOUNTRAIL CO., N. DAK.

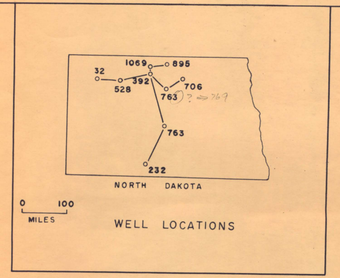
392
HARRISON-J. H. ANDERSON NO. 1
SW SW SEC. 21, T. 157 N., R. 85 W.
WARD CO., N. DAK.

769
CALVERT-FRED AND SIGNA WRIGHT NO. 1
NW NW SEC. 14, T. 157 N., R. 78 W.
MCHENRY CO., N. DAK.

706
SHELL-G. MARCHUS NO. 1
SE SE SEC. 23, T. 157 N., R. 70 W.
PIERCE CO., N. DAK.

36 MILES | 22 MILES | 50 MILES | 51 MILES



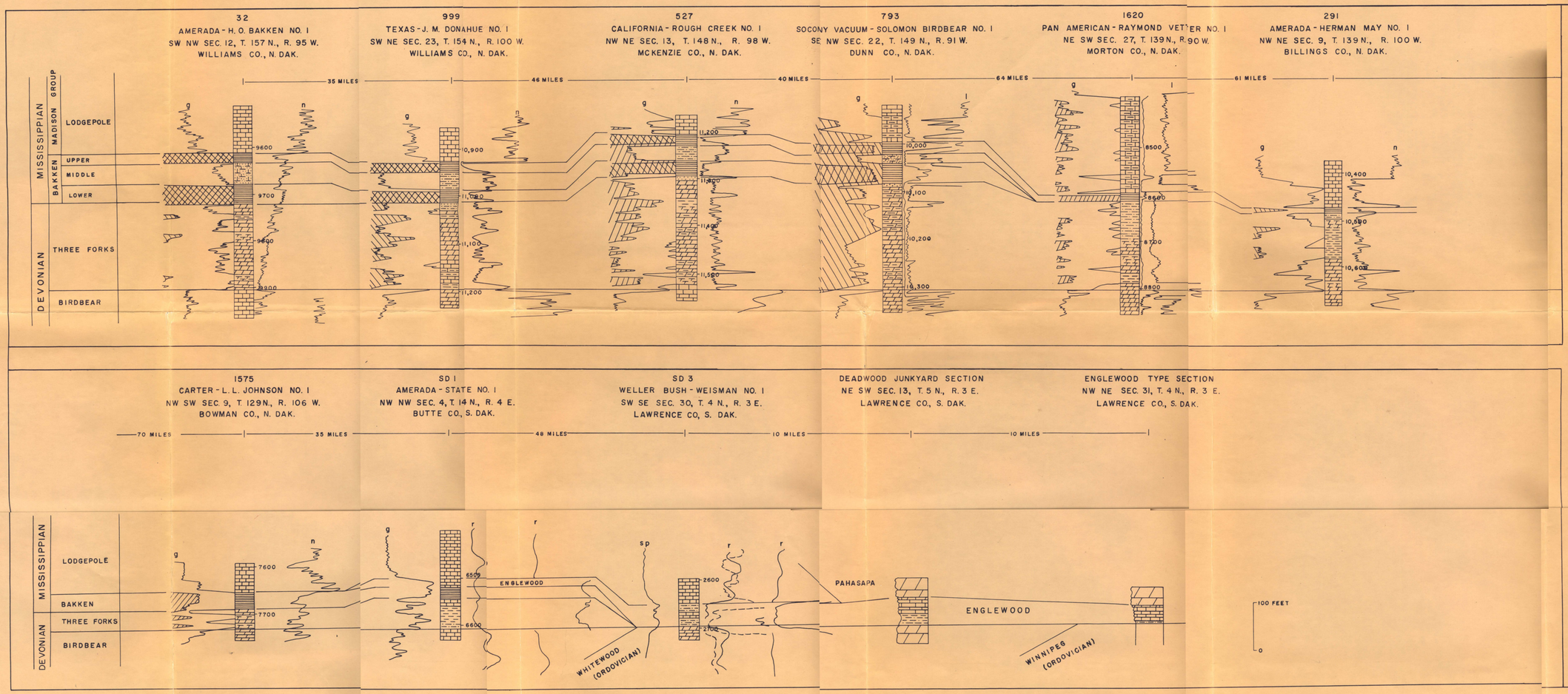


EXPLANATION

- LIMESTONE
- DOLOMITE
- SANDSTONE
- CALCAREOUS SANDSTONE
- SILTSTONE
- CARBONACEOUS SHALE
- SHALE
- ARGILLACEOUS LIMESTONE
- SHALY DOLOMITE
- CHERT
- g GAMMA RAY
- n NEUTRON RAY
- s.p. SPONTANEOUS POTENTIAL
- r RESISTIVITY

CROSS SECTIONS OF THE BAKKEN AND THREE FORKS FORMATIONS IN NORTH DAKOTA

Plate II



CROSS SECTIONS OF THE THREE FORKS, BAKKEN, AND ENGLEWOOD FORMATIONS IN NORTH DAKOTA AND SOUTH DAKOTA

Plate III