1984

Conodonts of the Bakken Formation (Devonian and Mississippian), Williston Basin, North Dakota

Michael D. Hayes
University of North Dakota

CONODONTS OF THE BAKKEN FORMATION (DEVONIAN AND MISSISSIPPIAN), WILLISTON BASIN, NORTH DAKOTA

by
Michael D. Hayes

Bachelor of Science, St. Lawrence University, 1981

A Thesis

Submitted to the Graduate Faculty

of the

University of North Dakota

in partial fulfillment of the requirements

for the degree of

Master of Science

Grand Forks, North Dakota

May
1984

This thesis submitted by Michael D. Hayes in partial fulfillment of the requirements for the degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

F. D. Holland Jr.
(Chairman)

Alan M. Cvancara

Richard D. LeFever

This thesis meets the standards for appearance and conforms to the style and format requirements of the Graduate School of the University of North Dakota, and is hereby approved.

Dean of the Graduate School

Permission

Title Conodonts of the Bakken Formation (Devonian and Mississippian), Williston Basin, North Dakota

Department Geology

Degree Master of Science

In presenting this thesis in partial fulfillment of the requirements for a graduate degree from the University of North Dakota, I agree that the Library of this University shall make it freely available for inspection. I further agree that permission for extensive copying for scholarly purposes may be granted by the professor who supervised my thesis work or, in his absence, by the Chairman of the Department or the Dean of the Graduate School. It is understood that any copying or publication or other use of this thesis or part thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and the University of North Dakota in any scholarly use which may be made of any material in my thesis.

Signature Michael D. Hayes

Date April 9, 1984

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

ACKNOWLEDGMENTS

Gratitude is expressed to my thesis committee of Drs. F. D. Holland, Jr., Alan M. Cvancara, and Richard D. LeFever for advice and assistance throughout the research and for critically reviewing drafts of the manuscript. Special thanks are extended to Dr. Holland for suggesting the research topic and providing guidance and encouragement throughout the study.

The University of North Dakota is gratefully acknowledged for financial assistance, materials, and work space during the course of my research. Financial assistance was provided by the University in the form of Graduate Teaching Assistance and through a Mining and Mineral Resources Research Institute Fellowship. Financial support, materials, and the assistance of personnel from the North Dakota Geological Survey is acknowledged and greatly appreciated. Thanks go to Dr. Robert Stevenson of the Natural Materials and Analytical Laboratory at the University of North Dakota for materials and use of the JEOL-35c Scanning Electron Microscope for photography of conodont specimens.

Dr. Gilbert Klapper of the University of Iowa is acknowledged with thanks for graciously examining (at my request) most of the conodont collection and discussing identifications of specimens, photographic preparation, and aspects of Bakken stratigraphy. Dr. Klapper's assistance in verifying many identifications is greatly appreciated, but I assume responsibility for conclusions presented herein.

Thanks are given to Rick L. Webster who aided me during the initial stages of the project and to Lawrence C. Thrasher who discussed many topics of Bakken stratigraphy with me as part of his concurrent study of Bakken macrofossils in North Dakota. Lorraine Fortin of the University of North Dakota Computer Center aided me in producing the final computer-generated manuscript.

The encouragement and support of my family and friends during the study is gratefully acknowledged. Sincerest thanks are given to my wife Kathryn for providing encouragement and sustenance throughout the study.

ABSTRACT

The Bakken Formation is a thin (maximum 145 ft., 44 m), predominantly clastic unit in the subsurface of the Williston Basin in the United States and Canada. The formation consists of two, mostly non-calcareous, grayish-black to brownish-black shales separated by light to dark gray, calcareous and dolomitic siltstone and fine-grained sandstone. The carbonaceous, black shales of the Bakken produce a distinctive geophysical marker and are a major source rock for hydrocarbons in the Williston Basin.

Conodonts were selectively sampled from cores of the Bakken in North Dakota in an effort to determine the age and thermal maturity of the formation. A diverse conodont collection of more than 700, mostly fragmentary, elements was obtained by disaggregating portions of the cores. Bakken conodonts are placed in 48 taxa and attributed to 17 form-genera. Specimens consist mostly of platform elements. Genera include Siphonodella, Pseudopolygnathus, Polygnathus, Bispathodus, "Spathognathodus", Palmatolepis, and Branmehla. Twenty-one biostratigraphically useful species of these genera were identified. Conodonts are unevenly distributed in the Bakken Formation. Most were obtained from thin (about 0.2 in., 0.5 cm), fossil-rich beds in the upper shale. Only rare, fragmentary conodonts were recovered from the middle member. Conodont evidence indicates that the Bakken Formation in North Dakota is Late Devonian and Early Mississippian in age. A small conodont fauna from the lower shale includes species of Palmatolepis and

Polygnathus and is tentatively considered of the Upper *Polygnathus styriacus* Zone (Famennian). Species of *Siphonodella*, *Pseudopolygnathus*, and *Polygnathus* dominate the upper shale fauna. Conodonts from the uppermost beds of the upper shale of the Bakken are of the Lower *Siphonodella crenulata* Zone (Kinderhookian). Conodont evidence from the Bakken indicates that portions of the formation are correlative with the Exshaw Formation in Alberta, Sappington Member of the Three Forks Formation in Montana, Leatham Formation in Utah and Idaho, middle member (Leatham Member) of the Pilot Shale in Utah and Nevada, Cottonwood Canyon Member of the Lodgepole Limestone in Montana, and the Englewood Formation in South Dakota. Paleontologic evidence suggests that an unconformity may occur at the contact between the middle member and upper shale of the Bakken and that this contact may coincide with the Devonian-Mississippian boundary.

Conodont color alteration index (CAI) values from the upper shale of the Bakken range from 1.5 (about 7,500 ft., 2,290 m) to 2.5 (about 10,400 ft., 3,170 m) and indicate that the Bakken has reached formation temperatures capable of oil generation at 7,500 feet in depth but may have exceeded oil generation temperatures below 10,000 feet (3,050 m).

Lithologic and paleontologic evidence suggests that the carbonaceous shales of the two shale members of the Bakken were deposited in an anoxic, offshore, marine environment. Bedding features and fossils of the middle member indicate a current-influenced, mostly aerobic marine environment. Regional evidence indicates that the lower shale and upper shale of the Bakken were deposited during episodes of widespread marine transgression and that middle member deposition occurred during a time of regional marine regression between these transgressions.

INTRODUCTION

Purpose

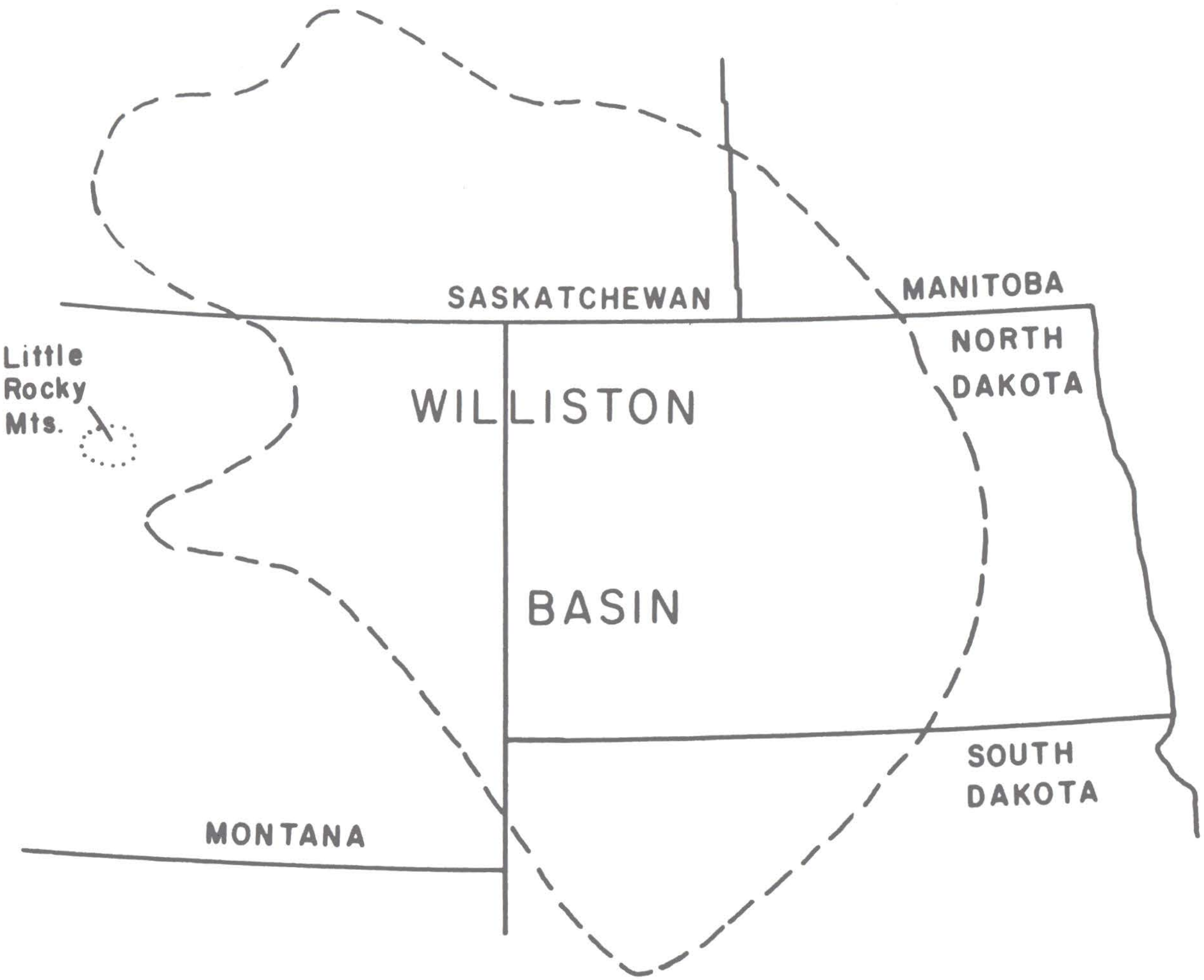
The carbonaceous, black shale of the Bakken Formation is a major source rock for hydrocarbons and a distinctive geophysical marker in the subsurface of the Williston Basin. The Bakken was initially considered entirely Mississippian in age, but regional paleontologic study has indicated that the Bakken is actually of both Devonian and Mississippian age. Despite the economic and stratigraphic significance of the Bakken, paleontologic study of the formation has been limited.

The primary purpose of this study is to identify and illustrate conodonts, obtained from cores of the Bakken, in an effort to determine the age of the formation in North Dakota. A secondary goal is to use the color of preserved conodonts as a geothermometer to assess the thermal maturity and, hence, the oil-generation potential of the Bakken Formation.

Geologic Setting

The Williston Basin is an intracratonic, structural, and sedimentary basin in portions of North Dakota, South Dakota, Montana, southern Saskatchewan, and southwestern Manitoba (Fig. 1). Major structural features of the Williston Basin, such as the Nesson and Cedar Creek

Figure 1. The position and extent of the Williston Basin and the Little Rocky Mountains. The outline of the Williston Basin was taken from Laird (1956, p. 16).


SASKATCHEWAN
MANITOBA
NORTH
DAKOTA
Little
Rocky
Mts.
WILLISTON
BASIN
SOUTH
DAKOTA
MONTANA

Anticlines, generally trend north and northwest (Fig. 2). Gerhard and others (1982, p. 991) speculated that: "structural grain of the region appears to be related to the offset in the Rocky Mountain chain between the north-trending southern Rocky Mountain province and the northwest-trending northern Rockies . . . ."

A stratigraphic record of nearly 16,000 feet (4,900 m) is present in the Williston Basin in western North Dakota and sedimentary rocks from the Cambrian through the Tertiary are preserved. Rocks of Paleozoic age in the Williston Basin are predominantly marine carbonates. The Bakken Formation, however, is a relatively thin (maximum thickness 145 ft., 44 m) clastic unit at the base of a thick (approximately 2,000 ft., 610 m) Mississippian carbonate and evaporite section.

The Bakken Formation occurs in all but the South Dakota portion of the Williston Basin and is almost entirely a subsurface unit except for a thin margin of the upper part exposed west of the Basin in the Little Rocky Mountains (Fig. 1) of central Montana. The Bakken in North Dakota overlies the shale, siltstone, and dolostone of the Three Forks Formation and is overlain by echinoderm-rich limestone of the Lodgepole Formation of the Madison Group. The stratigraphic position of the Bakken in North Dakota is shown in Figure 3. Three informal members of the Bakken are commonly recognized (Kume, 1963; Webster, 1982) and are referred to as the lower shale, middle member, and upper shale in this report. The Bakken Formation consists of mostly non-calcareous, grayish-black to brownish-black shale separated by a middle member composed mostly of calcareous to dolomitic siltstone and sandstone. The dark shales are rich in organic matter and are important source rocks

Figure 2. Major structural features in western North Dakota, eastern Montana, northeastern Wyoming, and northwestern South Dakota (from Anderson and Bluemle, 1982, p. 8).

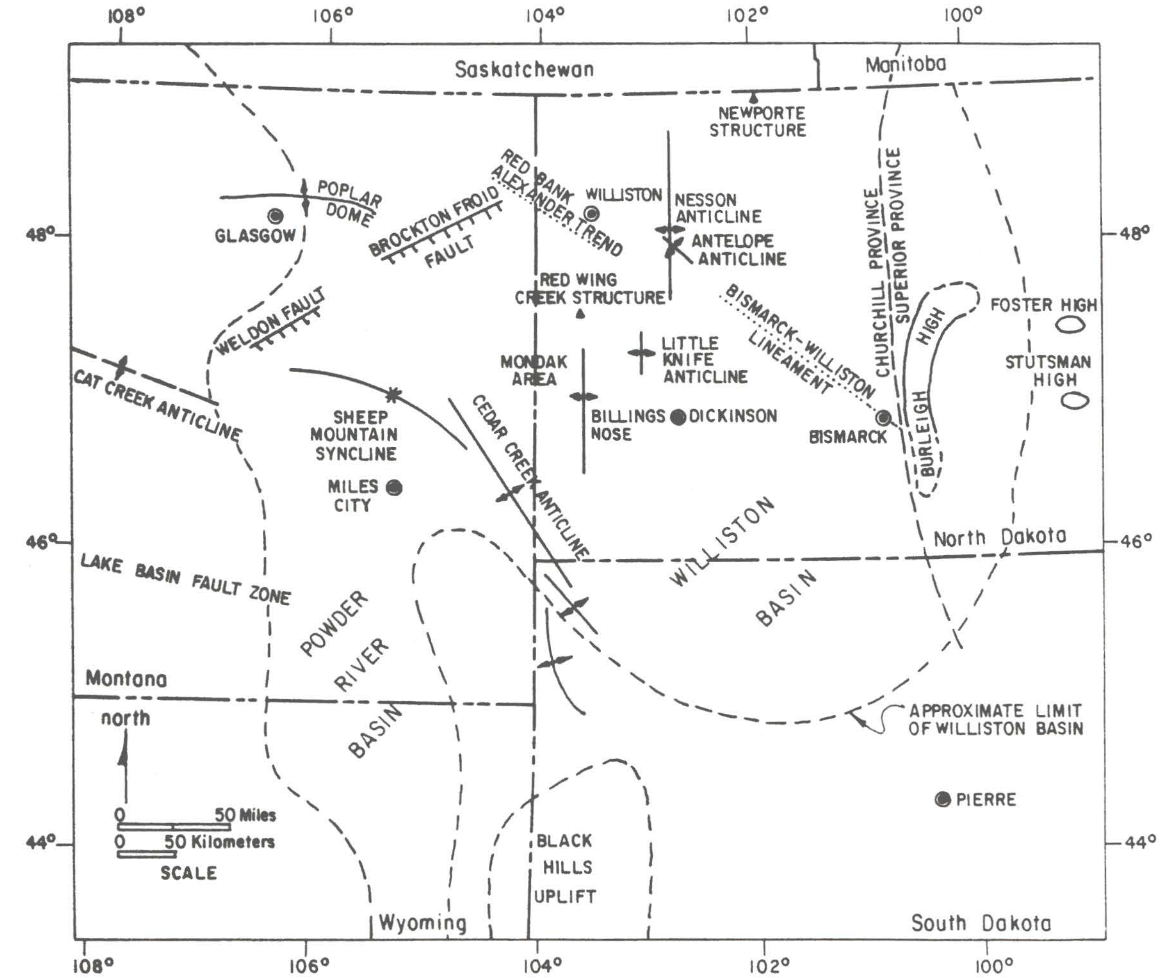
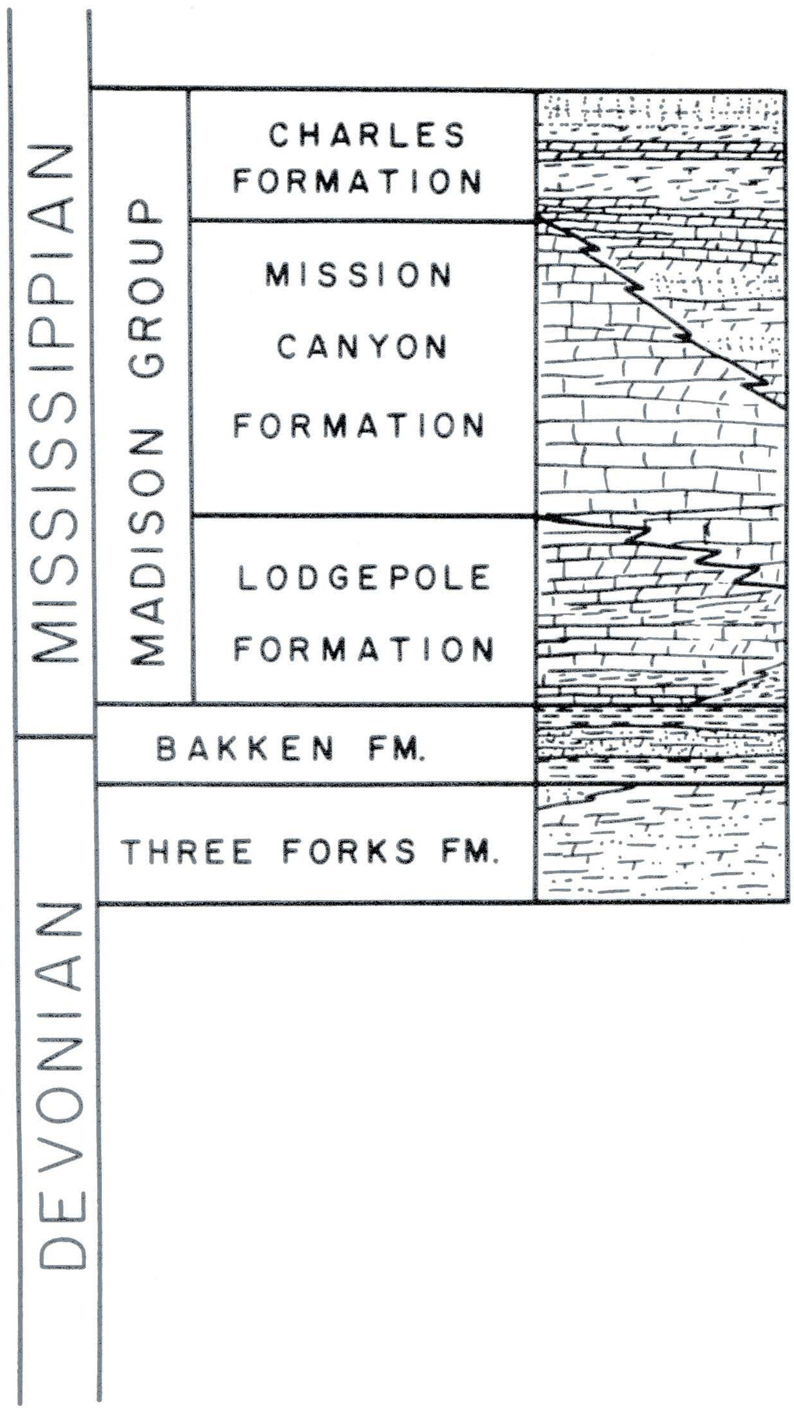

108°
106°
104°
102°
100°
48°
46°
44°
Saskatchewan
Manitoba
NEWPORTE STRUCTURE
POPLAR DOME
GLASGOW
BROCKTON FROID FAULT
RED BANK
ALEXANDER TREND
WILLISTON
NESSON ANTICLINE
ANTELOPE ANTICLINE
CHURCHILL PROVINCE
SUPERIOR PROVINCE
RED WING CREEK STRUCTURE
FOSTER HIGH
WELDON FAULT
BISMARCK-WILLISTON LINEAMENT
HIGH
LITTLE KNIFE ANTICLINE
MONDAK AREA
STUTSMAN HIGH
CAT CREEK ANTICLINE
SHEEP MOUNTAIN SYNCLINE
CEDAR CREEK ANTICLINE
BILLINGS NOSE
DICKINSON
BISMARCK
BURLEIGH
MILES CITY
WILLISTON
North Dakota
LAKE BASIN FAULT ZONE
BASIN
POWDER
RIVER
Montana
APPROXIMATE LIMIT OF WILLISTON BASIN
north
BASIN
0 50 Miles
0 50 Kilometers
SCALE
PIERRE
BLACK HILLS UPLIFT
Wyoming
South Dakota

Figure 3. A portion of the stratigraphic column of North Dakota showing the position of the Bakken Formation and adjacent units. Lithologies are redrafted from Bluemle and others (1980).


MISSISSIPPIAN
DEVONIAN
MADISON GROUP
CHARLES FORMATION
MISSION CANYON FORMATION
LODGEPOLE FORMATION
BAKKEN FM.
THREE FORKS FM.

for hydrocarbons in the Williston Basin. Indeed, Schmoker and Hester (1983, p. 2173) estimated that the United States portion of the Bakken Formation may have generated hydrocarbons equivalent to "132 billion bbl" of oil.

Stratigraphic units in the United States, which have general lithology and stratigraphic position similar to the lithology and setting of the Bakken Formation include the familiar Chattanooga Shale, New Albany Group, and the Antrim and Ohio Shales in the eastern United States. In western North America, the Cottonwood Canyon Member of the Lodgepole Limestone in Montana and the Madison Limestone in Wyoming, and the Englewood Formation in South Dakota have a stratigraphic position similar to that of the Bakken Formation. More significantly, Macqueen and Sandberg (1970) demonstrated that the Exshaw Formation in Alberta and the Sappington Member of the Three Forks Formation in Montana were once physically continuous with the lower shale and middle member of the Bakken. Later, Sandberg and Poole (1977, p. 172) indicated that the Leatham Formation in Utah and the middle member of the Pilot Shale in Utah and Nevada were also a part of this depositionally continuous rock body.

Previous Work

Bakken Formation

Early subsurface exploration activity in the Williston Basin revealed the presence of two, thin, black shales separated by gray siltstone at the base of the Madison Group. According to Nordquist

(1953, p. 72) workers commonly used the terms "Kinderhook" or "Englewood" for this clastic sequence. In an effort to end confusion resulting from informal use of these terms, the name Bakken was introduced by the Williston Basin Correlation Committee in 1953.

Nordquist (1953, p. 72) formally defined the subsurface strata that comprise the type section of the Bakken and discussed the thickness, lithology, geophysical response, and regional stratigraphic characteristics of the formation. On the basis of lithology and paleontologic evidence from assumed correlatives in Canada, Nordquist (1953, p. 74) considered the Bakken entirely Mississippian in age. As originally defined, the Bakken occurs in northern Montana, southern Saskatchewan, southwestern Manitoba, and northwestern North Dakota. Penner (1958, p. 264) proposed usage of the name Bakken for strata in southeastern Alberta that have a stratigraphic position and lithology similar to that of the typical Bakken in North Dakota. Sandberg and Hammond (1958), in a discussion of the Devonian System in the Williston Basin, questioned the opinion prevalent at the time, that the Bakken was entirely Mississippian.

Workers who have reported on Bakken stratigraphy in Canada include Reasoner and Hunt (1954), Fuller (1956), MacDonald (1956), Kents (1959), and McCabe (1959). The name "Coleville Sand" was used by Reasoner and Hunt (1954, p. 1539) for the middle member of the Bakken but, as discussed by Kume (1963, p. 41), use of this informal name should not be perpetuated. Fuller (1956, p. 18) noted that workers in the Williston Basin commonly used the characteristic geophysical log response of the Bakken as a "marker" to aid in subsurface correlation.

Brindle (1960) studied the macrofauna of subsurface Mississippian rocks in Saskatchewan partly in order to "provide a check on the validity" (p. 7) of correlating Mississippian carbonate rocks using clastic "marker" units like the Bakken. He recovered brachiopods from cores of the Bakken and "confidently ascribed" (p. 16) a early Kinderhookian age to the formation. Christopher (1961) corrected Brindle (1960) by pointing out that the earliest recognizable Kinderhookian fossils were reported by Brindle as from the middle member of the Bakken in Saskatchewan. Christopher (1961, p. 19) stated:

> Thus until paleontologic evidence is introduced to prove the Kinderhookian age of the Bakken lower shale member, the Devonian-Mississippian boundary is more appropriately placed at the base of the Middle sandstone.

In a report on the potential for radioactive waste disposal in the Williston Basin, Sandberg (1962a, p. 52) reported "the Bakken Formation is of Late Devonian (?) and Early Mississippian age and is disconformable with underlying and overlying strata." In his study of the stratigraphic relationship of the Bakken and Englewood Formations in North Dakota and South Dakota, Kume (1963, p. 4) reported "little or no success" in his attempt to disaggregate the black shales of the Bakken to obtain conodonts. Kume (1963) provided core descriptions, a summary of previous Bakken studies, and isopach maps of the three members of the Bakken in North Dakota. He considered the Bakken Mississippian in age, although he thought (p. 50) it conceivable that the Devonian-Mississippian boundary may "occur within the black shales." Ballard (1963) briefly reviewed Bakken stratigraphy in a discussion on the Paleozoic rocks of eastern North Dakota.

While the age of the Bakken has significance in interpreting the geologic history of the Williston Basin, the formation is also of importance economically because of the potential of the organic shales as hydrocarbon source rocks. Murray (1968, p. 58) related the source-rock potential of the Bakken to the "petroliferous" character and distinctive geophysical response of the formation. Williams (1974) used geochemical techniques in the Williston Basin to trace oil in overlying reservoir rocks to organic matter in the Bakken. Dow (1974) discussed the distribution and migration of oil in the Williston Basin in relation to probable source rocks and reported that the Bakken shales are effective source rocks where buried to a depth of 7,000 feet (2,134 m) or more. In a study of the petroleum geology of the Bakken Formation in Montana and North Dakota, Meissner (1978, p. 213) reported that the zone of hydrocarbon generation was non-planar and occurred at a depth "from about 6200 to 8200 feet." Thode (1981) analyzed sulfur isotope values for the three members of the Bakken Formation in North Dakota and those of oils in the Williston Basin and indicated that oil generation from the Bakken was limited to the lower shale.

Webster (1982) used organic carbon measurements, chromatographic analysis, pyrolysis, vitrinite reflectance, and visual kerogen typing to evaluate the Bakken as a source rock. He (p. 52) reported that the Bakken shales have a "very high" (average 11.33 percent) organic carbon value and indicated that the onset of hydrocarbon generation occurs at a depth of 9,000 feet (2,743 m) and "intense hydrocarbon generation" (p. 97) occurs at a depth of 10,000 feet (3,048 m). Hester and Schmoker (1983) produced preliminary, log-derived maps of the Bakken Formation in

North Dakota and Montana. Schmoker and Hester (1983) calculated organic carbon content for the Bakken shales and estimated the amount of hydrocarbons expelled from the United States portion of the formation.

The depositional environment of carbonaceous, black shales, such as those of the Bakken, has been the subject of much controversy. The high organic content, dark color, and abundant pyrite suggest deposition in oxygen-depleted water. A main point of contention in the controversy has concerned the depth of the water during deposition. In his discussion of the Bakken Formation, McCabe (1959, p. 44) noted that black shale rich in organic material "can be formed under conditions varying from deep-water marine to terrestrial swamp."

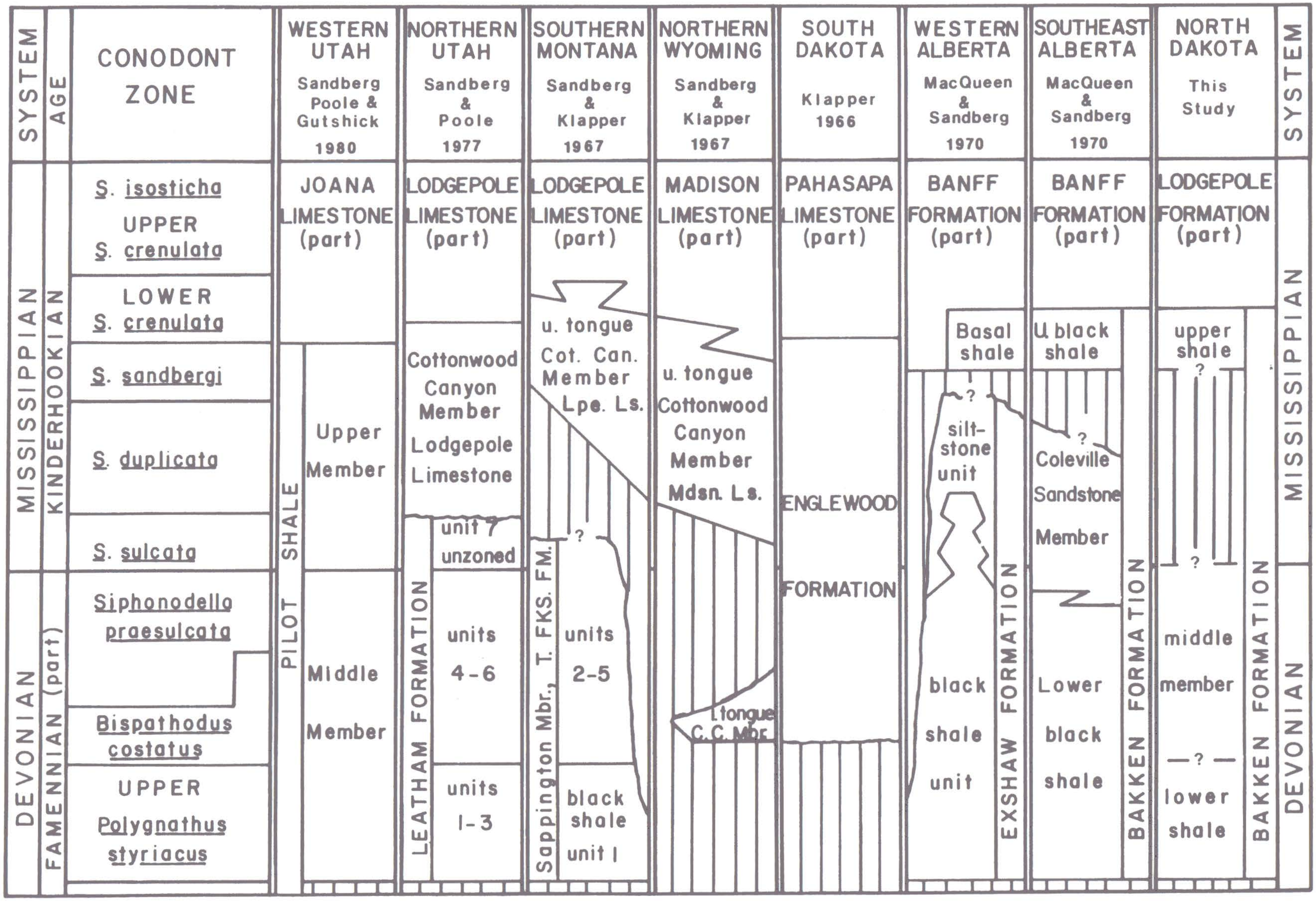
Fuller (1956) and McCabe (1959) believed that Bakken black shale deposition occurred in a vast marine swamp and that sediments of the middle member were the result of an influx of clastic debris from uplift of the periphery of the Williston Basin. MacDonald (1956), however, suggested that the black shales of the Bakken were deposited below wave base in marine waters at least 200 to 600 feet (61 m to 183 m) deep. Parrish (1982) speculated that the Bakken may have been deposited during an interregional upwelling event related to worldwide marine circulation patterns during the Paleozoic. Lineback and Davidson (1982) compared sedimentary patterns in the Williston Basin with those in the Illinois Basin and proposed that the Bakken may represent an episode of sediment-starved conditions in the Williston Basin during the early Mississippian. Webster (1982, p. 33) concluded that the "great predominance of amorphous-sapropelic organic matter (probable algal or phytoplankton origin) over terrestrial (woody or humic) material suggests an offshore marine depositional environment" for the Bakken shales.

Regional Conodont-Related Studies

The Exshaw, Leatham, and Englewood Formations; Sappington Member of the Three Forks Formation; Cottonwood Canyon Member of the Lodgepole Limestone; and the middle member of the Pilot Shale are relatively thin units that span (or are close to) the boundary between the Devonian and Mississippian Systems (Fig. 4) and crop out in the northern Rocky Mountain region. These units are similar to the Bakken Formation in lithology, fossil content, thickness, and age. Although paleontologic study of the Bakken has been limited, the conodont biostratigraphy of others of these lithostratigraphically similar rock units has been studied in more detail. As with the Bakken Formation, several of these units have had a history of equivocal age assignments. Conodonts have been widely studied and are now becoming recognized as the group of fossils most useful for precise biostratigraphic correlation of these rocks, especially for the black shales where biostratigraphically useful macrofossils are lacking.

Knechtel and Hass (1938) reported a Kinderhookian condont fauna from a black, fissile shale exposed at the base of the Lodgepole Limestone in the Little Rocky Mountains of Montana. Hass (1943) revised these identifications and, later, this thin black shale was recognized (Klapper, 1966, p. 10) as the margin of the upper shale of the Bakken Formation. Cooper and Sloss (1943) illustrated and described conodonts

Figure 4. Age, conodont zonation, and stratigraphic relationship of the Pilot Shale, Leatham Formation, Sappington Member of the Three Forks Formation, Cottonwood Canyon Member of the Lodgepole and Madison Limestones, Englewood Formation, Exshaw Formation, Bakken Formation and directly overlying units. Primary sources of information are shown above the units. Units 1-5 of the Sappington Member are from Sandberg (1965). Conodont zonation is from Sandberg (1979). Evidence for the stratigraphic position of the Bakken Formation in North Dakota is discussed in the text.


SYSTEM
AGE
CONODONT ZONE
WESTERN UTAH Sandberg Poole & Gutshick 1980
NORTHERN UTAH Sandberg & Poole 1977
SOUTHERN MONTANA Sandberg & Klapper 1967
NORTHERN WYOMING Sandberg & Klapper 1967
SOUTH DAKOTA Klapper 1966
WESTERN ALBERTA MacQueen & Sandberg 1970
SOUTHEAST ALBERTA MacQueen & Sandberg 1970
NORTH DAKOTA This Study
MISSISSIPPIAN
KINDERHOOKIAN
DEVONIAN
FAMENNIAN (part)
S. isosticha
UPPER S. crenulata
LOWER S. crenulata
S. sandbergi
S. duplicata
S. sulcata
Siphonodella praesulcata
Bispathodus costatus
UPPER Polygnathus styriacus
JOANA LIMESTONE (part)
PILOT SHALE
Upper Member
Middle Member
LODGEPOLE LIMESTONE (part)
Cottonwood Canyon Member Lodgepole Limestone
unit 7 unzoned
LEATHAM FORMATION
units 4-6
units 1-3
LODGEPOLE LIMESTONE (part)
u. tongue Cot. Can. Member Lpe. Ls.
Sappington Mbr., T. FKS. FM.
units 2-5
black shale unit I
MADISON LIMESTONE (part)
u. tongue Cottonwood Canyon Member Mdsn. Ls.
l. tongue C. C. Mbr.
PAHASAPA LIMESTONE (part)
ENGLEWOOD FORMATION
BANFF FORMATION (part)
Basal shale
silt-stone unit
black shale unit
EXSHAW FORMATION
BANFF FORMATION (part)
U. black shale
Coleville Sandstone Member
Lower black shale
BAKKEN FORMATION
LODGEPOLE FORMATION (part)
upper shale
middle member
lower shale
BAKKEN FORMATION
?

from a "Lower Mississippian" black shale in Montana and Alberta. Raasch (1956) provided a list of conodonts from the Exshaw Formation and Achauer (1959) reported conodont genera from strata in southwestern Montana that he considered the "Sappington formation." In his study, Achauer apparently included strata in the Sappington that are now considered part of the overlying Cottonwood Canyon Member of the Lodgepole Limestone. Müller (1962) illustrated a small conodont fauna from the Banff Formation in Alberta. Klapper and Furnish (1962) published a portion of a regional conodont study and indicated that the Devonian-Mississippian boundary in South Dakota was within the Englewood Formation.

In one of the earliest attempts to establish a conodont biozonation scheme for the Rocky Mountain region, Klapper (1966) described, illustrated, and discussed important conodont constituents from portions of the lower Lodgepole Limestone, upper Three Forks Formation, and the Englewood Formation. Sandberg and Mapel (1967) provided a synthesis of Devonian stratigraphy of the northern Great Plains and Rocky Mountain region and used conodont zones (Fig. 4) to show the time-stratigraphic position of rock units near the Devonian-Mississippian boundary. Sandberg and Klapper (1967) defined and described the Cottonwood Canyon Member of the Madison Limestone (or of the Lodgepole Limestone where the Lodgepole is the basal formation of the Madison Group) and discussed the conodont zonation and paleotectonic significance of the member. In their report, Sandberg and Klapper (1967) speculated on the depositional setting of the Bakken Formation and reviewed (p. B39) circumstantial conodont evidence, which indicated that the Bakken was both Devonian and

Mississippian in age. Sandberg and Gutshick (1969) used conodonts to determine that the age of the Leatham Formation was mostly Devonian and partly Mississippian. Macqueen and Sandberg (1970) discussed the stratigraphy and conodont zonation of the Exshaw Formation and determined that the Exshaw was both Devonian and Mississippian in age and physically continuous with the lower shale and middle member of the Bakken Formation and the Sappington Member of the Three Forks Formation. Sandberg and others (1972) refined and compared conodont zones in the western and central United States with those in Europe. They included descriptions and illustrations of zonally important conodonts from the Sappington Member of the Three Forks Formation, the Leatham Formation, and the Cottonwood Canyon Member of the Lodgepole Limestone.

As conodont zones were more widely established in the United States and Europe, it became apparent that somewhat different conodont faunas may be present within a single conodont zone. Sandberg (1976) attributed this distribution of conodont faunas within the widely recognized Polygnathus styriacus Zone (Upper Devonian) to the influence of different ecologic niches over a wide area. He recognized five distinctive biofacies, or lateral variations in the biologic constituents, in this zone in the western United States.

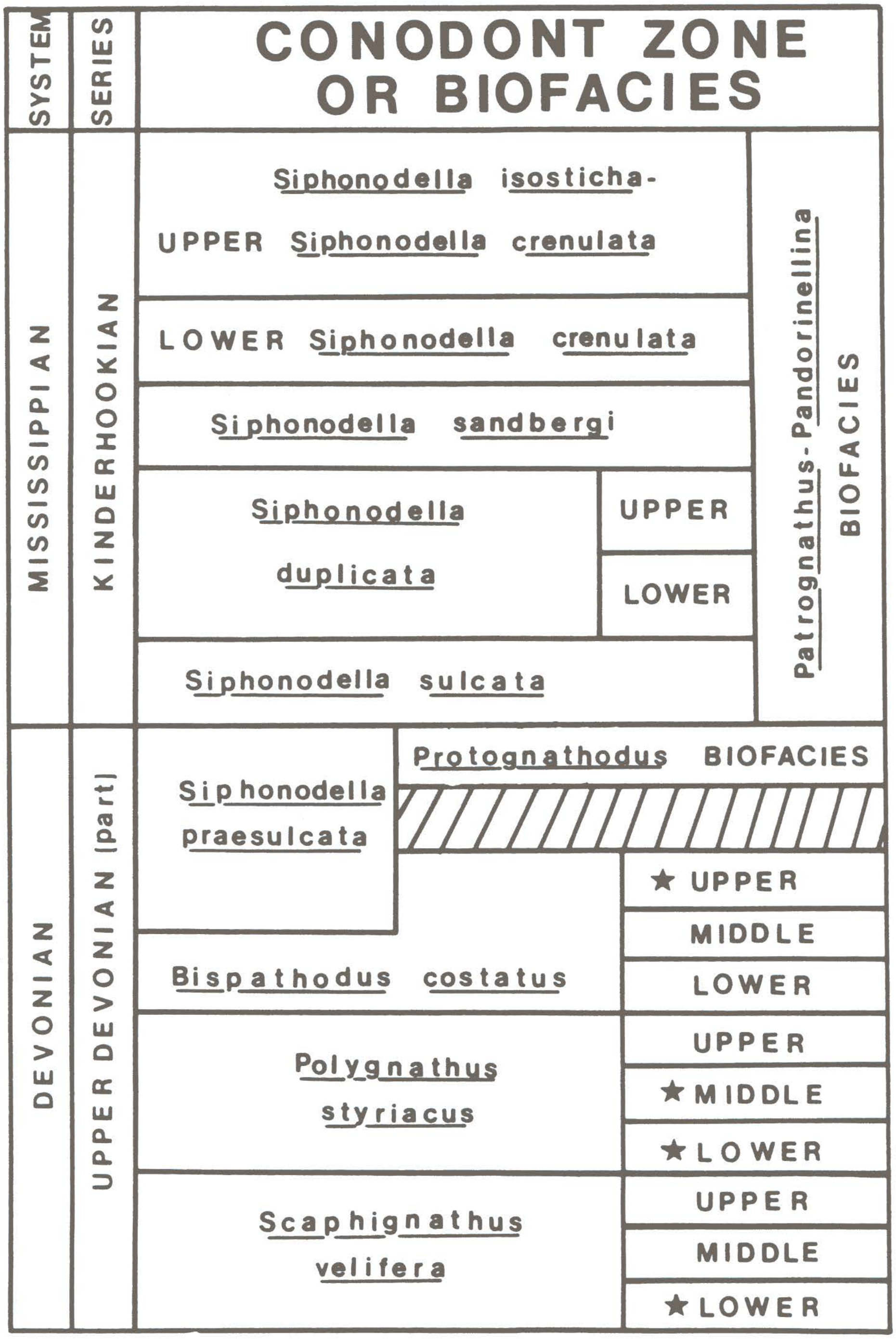
In a regional study of depositional patterns in the western United States during the Late Devonian, Sandberg and Poole (1977) discussed the conodont biostratigraphy of the Pilot Shale and reported that the middle member of the Pilot Shale was part of the depositionally continuous rock body that includes the Exshaw and Leatham Formations, the Sappington Member of the Three Forks Formation, and the lower two members of the

Bakken Formation. Their report also contains a discussion of deposition within conodont zones as indicative of rates of sedimentation within these zones. Sandberg and Ziegler (1979) elaborated on conodont biofacies within the Polygnathus styriacus Zone and illustrated and described important conodont taxa. Sandberg (1979) provided extensive faunal lists of important Devonian and Lower Mississippian conodont zonal constituents in the Great Basin and Rocky Mountain region and noted (p. 87) "a total of 56 conodont zones are now recognized in the Devonian and Lower Mississippian . . . ." The conodont biozonation scheme used herein, and shown on Figure 5, is from Sandberg (1979). Sandberg and Gutshick (1979) described the lithostratigraphy and biostratigraphy of Upper Devonian and Mississippian rocks in northern Utah and used conodont zones to determine rates of sedimentation in these rocks. Sandberg and others (1980) examined the stratigraphy and conodont zonation of the Pilot Shale and used conodont color to evaluate the oil-generation potential of the formation. Sandberg and others (1983) reviewed the geologic history of the Middle Devonian to Late Mississippian in the Overthrust Belt of the western United States. This report outlined in detail major tectonic events and paleogeographic settings during the interval of specific conodont biozones.

Regional Stratigraphy

During Late Devonian and Early Mississippian time, widespread clastic deposition occurred in the Williston Basin and adjoining northern Rocky Mountain region. Rock units deposited at this time

Figure 5. Conodont biozonation scheme redrafted from Sandberg (1979, p. 91, fig. 2; p. 98, fig. 3). Starred zones are those not recognized in the western United States. Cross-hatching shows unzoned intervals lacking diagnostic conodonts.

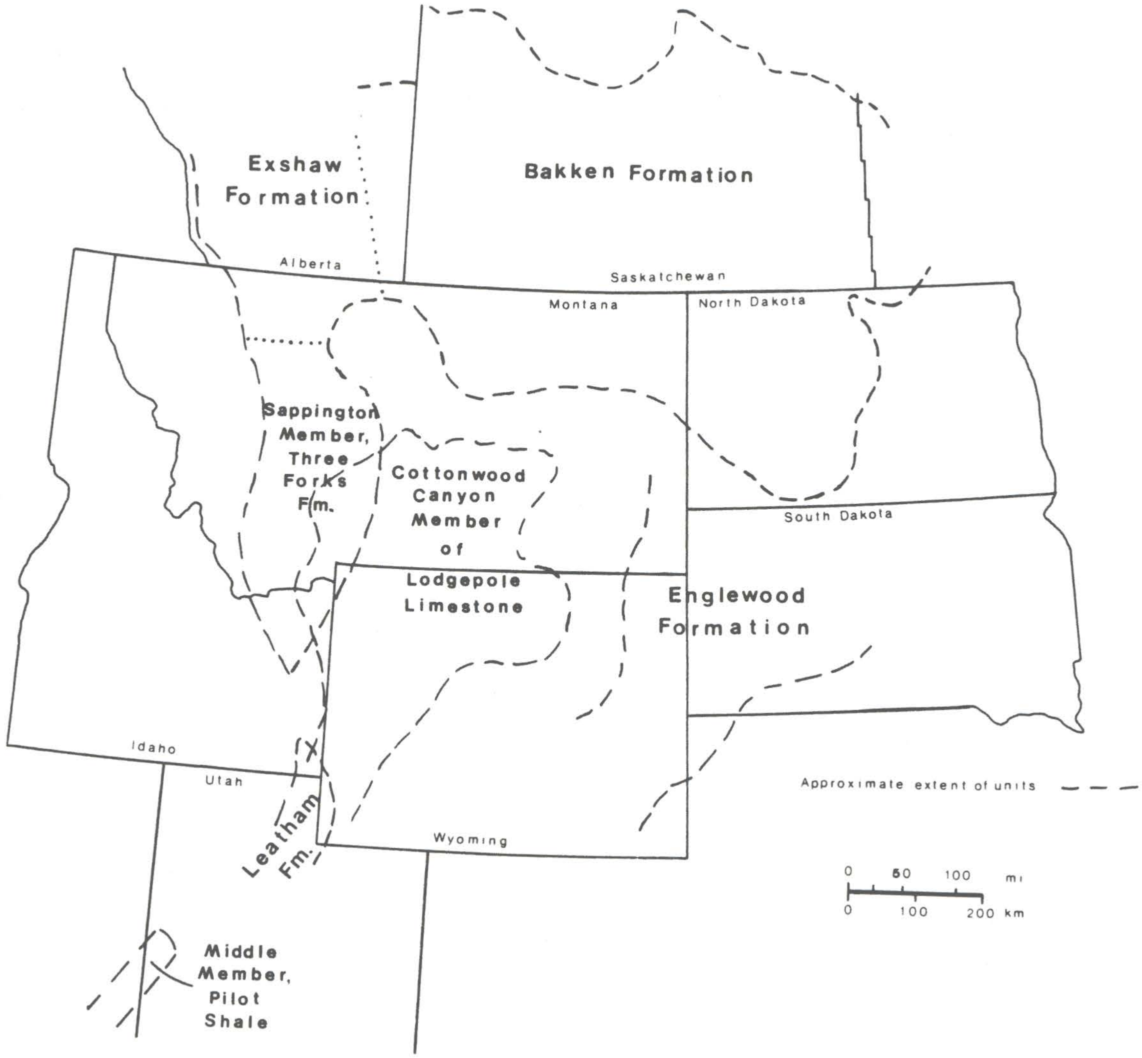

SYSTEM
SERIES
CONODONT ZONE OR BIOFACIES
MISSISSIPPIAN
KINDERHOOKIAN
Siphonodella isosticha-UPPER Siphonodella crenulata
LOWER Siphonodella crenulata
Siphonodella sandbergi
Siphonodella duplicata
UPPER
LOWER
Siphonodella sulcata
Patrognathus-Pandorinellina BIOFACIES
DEVONIAN
UPPER DEVONIAN (part)
Siphonodella praesulcata
Protognathodus BIOFACIES
★ UPPER
MIDDLE
LOWER
Bispathodus costatus
Polygnathus styriacus
UPPER
★ MIDDLE
★ LOWER
Scaphignathus velifera
UPPER
MIDDLE
★ LOWER

include the partly continuous Bakken Formation, Exshaw Formation, Sappington Member of the Three Forks Formation, Leatham Formation, middle member of the Pilot Shale, and the lithogenetically related Englewood Formation and Cottonwood Canyon Member of the Lodgepole Limestone. The approximate extent of these units is shown in Figure 6.

The lithology of these transitional Devonian-Mississippian units is primarily black carbonaceous shale and calcareous to dolomitic siltstone and sandstone. Thin (usually 0.5 to 4.0 in., 1.3 to 10.0 cm), conglomeratic sandstones or lag deposits commonly occur at the base of these units. These lags contain quartz sand, phosphatic debris, fish teeth and bones, and abundant conodonts. The lags are apparently discontinuous, but have been reported at the base of the Sappington Member of the Three Forks Formation (Sandberg and Klapper, 1967, p. B8), Exshaw Formation (Macqueen and Sandberg, 1970, p. 39), Leatham Formation (Sandberg and Gutshick, 1969, p. 70), middle member of the Pilot Shale (Gutshick and Rodriguez, 1979, p. 44), and the Cottonwood Canyon Member of the Lodgepole Limestone (Sandberg and Klapper, 1967, p. B29). A "pebble bed" at the base of the Bakken Formation in Saskatchewan that contains dolostone pebbles, abundant dark-brown phosphatic particles, and locally abundant, broken conodonts was reported by Fuller (1959, p. 23).

Regional studies indicate that the lower shale and middle member of the Bakken were, and mostly still are, physically continuous with the Exshaw Formation, Sappington Member of the Three Forks Formation, Leatham Formation, and middle member of the Pilot Shale. In latest Devonian time, portions of these units were deposited in an elongate

Figure 6. Approximate extent of the Bakken Formation, Exshaw Formation, Sappington Member of the Three Forks Formation, Leatham Formation, middle member of the Pilot Shale, Cottonwood Canyon Member of the Lodgepole Limestone, and Englewood Formation. Sources of information for this map include Christopher (1961, p. 9), Sandberg and Mapel (1967, p. 870-871), Macqueen and Sandberg (1970, p. 45), Sandberg and Poole (1977, p. 174), Meissner (1978, p. 207), and Gutshick and Rodriguez (1979, p. 37).



Exshaw Formation
Bakken Formation
Alberta
Saskatchewan
Montana
North Dakota
Sappington Member, Three Forks Fm.
Cottonwood Canyon Member of Lodgepole Limestone
South Dakota
Englewood Formation
Idaho
Utah
Wyoming
Leatham Fm.
Middle Member, Pilot Shale
Approximate extent of units
0 50 100 mi
0 100 200 km

series of depocenters between the Antler orogenic highlands to the west and the craton to the east (Gutshick and Rodriguez, 1979, p. 37, fig. 1). The lower black shale of this extensive depositional package apparently overlies a regional unconformity, and the base of the shale throughout its extent was deposited within the Upper Polygnathus styriacus Zone (Upper Devonian). Regional lithologic and paleontologic evidence indicates that an unconformity also lies on top of the unit of limestone, calcareous siltstone and sandstone atop the widespread black shale. Although the black shale and overlying siltstone and sandstone were depositionally continuous, and the lower part of this black shale was deposited within one conodont zone, the upper part of the black shale and portions of the siltstone or sandstone unit are not wholly the same age throughout their extent.

The Exshaw Formation was formally named by Warren (1937) for exposures of black shale and siltstone near Exshaw, Alberta and assigned a Devonian age on the basis of ammonoid cephalopods. Crickmay (1952) questioned the ammonoid identifications and asserted that the Exshaw was Mississippian. In 1970, Macqueen and Sandberg redefined the upper contact of the formation to include more of the siltstone that was originally considered part of the overlying Banff Formation. Macqueen and Sandberg (1970, p. 41) reported a maximum thickness of "about 166 feet" for the Exshaw and used conodonts to determine that the Devonian-Mississippian boundary was located "near the middle of the black shale unit" (p. 32). Their study indicated that, although the lower black shale unit of the Exshaw is physically continuous with the black shale of the Sappington Member of the Three Forks Formation and the lower black shale of the Bakken Formation, part of the black shale unit (where it grades laterally into the siltstone unit) of the Exshaw is considerably younger than the black shale in the Sappington Member and the lower black shale of the Bakken Formation. Macqueen and Sandberg's (1970, p. 50) time-stratigraphic correlations were based on conodont evidence that indicated the base of the Exshaw black shale was Devonian (Upper *Polygnathus styriacus* Zone), but upper portions of the shale are Mississippian (through the *Siphonodella duplicata* Zone).

The Sappington Member of the Three Forks Formation was initially (Berry, 1943) referred to as the "Sappington sandstone." Holland (1952) redefined the Sappington to include a black carbonaceous shale at the base and, on the basis of a macrofauna that correlated with that of the Louisiana Limestone in the Mississippi Valley, considered the unit Mississippian in age. Gutshick and others (1962) examined the biostratigraphy of the Sappington and divided the unit into lithologic subdivisions from A to I.

In a report that helped solidify the nomenclature of the Three Forks Formation, Sandberg (1965) reviewed the stratigraphy of the Sappington and argued that the 100-foot (30 m)-thick unit should be considered the uppermost member of the Three Forks Formation. Sandberg (1965) also divided the Sappington into lithologic subdivisions, but numbered the units in ascending order from 1 to 5. Later, Sandberg and others (1972) recognized a sixth unit in the Sappington Member. Sandberg and others (1972, p. 184) commented on the two sets of subdivisions proposed for the Sappington and noted that Gutshick and others (1962) had

> . . . recognized four widespread subdivisions of the basal black shale (unit 1), which they designated by the letters A to D in ascending order; their higher units E, F, G, and H correspond exactly to units 2, 3, 4, and 5 respectively.

Unit 6 (Sandberg and others, 1972) is a thin (61 cm), silty oolite that locally overlies unit 5 of the Sappington. Unit I (Gutshick and others, 1962) is now considered part of the overlying Cottonwood Canyon Member of the Lodgepole Limestone.

The black shale of the Sappington Member (unit 1, or subdivisions A through D) was deposited within the Upper *Polygnathus styriacus* Zone (Klapper, 1966, p. 5) and conodonts from unit 5 and 6 (Sandberg and others, 1972) of the overlying siltstone of the Sappington are of the Upper Devonian *Siphonodella praesulcata* Zone (Sandberg, 1979, p. 97).

Holland (1952, p. 1719) defined and described the Leatham Formation as ". . .shales, sandy shales, and nodular limestones which unconformably overlie the Devonian Jefferson Formation and conformably underlie the brownish black shale of the basal Mississippian Madison Formation." On the basis of fauna and lithology, Holland (1952, p. 1697) considered the Leatham and Sappington "contemporaneous" units. Sandberg and Gutshick (1969) included most of the dark shale, which Holland considered part of the basal Madison, within the Leatham Formation and then divided the Leatham into seven, numbered, lithologic subdivisions. According to Sandberg and others (1972, p. 186), units 1 to 3 of the Leatham Formation are lithologically similar to unit 1 (Sandberg, 1965) of the Sappington, and ". . . units 4 and 5 of the Leatham correspond to unit 2 of the Sappington." Unit six of the

Leatham is a siltstone similar to unit 3 (Sandberg 1965) of the Sappington Member. Unit seven of the Leatham was originally described as a 25-foot (8 m) section of carbonaceous shale, but this thickness was later reduced (Sandberg and Poole, 1977, p. 168) by 2.5 meters when it was determined that this part of the column was apparently part of the overlying Cottonwood Canyon Member of the Lodgepole Limestone.

Units 1-3 of the Leatham Formation were deposited during the time of the Upper Polygnathus styriacus Zone (Sandberg and Gutshick, 1969). Unit 4 of the Leatham is of the Devonian Middle Bispathodus costatus Zone and units 5 and 6 are of the Siphonodella praesulcata Zone (Sandberg and Poole, 1977, p.165, fig. 11). A diagnostic conodont fauna has not been reported for unit 7 of the Leatham Formation.

Spencer (1917) named and defined the the Pilot Shale for exposures of soft, carbonaceous shale west of Ely, Nevada. The formation is informally divided into lower, middle, and upper members of which the middle member is generally composed of black carbonaceous shale and overlying siltstone and limestone. Sandberg and Poole (1977) demonstrated that the middle member of the Pilot Shale was depositionally continuous with the Leatham Formation. Sandberg and others (1980, p. 72) applied the name Leatham Member to the middle member of the Pilot Shale and stated "The Leatham Member is faunally, lithologically, and sequentially identical to the type Leatham Formation" as redescribed by Sandberg and Gutshick (1969).

Sandberg and Poole (1977) reported that the Leatham Member of the Pilot Shale is entirely Devonian. The lower black shale of this middle member of the Pilot Shale is of the Upper Polygnathus styriacus Zone and the overlying siltstone ranges from the Middle Bispathodus costatus Zone to the Siphonodella praesulcata Zone (Sandberg and Poole, 1977, p. 154, fig. 6).

The Cottonwood Canyon Member of the Lodgepole Limestone and the Englewood Formation, although not presently continuous with the widespread shale and siltstone depositional complex that includes the lower shale and middle member of the Bakken, have thickness, stratigraphic position, and conodont faunas similar to this widespread depositional complex. The Cottonwood Canyon Member (dark shale unit of Sandberg, 1963; Klapper, 1966) was defined and described by Sandberg and Klapper (1967) and divided into a lower and an upper tongue. Both tongues have an eastern dolomitic facies and a western shale and siltstone facies. They (1967, p. B28) noted that the "most diagnostic criterion for recognizing" the zero to 80-foot (24 m)-thick member in outcrop "is the widespread occurrence of condensed or lag deposits." The upper tongue of the Cottonwood Canyon Member is more extensive than the lower tongue and unconformably overlies the Sappington Member of the Three Forks Formation in some areas (Fig. 4 and 6). Sandberg and Klapper (1967, p. B9, fig. 3) considered the lower tongue of the Cottonwood Canyon Member to be of the Lower Bispathodus costatus Zone and reported that the upper tongue ranges from the Mississippian Siphonodella sulcata Zone through the Lower Siphonodella crenulata Zone.

The Englewood Formation is composed of silty shale and argillaceous and dolomitic limestone (Kume, 1963, p.22) and is "very similar" (Sandberg and Klapper, 1967, p. B37) to the Cottonwood Canyon Member of the Lodgepole Limestone in terms of thickness, lithology, age, and conodont faunas. Klapper (1966, p. 10) reported a Devonian (Lower Bispathodus costatus Zone) conodont fauna from "10 to 34 feet below the top of the Englewood Formation at Boxelder Canyon . . .," South Dakota and reported that the Devonian-Mississippian boundary is "9 to 10 feet below the top of the Englewood Formation" there.

Regional studies (Sandberg and Mapel, 1967; Macqueen and Sandberg, 1970) have indicated that the upper shale of the Bakken Formation unconformably overlies the middle member of the Bakken. Thus, the upper shale of the Bakken Formation has a stratigraphic position similar to the upper tongue of the Cottonwood Canyon Member where that tongue overlies the Sappington Member of the Three Forks Formation and the Leatham Formation. Klapper (1966, p. 8-10) and Sandberg and Klapper (1967, p. B39) speculated that the upper shale of the Bakken Formation was Mississippian in age on the basis of evidence that included Kinderhookian (Lower Mississippian) conodonts (Knechtel and Hass, 1938; Hass, 1943) from the "Little Chief Canyon Member" of the Lodgepole Limestone. The "Little Chief Canyon Member" at its type locality (see Knechtel and others, 1954) in the Little Rocky Mountains of Montana has been recognized as the exposed margin of the upper shale of the Bakken Formation and thus, ". . . obviates the necessity of the term Little Chief Canyon Member" according to Sando and Dutro (1974, p.3).

A black or dark gray shale at the base of the Banff Formation in western Alberta has a lithostratigraphic position similar to that of the upper shale of the Bakken in the Williston Basin. Where the basal dark shale of the Banff Formation overlies the Exshaw Formation (Macqueen and Sandberg, 1970, p. 42), a shale-siltstone-shale sequence similar to that of the Bakken is preserved.

Materials and Methods

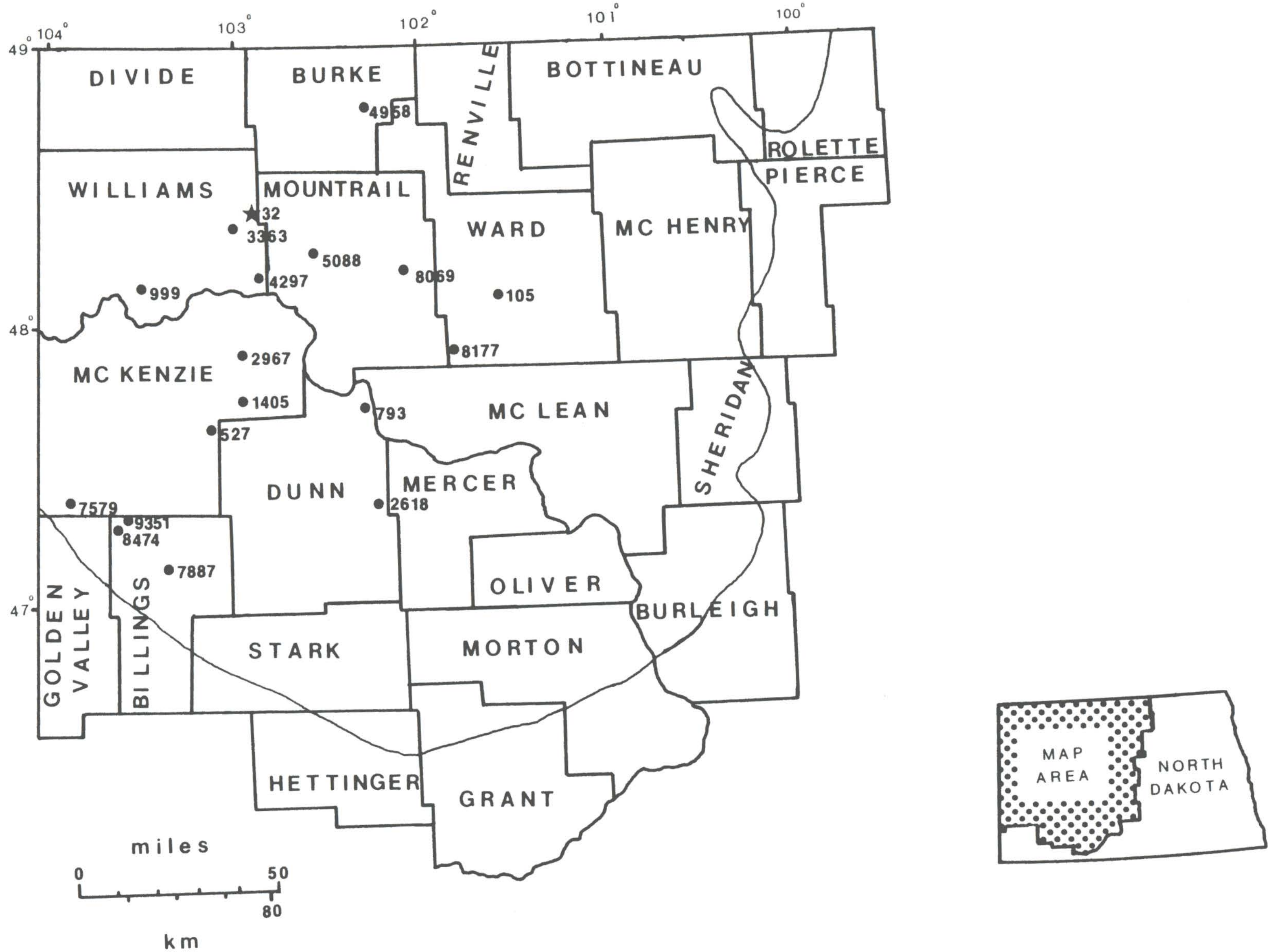
Materials

Material used included geophysical logs, cores, and thin sections of the Bakken Formation provided by the North Dakota Geological Survey (NDGS), Grand Forks, North Dakota. Cores from 17 wells, representing various amounts of the Bakken Formation, were examined in the Wilson M. Laird Core and Sample Library on the campus of the University of North Dakota. The location of the wells used and the NDGS well numbers are shown in Figure 7. Core diameter ranged from about 2.5 inches (6 cm) to about 5.0 inches (13 cm) and many of the cores had been previously slabbed or sampled. Cores varied from well preserved to poorly preserved. Most cores were stored in 3-foot core boxes with some core boxes containing composite samples representing up to 18 feet (5.5 m) of original length. The depth of the cored interval labeled on the core box is generally determined at the drillsite and does not always correspond exactly with the depth of the Bakken as picked on geophysical logs. Sample depths used, herein, are those from the exterior of the core box. Legal descriptions of wells used are presented in Appendix A. Appendix B shows the depths of the tops of formations and members as picked on logs.

Methods

Core examination was done with the aid of a handlens (14x) or binocular microscope. Relative core condition, lithology, color (according to Goddard and others, 1948), fossil occurrences, and bedding features were recorded, and core samples were taken during core examination. Core samples and conodont specimens were in most cases

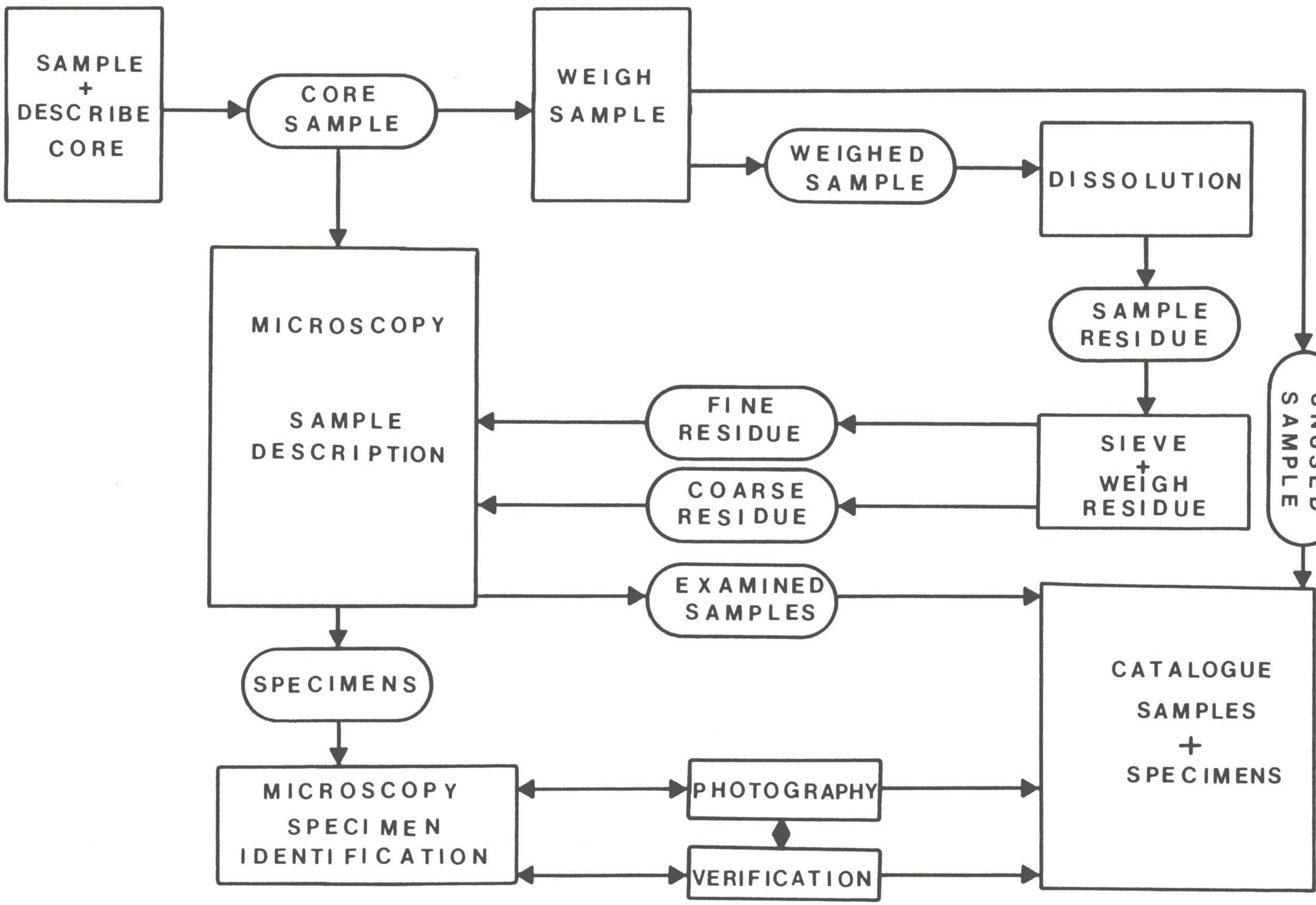
Figure 7. Maximum extent (from Webster, 1982) of the Bakken Formation in North Dakota and location of wells used in this study. Well numbers are those of the North Dakota Geological Survey. The starred well was not used, but marks the location of the type well (Amerada - H. O. Bakken No. 1) of the Bakken Formation.


104°
103°
102°
101°
100°
49°
48°
47°
DIVIDE
BURKE
RENVILLE
BOTTINEAU
ROLETTE
PIERCE
WILLIAMS
MOUNTRAIL
WARD
MC HENRY
MC KENZIE
MC LEAN
SHERIDAN
DUNN
MERCER
OLIVER
BURLEIGH
GOLDEN VALLEY
BILLINGS
STARK
MORTON
HETTINGER
GRANT
32
3363
4958
5088
8069
105
4297
999
8177
2967
1405
793
527
2618
7579
9351
8474
7887
miles
0
50
80
km
MAP AREA
NORTH DAKOTA

considered to have come from within the depth interval labeled on the exterior of the core box. In some core boxes, however, member contacts within the core necessitated more exact depth locations. Selective sampling and small sample weight were employed to minimize core destruction. A sample consisted of core pieces that were collected from loose rock chips in the core box or were broken from the core with a rock hammer. Most samples were about 200 grams in weight, but where portions of the core were limited, sample sizes were reduced accordingly. Samples from the upper and lower shales of the Bakken were collected in a selective, non-random manner, mostly where conodonts were observed. Samples of the middle member were collected less selectively than the shales because conodonts were not usually observable in the middle member.

Core samples were examined with a binocular microscope (10x to 60x) and those chosen for dissolution were weighed. Samples with observable conodonts were preferentially, although not exclusively, chosen for dissolution. The initial intent at the outset of the project was to identify conodonts on fracture surfaces of cores and supplement these specimens with conodonts obtained by disaggregating rock samples. As the study progressed, it became evident that conodonts examined on rock surfaces were usually inadequate for specific identification and those obtained from rock residues were of much greater use. Disaggregation of rock samples continued until it appeared a sufficiently numerous and diverse collection had been recovered to allow recognition of conodont biozone faunas. A flow chart illustrating the processing of core samples and conodont specimens is shown in Figure 8.

Figure 8. Flow chart of the processing of core samples and conodont specimens.


SAMPLE
+
DESCRIBE
CORE
CORE
SAMPLE
WEIGH
SAMPLE
WEIGHED
SAMPLE
DISSOLUTION
SAMPLE
RESIDUE
UNUSED
SAMPLE
MICROSCOPY
SAMPLE
DESCRIPTION
FINE
RESIDUE
COARSE
RESIDUE
SIEVE
+
WEIGH
RESIDUE
EXAMINED
SAMPLES
CATALOGUE
SAMPLES
+
SPECIMENS
SPECIMENS
MICROSCOPY
SPECIMEN
IDENTIFICATION
PHOTOGRAPHY
VERIFICATION

Part of a technique reported by Duffield and Warshauer (1979) was used to dissolve most of the 58 samples from 14 cores that were put into solution. Approximately one-half gallon (2 liters) of 4 percent to 6 percent sodium hypochlorite (household bleach) and 100 grams of sodium hydroxide ($NaOH$) were combined in a plastic container to produce a strong basic solution. Black shale samples were broken into thin (about 0.5 cm) pieces and placed in the solution for up to 16 weeks. Most middle member samples and some calcareous shale samples were placed into an approximate 10 percent solution of acetic or formic acid. The acid bath was changed as needed according to the vigor of the reaction. Both the acid and the bleach dissolution baths were replenished with water to offset evaporation and were, occasionally, gently stirred.

After the rock samples had dissolved appreciably, or had not responded well over time, the acid or bleach solution was decanted and the remaining residue was repeatedly washed with water and decanted slowly to remove only fine particles in suspension. This technique cleansed the residues of most clay-sized particles and left, in some well dissolved samples, the relatively heavy (specific gravity about 3.0) conodonts behind. The residue was allowed to dry and then sieved on a U.S. Standard Testing No. 7 Sieve (opening of 2.83 mm, 0.111 inches). The "coarse residue" (Fig. 8), which did not pass through the sieve, was weighed and this weight was subtracted from the initial sample weight to approximate the amount of rock that had disaggregated. The "fine residue" that passed through the sieve was examined and described under a microscope. Any complete conodonts, or fragmentary specimens that appeared potentially identifiable, were extracted with a small, wetted, No. 00 sable brush and transferred to a micropaleontological slide coated with gum tragacanth solution. Some silt-encrusted specimens were further cleaned by placing the specimens back into the bleach solution and gently brushing them with the sable brush. The data from the dissolution process are shown in Appendix C.

After the conodont fauna had been identified by the writer through examination of published descriptions and illustrations, Dr. Gilbert Klapper (University of Iowa) aided in the identification of a number of specimens. Conodont elements chosen for illustration were gold coated and photographed in the Natural Materials and Analytical Laboratory at the University of North Dakota. A Polaroid camera (Pos/Neg 52) attached to a JEOL-35c scanning electron microscope (SEM) was used to make initial photographs of the specimens. Negatives of the SEM photographs were then used to make prints. These prints were trimmed, mounted on black poster board with rubber cement and rephotographed by the Division of Biomedical Communications to produce the plates. The collection is stored at the University of North Dakota (UND) in Grand Forks. Conodont elements that are illustrated, and several specimens that were photographed on the SEM but are not illustrated, were assigned individual, four-digit, catalogue numbers of the UND paleontological collection. Specimens that were identified and counted, but not gold coated and photographed, were given a single catalogue number for all specimens of a taxon from each sample (identified by NDGS well number and core-box depth).

STRATIGRAPHY

Type Section

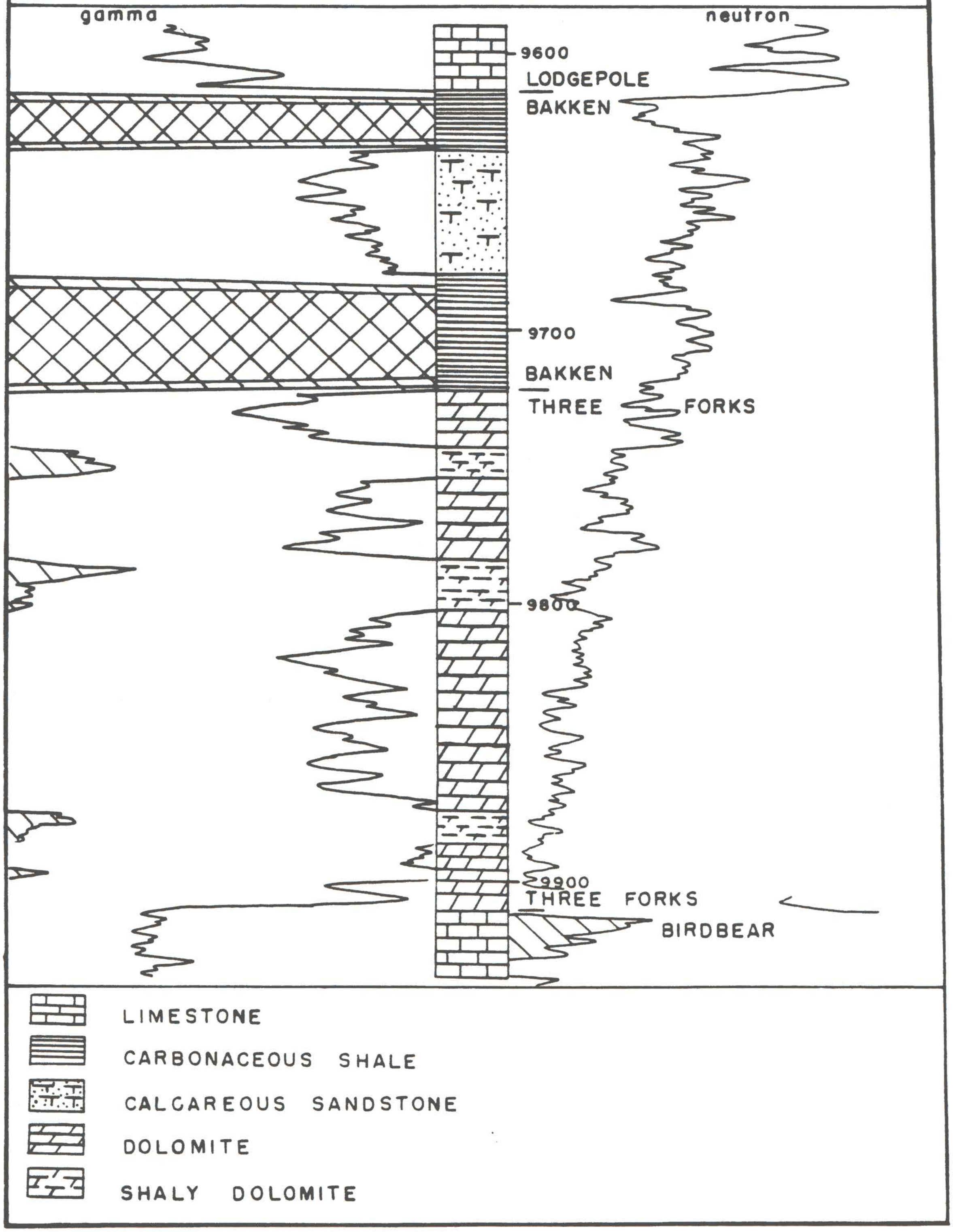
The type section of the Bakken Formation was formally defined by Nordquist (1953, p. 72) as 105 feet (32 m) of "strata occurring between the depths of 9615 feet and 9720 feet in the Amerada Petroleum Corporation H. O. Bakken No. 1 deep test" well (NDGS Well No. 32) in Williams County, North Dakota. Nordquist considered the lower, middle, and upper members of the Bakken as 25, 60, and 20 feet thick (8, 18, and 6 m). Nordquist (1953, p. 72) described the upper and lower shale members of the Bakken as very slightly calcareous, black, fissile shale and the middle member as dominantly light-gray to gray-brown, very fine grained, calcareous sandstone with minor amounts of gray-brown cryptocrystalline limestone.

Kume (1963) analyzed well cuttings and the gamma-ray log response of the type section of the Bakken and asserted (p. 31) that the members of the typical Bakken (in ascending order) were actually "40 feet, 45 feet, and 20 feet thick." Kume's illustration of the type section of the Bakken is shown as Figure 9.

Figure 9. Type section of the Bakken Formation (from Kume, 1963, p. 30). Cross-hatching marks where the gamma-ray log response is off-scale.

32

AMERADA-H.O. BAKKEN NO. 1
SW NW SEC. 12, T. 157 N., R. 95 W.
WILLIAMS COUNTY, NORTH DAKOTA



Geophysical Characteristics

The Bakken Formation, as noted by Nordquist (1953, p. 72) is "easily recognized . . . by its electrical and radioactive characteristics." The Bakken is thus widely used as a subsurface marker for geophysical correlation in the Williston Basin. The lower shale and the upper shale of the Bakken each characteristically has a high gamma-ray response indicating relatively strong natural radioactivity. The electrical resistivity of the two shales is high in the deeper (usually below 7,000 to 8,000 ft., 2,100 to 2,400 m) portions of the Basin and lower in shallower parts. Shale usually has low resistivity because of the conductivity of clay particles and highly conductive pore fluids. High resistivity shales suggest the presence of low conductivity material within the shale. McCabe (1959, p. 19) suggested that the high resistivity of the shales in the deeper portions of the Williston Basin may represent "extremely high organic content." Murray (1968, p. 59) suggested the "infinite" resistivity of the Bakken shales in the center of the Williston Basin "indicates that their pore space is hydrocarbon saturated." Following this line of reasoning, Meissner (1978, p. 213) indicated that

> the relatively rapid depth-related change from low to high resistivity . . . is believed to represent the onset of "maturity" or hydrocarbon generation and consequent replacement of high-conductive pore water in the organic shales with nonconductive hydrocarbons.

Meissner (1978, p. 212) attributed the "unusually low" sonic velocity (high transit time) of the Bakken shales mostly to the large amount of low-velocity organic matter in the shales. The geophysical log repsonse of the middle member of the Bakken is typical of carbonate rock or well-cemented, fine-grained clastic rock. Figure 10 displays the gamma-ray, resistivity, and sonic log response of the Bakken in NDGS Well No. 5088 in Mountrail County as characteristic of the deeper portions of the Williston Basin.

Areal Extent

The limits of the three members of the Bakken Formation in North Dakota have an onlapping relationship where each successive member is more extensive than the previous one (Fig. 11). It is uncertain whether the southern and eastern limits of the Bakken members in North Dakota are depositional, erosional, or both. No physical evidence was observed in the cores that indicated erosion occurred above the lower shale of the Bakken. Christopher (1961, p. 42), however, reported erosional features, such as black shale clasts, oxidized shale, and possible filled mudcracks at the contact between the lower shale and middle member of the Bakken in Saskatchewan. In most places where observed, the contact between the middle member and the upper shale of the Bakken is abrupt, but appears conformable. In one core (NDGS Well No. 7579) from McKenzie County, however, an irregular surface covered with pyritized clasts and fragmentary conodonts is preserved at the top of the middle member. Regional study (Macqueen and Sandberg, 1970, p. 50, fig. 4) has suggested that an unconformity exists between the middle member and upper shale of the Bakken Formation. The contact between the upper shale of the Bakken and the overlying Lodgepole Formation in North Dakota appears conformable in core.

Figure 10. Log response, lithology, and abbreviated core description of the Bakken Formation and adjacent units in the Shell Oil Company - Shell-Texel No. 21-35 (NDGS Well No. 5088), NE1/4 NW1/4 sec. 35, T. 165 N., R. 93 W., Mountrail County, North Dakota. Core description depths are from core boxes. Abbreviations of fossils are brachiopods (brachs.), and conodonts (conos.).

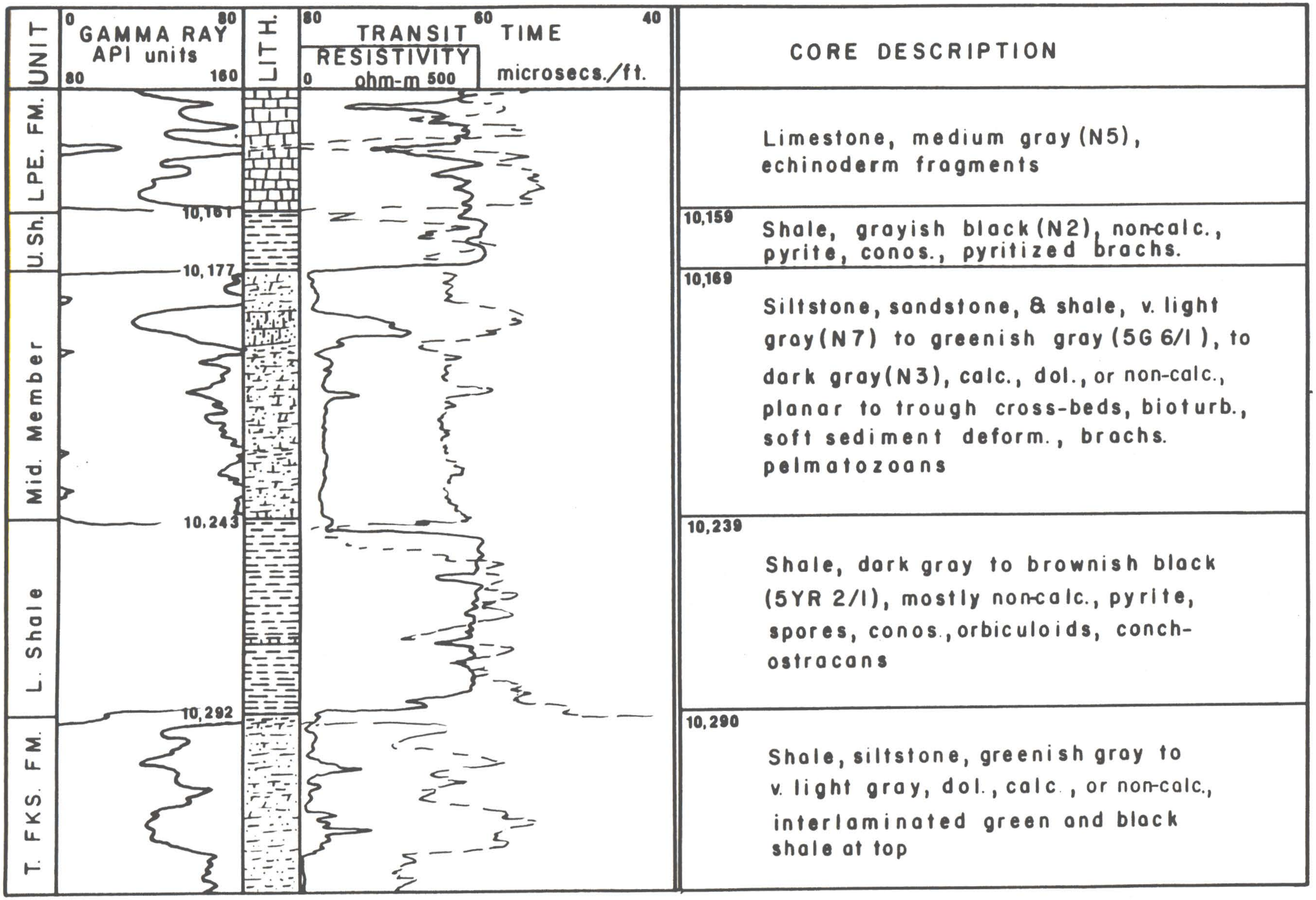
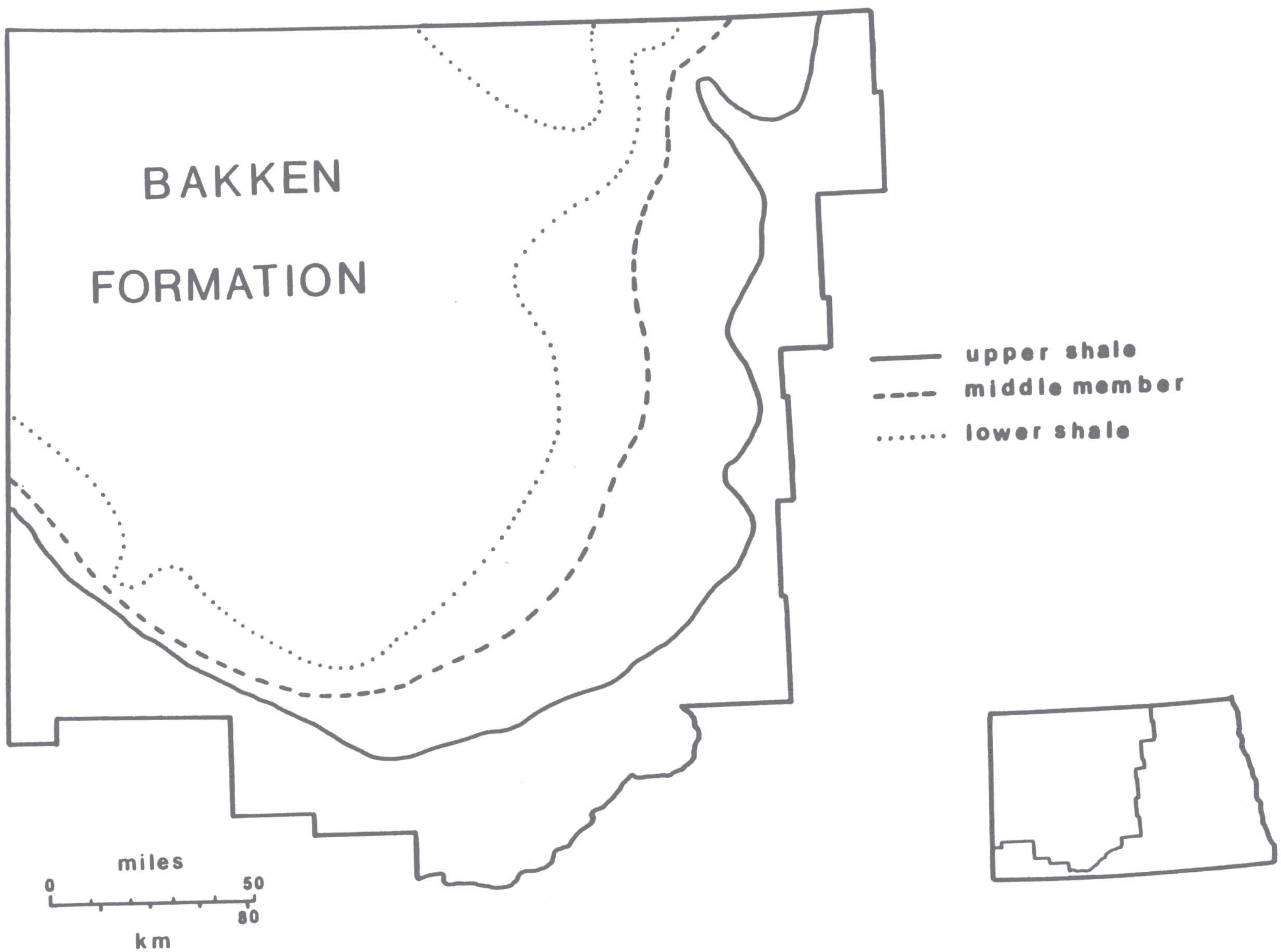

UNIT
GAMMA RAY
API units
0
80
80
160
LITH.
TRANSIT TIME
80
60
40
RESISTIVITY
0
ohm-m 500
microsecs./ft.
CORE DESCRIPTION
LPE. FM.
U. Sh.
Mid. Member
L. Shale
T. FKS. FM.
10,161
10,177
10,243
10,292
Limestone, medium gray (N5), echinoderm fragments
10,159
Shale, grayish black (N2), non-calc., pyrite, conos., pyritized brachs.
10,169
Siltstone, sandstone, & shale, v. light gray (N7) to greenish gray (5G 6/1), to dark gray (N3), calc., dol., or non-calc., planar to trough cross-beds, bioturb., soft sediment deform., brachs. pelmatozoans
10,239
Shale, dark gray to brownish black (5YR 2/1), mostly non-calc., pyrite, spores, conos., orbiculoids, conch-ostracans
10,290
Shale, siltstone, greenish gray to v. light gray, dol., calc., or non-calc., interlaminated green and black shale at top

Figure 11. Limits of the lower shale, middle member, and upper shale of the Bakken Formation in North Dakota (redrafted from Webster, 1982, p. 11).


BAKKEN
FORMATION
upper shale
middle member
lower shale
miles
0
50
80
km

Thickness

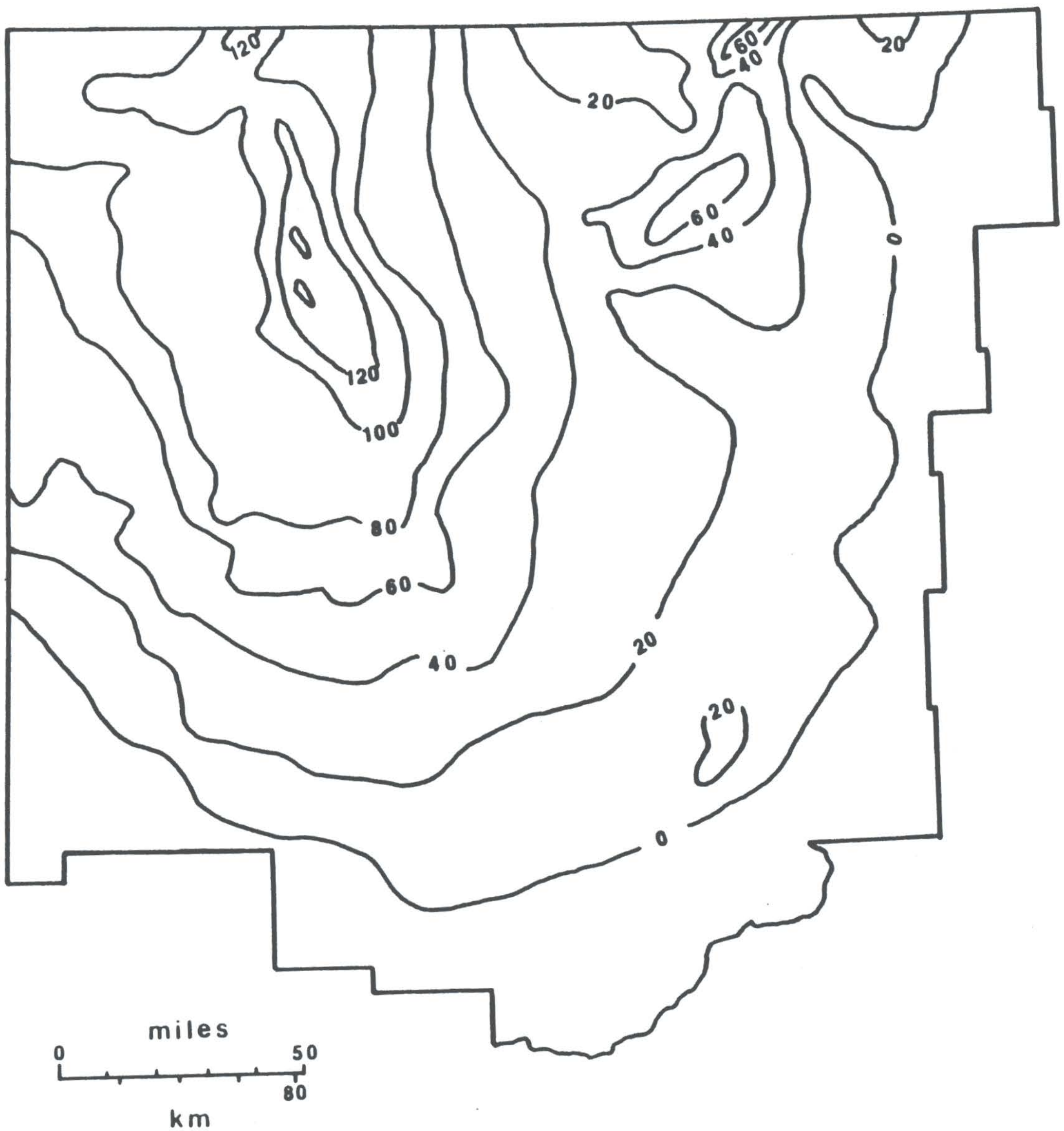
The Bakken Formation in North Dakota reaches a maximum thickness of 145 feet (44 m) in western Mountrail County and thins toward its southern and eastern limits (Fig. 12). Webster (1982) reported that the maximum thicknesses of the Bakken members in North Dakota are 50, 85, and 23 feet (15, 26, and 7 m) for the lower shale, middle member, and upper shale. In North Dakota, the upper shale of the Bakken is generally thinner, and more consistent in thickness than the lower shale.

An elongate area, which trends north-south just east of the present Nesson Anticline, is the area of maximum thickness of the Bakken Formation and apparently represents a depocenter during the time of Bakken deposition. Anomalous thickening of the Bakken in Bottineau and McHenry Counties has been attributed (Webster, 1982, p. 17) to salt collapse of the Devonian Prairie Formation or to possible pre-Bakken erosion of the Three Forks Formation, which may have allowed extra Bakken deposition in low areas. A lack of thinning in the Bakken Formation over the Nesson Anticline suggests that this structure was not a positive feature during Bakken deposition.

Structural Configuration

Webster (1982) produced a detailed structure contour map of the top of the Bakken Formation in North Dakota (Fig. 13). This map clearly illustrates the structure of the Nesson Anticline. The deepest burial of the Bakken in North Dakota occurs in Dunn and McKenzie Counties. Shallowest burial is in Rollette County along the northeastern limit of

Figure 12. Isopach map of the Bakken Formation in North Dakota (modified from Webster, 1982, p. 18). Contour interval is 20 feet (6 m).


120
120
100
80
60
40
20
20
60
40
20
60
40
0
20
20
0
miles
0
50
80
km

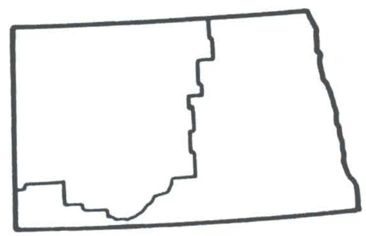
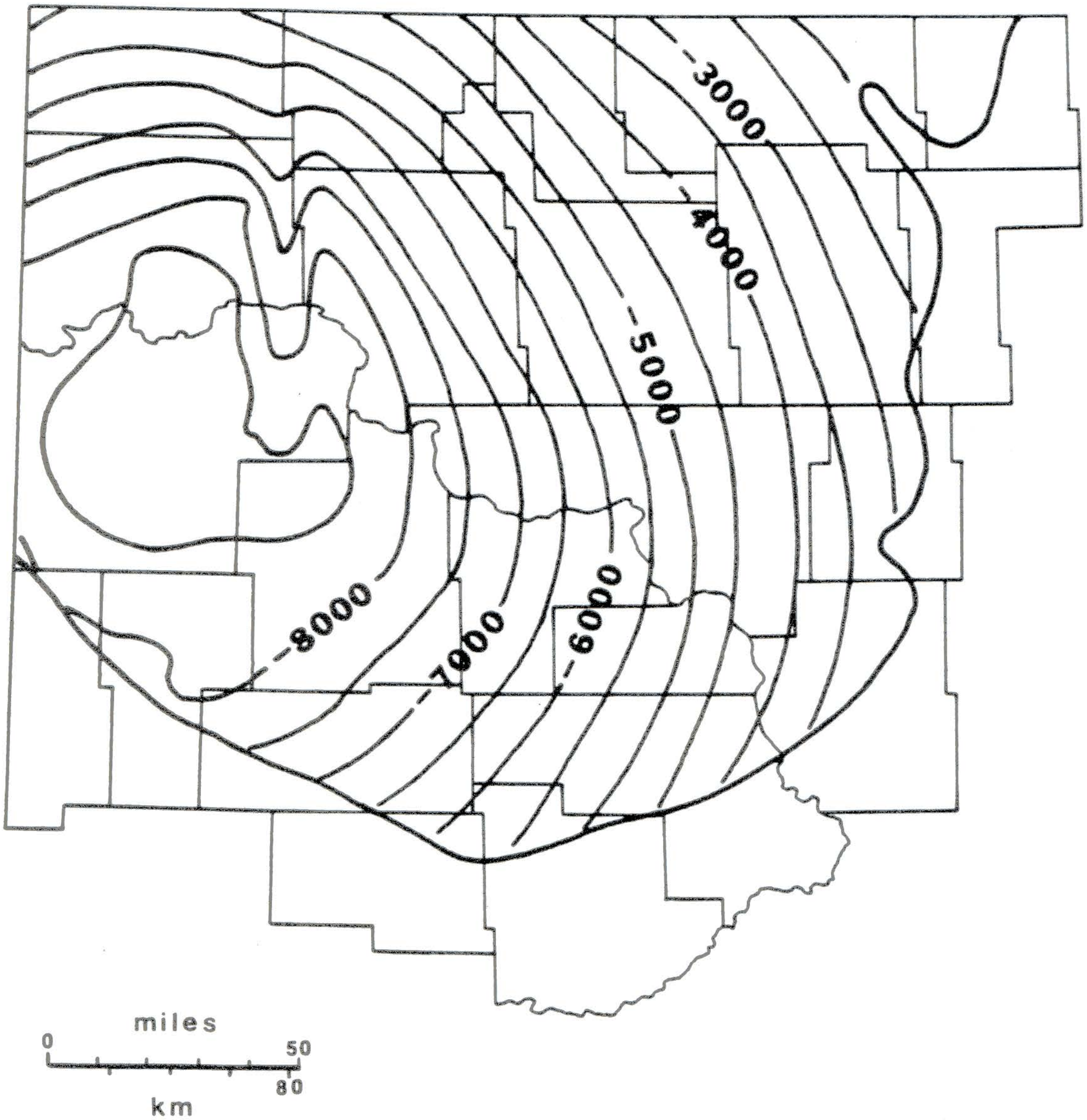


Figure 13. Structure contour map of the top of the Bakken Formation in North Dakota (slightly modified from Webster, p. 12). Datum is sea level and contour interval is 500 feet (152 m).



3000
4000
5000
6000
7000
8000
miles
0
50
80
km

the formation. To approximate total burial depth, one can add 2,000 feet to the structure contour elevations.

Lithology

The Bakken Formation essentially consists of two, black to dark gray, mostly non-calcareous shales separated by gray, calcareous siltstone and sandstone, and silt-rich limestone. Examination of cores, thin sections, and insoluble residues of the Bakken reveals a wide variety of lithologies, textures, and fossils. Core descriptions of selected wells are presented in Appendix D.

Lower Shale

The lower shale of the Bakken Formation is dominantly non-calcareous, fissile shale with lesser amounts of siltstone, limestone, and sandstone. Along clean, dry surfaces of the core, the lower shale generally appears dark gray (N3) to black (N1) with more silty portions somewhat lighter (medium gray, N5). The lower shale is finely laminated to massive, and apparently unburrowed. Laminations are characteristically parallel, even, and very closely spaced. The shale is generally hard, but portions are somewhat soft and "wax-like." Breakage of the core usually results in platy fracture along one or more of the laminations. In some parts, however, fracture is blocky and irregular, and nearly conchoidal in more siliceous sections. Pyrite is abundant and commonly concentrated in thin, wispy laminae, or in nodules up to two inches (5.0 cm) in diameter (NDGS Well. No. 5088). Fracture surfaces subparallel to bedding are in some places partly covered with resinous or vitreous pods of carbonaceous material ("dead oil"). Less commonly, subvertical healed fractures lined with calcite and pyrite can be observed. Thin-section examination of the shale revealed abundant amber, organic material, and some dolomite.

The lower shale contains thin (usually only a few feet), dark gray limestone that is typically argillaceous and, in some places, coarsely crystalline. Limestone was observed at various horizons within the lower shale in four cores (NDGS Well Nos. 793, 1405, 5088, 8069). Dark greenish gray (5 GY 4/1) shale is also present within the lower part of the lower shale in NDGS Well No. 8177 in Ward County.

An unusual feature of the lower shale is a thin (about one inch, 2.5 cm), coarse, lag sandstone at its base. Constituents of the basal lag are generally poorly sorted and appear to be floating in a shale matrix. The sandstone overlies an irregular contact between the lower shale and underlying dolomitic siltstone and shale of the Three Forks Formation in NDGS Well No. 9351 near the southern limit of the Bakken lower shale in Billings County. In this well, the lower shale is approximately one foot (30 cm) thick. The sandstone contains abundant fragmentary conodonts, pyritized clasts (about 0.5 cm diameter), phosphatic particles, fish bones, subangular quartz sand and silt, chert, carbonate debris, and rounded pebbles (about 1 cm diameter).

Fossils in the lower shale include abundant algal plant spores (Tasmanites sp.), less common conodonts, inarticulate brachiopods (Lingula sp., Orbiculoidea sp.), fish teeth, bones, and scales, conchostracans, and rare ostracods, woody plant fragments, and sponge spicules. Spores are usually about 1 mm in diameter and are commonly preserved as translucent, amber discs. Many spores have been replaced by pyrite and appear, megascopically, as golden flecks in the shale. Other spores are preserved as uncompressed, pyrite-filled spheres. Conodonts are mostly scattered throughout the lower shale, but are locally concentrated in thin, silt-rich, laminae and within the basal lag. Conchostracans are also usually scattered, but an approximately eight-centimeter-thick zone of siltstone with abundant conchostracans is present at the top of the lower shale in NDGS Well No. 5088.

Middle Member

The middle member of the Bakken Formation mainly consists of interbedded siltstone and sandstone with lesser amounts of shale and limestone. The color of this member is variable, but the siltstone and sandstone are mostly light gray (N7) to medium dark gray (N4). Shale in the middle member is commonly greenish gray (5G 6/1) or medium bluish gray (5 B 5/1) and the limestone tends to be medium gray (N5). Bedding of the middle member is irregularly disrupted by bioturbation, especially in more argillaceous portions. The siltstone and sandstone are commonly massive or coarsely bedded, and occasionally have trough or planar crossbedding. Limestone in the middle member is usually rich in quartz sand and silt and less commonly oolitic.

Quartz, in the form of subangular to subrounded sand and silt is the dominant clastic constituent of the middle member. Thin-section examination revealed the presence of calcite, dolomite, silica, and pyrite cement. Much of the middle member is well-sorted and in places shows evidence of soft-sediment deformation, such as microfaults and flow structures. Insoluble residues of the middle member are dominated by quartz silt and sand, but also contain feldspar, chert, uncommon glauconite, and silicified or pyritized fossils.

The middle member of the Bakken has a more diverse macrofauna (currently being studied by Lawrence C. Thrasher) than either of the shales. Fauna of the middle member includes common to locally abundant articulate brachiopods and less common inarticulate brachiopods. Pelmatozoan fragments, gastropods, and various trace fossils (?*Scalarituba* sp.) are also present. Core examination revealed rare fragmentary conodonts, plant spores, and ostracods. Acid dissolution of an oolitic limestone in the middle member (NDGS Well No. 527) yielded a diverse silicified fauna including brachiopods, a coral (*Syringopora* sp.), and a possible agglutinated foraminiferid. A few fragmentary conodonts were observed in residues of the middle member. Articulate brachiopods were found both articulated and disarticulated.

Upper Shale

The lithology of the upper shale is similar to that of the lower shale. It differs largely by an apparent lack of crystalline limestones and greenish gray shale, and contains more conodonts. The upper shale is generally black (N1) to dark gray (N3) and non-calcareous, although thin (2.5 cm) beds of calcareous quartz siltstone are present (NDGS Well No. 793). The upper shale member is mostly composed of thinly laminated or massive shale with uncommon, poorly sorted beds (most about 1 cm thick) composed of silt-size conodont fragments, quartz, and carbonate minerals (Fig. 14).

The upper shale contains thin (about 0.5 cm), coarse, lag sandstone, rich in conodonts, fish bones and teeth, and phosphatic particles (Fig. 15). The two best-developed lags were observed at separate levels within the upper shale of NDGS Well No. 793. The fabric and composition

Figure 14. Photomicrograph of a thin section of laminated siltstone in the upper shale of the Bakken Formation (10,500 feet in NDGS Well No. 7579, Billings County). Lighter-colored, silt-sized particles in the center of the of the figure are composed mostly of conodont fragments with lesser amounts of quartz and carbonate minerals. The large, light-colored clast in the upper right portion of the figure is a conodont fragment (10X).

Figure 15. Photomicrograph of a bedding surface of a bleached, lag sandstone from the upper shale of the Bakken Formation (10,000-10,018 feet in NDGS Well No. 793, Dunn County). Darker clasts consist mostly of conodonts, fish teeth, and other phosphatic debris (12X).

of the lag sandstones of the upper shale are similar to those of the lower shale basal lag. However, no obvious sharp lithologic break, like that below the lower shale lag, occurs beneath the upper shale lags. Constituents of the upper shale lags appear slightly sorted in thin sections and insoluble residues, but most appear unabraded.

In addition to abundant conodonts, other fossils in the upper shale include fish teeth, bones, and scales, rare woody plant fragments, inarticulate brachiopods, and spores. Some of the fish teeth in the upper shale are over 5 mm in length. A 2-cm-thick zone of abundant, apparently reworked, pyritized, articulate brachiopods is present at the base of the upper shale in NDGS Well No. 5088.

Underlying Unit

The Bakken Formation in North Dakota is underlain by the Three Forks Formation. The type section of the Three Forks Formation is near Logan, Montana. Sandberg and Hammond (1958) advocated the use of uniform nomenclature for Devonian rocks in the subsurface of the Williston Basin and in Montana and northern Wyoming. Sandberg (1965) discussed the stratigraphy, regional correlation, and nomenclatorial history of the Three Forks and formally divided the formation into three members. In ascending order these units are the Logan Gulch Member, the Trident Member, and the Sappington Member. Only the lower two members of the typical Three Forks are equivalent to, and continuous with the Three Forks Formation of the Williston Basin. Sandberg (1962b p. 34) indicated that the Logan Gulch Member made up the bulk of the Three Forks Formaton in the Williston Basin and said that only the upper "5 to

25 feet" of the Three Forks Formation in the Basin is "equivalent" to the Trident Member. The upper part of the Trident Member of the Three Forks Formation in Montana is Late Devonian (Scaphignathus velifera Zone) in age (Klapper, 1966, p. 6).

In North Dakota, the Three Forks Formation reaches a maximum thickness of 250 feet (76 m) in eastern McKenzie County. Kume (1963, p. 32) reported that the Three Forks Formation in North Dakota ". . . consists of greenish gray shale, brownish gray dolomite, quartzose sandstone, yellow-gray dolomite, reddish brown shale, and light gray siltstone." Quartzose sandstone that occurs locally at the top of the Three Forks Formation in the Williston Basin has been referred to (Kume, 1963, p. 33) informally as the "Sanish Sand."

The contact between the Three Forks Formation and the lower shale of the Bakken Formation is usually abrupt, but it appears as a transitional zone of interlaminated greenish-gray shale and dark gray shale in NDGS Well No. 5088 in Mountrail County. On geophysical logs, the contact between the lower shale of the Bakken and the underlying Three Forks is picked by the characteristically strong gamma-ray response of the Bakken lower shale. Where the lower shale is absent and the middle member of the Bakken directly overlies the Three Forks Formation, picking the contact on logs, or in the core, is difficult because the middle member of the Bakken and the Three Forks Formation have similar lithologies. In the center of the Williston Basin, the contact between the subsurface Three Forks Formation and the Bakken lower shale appears conformable, although the contact is usually marked by an abrupt change in color and lithology. Along the margins of the Basin, the contact is irregular and thin sandstones have been observed at the base of the Bakken by Fuller (1956, p. 23) in Saskatchewan and in NDGS Well No. 9351 in Billings County during this study. Although physical evidence is not convincing, regional paleontologic study (Macqueen and Sandberg, 1970) suggests that a disconformity may exist between the Three Forks Formation and the Bakken Formation in the Williston Basin.

Overlying Unit

In North Dakota the Bakken Formation is overlain by the Lodgepole Formation of the Madison Group. In ascending order, the Madison Group consists of the Lodgepole, Mission Canyon, and Charles Formations. Use of the Lodgepole and Mission Canyon subdivisions of the Madison Group was casually extended (further discussion in Fuller, 1956, p. 13) into the Williston Basin. The Lodgepole, Mission Canyon, and Charles Formations are facies of each other within the Madison Group in the Williston Basin. The type section of the Lodgepole Limestone is in Little Chief Canyon in the Little Rocky Mountains of Montana. At the type section, the Lodgepole Limestone overlies the margin of the upper shale of the Bakken Formation (Sando and Dutro, 1974). Conodonts (Sandberg and Klapper, 1967, p. B43), corals, and foraminiferids (Sando and Dutro, 1974) indicate that the Lodgepole Limestone directly above the Bakken Formation at Little Chief Canyon is Kinderhookian (Lower _Siphonodella_ _crenulata_ Zone) in age.

The Lodgepole Formation reaches a maximum thickness of "900 feet" (Heck, 1979, p. 9) in North Dakota. Where observed above the Bakken in cores, the Lodgepole consists of dark gray to brownish-gray, argillaceous, bioclastic limestone. In cores, the contact between the upper shale of the Bakken and the Lodgepole Formation is commonly marked by an abrupt change from black, non-calcareous shale to dark gray, argillaceous limestone, but it appears conformable. The upper contact of the Bakken with the Lodgepole has been considered unconformable (McCabe, 1959, p. 20; Sandberg, 1962a, p. 52), but more recent regional work (Macqueen and Sandberg, 1970) suggests that the Bakken Formation is conformable with the overlying Lodgepole Formation. As with the lower contact of the Bakken, the upper contact of the Bakken can be picked on logs by the strong gamma-ray response of Bakken shale.

Thin dark shale, which superficially resembles the Bakken shales, has been recognized within the lower Lodgepole in the Williston Basin. Webster (1982, p. 13) reported a "thin, black shale and black organic-rich limestone" above the Bakken in McKenzie, Billings, Dunn, and Mountrail Counties in western North Dakota, and Fuller (1956, p. 25) reported a similar unit in Saskatchewan. As noted by Webster (1982, p. 13), this dark shale is usually separated from the upper Bakken by gray to brownish-gray, pelmatozoan limestone.

Dark gray to black shale has also been recognized within the Lodgepole Formation in central North Dakota and southern Manitoba in a position east of the shales discussed by Fuller (1956) and Webster (1982). These more eastern shales have a maximum thickness of about 90 feet (27 m). In North Dakota, one of these shales has been called the "Carrington shale facies" of the Lodgepole Limestone (Bjorlie, 1979).

CONODONT FAUNA

Composition

Bakken conodonts are placed in 48 taxa and attributed to 17 form-genera. The abundance and distribution of taxa, and the sample depth and NDGS well number are shown on Figure 16. The collection is composed mostly of platform (pectiniform) elements, and to a lesser degree, barlike (ramiform) elements. Conelike (coniform) elements are uncommon. Platform genera include (in decreasing order of abundance) *Siphonodella*, *Pseudopolygnathus*, *Polygnathus*, *Bispathodus*, "*Spathognathodus*", *Palmatolepis*, and *Branmehla*. Twenty-one biostratigraphically useful species of these genera were identified. As a whole, the conodont collection obtained from the Bakken contains juveniles to probable gerontic specimens. No natural conodont assemblages were found.

Distribution

Conodonts are unevenly distributed within the Bakken Formation. Nearly all conodonts were obtained from the lower shale and upper shale of the Bakken. Only rarely were conodonts found in cores or residues of the middle member. Conodonts in the shales are distributed in two generalized ways. The most commonly observed type of occurrence is individual or several specimens scattered along fracture surfaces

Figure 16. Abundance and distribution of conodonts obtained from the lower shale, middle member, and upper shale of the Bakken Formation. Recorded conodonts were obtained almost exclusively from residues of the Bakken with the exception of six lower shale specimens, which were identified on core pieces and are marked by asterisks on the figure. The Lower *Siphonodella crenulata* Zone is abbreviated as L. *S. crenulata* Zone.

KEY (WELL & DEPTH)	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA	BB
NORTH DAKOTA GEOLOGICAL SURVEY WELL NUMBER	527	2618	2618	3363	3363	3363	5088	5088	8069	8177	9351	8177	9351	105	105	793	793	4297	4297	5088	5088	7887	8177	8474	9351	9351	9351	9351
CORE-BOX DEPTH IN FEET	11,268-71	9,830-33	9,828-30	10,219-21	10,215-19	10,213-15	10,277-83	10,240-43	9,204	8,665-67	10,469.5	8,651-54	10,460-69	7,568-71	7,562-68	10,000-18	9,994-97	9,907-10	9,895-98	10,167-69	10,156-60	10,790-92	8,637	10,362-65	10,456-57	10,454-56	10,452-54	10,449-51
AGE — MISS. ▲ L. *S. crenulata* ZONE; △ KINDERHOOKIAN UNDIF.; DEV. ○ FAMENNIAN UNDIF.		○					○		○	○	○			△		△	▲	△	△		▲	△	△	△		△	△	▲
BAKKEN MEMBER	LOWER SHALE											MID.		UPPER SHALE														
CONODONT TAXA																												
Bispathodus aculeatus aculeatus																3		1					3			5		1
B. jugosus											1																	
B. stabilis					2					5	1									1								
Branmehla inornata			1*	1	1	2		1	1*	8	2												1					
Bryantodus cf. *B. planus*																		1					1					
B. sp. A																1												
B. sp. B																1												
B. sp. indet.										2						4	1						5					
Dinodus sp. indet.																			1									
Elictognathus laceratus																1	1											
Hibbardella sp. indet.											1										1							
"Hindeodella" cf. *"H." subtilis*								1																				
Ligonodina cf. *L. panderi*					1					1	1																	
L. sp. A																	1											
L. sp. indet.															2		2		1									1
Metaprioniodus biangulatus																								1				
"Neoprioniodus" alatus																	2				1							
"N." cf. "N." barbatus																	1											
"N." sp. indet.										2	2			1		1	4									1		2
Ozarkodina sp. A																	1											
O. sp. B								1																				
O. sp. indet.								3		2						1		2					2					
Palmatolepis gracilis sigmoidalis		1*					9		1*	2																		
P. sp. indet.							3				2																	
Polygnathus communis communis										2				4		21	2	11		4		3	5			10		
P. distortus																	11	2										
P. inornatus																8	11						1				1	1
P. longiposticus																	2	6									1	
P. cf. *P. nodocostatus*							2				3																	
P. sp. indet.			1*				5			2	2					5	19	3					4	1				3
Pseudopolygnathus marginatus																1		1					1					
P. primus															2	39	5	5				1	17			2	2	
P. sp. indet.																17	5	2					16					
Siphonodella cooperi																2	8	2										1
S. crenulata																	7				2							1
S. duplicata																24		6					5			2	5	
S. cf. *S. isosticha*																1												
S. obsoleta																	1											1
S. quadruplicata																6	8	1									1	2
S. sandbergi																	4											
S. sp. indet.														1		43	23	21				3	6	9		2	5	3
"Spathognathodus" crassidentatus																1												
"S." strigosus	1*																											
"S." sp. indet.				3			4	2		6	3					7	1						1	1		2		
Synprioniodina cf. *S. delicatula*																										1		
S. sp. indet.							2			2					1			1		1			1			3		
coniform sp. A										2																		
coniform sp. B							4	1																				
ramiform sp. indet.					1		1	3		6	6	4	1	3	6	11	4	2	2	12	9	6	26	11	1	24	2	1

subparallel to bedding in the shale. A numerically more significant type of occurrence is in thin, fossil-rich, siltstone and sandstone lags. Most of these fossil-rich lags were observed in the upper shale of the Bakken.

The conodont collection from the Bakken Formation was obtained almost entirely from insoluble residues of the shales. Twenty-eight of the 58 samples (Appendix C) put into dissolution baths yielded identifiable conodonts. Excluding indeterminate ramiform elements, a total of 657 conodonts was identified from the Bakken Formation. The concentration of conodonts in insoluble residues of the Bakken ranged from zero to more than 60 conodonts from a 0.9-gram sample from the upper shale (NDGS Well No. 4297 in Williams County) that mostly contained relatively small (generally less than 1 mm in length) specimens. A concentration of about 22 conodonts per gram of dissolved rock was recorded for one of the upper shale lags that contained mostly somewhat larger (about 2 mm long) conodonts. Six specimens (marked by asterisks on Figure 16) were identified on core pieces of the lower shale and added to the fauna from this member to augment its limited collection. The 28 productive samples are encoded by a key letter on Figure 16 and where discussed in the text are indicated by this letter.

Most (544 specimens or about 83 percent) of the collection was obtained from the upper shale of the Bakken and more than half (310 specimens) of the upper shale fauna was recovered from two (P, Q) conodont-rich lags from NDGS Well No. 793 in Dunn County. These two upper shale lags also have the highest, although not identical, diversity in taxa (20 for P, 22 for Q). Samples from NDGS Well No. 5088 yielded identifiable conodonts from both Bakken shales. Disaggregation of portions of cores from NDGS Well Nos. 8177 (Ward County) and 9351 (Billings County) produced conodont elements from all three members of the Bakken.

The lower shale yielded 113 specimens or roughly 17 percent of the total collection. Twenty taxa were recovered from the lower shale and nine of these were restricted to the lower shale. Polygnathus, Palmatolepis, Branmehla, and "Spathognathodus" are the most common genera in the lower shale and Branmehla inornata (="Spathognathodus" inornatus) is the most abundant species in the lower shale. Species of Palmatolepis were found only in the lower shale. Only five fragmentary, indeterminate, ramiform elements were recovered from the middle member.

Thirty-eight taxa were identified from the upper shale of the Bakken and 28 of these were found only in the upper shale. Siphonodella, Pseudopolygnathus, and Polygnathus are the most abundant genera in the upper shale fauna and species of these three genera from the upper shale account for slighty more than 70 percent of the conodonts contained in the entire Bakken collection. Siphonodella and Pseudopolygnathus were found only in the upper shale and Siphonodella has the greatest number of species (7) of any genus in the collection.

Preservation

Where observed in core, unconcentrated conodonts found scattered on fracture surfaces in the upper and lower shale of the Bakken did not appear oriented, or sorted in size, and consisted mostly of unabraded, complete, but cracked specimens. The fossil-rich lags, however, appeared somewhat size-sorted and range from slightly-laminated siltstone (Fig. 14) to poorly-sorted sandstone (Fig. 15). The coarser lags generally contained larger and better preserved conodonts than the silt-rich lags. Although some conodonts from the coarser lags showed evidence of abrasion, most conodonts from these lags appeared unabraded and complete, yet cracked. However, conodonts from the basal, lag sandstone of the Bakken (NDGS Well No. 9351) were more fragmentary and abraded than most conodonts from coarse-grained upper shale lags. All conodonts observed in cores of the middle member of the Bakken were fragmentary and highly abraded.

Whereas many conodonts observed in cores of the upper and lower shales of the Bakken were complete, almost all conodonts recovered from insoluble residues of the Bakken shales were fragmentary even though the samples were treated as gently as possible. Only rarely was the free-blade attached on platform elements and commonly the distal portion of denticles was absent. The shale matrix was commonly not completely removed from specimens in the residues, as is shown on many of the illustrated specimens. In some cases, cracked specimens were found intact in the residues because the shale matrix within the cracks held the conodont pieces together (Pl. 1, figs. 3, 13; Pl. 2, fig. 12; Pl. 3, figs. 6, 9, 11, 12). Conodonts from residues of the middle member, as with those observed in cores of this member, were fragmentary and abraded.

Color

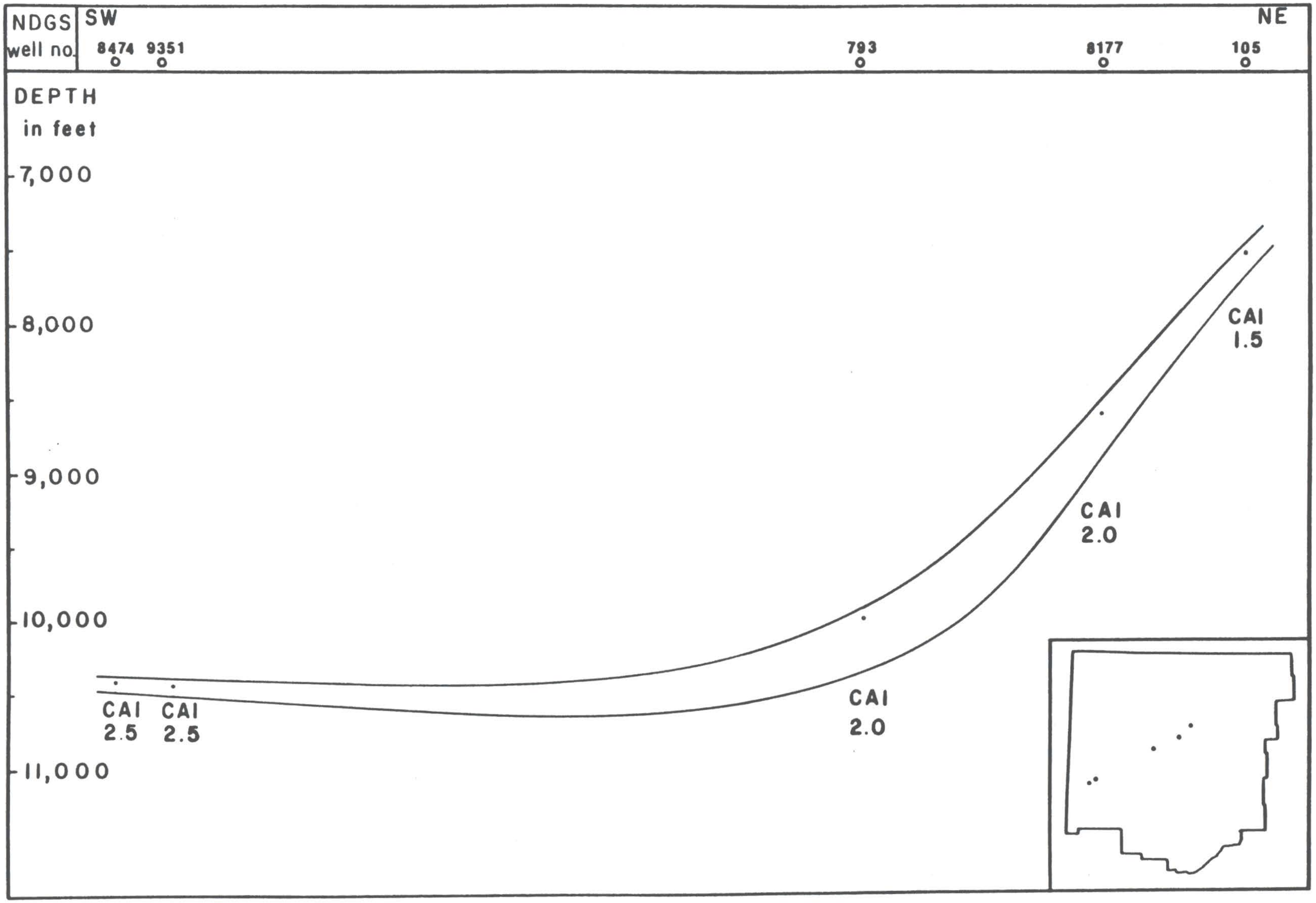
Epstein and others (1977) determined that alteration in conodont color from pale yellow to black is time and temperature dependent and can be used as a geothermometer to evaluate the hydrocarbon generation potential of their host rocks. They established (p. 1) a color alteration index (CAI) for conodonts that ". . . does not provide thermal thresholds for oil generation, but does provide thermal cutoffs for oil, condensate, and dry gas production." Epstein and others (1977) used field and laboratory experiments to establish temperature ranges for CAI values.

During examination of the residues of the Bakken, it was recognized that the color of conodonts varied from amber to black within individual samples and between samples. Within a sample, thin and small elements were lighter in color than more robust elements. In some residues, anomalous specimens were darker than others of equal size. In order to evaluate the thermal maturity of the Bakken Formation in North Dakota using conodonts, the color alteration index of conodont elements from five wells was determined. The five samples range in depths from the shallowest (NDGS Well No. 105 at about 7,500 ft., 2,280 m) to nearly the deepest (NDGS Well Nos. 8474 and 9351 at about 10,400 ft., 3,170 m) Bakken core examined. A single conodont element, each of approximately equal size and thickness, was chosen from a residue sample of the upper shale in each of the five wells to determine the CAI value. The five specimens were then placed on a gray background and visually compared to the CAI color chart (Epstein and others, 1977, p. 6) and assigned a CAI value.

The results of the CAI evaluation are diagramatically shown on Figure 17. The CAI values of Bakken conodonts range from 1.5 in the shallowest sample to 2.5 in the two deeper samples. A CAI value of 2.5 was chosen for conodonts from the deeper samples because their color fit between the colors of CAI values 2.0 and 3.0. The results show a pattern of darkening conodont color from "very pale brown" to "dark brown" and thus, an increase in the thermal maturity with depth for the Bakken.

A CAI value of 1.5 indicates a temperature range of 50 to 90 degrees Celsius (122 to 194 degrees Fahrenheit) and a CAI value of 2.0 indicates a range of 60 to 140 degrees Celsius (140 to 284 degrees Fahrenheit). Using the temperature versus depth plot illustrated by Epstein and others (1977, p. 11, fig. 9), a CAI value of 2.5 indicates temperatures between approximately 100 and 140 degrees Celsius (212 to 284 degrees Fahrenheit).

Figure 17. Schematic diagram of the conodont color alteration index (CAI) values from five locations in the upper shale of the Bakken Formation. The arcuate lines proportionally represent the thickness of the Bakken Formation on the basis of the five locations. Distances between locations are proportional. Depths are total depths from the Kelly Bushing. Because the Kelly Bushing elevations of the five wells are all approximately 2,000 feet; this schematic representation of the Bakken mimics the structure of the formation.


NDGS
well no.
SW
NE
8474
9351
793
8177
105
DEPTH
in feet
7,000
8,000
9,000
10,000
11,000
CAI
2.5
CAI
2.5
CAI
2.0
CAI
2.0
CAI
1.5

DISCUSSION

Distribution of Conodonts

Scattered, mostly well-preserved and unsorted conodonts in the upper and lower shales of the Bakken suggest deposition in an environment with minimal current activity. However, conodont-rich lags in sandstone and siltstone suggest reworking of conodonts by gentle currents. Although the lag at the base of the lower shale and those within the upper shale are lithologically similar, it is uncertain that they are wholly of the same origin.

The occurrence of fossil-rich lags has been discussed in general by Twenhofel (1936), McGugan (1965), and Conkin and Conkin (1973) and specifically for regional lithostratigraphic equivalents of the Bakken by Sandberg and Klapper (1967) and Sandberg (1969). McGugan (1965, p. 127) suggested that lags are caused by "stratigraphic condensation" where "extremely slow net deposition" allows build-up of fossil debris without dilution from sediment and by "stratigraphic concentration", which results from reworking and winnowing of sediment. In describing conodont-rich lags in the Cottonwood Canyon Member of the Lodgepole Limestone, Sandberg and Klapper (1967, p. B29) considered the thin units "transgressive lag (or condensed) deposits." Gutshick and others (1976, p. 94) stated that: "Diastrophic fluctuations during the Antler orogeny produced unconformities and subsequent superposed transgressive marine lag deposits."

Conodont-rich lag deposits in the shales of the Bakken Formation probably formed initially during periods of slow deposition, but the apparent size-sorting and occasional worn conodonts and other fossil debris suggest the lag sandstones and siltstones were winnowed and enriched by current activity. Possibly, the lag sandstones composed of conodonts, fish parts, quartz grains, and phosphatic debris (Fig. 15) represent coarser material reworked on a surface of slow deposition and the laminated siltstones composed mostly of conodont fragments (Fig. 14) are the finer fraction removed from such a surface. Such an interpretation suggests a depositional surface discontinuously covered with fossiliferous sandstone and siltstone. The lag deposits in the Bakken shales may thus mark the position of small-scale depositional hiatuses.

Conodont zones have been used to determine rates of sedimentation in Upper Devonian and Lower Mississippian rocks by Sandberg and Poole (1977) and Sandberg and Gutshick (1979). Conodont zonal evidence obtained during this project is insufficient to determine sedimentation rates for members of the Bakken Formation because the age of either the top or the bottom of each of the three members has not been established. However, sedimentation rates calculated by Sandberg and Gutshick (1979, p. 131-132) for the Cottonwood Canyon Member of the Lodgepole Limestone, which has a lithostratigraphic position and lag deposits similar to the upper shale of the Bakken, indicate that deposition "was exceedingly slow" (about 1-3 meters/million years) at this time. Thus, it appears from regional evidence that the upper shale of the Bakken may have been deposited during slow rates of sedimentation.

Several factors may explain the relative lack of conodonts in the middle member of the Bakken. An environment unfavorable to conodonts may have prevailed during the time of middle member deposition. A more likely explanation, in view of evidence suggesting at least periodic slow rates of sedimentation during Bakken upper shale deposition, may be that considerably higher rates of sedimentation occurred during deposition of the middle member and that the relative lack of conodonts in the middle member is thus caused by their dilution by more available sediment. Moreover, conodonts may have been broken during transportation and deposition of the coarser sediments of the middle member. Possibly, all three factors contributed to the paucity of conodonts in the middle member.

Preservation

Observation of many complete, yet cracked, conodonts in cores of the shales of the Bakken indicates that much conodont breakage occurred after deposition of the shales. Dissolution of the shales, allowing fragments of cracked conodonts to separate in the residue, accounts for the mostly fragmentary condition of specimens in the collection. Some conodonts from lag sandstones in the upper shale and most conodonts from the basal lag of the lower shale showed evidence of abrasion and, thus, indicate that some conodont elements were transported prior to final deposition. Most specimens from the shales, however, are apparently unabraded and nearly complete except for cracking and do not suggest significant reworking. Highly abraded, fragmentary conodonts from the middle member of the Bakken suggest considerable wear unlike the condition of specimens from the shales.

Conodont Biozonation

Detailed study of conodont faunas in Upper Devonian and Lower Mississippian rocks has resulted in refined, worldwide biostratigraphic zonation. In this portion of the Paleozoic, rapidly evolving platform elements provide the basis for conodont zonation. The base of a conodont zone is usually defined by the stratigraphic first occurrence of a particular taxon. In practice, the zonal definer may be absent or rare in a fauna and the zone is then recognized by the joint occurrence of several characteristic taxa. Phyletic changes in the genus *Palmatolepis* are the basis for most of the Upper Devonian conodont zones. Kinderhookian zonation is based on species of *Siphonodella*. Sandberg (1979) recently reviewed the conodont zonation of the Devonian and Lower Mississippian in the Rocky Mountain region and provided lists of important faunal constituents. He (1979, p. 98) noted that the *Siphonodella* zonation "is applicable worldwide" and the first occurrence of *Siphonodella sulcata* can be used to mark the Devonian-Mississippian boundary.

Lower Shale

Five samples (B, G, I, J, K) contain conodonts that indicate the lower shale of the Bakken is Late Devonian (Famennian) in age. None of the five samples can individually be assigned to a particular conodont zone, but the samples considered as one suggest that the lower shale is of the Upper *Polygnathus styriacus* Zone. The base of the Upper *Polygnathus styriacus* Zone is defined by the first occurrence of *Pseudopolygnathus brevipennatus* and the top of the zone is defined by the first occurrence of *Bispathodus costatus*. In the Rocky Mountain region these two species are scarce and the zone is recognized by the association of *Palmatolepis rugosa rugosa*, *Palmatolepis gracilis sigmoidalis*, *Pseudopolygnathus marburgensis marburgensis*, and *Bispathodus jugosus* before the first occurrence of *Bispathodus aculeatus* in the *Bispathodus costatus* Zone.

The stratigraphically lowest sample (K) from the lower shale of the Bakken Formation was obtained from the basal lag sandstone in NDGS Well No. 9351 in Billings County and contains a single fragmentary specimen of *Bispathodus jugosus*. *Palmatolepis gracilis sigmoidalis* was found in four (B, G, I, J) samples from near the middle of the lower shale. Collectively, the lower shale fauna includes *Palmatolepis gracilis sigmoidalis*, *Bispathodus jugosus*, *Polygnathus* cf. *P. nodocostatus*, and *Branmehla inornata* (="*Spathognathodus*" *inornatus*), and is suggestive of either the Upper *Polygnathus styriacus* Zone or the younger *Bispathodus costatus* Zone. The lower shale fauna is, however, tentatively considered to be of the Upper *Polygnathus styriacus* Zone on the basis of the absence of *Bispathodus aculeatus*.

Middle Member

The small collection of fragmentary, indeterminate conodonts from the middle member of the Bakken Formation contains no biostratigraphically useful specimens.

Upper Shale

Conodont evidence from the upper shale of the Bakken indicates this member is entirely Mississippian (Kinderhookian) in age and the top of the upper shale is of the Lower *Siphonodella crenulata* Zone. The Lower *Siphonodella crenulata* Zone is defined by the first occurrence of

Siphonodella crenulata in the absence of Gnathodus delicatus. Three samples (Q, U, BB) obtained from 1 to 4 feet (0.3 m to 1.2 m), the top foot (0.3 m), and 1 to 2 feet (0.3 m to 0.6 m) from the top of the Bakken contain Siphonodella crenulata and are considered of the Lower Siphonodella crenulata Zone. Three samples (W, R, P) containing Pseudopolygnathus marginatus, which according to Sandberg (1979, p. 100) has its first occurrence in the Lower Siphonodella crenulata Zone, may also be of the Lower Siphonodella crenulata Zone, but are here not considered as definitely of this zone in the absence of Siphonodella crenulata. Notably, sample W, which was obtained from the upper shale in Ward County only 2.5 feet (0.8 m) above the contact with the middle member, contains distinctive Kinderhookian conodonts, but it lacks the species diversity in Siphonodella of other numerically well represented upper shale samples.

Age

The Bakken Formation was originally (Nordquist, 1953) considered entirely Mississippian in age. Christopher's (1961) interpretation of the brachiopod fauna from Saskatchewan reported by Brindle (1960) suggested that the Bakken was of both Devonian and Mississippian age with the systemic boundary at the base of the middle member. Regional conodont evidence examined by Sandberg and Klapper (1967) also indicated a Devonian and Mississippian age for the Bakken. Macqueen and Sandberg (1970) used conodont and spore evidence to determine that the Bakken was both Devonian and Mississippian in the subsurface of Alberta and they speculated that the systemic boundary occurred within the middle member of the Bakken.

Based on a small, but biostratigraphically useful conodont fauna from the lower shale, and an abundant fauna from the upper shale, the Bakken Formation in North Dakota is considered both Late Devonian (Famennian) and Early Mississippian (Kinderhookian) in age (Fig. 4). The lower shale contains conodonts tentatively considered of the Upper Polygnathus styriacus Zone. No biostratigraphically useful conodonts were recovered from the middle member. Conodonts from the upper shale of the Bakken are dominated by species of Siphonodella and are of the Lower Siphonodella crenulata Zone in the uppermost part of the upper shale. Considering the relative thinness of the Bakken, the formation has a large time-stratigraphic span. Several conodont zones between the Upper Polygnathus styriacus Zone and the Lower Siphonodella crenulata Zone were not recognized in the Bakken. It is likely that some part of these as-yet-unrecognized zones is present within the middle member of the Bakken and perhaps portions of the shales (or more likely, within the upper shale).

The Devonian-Mississippian boundary seemingly occurs within the Bakken Formation in North Dakota. The exact position of the systemic boundary within the Bakken is uncertain, but paleontologic evidence suggests that it occurs at, or near, the contact between the middle member and upper shale of the Bakken and that it may coincide with a regionally extensive unconformity. Preliminary study of the macrofauna of the Bakken in North Dakota (Lawrence C. Thrasher, oral communication, 1983) suggests that the middle member of the Bakken contains a Syringothyris brachiopod fauna that is similar to the fauna of the Louisiana Limestone (now considered Devonian) in the Mississippi River

Valley. Abruptly overlying the middle member of the Bakken, the upper shale has distinctive Lower Mississippian conodonts that apparently are not earliest Kinderhookian. Although present conodont evidence is insufficient to document an hiatus at this position in North Dakota, conodonts from the lower part of the upper shale and brachiopods from the middle member suggest that at least part of the lowermost Mississippian is not preserved between the middle member and upper shale of the Bakken Formation. Further conodont evidence is needed, especially from the middle member and across the contact of the middle member and upper shale, to establish the position of the Devonian-Mississippian boundary in North Dakota.

Regional Correlation

The Bakken Formation was deposited penecontemporaneously with thin, predominantly clastic, units that include the Exshaw Formation, Sappington Member of the Three Forks Formation, Leatham Formation, middle member (Leatham Member) of the Pilot Shale, Cottonwood Canyon Member of the Lodgepole Limestone, and Englewood Formation (see Fig. 4) in the northern Rocky Mountain region.

Tentative assignment of conodonts from the lower shale of the Bakken to the Upper *Polygnathus styriacus* Zone indicates that, in addition to the physical continuity of the lower shale of the Bakken with the black shale in the Exshaw, Sappington, Leatham, and Leatham Member of the Pilot, the base of the regionally extensive shale was deposited within the same conodont zone throughout its extent. This extensive biostratigraphic equivalency suggests that initiation of black shale deposition in the region was virtually isochronous. Conodont evidence from Alberta reported by Macqueen and Sandberg (1970), however, indicates that the age of the top of the black shale is not everywhere the same. Regional paleontologic evidence indicates the siltstone, sandstone, and limestone body that overlies the extensive black shale is mostly Devonian in the Sappington Member of the Three Forks Formation, Leatham Formation, and Leatham Member of the Pilot Shale, but is mostly Mississippian in the Exshaw Formation and upper part of the middle member (Coleville Sandstone Member) of the Bakken Formation in southeast Alberta (Fig. 4).

In North Dakota, the top of the upper shale of the Bakken yields conodonts of the Lower Siphonodella crenulata Zone. This zone is equivalent to the zone at the top of the Englewood Formation in South Dakota and the top of the Cottonwood Canyon Member of the Lodgepole Limestone in Montana and Wyoming. Conodont zonation of the Lodgepole Limestone, where it overlies the upper shale of the Bakken Formation in the Little Rocky Mountains of Montana, suggests that the lower part of the Lodgepole Formation in North Dakota was deposited within the same conodont zone as the uppermost part of the upper shale of the Bakken Formation in North Dakota. Nearly equivalent ages for the uppermost Bakken Formation and lowermost Lodgepole Formation in North Dakota may indicate continuous deposition between the Bakken and Lodgepole or may be evidence of simultaneous Bakken and Lodgepole deposition in a lateral facies relationship.

Conodont Geothermometry

Hydrocarbon generation amounts are influenced (according to Phillipi 1965, p. 1043) by three factors: 1) amount and type of the organic material; 2) catalytic effects of the sediment; and 3) thermal history of the source rock. An important, and difficult to obtain, part of the thermal history of a source rock is the maximum temperatures to which the rock has been subjected. Color alteration index (CAI) values of conodonts can be used as a geothermometer to provide the maximum temperature that a host rock has attained. A conodont element with a CAI of 1.0 (pale yellow) is unaltered. Harris (1981, p. W58) reported that ". . . color alteration begins beyond the threshold of hydrocarbon generation" and "a CAI of 1.5 to 2 is at the deadline for oil and condensate production. . . ". Thus, the CAI value of 1.5 from the shallowest (7,568-7,562 feet) sample in NDGS Well No. 105 to a value of 2.0 in NDGS Well No. 793 at a depth of about 10,000 feet (3,050 m) suggests that the potential for oil and condensate generation has been reached for organic material now between these depths. The two deeper samples at about 10,400 feet (3,170 m) in depth, have CAI values of 2.5 that indicate the Bakken may have exceeded the thermal cutoff for oil and condensate generation at this depth. The CAI value of 2.5 is, however, within the upper thermal boundary of dry gas generation.

Conodont color suggesting possible oil generation from the Bakken at 7,500 feet (2,290 m) in depth is in agreement with geochemical assessment of the formation by Dow (1977), which indicated hydrocarbon generation below 7,000 feet (2,130 m). The CAI results also correspond with the work of Meissner (1978) who used geophysical logs of the Bakken to determine that hydrocarbon generation occurred below an uneven zone from 6,200 to 8,200 feet (1,890 to 2,500 m) deep. The CAI results indicate possible oil generation from shallower depths than the 9,000-foot (2,740 m) "onset" of hydrocarbon generation reported by Webster (1982, p. 82) from geochemical analysis of the Bakken. CAI values of 2.5 obtained for specimens from about 10,400 feet (3,170 m) in depth indicate that the Bakken may have completed oil generation at that depth. This interpretation may be supported by analysis of the burial history presented by Webster (1982, p. 79), which suggested that oil generation in the Bakken has been completed in the "deepest part" of the Williston Basin. The maximum formation temperatures indicated by the CAI values, from the five samples examined, compare favorably with formation temperatures of the Bakken calculated from bottom hole temperatures by Schmoker and Hester (1983, p. 2171, fig. 11). Correspondence between maximum formation temperatures in the Bakken determined from conodonts and present-day formation temperatures indicated by bottom-hole temperatures suggests that the Bakken is presently near its maximum formation temperatures.

Conodont Paleoecology

Conodonts were once generally considered wholly pelagic organisms whose distribution, unlike most fossils, was relatively unaffected by variations in their environment. This view was based on the occurrence of conodonts in a wide variety of marine rocks, including black shales, that were apparently deposited during toxic bottom conditions. Detailed study of conodont faunas has revealed, however, that variations in faunal constituents do occur within individual conodont zones. The environmental factors, such as pH, salinity, temperature, or water turbulence that may have affected conodont distribution are not well understood; but patterns in conodont distribution show lateral segregation of faunas, or biofacies, from nearshore to offshore.

Sandberg (1976) recognized five conodont biofacies within the Polygnathus styriacus Zone in the northern Rocky Mountain region and compared the biofacies to the lithofacies and paleotectonic setting of the time. Sandberg (1976, p. 175) related the conodont biofacies to paleotectonic settings ranging from offshore bank and lagoon to continental rise. Sandberg and Ziegler (1979) later identified three additional shallow-water biofacies in the Polygnathus styriacus Zone. Conodont biofacies of the Polygnathus styriacus Zone are named and recognized by the one or two dominant platform genera in the fauna. For example, the "palmatolepid-bispathodid biofacies" (Sandberg, 1976) is dominated by species of Palmatolepis and Bispathodus.

Conodonts from the lower shale of the Bakken are tentatively considered of the Upper Polygnathus styriacus Zone and can thus be compared with the biofacies of this zone recognized by Sandberg (1976) and Sandberg and Ziegler (1979), and used to help interpret the depositional setting of the Bakken Formation. Eighty platform elements (Bispathodus, Branmehla, Palmatolepis, Polygnathus, "Spathognathodus") were recovered from the lower shale of the Bakken and are composed of roughly 23 percent Palmatolepis, 21 percent Polygnathus, 11 percent Bispathodus, and about 45 percent "Spathognathodus" (including Branmehla and "Spathognathodus"). The Bakken lower shale conodont fauna most closely matches the ratio of elements from the "palmatolepid-bispathodid" biofacies as described by Sandberg (1976, p. 181-182), but contains a considerably higher ratio of "*Spathognathodus*". Sandberg (1976, p. 181) reported that "the palmatolepid-polygnathid biofacies was deposited in shallow to moderately deep water on the continental shelf." Not surprisingly, the continuous, black shale in the Exshaw Formation, Sappington Member of the Three Forks Formation, Leatham Formation, and Leatham Member of the Pilot Shale also contains conodonts mostly of the "palmatolepid-polygnathid" biofacies (Sandberg, 1976, p. 175).

Conodonts from the upper shale of the Bakken are composed mostly of species of *Siphonodella*, *Pseudopolygnathus* and to a lesser degree *Polygnathus*, and conodonts from the top of the upper shale are of the Lower *Siphonodella crenulata* Zone. Conodont biofacies distribution for the Lower *Siphonodella crenulata* Zone has not been reported in as much detail as for the *Polygnathus styriacus* Zone. However, the abundance of *Siphonodella* and *Pseudopolygnathus* in the upper shale of the Bakken indicates relatively deep water deposition for this member. Clarke (1981, p. W88) reported that Lower Mississippian rocks, in general, contain "a deeper water *Siphonodella*-*Pseudopolygnathus* fauna" and a "contemporary shallow water *Spathognathodus*-*Polygnathus*-*Clydagnathus* group." In addition, Sandberg and Gutshick (1983, p. 221) indicated that the Lower *Siphonodella crenulata* Zone was deposited during a "highstand" of sea level and includes a "pelagic *Siphonodella* biofacies."

Depositional Environments

During the Late Devonian and Early Mississippian, widespread black shale deposition occurred on the North American craton (Gutshick and Moreman, 1967). The environment of deposition of these shales has been the subject of much controversy. Although most workers agree the black, carbonaceous shales were deposited in anoxic bottom conditions, opinions differ concerning the underlying cause of anoxic conditions and the water depth during black shale deposition. The scope of this report does not permit discussion of all viewpoints concerning the formation of black shale, but good references on this subject include Rich (1951), Rhoads and Morse (1971), Heckel (1977), Heckel and Witzke (1979), Demaison and Moore (1980), and Parrish (1982).

Anoxic, or anaerobic conditions develop in an aqueous environment when the oxygen supply in the water column no longer meets the demand of aerobic organisms. Important to the continuation of anoxic conditions is a lack of mixing between oxygen-poor and oxygen-rich water. Circulation can be limited by physical barriers, such as a sill or algal flotant, or by stratification of the water column because of temperature or salinity differences. In an oxygen-depleted marine environment, original textures and organic content are preserved in underlying sediments because of restricted benthic scavenging.

Several settings, which may be conducive to black shale formation, have been suggested for the Bakken. Fuller (1956, p. 24) noted that "the great extent and lithologic constancy of the twin black shales" and middle member of the Bakken "reveal a very uniform depositional environment." He (1956, p. 24) thought the black shales were formed "in a vast swamp" and "an incursion of sea-water, accompanied by transgression and slightly more vigorous erosion along the stable margins of the basin" resulted in middle member sedimentation. McCabe (1959, p. 44) considered the "most likely" environment for Bakken black shale deposition "a widespread marine swamp with restriction of circulation due to prolific organic development" and that middle member deposition was the result of an "influx of shallow marine clastics." In contrast to Fuller and McCabe, MacDonald (1956, p. 12) argued that the black shales of the Bakken were deposited in a relatively deep water, "fondo" (Rich, 1951), marine environment with a wave base "between 200 and 600 feet beneath the surface."

Sandberg and Klapper (1967, p. B63) reported that the lower shale of the Bakken and its lithologic equivalents in the region were formed during a "very late Devonian" marine transgression, and were ". . . deposited penecontemporaneously in shallow basins interspersed among areas of uplift during episodes of lessened orogenic activity." They considered the middle member of the Bakken to have been deposited during marine regression and increased orogenic activity and erosion and suggested that the upper shale was deposited during another marine transgression in Early Mississippian time.

Parrish (1982) speculated that the cause of anoxic conditions during deposition of the Bakken Formation was the development of an interregional upwelling event. During upwelling, oxygen-poor, but nutrient-rich, subsurface water is drawn to the surface and can result in increased biologic activity, such as plankton blooms. Apparently, the abundance of organic matter from increased biologic activity causes a large demand for oxygen in the water column that can result in anoxic conditions below the zone of upwelling (Demaison and Moore, 1980, p. 1195).

Lineback and Davidson (1982) proposed that the Bakken shales were deposited during expansion of anaerobic, ocean-basin waters into the cratonic Williston Basin. They believed anaerobic conditions eventually resulted in sediment starvation in the central Williston Basin during the early Mississippian. Lithofacies and biofacies patterns of sediment-starved basins during the Mississippian have been discussed by Sandberg and Gutshick (1980). According to Lineback and Davidson, the central Basin became sediment starved because anoxia reduced carbonate production in the deeper Basin and a lack of significant currents did not spread carbonates produced in aerobic waters on the margins. Lineback and Davidson (1982, p. 126) suggested that the Bakken shales were a deeper-water lithofacies and that "parts of the Three Forks were deposited on the shelf under dysaerobic conditions as the Bakken was deposited basinward under anaerobic conditions." They (p. 126) further implied that parts of the Lodgepole Formation may have been penecontemporaneously "deposited in aerobic waters near shore beyond the present erosional limit."

Lithologic and paleontologic evidence from the Bakken suggests the lower and upper shales were deposited in an offshore, anoxic, marine environment devoid of significant current activity during a time of relatively slow sedimentation rates. Evidence for anoxic conditions during Bakken black shale deposition includes dark color, abundant pyrite, extremely high organic content, and rare benthic fauna.

Conodonts and fish remains indicate that an oxygenated zone existed above anoxic bottom conditions. Some of the inarticulate brachiopods found in the black shales may have also lived in this aerated zone, perhaps attached to floating debris, such as the rare, terrestrial, woody plant fragments found in the shales. The fauna of the Bakken is predominantly marine, although the conchostracans, which were most commonly observed in the lower shale of the Bakken, may indicate slightly brackish water conditions (Gutshick and Rodriguez, 1979, p. 44) at times. Fine particle size, finely laminated texture, and apparently good initial preservation of most conodonts suggests deposition of the Bakken lower and upper shales in minimal current activity. Lag deposits containing fossil concentrations probably represent times of particularly slow sedimentation and simultaneous winnowing-out of much of the fine sediment leaving concentrations of fossil debris. Conodont biofacies indicative of a continental shelf environment (not nearshore) during lower shale deposition and a pelagic environment during upper shale deposition, together with an abundance of marine algal spores and paucity of terrestrial organics suggest an offshore, marine, depositional setting during sedimentation of the Bakken shales. Remarkable lithologic consistency over a wide area also argues for an offshore marine environment during Bakken black shale deposition. Nearly continent-wide black shale deposition during the Late Devonian and Early Mississippian points toward an interregional cause for anoxic conditions in the Bakken Formation. Perhaps widespread stratification of the water column or upwelling currents caused anoxic conditions.

Lithology and fossil content of the middle member of the Bakken Formation suggest deposition during mostly aerobic marine conditions and moderate current activity. The occurrence of greenish-gray shale, medium gray siltstone, and common pyrite suggests dysaerobic conditions may have existed at times, but much of the middle member has a light color and contains trace fossils and an abundant benthic fauna (brachiopods, gastropods, a coral, etc.) indicative of shallow marine conditions. Larger particle size, and high energy textural features, such as cross-bedding, ripples, oolites, and abraded fossils, indicate an environment affected by stronger currents and possibly shallower water than during Bakken black shale deposition.

Depositional History

The depositional history of the Bakken Formation is related to other thin, predominantly clastic rock units that have a stratigraphic position near the Devonian-Mississippian boundary in the northern Rocky Mountain region. Detailed study of these thin rock units, especially where they crop out, has yielded much information about their lithology, fossils, and depositional history. The lower shale and the middle member of the Bakken are a northeastern extension of an elongate north-south trending body of black shale and overlying silt-rich sediment. This once-continuous rock body was penecontemporaneously deposited between the Antler orogenic highlands to the west and the craton to the east. This extensive black shale and siltstone package is apparently bounded below and above by widespread unconformities (Sandberg and Mapel, 1967, p. 846-847, fig. 2). In the Williston Basin, the upper shale of the Bakken Formation overlies this widespread shale and siltstone body. Detailed regional study (Sandberg and others, 1983) indicates that the black shales of the Bakken were deposited during separate marine transgressions and the middle member is a largely regressive marine deposit.

Sedimentation of the Three Forks Formation ended in the Williston Basin with deposition of green laminated shales lithologically similar to the Trident Member of the typical Three Forks Formation. Regionally, the Trident Member of the Three Forks Formation and its lithologic correlatives are disconformably overlain by black carbonaceous shale that in the Williston Basin consists of the lower shale of the Bakken Formation. Physical evidence of erosion between the subsurface Three Forks Formation and the lower shale of the Bakken was observed only along the margin of the Bakken Formation in the Williston Basin in North Dakota. Gradational contacts and abrupt, but not irregular, contacts between the Bakken and Three Forks in the deeper portions of the Basin suggest that subaerial exposure did not occur in the central Williston Basin of North Dakota between deposition of the Three Forks Formation and the lower shale of the Bakken Formation.

Conodonts from the lower shale of the Bakken in North Dakota are tentatively considered of the Upper Polygnathus styriacus Zone and thus indicate that the initiation of Bakken lower shale deposition in North Dakota was nearly isochronous with the physically continuous black shale along the western cratonic margin of North America. This apparent time-stratigraphic correlation of the base of the regionally extensive black shale suggests rapid transgression of an anoxic marine sea during the time of the Upper *Polygnathus styriacus* Zone. An alternate explanation, as suggested by Lineback and Davidson (1982, p. 130) may be that an anoxic marine environment developed rapidly in the Williston Basin, but not necessarily with an attendant rise in sea level.

The middle member of the Bakken was deposited during a time of increased clastic influx and stronger current activity in the Williston Basin than during Bakken black shale deposition. Although adequate conodont evidence was not obtained to assess the time-stratigraphic relationship between the lower shale and middle member of the Bakken, regional paleontologic study (Macqueen and Sandberg, 1970) and regular contacts between these members suggest that essentially continuous deposition occurred between the lower shale and middle member of the Bakken.

Although substantial regional lithologic and paleontologic evidence indicates an unconformity overlies the widespread siltstone body that includes the middle member of the Bakken, only in wells near the limits of Bakken in North Dakota (NDGS Well No. 7579) does it contain clasts and broken conodonts possibly indicative of erosion. However, paleontologic evidence of an unconformity between the middle member and upper shale of the Bakken includes an apparent faunal discontinuity between these units. On the basis of preliminary analysis of the macrofauna of the middle member, which indicates a late Devonian age for this member, and a Kinderhookian, although apparently not earliest Kinderhookian, conodont fauna from the lower part of the upper shale, a period of non-deposition or erosion between these units seems likely.

The contact between the upper shale of the Bakken and the overlying Lodgepole Formation is gradational in most places and commonly appears conformable. Conodont evidence from the base of the Lodgepole Limestone in the Little Rocky Mountains of Montana, suggests that the lowermost Lodgepole Formation in North Dakota was probably initially deposited within the Lower Siphonodella crenulata Zone, as was the uppermost Bakken, and thus strongly suggests continuous deposition between these units. Regional study of the Lower Siphonodella crenulata Zone indicates that this zone was deposited during a time of rapid transgression, accompanying eustatic rise in sea level, and deep marine sedimentation.

Future Study

Problems for future study include further examination and disaggregation of more samples of all three members of the Bakken Formation for conodonts, especially near member contacts. A more complete accounting of the lateral and vertical distribution of the fossil-rich lags in the Bakken shales may help in understanding the depositional environment of the Bakken black shales. Conodont zonation of the subjacent Three Forks Formation and the overlying Lodgepole Formation would help determine the extent of continuity of sedimentation across formation contacts of the Bakken. Detailed petrographic examination, emphasizing the physical characteristics of the formation and member contacts of the Bakken, may be helpful in determining the degree of continuity of sedimentation across these contacts. More lithologic and fossil evidence is needed from the Bakken Formation along the margins of the Williston Basin particularly where the relation of the Bakken to the "Carrington shale facies" of the Lodgepole Formation is not clear.

SUMMARY OF CONCLUSIONS

1) Disaggregation of the lower shale and upper shale of the Bakken Formation in a solution of household bleach and sodium hydroxide (NaOH) yielded a fragmentary, but diverse conodont collection of 48 taxa assigned to 17 form-genera. The collection consists mostly of platform elements and includes (in decreasing order of abundance) *Siphonodella*, *Pseudopolygnathus*, *Polygnathus*, *Bispathodus*, "*Spathognathodus*", *Palmatolepis*, and *Branmehla*.

2) Conodonts are unevenly distributed in the Bakken Formation. Thin, fossil-rich sandstone and siltstone lags in the lower shale and upper shale of the Bakken contain most of the specimens. These lags are likely the result of a combination of slow sedimentation rates and gentle reworking of sediments.

3) Conodont evidence indicates that the Bakken Formation in North Dakota is Late Devonian (Famennian) and Early Mississippian (Kinderhookian) in age. *Palmatolepis*, *Polygnathus*, and *Branmehla* are the most abundant genera in the lower shale, and these taxa are tentatively considered of the Upper *Polygnathus styriacus* Zone. Species of *Siphonodella*, *Pseudopolygnathus*, and *Polygnathus* dominate the upper shale fauna. The presence of *Siphonodella crenulata* together with an absence of *Gnathodus delicatus* in the uppermost beds of the upper shale indicates that the top of the upper shale is of the Lower *Siphonodella crenulata* Zone.

4) Although physical evidence in cores of the Bakken mostly suggests continuous sedimentation in the Williston Basin during Bakken deposition, paleontologic evidence indicates that a disconformity or a paraconformity occurs between the middle member and the upper shale of the Bakken Formation in North Dakota. Paleontologic evidence also suggests that the contact between the middle member and upper shale of the Bakken may correspond with the Devonian-Mississippian systemic boundary.

5) Conodont evidence from the Bakken Formation in North Dakota indicates that portions of the Bakken are correlative with other thin, predominantly clastic units in the northern Rocky Mountain region that include the Exshaw, Leatham, and Englewood Formations, and the Sappington Member of the Three Forks Formation, middle member (Leatham Member) of the Pilot Shale, and Cottonwood Canyon Member of the Lodgepole Limestone.

6) Conodont color alteration index (CAI) values taken on five, ramiform conodont elements from the upper shale of the Bakken Formation range from 1.5 (pale yellow) to 2.5 (brown) and indicate a pattern of increasing temperature with depth and formation temperatures capable of oil and condensate generation below a depth of 7,500 feet (2,290 m). However, the Bakken may have exceeded formation temperatures optimum for oil generation below a depth of 10,000 feet (3,050 m).

7) Lithologic and paleontologic evidence suggests that the Bakken shales were deposited in an anoxic, marine environment during minimal current activity and slow sedimentation rates. Middle member deposition

occurred in a mostly aerobic, current-influenced, marine environment, perhaps during faster sedimentation rates and in shallower water than during Bakken black shale deposition. Both the lower shale and upper shale conodont faunas of the Bakken indicate that the shales were deposited in an offshore, marine environment during episodes of marine transgression.

SYSTEMATIC PALEONTOLOGY

Individual conodont elements are components of a multielement skeleton. Much recent work has employed a multielement approach to the taxonomy of conodonts; but traditionally, conodont elements have been described and classified as individual form-taxa. Herein, conodont elements are described and classified as form-taxa and arranged in alphabetical order by genera. The form-genera "*Hindeodella*", "*Neoprioniodus*", and "*Spathognathodus*" are enclosed in quotation marks because *Hindeodella*, *Neoprioniodus*, and *Spathognathodus* are invalid names, but are used here because of the lack of valid names. *Hibbardella*, *Ozarkodina*, *Palmatolepis*, and *Polygnathus*, although valid multielement genera, are used here as single element form-genera. The abundance and distribution of conodont taxa obtained from the Bakken Formation are shown on Figure 16.

Various notation schemes have been developed by conodont workers to categorize analogous, and perhaps homologous, elements of conodonts. Sweet (1981a, p. W18-W19) recommended a notation scheme that is based on a bisymmetrical, seximembrate apparatus and is separated into three position categories. These three location categories are designated by the the letters P, M, and S and are commonly subdesignated by subscripts. The apparatus-based position of form-genera from the Bakken Formation is noted in those cases where this position was obtained from published reports.

Synonomies used herein are abbreviated for most genera and subgeneric taxa; because most of the taxa are well known. The synonomies include the most recent works available that contain illustrations, descriptions, or diagnoses, and some older references that provide good illustrations or illustrate taxa from rock units of this region.

Because of the use of both older and more recent references, the descriptive terminology of various authors is used herein. Most, if not all, of the terms are defined in a glossary of conodont morphologic and structural terms prepared by Sweet (1981b, p. W60-W68).

Phylum CONODONTA Eichenberg, 1930

Class CONODONTA Eichenberg, 1930

Order CONODONTOPHORIDA Eichenberg, 1930

Genus *Bispathodus* Müller, 1962

Bispathodus (Müller). Ziegler, Sandberg, and Austin, 1974, p. 100.

Bispathodus Müller. Ziegler, 1975, p. 13-15. Klapper and others, 1981, p. W164.

Type species.--*Spathodus spinulicostatus* Branson, 1934.

Diagnosis.--". . . P element characterized by one or more accessory (clearly separated) or satellite (barely split) denticles on the right side of the blade. Where the side denticles are clearly separated, they may occur as round peg-like nodes, transversely elongate ridge-like nodes, nodes connected to the main blade by ridges, or sharp transverse ridges. The basal cavity, which is expanded laterally beyond the vertical sides of the blade, is either centered approximately below the midpoint of the blade or extended from there to the posterior tip. Left-side denticles may be present in the posterior part of the blade, but they do not occur to the exclusion of right-side denticles nor do they advance anteriorward of the basal cavity" (Ziegler, Sandberg, and Austin, 1974, p. 100).

Remarks.--The size, shape, and position of the basal cavity and accessory denticles are the primary features used to distinguish subgeneric taxa of *Bispathodus*. *Bispathodus* is a possible multielement genus that ranges from the Late Devonian to Early Mississippian and contains several biostratigraphically useful species.

Bispathodus aculeatus (Branson and Mehl, 1934)

Diagnosis.--"Bispathodus aculeatus is a species of the genus Bispathodus with one or more lateral nodes or transverse ridges on the right side of the blade in a central position, more or less above the basal cavity and not extending to the posterior tip of the blade. In some specimens the side denticles may be only slightly split from the main blade denticles. On the left side a node, denticle, or nodose ridge may be present on the upper surface of the basal cavity or on the blade above it" (Ziegler, Sandberg , and Austin, 1974, p. 100).

Remarks.--Subspecies of B. aculeatus are distinguished according to the development of the anterior part of the blade and the position of side denticles.

Bispathodus aculeatus aculeatus (Branson and Mehl, 1934)

Pl. 2, figs. 13, 14, 19, 20

Spathodus aculeatus Branson and Mehl, 1934a, p. 186, pl. 17, figs. 11, 14.

Spathodus tridentatus Branson, 1934, p. 307, pl. 27, fig. 26.

Spathognathodus aculeatus (Branson and Mehl). Klapper, 1966, p. 24-25, pl. 6, figs. 15-17.

Bispathodus aculeatus aculeatus (Branson and Mehl). Ziegler, Sandberg, and Austin, 1974, p. 101, pl. 1, fig. 5; pl. 2, figs. 1-8. Ziegler, 1975, p. 19-21 (further synonomy), pl. 1, figs. 1-4.

Diagnosis.--"A subspecies of Bispathodus aculeatus in which the anterior part of the blade is even-topped, or highest at the center or anterior to the center. One or more accessory denticles are present above the basal cavity on the right side of the blade" (Ziegler, Sandberg, and Austin, 1974, p. 101).

Remarks.--Forms of this subspecies with nodes, ridges, or a longitudnal bulge on the left side of the blade are transitional to *Pseudopolygnathus*. The subspecies ranges from the upper part of the Lower *Bispathodus costatus* Zone (Upper Devonian) worldwide through the Lower *Siphonodella crenulata* Zone (Lower Mississippian) in the Rocky Mountains (modified from Ziegler, Sandberg, and Austin, 1974, p. 101).

Material.--Thirteen specimens were obtained from the upper shale. In the collection, most specimens of *B. aculeatus aculeatus* are fragmentary and commonly are missing portions of the anterior and posterior blade. A specimen is illustrated (Pl. 2, fig. 13) that exhibits barely split denticles and two denticles above the basal cavity on the left side. Another specimen (Pl. 2, fig. 14) has well developed transverse ridges and nodes on the right side of the blade. Fused denticles and a relatively small basal cavity characterize a large specimen (Pl. 2, fig. 19) that is a probable gerontic specimen.

Bispathodus jugosus (Branson and Mehl, 1934)

Pl. 2, fig. 15

Spathodus jugosus Branson and Mehl, 1934a, p. 190, pl. 17, figs. 19, 22.

Bispathodus jugosus (Branson and Mehl). Ziegler, Sandberg, and Austin, 1974, p. 103, pl. 1, figs. 3, 4; pl. 3, figs. 19, 23, 26. Ziegler, 1975, p. 37-39, pl. 3, figs. 1-4.

Diagnosis.--Large, asymmetrical basal cavity and a far anterior row of right-side denticles that are parallel to main-blade denticles (modified from Ziegler, 1975, p. 38).

Remarks.--B. jugosus is a Devonian species that ranges from the middle of the Upper Polygnathus styriacus Zone to the lower part of the Middle Bispathodus costatus Zone (Ziegler, 1975, p. 39).

Material.--A single fragmentary specimen was recovered from the lower shale. Both lateral margins of the basal cavity and the anterior and posterior ends of the blade are broken on the specimen. Identification of the partly silt-encrusted specimen is based on the inferred large size and asymmetrical outline of the basal cavity and the accessory denticles parallel to main-blade denticles.

Bispathodus stabilis (Branson and Mehl, 1934)

Pl. 2, fig. 12

Spathodus stabilis Branson and Mehl, 1934a, p. 188, pl. 17, fig. 20.

Spathognathodus stabilis (Branson and Mehl). Klapper, 1966, p. 23 (further synomomy), pl. 5, fig 6 (only).

Bispathodus stabilis (Branson and Mehl). Ziegler, Sandberg, and Austin, 1974, p. 103-104, pl. 1, fig. 10; pl. 3, figs. 1-3. Ziegler, 1975, p. 47-49, pl. 2, figs. 9-12. Norris, 1981, p. 1277, pl. 2, figs. 1, 3, 4, 7.

Diagnosis.--"Single-rowed, straight to slightly incurved. Unit arched especially from anterior end of basal cavity to posterior end of the blade. Denticles usually 20 or more in large specimens . . . . Symmetrical basal cavity widest anteriorly, usually extending to near posterior end" (Klapper, 1966, p. 23).

Remarks.--According to Ziegler, Sandberg, and Austin (1974, p. 97) "*B. stabilis* is the only species of *Bispathodus* that does not have accessory denticles on the right side of the blade. Its relationship to the double rowed members of the *Bispathodus* group is clearly evidenced, however, by its tendency to develop widened or barely split satellite denticles at several stages during its evolution." Although several morphotypes of *B. stabilis* have been recognized (Ziegler, Sandberg, and Austin, 1974; Sandberg and Ziegler, 1979), the limited material in the collection is not separated into morphotypes. *B. stabilis* ranges from the Upper *Palmatolepis marginifera* Zone (Devonian) to the Upper *Siphonodella crenulata* Zone (Ziegler, 1975, p. 48).

Material.--Eight specimens were recovered from the lower shale and one specimen was recovered from the upper shale. Most are missing the anterior blade and were mostly distinguished from "*Spathognathodus*" by the relatively wide basal cavity of *B. stabilis*. Both lateral margins of the basal cavity are broken on the illustrated specimen.

Genus *Branmehla* Hass, 1959

Branmehla Hass, 1959, p. 381. Austin and others, 1981, p. W172.

Type species.--*Spathodus inornatus* Branson and Mehl, 1934.

Diagnosis.--Single-rowed, bladelike element with basal cavity near posterior end. Element may be slightly flexed inward and the basal cavity may have prominent lips.

Remarks.--Hass (1959 p. 381) stated that *Branmehla* differs from "*Spathognathodus*" in that the basal cavity "is near the anterior end of the unit instead of being more or less equidistant from the anterior and posterior extremities". Using orientation of the element that is now generally used and followed here, the position of the basal cavity is considered to be near the posterior end. Austin and others, (1981, p. W172) considered Branmehla a Pa element.

Branmehla inornata (Branson and Mehl, 1934)

Pl. 2, figs. 1, 6

Spathodus inornatus Branson and Mehl, 1934a, p. 185, pl. 17, fig. 23.

Spathodus mediocris Branson and Mehl, 1934b, p. 277-278, pl. 22, fig. 21.

Spathognathodus exochus Cooper, 1939, p. 413, pl. 45, fig. 30. Cooper, 1943, in Cooper and Sloss, p. 175, pl. 28, fig. 16.

Spathognathodus flexus Thomas, 1949, p. 429, pl. 2, fig. 20.

Spathognathodus inornatus (Branson and Mehl). Cooper, 1943, in Cooper and Sloss, p. 175, pl. 28, fig. 9. Rexroad, 1969, p. 47, pl. 6, figs. 1, 2. Wang and Ziegler, 1982, pl. 1, fig. 9.

Spathognathodus mediocris (Branson and Mehl). Cooper, 1943, in Cooper and Sloss, p. 175, pl. 28, fig. 5.

Spathognathodus praelongus Cooper, 1943, in Cooper and Sloss, p. 175, pl. 28, fig. 14. Klapper, 1966, p. 24, pl. 6, fig. 23.

Branmehla inornata (Branson and Mehl). Hass, 1959, p. 381, pl. 50, fig. 3.

Diagnosis.--Blade slightly curved, thickest along lateral midline, and widest at basal cavity. Basal cavity located near posterior end of blade. Highest denticle above basal cavity. Blade posterior of basal cavity straight to slightly arched downward.

Denticles decline rapidly posterior of basal cavity and gently toward anterior tip.

Remarks.-- B. inornata ranges from the "high Upper Devonian to lowermost Mississippian" (Hass, 1959, p. 381).

Material--Seventeen, mostly fragmentary, specimens of B. inornata were recovered from the lower shale and a single specimen was recovered from the upper shale. This species is the most numerous of those in the lower shale.

Genus Bryantodus Bassler, 1925

Bryantodus Bassler, 1925, p. 219. Huddle, 1968, p. 9. Austin and others, 1981, p. W172.

Type species.--Bryantodus typicus Bassler, 1925.

Diagnosis.--"Conodont with more or less arched and bowed triangular bars that are broad or flanged orally and thinner along the aboral midline. Distinct cusp and basal cavity with or without lips in the central third of the bar; denticles closely spaced" (Huddle, 1968, p. 9). Bryantodus is distinguished from specimens of form-genus Ozarkodina by its conspicuous main cusp and thickened oral bar.

Remarks.--Austin and others (1981, p. W172) considered Bryantodus a Pb element. As noted by Huddle (1968, p. 10), Bryantodus needs revision because species are recognized on the basis of few specimens and poor understanding of their range in variation. The genus ranges from the Middle Silurian to the Middle Pennsylvanian (Huddle, 1968, p. 9).

Bryantodus cf. B. planus Branson and Mehl, 1934

Pl. 3, fig. 15

Bryantodus planus Branson and Mehl, 1934b, p. 284, pl. 23, fig. 6.

Diagnosis.--Moderately thick blade, slightly concave inward and moderately arched. Anterior limb denticles about seven, subequal, laterally compressed but distinct; inclined posteriorly and slightly recurved. Apical denticle about twice as wide and long as other denticles. Posterior denticles about ten, somewhat smaller than anterior denticles, inclined posteriorly and in contact to near their apices. Aboral edge of blade sharp, without apical lip; apical pit circular, very small (modified from Branson and Mehl, 1934b, p. 284).

Remarks.--Although specimens from the Bakken closely match the description of B. planus Branson and Mehl, a slight flare of the margins of the basal cavity and an inexact match in the number of anterior and posterior denticles to those of B. planus Branson and Mehl are the basis for the comparison to B. planus rather than assignment of the Bakken specimens to that species.

Material.--Two specimens were obtained from the upper shale.

Bryantodus sp. A

Pl. 3, fig. 13

Description.--Anterior blade with seven denticles, sharp aborally, broad orally. Apical denticle laterally compressed, slightly inclined posteriorly. Posterior blade broad orally and flattened aborally with laterally compressed denticles. Basal pit about as wide as aboral posterior blade and elongate.

Remarks.--The illustrated specimen resembles the description of *B. typicus* Bassler, but the lack of an aboral apical projection and fragmentary preservation of the specimen does not allow for assignment or confident comparison to that species.

Material.--Single, fragmentary specimen recovered from the upper shale.

Bryantodus sp. B

Pl. 3, fig. 14

Description.--Slightly arched, thin blade with sharp aboral edge and small, thin basal pit. Anterior denticles compressed, but mostly distinct, uneven in height and inclined posteriorly. Preserved posterior denticles shorter than anterior denticles.

Material.--One specimen missing part of the posterior blade was recovered from the upper shale.

Bryantodus sp. indeterminate

Remarks.--Collection composed of small, or fragmentary specimens with a characteristically widened bar.

Material.--Two specimens from the lower shale, and ten specimens from the upper shale, were recovered.

Genus *Dinodus* Cooper, 1939

Dinodus Cooper, 1939, p. 386. Klapper, 1966, p. 24-25. Austin and Rhodes, 1981, p. W170.

Type species.--*Dinodus leptus* Cooper, 1939.

Diagnosis.--"Highly arched, strongly compressed blades composed of extremely thin, high denticles fused to nearly their tips and lacking distinct main cusp. Unit asymmetrical or nearly symmetrical consisting of either 2 or 3 processes. Surface covered with small pits. Conspicuous flange near lower margin" (Klapper, 1966, p. 24).

Remarks.--*Dinodus* is a Lower Mississippian genus.

Dinodus sp. indeterminate

Pl. 3, fig. 8

Remarks.--The specimen has characteristics diagnostic of the genus, but it is too fragmentary for specific identification or characterization.

Material.--A single fragmentary specimen was recovered from the upper shale.

Elictognathus Cooper, 1939

Solenognathus Branson and Mehl, 1934b, p. 270-271.

Elictognathus Cooper, 1939, p. 386-387. Klapper, 1966, p. 25 (further synonomy). Austin and Rhodes, 1981, p. W170.

Solenodella Branson and Mehl, 1944, *in* Shimer and Shrock, p. 244.

Type species.--*Solenognathus bialata* Branson and Mehl, 1934.

Diagnosis.--"Element slightly arched; basal part of extremity flexed inward in some; inner side near lower margin in some with narrow platform and denticulate parapet; cusp prominent, or 2 or 3 prominent denticles; basal cavity elongate and small, keel distinct" (Austin and Rhodes, 1981, p. W170).

Elictognathus laceratus (Branson and Mehl, 1934)

Pl. 3, figs. 11, 16

Solenognathus lacerata Branson and Mehl, 1934b, p. 271, pl. 22, figs. 5, 6.

Solenognathus costata Branson, 1934, p. 332, pl. 27, fig. 7.

Elictognathus lacerata (Branson and Mehl). Hass, 1959, p. 386-387, pl. 49, figs. 1-8, 12. Rexroad and Scott, 1964, p. 26-27, pl. 3, figs. 18-20. Klapper, 1966, p. 26, pl. 5, figs. 18-21.

Elictognathus costata (Branson). Rexroad and Scott, 1964, p. 25-26, pl. 3, fig. 24.

Elictognathus costatus (Branson). Rexroad, 1969, p. 14-15, pl. 1, figs. 6-8.

Elictognathus laceratus (Branson and Mehl). Rexroad, 1969, p. 15-16, pl. 1, figs. 15-19. Thompson and Fellows, 1970, p. 81 (further synonomy), pl. 5, figs. 20, 21.

Diagnosis.--"Narrow ridge on outer side, narrow ridge to prominent shelf on inner side of blade near lower margin" (Klapper, 1966, p. 26). There may be 1 to 3 prominent denticles in the apical region and some specimens may have prominent anterior denticles as well.

Remarks.--Branson and Mehl (1934b, p. 271) and Hass (1959) noted the variable characteristics of denticulation of E. laceratus. Rexroad and Scott (1964) and Rexroad (1969), however, considered E. costatus a separate species mostly on the basis of its lacking prominent anterior denticles. Klapper (1966, p. 26-27), noting the varible and non-diagnostic oral denticulation of the species, chose to synonomize E. costatus and E. laceratus. In this report, E. costatus is considered a junior subjective synonym of E. laceratus because it is thought that anterior oral denticulation is an insufficient characteristic to separate two distinct species. A specimen with two prominent anterior denticles (Pl. 3, fig. 11) and a specimen without prominent anterior denticles are illustrated. E. laceratus is a Lower Mississippian species (Klapper, 1966, p. 27).

Material.--Two specimens of E. laceratus were recovered from the upper shale. One of the figured specimens (Pl. 3, fig. 16) is missing part of the posterior blade.

Genus Hibbardella Bassler, 1925

Hibbardella Bassler, 1925, p. 219. Huddle, 1968, p. 13.

Type species.--Prioniodus angulatus Hinde, 1879.

Diagnosis.--"Conodonts consisting of a denticulated posterior bar, terminal cusp, and symmetrical anterior arch. Bars thick and round. Denticles thick and rounded" (Huddle, 1968, p. 13).

Remarks.--Multielement Hibbardella consists of a quinquimembrate or seximembrate apparatus with P, M, and S elements (Klapper and Bergstrom, 1981, p. W149) of which form genus Hibbardella, used herein, is a probable Sa element. The stratigraphic range of form-genus Hibbardella is Ordovician to Triassic (Huddle, 1968, p. 13).

Hibbardella sp. indeterminate

Pl. 3, fig. 6

Description.--Hibbardellan element with small basal cavity and laterally compressed main cusp that is curved backward.

Material.--Two fragmentary specimens, one each from the upper shale and lower shale, were recovered. Both specimens have a broken posterior bar and anterior arch.

Genus "Hindeodella" Bassler, 1925

Hindeodella Bassler, 1925, p. 219. Huddle, 1968, p. 15.

Type species.--Hindeodella subtilis Bassler, 1925.

Diagnosis.--" A denticulated unit consisting of a long posterior bar, a main cusp, a basal cavity and a short anterior bar. The bar denticles are closely set and commonly of two sizes with a group of smaller sized denticles separating larger sized ones. Main cusp larger than bar denticles. Basal cavity small" (Huddle, 1968, p. 15).

Remarks.--Hindeodellan elements are long-ranging and occur in a wide variety of apparatuses. In multielement notation, "Hindeodella" is an S element. Klapper and Phillip (1971) tentatively proposed synonomy of Polygnathus and Hindeodella. Following Klapper and others (1981), Hindeodella is considered invalid and is thus placed in quotes. Species of "Hindeodella" have been distinguished by the arrangement of denticles, anterior bar form, and presence or absence of posterior bar deflections. Huddle (1968, p. 15) noted the difficulty of obtaining the complete delicate specimens of the genus and added that the validity of many species must be placed in doubt because of limited examination of complete specimens.

"*Hindeodella*" cf. "*H*." *subtilis* Ulrich and Bassler, 1926

Pl. 3, fig. 3

Hindeodella subtilis Bassler. Huddle, 1968, p. 16-18 (further synonomy), pl. 5, figs. 5, 7, 8, 10-15.

Hindeodella subtilis Ulrich and Bassler. Wang and Ziegler, 1982, pl. 2, fig. 22.

Diagnosis.--"Posterior bar long, thin with the thickest part near the upper edge; bears larger denticles separated by two to four smaller denticles. Anterior bar short, strongly curved inward and projects slightly below the posterior bar, bearing 10 to 14 denticles of two sizes. Aboral side tends to be sharp edged and thin near the posterior end" (Huddle, 1968, p. 17).

Remarks.--The single specimen compared to the type species is the only positively identified specimen of the genus in the collection. The element compares favorably with *H. subtilis* Bassler, but has a weakly incurved anterior bar and is a small specimen. Synonomy of this species provided by Huddle (1968) includes several species of "*Hindeodella*" reported by Cooper and Sloss (1943). Many species, herein considered indeterminate ramiform elements, are probably posterior bars of this species.

Material.--One, small, mostly complete specimen was recovered from the lower shale.

Genus *Ligonodina* Bassler, 1925

Ligonodina Bassler, 1925, p. 218. Huddle, 1968, p. 18. Austin and others, 1981, p. W177.

Type species.--*Ligonodina pectinata* Bassler, 1925.

Diagnosis.--"A pick-shaped conodont with a large cusp and denticulated posterior bar and anticusp. The denticles on the anticusp point inward about at right angles to the plane of the bar and the cusp. Basal cavity a small pit beneath the cusp. Aboral side of posterior bar and anticusp usually grooved along the midline" (Huddle, 1968, p. 18).

Remarks.--In multielement classification _Ligonodina_ is considered an Sc element (Austin and others, 1981, p. W177). _Ligonodina_ ranges from the Middle Ordovician to Middle Triassic (Huddle, 1968, p. 18).

Ligonodina cf. _L_. _panderi_ (Hinde, 1879)

Pl. 3, fig. 3

Ligonodina _panderi_ (Hinde). Huddle, 1968, p. 19-20 (further synonmy), pl. 9, fig. 11; pl. 10, figs. 1-8, 11. Wang and Ziegler, 1982, pl. 2, figs. 9, 23.

Diagnosis.--Posterior bar heavy and rounded. Denticles are rounded and usually fewer than ten. Large, rounded cusp curved toward posterior. Heavy anticusp, not offset, strongly curved toward rear; four or five denticles. Basal cavity small (modified from Huddle, 1968, p. 19).

Remarks.--The illustrated specimen differs from _L_. _panderi_ by not having the anticusp curved strongly toward the posterior. The specimen does, however, have a thick bar, cusp, and anticusp. Like most specimens of _Ligonodina_ in the collection, the figured specimen (Pl. 3, fig. 3) is missing most of the posterior bar.

Material.--Three fragmentary specimens were recovered from the lower shale.

Ligonodina sp. A

Pl. 3, fig. 2

Description.--Posterior bar thin with discrete denticles and thickest at midlength. Cusp laterally compressed; slightly curved to rear. Offset anticusp with three denticles strongly curved rearward.

Remarks.--The figured specimen of this species is the best preserved member of this genus in the collection. The specimen was recovered from high in the upper shale. The species can be distinguished from *Ligonodina* cf. *L*. *panderi* by the thinner, less massive and more erect cusp and stronger posterior curve of the anticusp on *L*. sp. A.

Material.--A single specimen was recovered from the upper shale.

Ligonodina sp. indeterminate

Pl. 3, fig. 4

Material.--Six fragmentary specimens were obtained from the upper shale. The elements have a denticulate posterior bar, where preserved, and an anticusp, but are too fragmentary for specific characterization or identification.

Metaprioniodus Huddle, 1934

Metaprioniodus Huddle, 1934, p. 57. Austin and others, 1981, p. W177.

Type species.--*Metaprioniodus biangulatus* Huddle, 1934.

Diagnosis.--Bar heavy, denticles discrete, cusp large and near posterior end. Downward deflection at tip of posterior bar; denticles increase in size from cusp to posterior. Basal pit is small.

Metaprioniodus biangulatus Huddle, 1934

Pl. 3, fig. 10

Metaprioniodus biangulatus Huddle, 1934, p. 57-58, pl. 11, figs. 12, 13.

Diagnosis.--The type species is distinguished by its heavy posterior bar and denticles and large posterior deflection.

Remarks.--*M. biangulatus* is a Lower Mississippian species (Austin and others, 1981, p. W177).

Material.--A single specimen was found in the upper shale and is illustrated. The specimen is broken at the cusp and is missing the anterior bar.

"*Neoprioniodus*" Rhodes and Müller, 1956

Neoprioniodus Rhodes and Müller, 1956, p. 698-699. Huddle, 1968, p. 24-25 (further synonomy).

Type species.--*Prioniodus conjunctus* Gunnell, 1933.

Diagnosis.--"Posterior bar straight or arched; cusp and anticusp terminal, with basal cavity beneath cusp. Denticles in posterior bar discrete or fused. Anticusp not denticulated in most species, but some species have a few denticles . . ." (Huddle, 1968, p. 24).

Remarks.--Specimens of "*Neoprioniodus*" in the collection can be distinguished from *Synprioniodina* by their nondenticulate cusp.

"Neoprioniodus" alatus (Hinde, 1879)

Pl. 3, fig. 5

Neoprioniodus alatus (Hinde). Huddle, 1968, p. 25, pl. 6, figs. 1, 2.
Wang and Zeigler, 1982, pl. 2, fig. 38.

Neoprioniodus cf. N. latus (Bischoff). Rexroad, 1969, p. 29-30, pl. 7, figs. 15-17.

Diagnosis.--". . . Conodont characterized by a short posterior bar with confluent denticles and a broad, flat, sharp-edged cusp and anticusp. Most specimens lack denticles on the anticusp . . ." (Huddle, 1986, p. 25). "The anterior edge of the anticusp is sharp; the posterior edge is wedge shaped and bears a faint groove extending from the tiny pit, which is no more than a slight widening and deepening of the groove" (Rexroad, 1969, p. 29).

Material.--Three incomplete specimens were obtained from the upper shale.

"Neoprioniodus" cf. "N." barbatus (Branson and Mehl, 1934)

Pl. 3, fig. 1

Prioniodus barbatus Branson and Mehl, 1934b, p. 288. pl. 23, figs. 19, 20.

Neoprioniodus barbatus (Branson and Mehl). Rexroad, 1969, p. 27, pl. 7, figs. 11-14.

Diagnosis.--Flared inner lateral lip along basal cavity. "Bar denticles very slender, closely crowded with a tendency for the apices to widen and fuse so as to form a continuous sharp edge" (Branson and Mehl, 1934b, p. 288).

Remarks.--The single fragmentary specimen of "*Neoprioniodus*" cf. "*N*." *barbatus* can be distinguished from specimens of "*N*." *alatus* by its shorter and thicker anticusp and the more straight anterior edge of the cusp when observed laterally.

Material.--One specimen was recovered from the upper shale.

"*Neoprioniodus*" sp. indeterminate

Material.--Four fragmentary specimens from the lower shale and nine incomplete specimens from the upper shale were recovered. These specimens are clearly of this genus but are too fragmentary for specific identification.

Genus *Ozarkodina* Branson and Mehl, 1933

Ozarkodina Branson and Mehl, 1933, p. 51.

Type species.--*Ozarkodina typica* Branson and Mehl, 1933.

Diagnosis.--Bladelike, denticulate, arched element with a larger denticle near the mid-length. Denticles subequal in size, laterally compressed and sharp edged. Basal cavity beneath main denticle (modified from Branson and Mehl, 1933, p. 51).

Remarks.--Multielement *Ozarkodina* has a seximembrate apparatus and ranges from the Ordovician to Lower Devonian (Klapper and others, 1981, p. W165). Ozarkodiniform elements are part of many multielement genera. The form-genus *Ozarkodina* as used here is distinguished from *Bryantodus* by the thinner blade and lack of a prominent cusp, although there may be a prominent denticle on *Ozarkodina*.

Ozarkodina sp. A

Pl. 3, fig. 9

Description.--Slightly arched blade, anterior and posterior blade is of roughly equal length. Blade deflected laterally at mid-length. Apical denticle about twice the width of other denticles.

Material.--One element was recovered from the upper shale.

Ozarkodina sp. B

Pl. 3, fig. 12

Description.--The element is low-arched, and bladelike with longer posterior blade, slight deflection, and small basal cavity.

Remarks.--Ozarkodina sp. B has more denticles on the posterior blade than O. sp. A. Although both specimens are cracked, O. sp. B appears to have had a less arched blade and less lateral deflection of the blade.

Material.--A single specimen was recovered from the lower shale.

Ozarkodina sp. indeterminate

Material.--Five fragmentary specimens from the lower shale and five incomplete specimens from the upper shale were recovered. These specimens have the characteristics of the genus, but are too fragmentary for specific identification or charaterization.

Genus Palmatolepis Ulrich and Bassler, 1926

Palmatolepis Ulrich and Bassler, 1926, p. 49. Ziegler, 1973, p. 253-256. Klapper and others, 1981, p. W165.

Diagnosis.--Asymmetric platform conodont having a more or less large and arched plate, a free and fixed blade with carina and central (azygous) node. The conspicuous node is generally located over the position of the basal pit on the lower surface. Upper surface ornamentation varies in coarseness and density (modified from Ziegler, 1973, p. 253).

Remarks.--Palmatolepis is a Pa element in a seximembrate apparatus (Klapper and others, 1981, p. W165; Puchkov and others, 1982). Two important characteristic features for discriminating between species of Palmatolepis are platform outline and upper surface sculpture. The genus evolved from wide-plated Polygnathus stock at the beginning of the Late Devonian. Species of Palmatolepis are important guide fossils for the Upper Devonian because of their wide geographic distribution and short stratigraphic range (modified from Ziegler, 1973, p. 254).

Palmatolepis gracilis Branson and Mehl, 1934

Diagnosis.--"Palmatolepis gracilis is a species of Palmatolepis characterized by a narrow platform that appears to be smooth under optical microscope examination and a keel that is strongly deflected laterally beneath the central node" (Ziegler, 1977, p. 314).

Remarks.--"Palmatolepis gracilis ranges higher than any other species of Palmatolepis and approaches the Devonian/Carboniferous boundary" (Ziegler, 1977. p. 314).

Palmatolepis gracilis sigmoidalis Ziegler, 1962

Pl. 2, figs. 18, 23

Palmatolepis glabra Ulrich and Bassler. Cooper, 1943, in Cooper and Sloss, p. 170, pl. 29, fig. 5 (not fig. 36).

Palmatolepis deflectens sigmoidalis Ziegler, 1962, p. 56-57, pl. 3, figs. 24-28.

Palmatolepis gracilis sigmoidalis Ziegler. Klapper, 1966, p. 31, pl. 6, fig. 8. Ziegler, 1977, p. 323-324, pl. 7, figs. 13-16. Sandberg and Ziegler, 1979, p. 178, pl. 1, figs. 3-5.

Diagnosis.--" A subspecies of Palmatolepis gracilis characterized by a strongly sigmoidal blade and carina and by short, extremely small platform . . . . The platform is so diminutive that it consists only of raised rims separated by narrow grooves from the carina" (Ziegler, 1977, p. 323).

Remarks.--The subspecies ranges from the Upper Polygnathus styriacus Zone into the highest part of the Siphonodella praesulcata Zone (Sandberg and Ziegler, 1979, p. 178).

Material.--Thirteen mostly incomplete specimens were recovered from the lower shale. An unusually complete specimen, missing only the extreme posterior end, is figured (Pl. 2, fig. 18). The other figured specimen has preservation more representative of the other specimens of this subspecies in the collection.

Palmatolepis sp. indeterminate

Pl. 2, fig. 22

Material.--Five fragmentary specimens were obtained from the lower shale. These specimens have characteristics of the genus but are not complete enough for specific identification. As the figured specimen shows, these elements include species of Palmatolepis other than P. gracilis. The figured specimen is the most complete of these indeterminate elements and is much larger than specimens of P. gracilis sigmoidalis.

Polygnathus Hinde, 1879

Polygnathus Hinde, 1879, p. 361. Klapper, 1966, p. 19. Klapper and others, 1981, p. W162-W164.

Type species.--Polygnathus dubius Hinde, 1879.

Diagnosis.--Platform outline usually lanceolate, and tapers toward posterior tip. Most forms have anterior free blade. Aboral surface has raised keel, throughout length and large, circular or ovate basal cavity with strong lips (modified from Rexroad and Scott, 1964, p. 32; Klapper, 1966, p. 15).

Remarks.--Polygnathus is a Pa element in a seximembrate apparatus (Klapper and others, 1981, p. W162). Species of Polygnathus are distinguished primarily by platform shape and upper surface ornamentation. Rexroad and Scott (1964, p. 32) said, "The genus Polygnathus is a prominent element in most late Devonian and early Mississippian conodont faunal assemblages. Many species of this genus are excellent biostratigraphic markers, and several stratigraphically important Devonian and Mississippian genera, such as _Ancyrodella_, _Polyphodonta_, and _Siphonodella_, evolved directly from _Polygnathus_ . . . ."

Polygnathus communis Branson and Mehl, 1934

Diagnosis.--"Unornamented or weakly ornamented, lanceolate, or ovate platform. Basal cavity elliptical. Keel low lying in depression immediately behind basal cavity" (Klapper, 1966, p. 21).

Remarks.--_Polygnathus communis_ is long-ranging and the most common and highest-ranging species of _Polygnathus_. Several subspecies of _P. communis_ are distinguished by ornamentation.

Polygnathus communis communis Branson and Mehl, 1934

Pl. 2, figs. 9-11

Polygnathus communis Branson and Mehl, 1934b, p. 293, pl. 24, figs. 1-4. Klapper, 1966, p. 21, pl. 6, figs. 6, 11.

Polygnathus communis communis Branson and Mehl. Rexroad and Scott, 1964, p. 33-34, pl. 2, figs. 17, 18. Rexroad, 1969, p. 33-34 (further synonomy), pl. 5, figs. 7-10. Norris, 1981, p. 1280, pl. 1, figs. 1, 2; pl. 2, figs. 11, 12. Wang and Ziegler, 1982, pl. 1, figs. 2, 3.

Diagnosis.--"The upper surface of this subspecies has a single medial carina and is otherwise unornamented" (Rexroad and Scott, 1964, p. 34).

Remarks.--*P*. *communis communis* is the most cosmopolitan and common subspecies of *P*. *communis* and is the most abundant taxon of *Polygnathus* in the collection. The subspecies ranges from the Middle *Palmatolepis crepidula* Zone (Devonian) through the *Doliognathus latus* Zone (Mississippian) (Sandberg and Ziegler, 1979, p. 188).

Material.--Two specimens from the lower shale and 60 specimens from the upper shale were recovered. Only three specimens had more than a small portion of the free blade attached. Most specimens in the collection are preserved as are those illustrated on Pl. 2, fig. 9, 10, but an unusually well preserved specimen is also figured (Pl. 2, fig. 11).

Polygnathus distortus Branson and Mehl, 1934

Pl. 1, figs. 13, 14

Polygnathus distorta Branson and Mehl, 1934b, p. 294, pl. 24, fig. 12.

Polygnathus inornata Branson. Klapper, 1966, p. 19-20, pl. 1, figs. 11, 12 (only); pl. 4, fig. 3 (only).

Polygnathus distortus Branson and Mehl, Klapper, 1975, p. 279-280, pl.4, fig. 3.

Diagnosis.--"*Polygnathus distortus* has a characteristic platform outline that serves to distinguish it from *P*. *inornatus* E. R. Branson. The posterior is bluntly terminated in a round, convex curve in *P*. *distortus*, whereas the termination is sharply pointed with a sinus just to the anterior in the outer margin of *P*. *inornatus*. Additionally, *P*. *distortus* is characterized by two strong anterior rostral ridges on the left side of the platform and a deep and long outer adcarinal groove" (Klapper, 1971, p. 6).

Remarks.--Some of the smaller specimens of P. distortus have a less blunt posterior than larger specimens. The species ranges from the Siphonodella sandbergi-Siphonodella duplicata Zone to the Lower Siphonodella crenulata Zone (Klapper, 1975, p. 280).

Material.--Thirteen specimens were recovered from the upper shale and all are missing portions of the free blade.

Polygnathus inornatus Branson, 1934

Polygnathus inornata Branson, 1934, p. 309, pl. 25, figs. 8, 26.

Klapper, 1966, p. 19-20, pl. 1, figs. 9, 10, 13, 14 (only); pl. 4, figs. 2-4 (only).

Polygnathus inornatus Branson. Klapper, 1975, p. 293-297 (further synonomy), pl. 4, figs. 1, 2, 4. Wang and Ziegler, 1982, pl. 1, fig. 21.

Diagnosis.--Lanceolate, with short, high free blade and straight to curved carina. Deep troughs between carina and margins at anterior of platform. Right anterior margin characteristically upturned higher than left margin.

Remarks.--Most specimens in the collection have only a portion of the free blade preserved. One of the figured specimens (Pl. 1, fig. 1) is an exception to this common type of preservation. Although not clear on the plate, the orally viewed specimen (Pl. 1, fig. 1) has a right anterior margin much higher than the left margin. In the absence of the characteristic short, free blade, specimens of P. inornatus were distinguished from P. longiposticus by their deep, anterior, adcarinal grooves and high right margin. Klapper (1975, p. 295) stated that the species is Kinderhookian in age in North America.

Material.--Twenty-two mostly incomplete specimens were recovered from the upper shale.

Polygnathus longiposticus Branson and Mehl, 1934

Pl. 1, figs. 3, 4

Polygnathus longipostica Branson and Mehl, 1934b, p. 294, pl. 24, figs. 8-11. Klapper, 1966, p. 20-21, pl. 4, figs. 1, 5.

Polygnathus longiposticus Branson and Mehl. Klapper, 1975, p. 303-306 (further synonomy), pl. 6, fig. 1.

Diagnosis.--"Lanceolate, with relatively long free blade and attenuate posterior end. Platform may or may not reach posterior tip. Denticles of carina lowest near mid-length. Anterolateral margins of platform upturned to about level of carina. Basal cavity circular or ovate, relatively large, with or without lips" (Klapper, 1966, p. 20).

Remarks.--*P*. *inornatus* is a Kinderhookian species in North America (Klapper, 1975, p. 305).

Material.--Nine specimens, all with broken free blades, were recovered from the upper shale.

Polygnathus cf. *P*. *nodocostatus* Branson and Mehl, 1934

Pl. 2, figs. 16, 17

Polygnathus nodocostata Branson and Mehl, 1934a, p. 246-247, pl. 20, figs. 9-13; pl. 25, fig. 15. Anderson, 1966, p. 412, pl. 51, figs. 8, 12, 13.

Description.--Platform arched, oral surface covered with nodes in vague longitudnal rows. Aboral surface has strong keel and slit-like basal cavity on keel.

Remarks.--Branson and Mehl (1934a) noted the variability of *P. nodocostatus*. The specimens recovered are small, fragmentary, and mostly encrusted with silt. Because of the limited material, poor preservation, and poorly developed longitudnal rows of nodes, the specimens are compared to *P. nodocostatus* rather than assigned to that species.

Material.--Five specimens, all missing the free blade, were recovered from the lower shale.

Polygnathus sp. indeterminate

Material.--Ten specimens from the lower shale and 35 specimens from the upper shale were obtained. The material may contain more than one species of *Polygnathus*, but is too poorly preserved for specific identification.

Genus *Pseudopolygnathus* Branson and Mehl, 1934

Pseudopolygnathus Branson and Mehl, 1934b, p. 297. Klapper, 1981, p. 355-356. Klapper and others, 1981, p. W166.

Type species.--*Pseudopolygnathus prima* Branson and Mehl, 1934.

Diagnosis.--Elongate platform, ornamented on upper surface by prominent nodes or transverse ridges. Wide free blade, shallow basal cavity with wide lips at anterior end of platform. Basal pit often more wide than long (modified from Branson and Mehl, 1934b; Rexroad and Scott, 1964).

Remarks.--Pseudopolygnathus is a P element of an unknown apparatus. The widely flared basal cavity can be used to distinguish Pseudopolygnathus from Polygnathus. The genus ranges from the Late Devonian to Early Mississippian.

Pseudopolygnathus marginatus (Branson and Mehl, 1934)

Pl. 2, fig. 8

Polygnathus marginata Branson and Mehl, 1934b, p. 294-295, pl. 23, figs. 25-27. Rexroad and Scott, 1964, p. 37, pl. 2, fig. 29.

Pseudopolygnathus marginata (Branson and Mehl). Klapper, 1966, p. 13, pl.1, figs. 1-6.

Pseudopolygnathus marginatus (Branson and Mehl). Rexroad, 1969, p. 39, pl. 4, figs. 11-13.

Diagnosis.--"Lanceolate with platform equally developed on both sides. Platform bears transverse ridges; unit slightly arched. Raised keel present throughout length, interrupted only by basal cavity. Narrow groove, continuous with keel, traverses basal cavity. Basal cavity nearly symmetrical with charateristic sinus in its flared margins, on both sides, near posterior termination of cavity. Crimp is broad in mature specimens" (Klapper, 1966, p. 13).

Material.--Three fragmentary specimens were recovered from the upper shale.

Pseudopolygnathus primus Branson and Mehl, 1934

Pl. 2, figs. 2, 3, 4, 5

Pseudopolygnathus prima Branson and Mehl, 1934b, p. 298, pl. 24, figs. 24, 25. Klapper, 1966, p. 14, pl. 4, fig. 8.

Pseudopolygnathus dentilineata Branson, 1934, p. 317, pl. 26, fig. 22. Klapper, 1966, p. 14-15, pl. 5, figs. 10, 11.

Pseudopolygnathus primus Branson and Mehl, Klapper, 1981, p. 401-408 (further synonomy), pl. 3, figs. 1, 3; pl. 4, figs. 1, 5-7; pl. 5, figs. 1-5.

Diagnosis.--Right side of platform more fully developed anteriorly along the blade. Irregular transverse ridges or nodes on both sides of the platform. Free blade increases rapidly in height anterior of platform.

Remarks.--This species, as described by Klapper (1981, p. 401-402) and followed here, is highly variable in terms of basal cavity size, dentition, and platform outline. P. dentilineatus had been distinguished (Klapper, 1966, p. 14-15) from P. primus on the basis of the size of the basal cavity relative to the width of the platform. Klapper (1966, p. 14) considered this distinction "arbitrary" and subsequently (Klapper, 1981) synonomized the species. The specimen figured (Pl. 2, fig. 2), showing an aboral view, has a basal cavity that is open to near the posterior tip. Most specimens in the collection typically have a basal cavity that does not extend as far to the posterior as this specimen. A large specimen is figured (Pl. 2, fig. 5) that is a mature element and is broken at the anterior and posterior ends. P. primus is the single most abundant species in the Bakken collection. P. primus is a Kinderhookian species in North America.

Material.--Seventy-three specimens were recovered from the upper shale and range from incomplete and poorly preserved to mostly complete and well preserved.

Pseudopolygnathus sp. indeterminate

Material.--Forty specimens were recovered from the upper shale. Specimens are mostly fragmentary and some have silt-encrusted oral surfaces. Although the specimens are clearly of this genus, the specimens are indeterminate because the material is both fragmentary and in many cases the oral surface is obscured by silt.

Siphonodella Branson and Mehl, 1944

Siphognathus Branson and Mehl, 1934b, p. 295.

Siphonodella Branson and Mehl, 1944, p. 245. Klapper, 1966, p. 15-16. Klapper, 1973, p. 451-452. Klapper and others, 1981, p. W166.

Type species.--*Siphonognathus duplicata* Branson and Mehl, 1934.

Diagnosis.--"Lanceolate, asymmetrical platform highly arched with apex of arch at or near position of basal cavity. Anterior rostral or spoutlike extension of platform well developed in all but earliest species. Rostrum arched downward anteriorly and at least slightly incurved. It bears longitudnal (rostral) ridges on the upper side. Outer side of platform at least as wide as inner side, and may be more than twice that width. Carina well developed on the platform, extending anteriorly as a free and fixed blade.

Raised keel present on lowed side in front of basal cavity. This anterior portion of keel bears median groove throughout its length. Basal cavity narrow expansion of median groove in keel. Cavity in mature specimens small and slitlike, without lips. Keel either absent or represented only by thin groove behind basal cavity, except near posterior end where it is raised. Area immediately behind basal cavity characteristically flattened or beveled. Crimp is broad" (Klapper, 1966, p. 15).

Remarks.--Lower surface morphology is used to differentiate *Siphonodella* from *Polygnathus*. *Polygnathus* has a raised keel, interrupted only by a relatively large basal cavity, throughout the length of the platform. In contrast, the keel in *Siphonodella* is either absent or represented by a thin groove for some distance posterior to the basal cavity. Upper surface morphology is used to differentiate species of *Siphonodella* (modified from Klapper, 1966, p. 15).

Only the P element of *Siphonodella* is known. Sandberg and others (1978) recognized 17 species and morphotypes of *Siphonodella*. World-wide occurrence, rapid evolution, and distinctive morphology of *Siphonodella* is the basis for precise biostratigraphic zonation in the uppermost Devonian and Lower Mississippian. *Siphonodella* is the most abundant and diverse genus in the collection with over 200 specimens and seven species from the upper shale of the Bakken.

Siphonodella cooperi Hass, 1959

Pl. 1, fig. 7

Siphonodella cooperi Hass. Rexroad and Scott, 1964, p. 43-44, pl. 3, figs. 27-29. Klapper, 1966, p. 16, pl. 2, figs. 10, 11; pl. 3, figs. 1-4. Klapper, 1971, p. 10, figs. 13-15; pl. 2, figs. 1-3. Klapper, 1975, p. 345-348 (further synonomy), pl. 2, figs. 4, 5.

Diagnosis.--"In representative specimens of Siphonodella cooperi the longest rostral ridge either curves out to terminate posteriorly at midlength of the outer margin or forms that margin throughout its course. Number of rostral ridges varies from two to three. Outer posterior platform bears transverse ridges, inner platform is nodose" (Klapper, 1971, p. 10).

Remarks.--Specimens of S. cooperi with three rostral ridges are difficult to distinguish from S. quadruplicata with three rostral ridges; but the raised margin of the outer platform distinguishes S. cooperi. The figured specimen (Pl. 1, fig. 7), although fragmentary, has a raised outer margin and the terminations of two rostral ridges. Sandberg and others (1978) recognized two morphotypes of S. cooperi on the basis of the development of the rostral ridges. Both of the morphotyoes are present in the material, but they are considered a single, variable species in this report. The species ranges from the Kinderhookian Siphonodella sanbergi-Siphonodella duplicata Zone to the Lower Siphonodella crenulata Zone (Klapper, 1975, p. 346).

Material.--Thirteen fragmentary and mostly poorly preserved specimens were recovered from the upper shale.

Siphonodella crenulata (Cooper, 1939)

Pl. 1, figs. 15, 16

Siphonognathus crenulata Cooper, 1939, p. 409, pl. 41, figs. 1, 2.

Siphonodella crenulata (Cooper). Klapper, 1966, p. 18, pl. 3, figs. 5-8. Rexroad, 1969, p. 42, pl. 2, figs. 9, 10. Klapper, 1973, p. 455-456, pl. 1, fig. 2.

Diagnosis.--"Representative specimens of Siphonodella crenulata have a markedly asymmetrical platform outline. Outer margin characteristically crenulate, inner margin may have a sharp angular bend at midlength. Two short rostral ridges; only exceptionally are there three. In mature specimens, outer posterior platform bears weak transverse ridges, inner platform is nodose (Klapper, 1971, p. 10).

Remarks.--The two specimens illustrated are incomplete. The specimen illustrated (Pl. 1, fig. 15) in aboral view shows the platform posterior of the basal cavity. An oral view of a different specimen (Pl. 1, fig. 16) shows a specimen that is missing the rostral region and free blade. Sandberg and others (1978) recognized two morphotypes of S. crenulata. The material in this collection has strong tranverse ridges on the outer platform suggestive of morphotype 1. The species ranges from the base of the Lower Siphonodella crenulata Zone to the S. isosticha-Upper S. crenulata Zone (Sandberg and others, 1978, p. 111).

Material.--Ten incomplete specimens were obtained from the upper shale, and the material includes nine partial platforms and one rostral area.

Siphonodella duplicata (Branson and Mehl, 1934)

Pl. 1, figs. 5, 6

Siphonognathus duplicata Branson and Mehl, 1934b, p. 296-297, pl. 24, figs. 16, 17.

Siphonodella duplicata (Branson and Mehl). Klapper, 1966, p. 18, pl. 4, fig. 13. Klapper, 1975, p. 349-352, pl. 2, fig. 6.

Diagnosis.--"Transverse ridges on both sides of platform. Two rostral ridges usually form margins of well-developed rostrum. Outer lateral lobe not developed" (Klapper, 1966, p. 18).

Remarks.--*S*. *duplicata* includes forms with transversely aligned nodes on the inner platform. A form with inner nodes is figured (Pl. 1, fig. 5) along with a form with strong transverse ridges on both sides (Pl. 1, fig. 6). Sandberg and others (1978) distinguished two morphotypes of *S*. *duplicata* (Branson and Mehl) and a separate species of *Siphonodella*, *S*. *duplicata* *sensu* Hass, 1959. According to Sandberg and others (1978), *S*. *duplicata* *sensu* Hass has random nodes on the inner platform and two rostral ridges. Both morphotypes of *S*. *duplicata* (Branson and Mehl) and several specimens similar to *S*. *duplicata* *sensu* Hass are present in the collection, but are considered a single variable species in this report. Both figured specimens are incomplete. One specimen (Pl. 1, fig. 5) is missing the posterior tip and free blade and the other figured specimen is missing the free blade. *S*. *duplicata* is the most abundant *Siphonodella* in the collection.

Material.--The collection contains 42 mostly fragmentary specimens obtained from the upper shale.

Siphonodella cf. *S*. *isosticha* (Cooper, 1939)

Pl. 1, fig 12

Siphonognathus *isosticha* Cooper, 1939, p. 409, pl. 41, figs. 9, 10.

Siphonodella *isosticha* (Cooper). Klapper, 1966, p. 17, pl. 2, figs. 9, 12 (only). Klapper, 1971, p. 10, pl. 1, fig. 16. Klapper, 1973, p. 459, pl. 1, fig. 3.

Description.--Outer rostral ridge forms the outer margin. Outer platform has weak transverse ridges near the outer margin and weak nodes near the carina. The inner margin is weakly nodose.

Remarks.--The figured specimen is missing the inner rostral ridge and free blade. A morphotype (not found) of *S*. *isosticha* (Cooper) in which the longest rostral ridge terminates on the platform, midway between the margin and carina, has been recognized (Klapper, 1971, p. 12; Sandberg and others, 1978, p. 105-106). The single fragmentary specimen from the upper shale most closely conforms to the description of *S*. *isosticha* (Cooper) of Klapper (1971, p. 10). If the specimen were more strongly ornamented it would likely be compared to *S*. *cooperi* Hass as well as to *S*. *isosticha*.

Siphonodella *obsoleta* Hass, 1959

Pl. 1, fig. 11

Siphonodella *obsoleta* Hass, 1959, p. 392-393, pl. 47, figs. 1, 2. Müller, 1962, p. 1388, text-figs. 4, 8. Klapper, 1966, p. 17, pl. 4, figs. 17, 19 (only). Rexroad, 1969, p. 44, pl. 3, fig. 6. Klapper, 1971, p. 12, pl. 1, fig. 25. Klapper, 1973, p. 463-464, pl. 1, fig. 7.

Diagnosis.--"Representative specimens of Siphonodella obsoleta have a long rostral ridge that extends to near the posterior end of the outer platform. Outer posterior platform weakly ornamented or smooth between the long rostral ridge and carina. Rostral ridges vary from two to four in number; platform is long and relatively narrow" (Klapper, 1971, p. 12).

Remarks.--The species ranges from the Siphonodella sandbergi Zone to the Gnathodus punctatus Zone in North America (Klapper, 1973, p. 463).

Material.--Two specimens were recovered from the upper shale and are complete except they are missing part of the free blade.

Siphonodella quadruplicata (Branson and Mehl, 1934)

Pl. 1, figs. 8-10, 17

Siphognathus quadruplicata Branson and Mehl, 1934b, p. 295-296, pl. 24, figs. 18-20 (only).

Siphonodella quadruplicata (Branson and Mehl). Müller, 1962, p. 1388, text-fig. 5. Klapper, 1966, p. 17-18, pl. 2, figs. 5-8; pl. 3, figs. 9-12; pl. 4, figs. 16-20. Rexroad, 1969, p. 44-45, pl. 2, figs. 11-12. Klapper, 1971, p. 12, pl. 1, figs. 22-24. Klapper, 1973, p. 465-466, pl. 1, fig. 6.

Diagnosis.--"In representative specimens of Siphonodella quadruplicata the posterior termination of the innermost rostral ridge on the outer platform is adjacent to the position where the carina begins to incurve and between the carina and margin. Number of rostral ridges varies from three to five. Outer posterior platform bears transverse ridges, inner platform is nodose" (Klapper, 1971, p. 12).

Remarks.--"The posterior termination of the longest (innermost) rostral ridge, on the outer side of the platform, is about halfway between the carina and the lateral margin in S. quadruplicata, whereas it is at the lateral margin in S. cooperi Hass" (Klapper, 1973, p.465). A specimen is figured (Pl. 1, Fig. 17) that does not conform exactly to the description of S. quadruplicata in that the innermost rostral ridge on the outer platform extends partly onto the platform. Although silt obscures the rostral area, four rostral ridges are present and the outer platform is ornamented, thus the specimen can not be assigned to S. cooperi because of the four rostral ridges nor to S. obsoleta because of the outer platform ornamentation. The specimen is, thus, tentatively included in S. quadruplicata. The species ranges from the S. sandbergi Zone to the Lower S. crenulata Zone (Klapper, 1973, p. 466).

Material.--Eighteen mostly fragmentary specimens were recovered from the upper shale. One of the figured specimens (Pl. 1, fig. 8) is, perhaps, the best preserved Siphonodella in the collection.

Siphonodella sandbergi Klapper, 1966

Pl. 1, fig. 18

Siphonodella sandbergi Klapper, 1966, p. 19, pl. 4, figs. 6, 10-12, 14, 15. Thompson and Fellows, 1970, p. 109, pl. 7, figs. 9, 11-13. Klapper, 1973, p. 467-468, pl. 1, fig. 5.

Diagnosis.--"Broad, short, with nodes on inner sides of platform. On outer side, at least one rostral ridge (usually the innermost) extends to near posterior end. Ornament weak to absent between this ridge and carina. Five to 6 rostral ridges present" (Klapper, 1966, p. 19).

Remarks.--The species ranges from the base of the *Siphonodella sandbergi* Zone into the Lower *Siphonodella crenulata* Zone (Sandberg and others, 1978, p. 109).

Material.--Four heavily silt-encrusted specimens were recovered from the upper shale.

Siphonodella sp. indeterminate

Material.--One-hundred and sixteen specimens that could not be assigned to species were obtained from the upper shale. The material includes fragmentary and juvenile specimens and some mature specimens too covered with silt on the oral surface to identify to species. Many specimens missing the rostrum, which is often necessary for species identification, are assigned here.

Genus "*Spathognathodus*" Branson and Mehl, 1941

Spathognathodus Branson and Mehl, 1941, p. 98.

Type species.--*Spathodus primus* Branson and Mehl, 1933.

Diagnosis.--Unit is bladelike and the basal cavity in most species is in the middle one-third of the unit. Basal cavity is small in some forms, but many forms have expanded lips. The main axis is straight or flexed slightly inward. The lower edge of the unit is straight and not greatly arched (modified from Rexroad and Scott, 1964, p. 46-47).

Remarks.--The type species of *Spathognathodus* has been considered (Klapper and Phillip, 1971) a Pa element *Ozarkodina*.

"Spathognathodus" crassidentatus (Branson and Mehl, 1934)

Pl. 2, fig. 21

Spathodus crassidentatus Branson and Mehl, 1934b, p. 276, pl. 22, fig. 7 (not fig. 8).

Spathognathodus crassidentatus (Branson and Mehl). Klapper, 1966, p. 23, pl. 5, figs. 15-17. Rexroad, 1969, p. 46-47, pl. 6, figs. 6-8.

Diagnosis.--"Single rowed, straight to incurved, and slightly arched. Two main denticles, markedly higher and wider than the others, located at the anterior end of the blade. Denticles form convex arc from position above basal cavity to posterior tip. Basal cavity extends somewhat in front of midlength to near posterior end. Nearly symmetrical basal cavity rounded anteriorly tapering sharply toward posterior end" (Klapper, 1966, p. 23).

Remarks.--"S." crassidentatus is a Lower Mississippian species in North America.

Material.--A single, well preserved specimen was recovered from the upper shale.

"Spathognathodus" strigosus (Branson and Mehl, 1934)

Pl. 2, fig. 7

Spathodus strigosus Branson and Mehl, 1934a, p. 187, pl. 17, fig. 17.

Spathognathodus strigosus (Branson and Mehl). Rexroad, 1969, p. 48, pl. 6, fig. 3. Wang and Ziegler, 1982, pl. 2, figs. 11-16.

Diagnosis.--Blade thin, slightly curved laterally. Oral outline nearly straight anteriorly; posterior curves abruptly downward to aboral edge. Aboral outline straight in the anterior half and slightly arched posteriorly. Basal pit exceptionally small, somewhat back of mid-length; faint lip at lower edge of blade. Denticles about 24 with sharply pointed apices; compressed but unfused for most of their length (modified from Branson and Mehl, 1934a, p. 187).

Remarks.--The specimen identified and illustrated is embedded on a piece of the lower shale. The specimen of *Spathognathodus strigosus* (Branson and Mehl) illustrated by Rexroad (1969, pl. 6, fig. 3) appears to have a more strongly flared basal margin than the specimen from the Bakken, but otherwise otherwise appears to have the characteristics of the species and is thus, included in the synonomy.

Material.--A single specimen was obtained from the lower shale.

"*Spathognathodus*" sp. indeterminate

Material.--Eighteen specimens from the lower shale and 12 from the upper shale were recovered. All specimens recovered are fragmentary and some are encrusted in silt.

Genus *Synprioniodina* Bassler, 1925

Synprioniodina Bassler, 1925, p. 219. Huddle, 1968, p. 45.

Type species.--*Synprioniodina alternata* Bassler, 1925.

Diagnosis.--"Posterior bar arched and bowed with anteriorly directed, closely spaced, discrete or fused denticles; terminal cusp and denticulated anticusp. The posterior bar and anticusp form an arcuate aboral angle in mmost species. Basal cavity beneath cusp expanded on the inner side" (Huddle, 1968, p. 45).

Remarks.--Synprioniodina is an M element in multielement classification (Austin and others, 1981, p. W 179). Synprioniodina is generally distinguished from specimens of "Neoprioniodus" by the denticulate anticusp of the former. Most specimens of Synprioniodina in the collection are considered indeterminate because they consist of only the apex of the anticusp and anterior bar.

Synprioniodina cf. S. delicatula Branson and Mehl, 1934

Pl. 3, fig. 7

Synprioniodina(?) delicatula Branson and Mehl, 1934b, p.292, pl. 23, figs. 23, 24.

Synprioniodina delicatula Branson and Mehl, Rexroad and Scott, 1964, p. 49, pl. 8, figs. 1-4.

Diagnosis.--Posterior limb thin, bladelike, nearly straight with sharp aboral edge; denticles very small and slender, in close contact to their apices, increasing in length anteriorly. Main denticle compressed laterally with sharp anterior and posterior edges. Liplike extension at the base of the main denticle (modified from Branson and Mehl, 1934b, p. 292).

Remarks.--The figured specimen compares closely with the description of S. delicatula provided by Branson and Mehl (1934b) and the specimens illustrated by Rexroad (1969). The inability to determine denticle lengths near the main denticle and the broken posterior bar on the Bakken specimens restricts confident assignment to S. delicatula.

Material.--A single specimen was recovered from the upper shale.

Synprioniodina sp. indeterminate

Material.--Four specimens from the lower shale and seven specimens from the upper shale that have characteristics of the genus were obtained.

coniform sp. A

Pl. 3, figs. 18, 19

Description.--A nongeniculate, coniform element with a widely flared, striated base and deep conical basal cavity. Cusp is subcircular in cross section at mid-height and laterally compressed toward the posterior. Posterior portion of element is longitudinally channeled and covered with prominent costae and numerous finer striae.

Material.--Two specimens were recovered from the lower shale. Both specimens have broken cusps.

coniform sp. B

Pl. 3, fig. 20

Description.--A coniform element with a smooth surface and subcircular cusp and slightly flared basal margin and moderately deep basal cavity.

Remarks.--These elements are generally smaller and thinner than coniform sp. A and have a less flared basal margin.

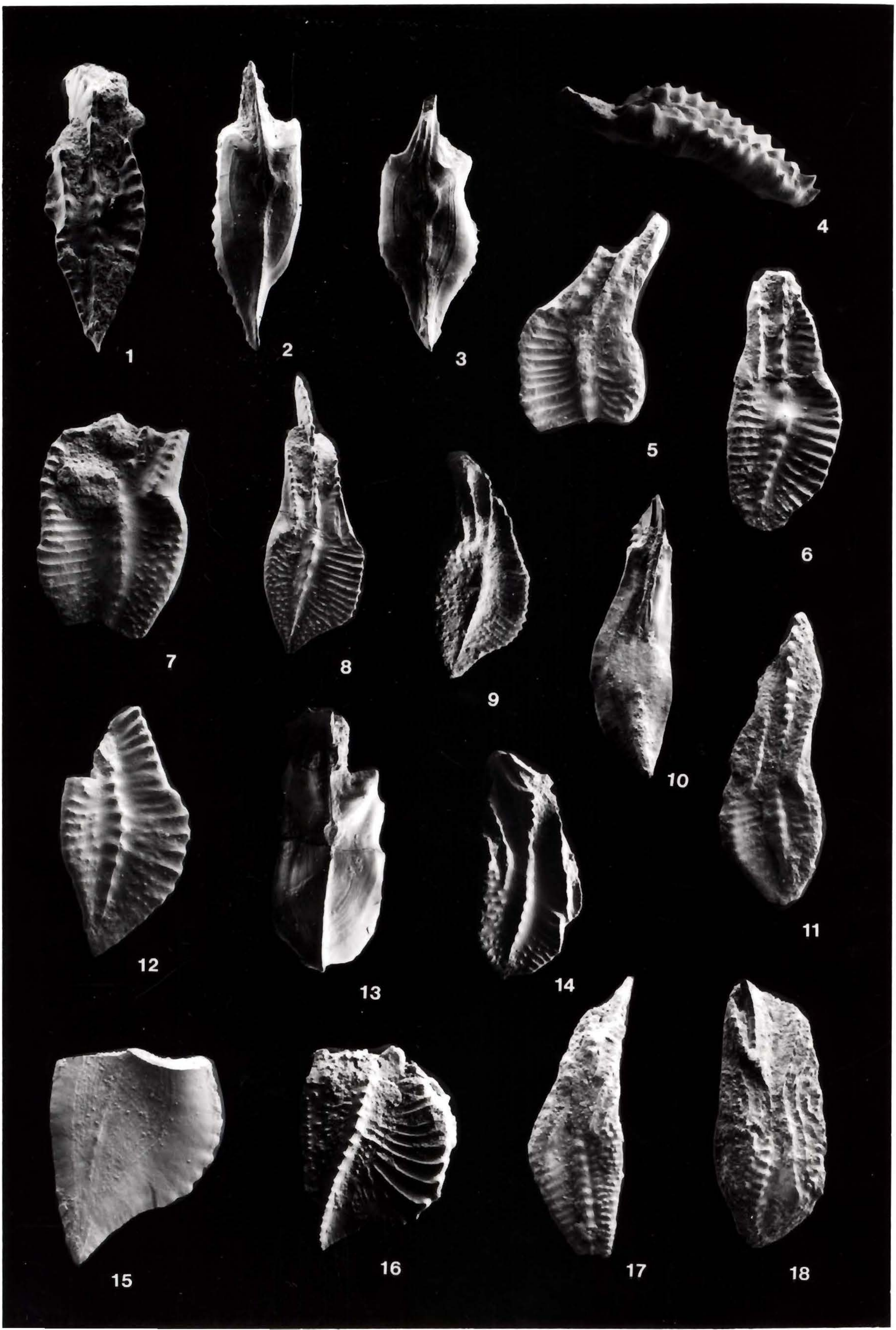
Material.--Five elements were obtained from the lower shale.

ramiform sp. indeterminate

Material.--Material consists of fragmentary, barlike elements. Seventeen specimens from the lower shale, five from the middle member, and 127 from the upper shale were recovered. Many of the specimens appear to be posterior bars of *Hindeodella* or *Ligonodina* elements.

EXPLANATION OF PLATE 1

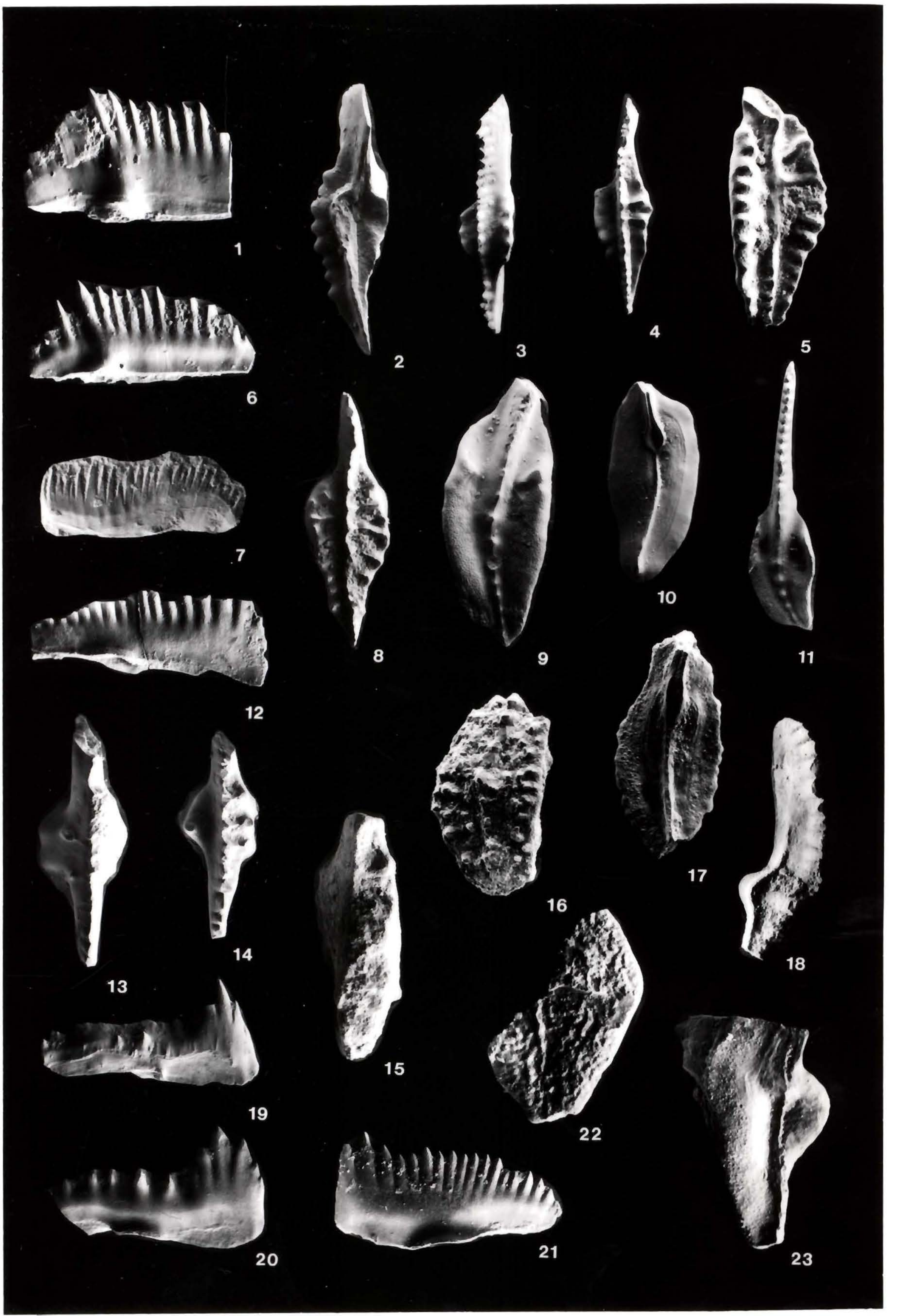
Figure	
1, 2	Polygnathus inornatus Branson. 1, upper view of UND 2500., x33, upper shale (Key Q). 2, lower view of UND 2501., x25, upper shale (Key Q).
3, 4	Polygnathus longiposticus Branson and Mehl. 3, lower view of UND 2502., x24, upper shale (Key AA). 4, oblique lateral view of UND 2503., x26, upper shale (Key Q).
5, 6	Siphonodella duplicata Branson and Mehl. 5, upper view of UND 2504., x36, upper shale (Key Key P). 6, upper view of UND 2505., x26, upper shale (Key P).
7	Siphonodella cooperi Hass. upper view of UND 2506., x39, upper shale (Key P).
8-10, 17	Siphonodella quadruplicata (Branson and Mehl). 8, upper view of UND 2507., x26, upper shale (Key P). 9, upper view of UND 2908., x22, upper shale (Key Q). 10, lower view of UND 2509., x31, upper shale (Key Q). 17, upper view of UND 2516., x31, upper shale (Key Q).
11	Siphonodella obsoleta Hass. upper view of UND 2510., x36, upper shale (Key Q).
12	Siphonodella cf. S. isosticha (Cooper). upper view of UND 2511., x34, upper shale (Key P).
13, 14	Polygnathus distortus Branson and Mehl. 13, lower view of UND 2512., x23, upper shale (Key Q). 14, upper view of UND 2513., x24, upper shale (Key Q).
15, 16	Siphonodella crenulata (Cooper). 15, lower view of UND 2514., x60, upper shale (Key Q). 16, upper view of UND 2515., x21, upper shale (Key Q).
18	Siphonodella sandbergi Klapper. upper view of UND 2517., x31, upper shale (Key Q).



1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18

EXPLANATION OF PLATE 2

Figure	
1, 6	Branmehla inornata (Branson and Mehl). 1, right lateral view of UND 2518., x48, lower shale (Key J). 6, right lateral view of UND 2523., x36, lower shale (Key J).
2-5	Pseudopolygnathus primus Branson and Mehl. 2, oblique lower view of UND 2519., x32, upper shale (Key W). 3, oblique upper view of UND 2520., x42, upper shale (Key P). 4, upper view of UND 2521., x24, upper shale (Key P). 5, upper view of UND 2522., x30, upper shale (Key P).
7	"Spathognathodus" strigosus (Branson and Mehl). left lateral view of UND 2524., x18, lower shale (Key A), embedded in matrix.
8	Pseudopolygnathus marginatus Branson and Mehl. upper view of UND 2525., x35, upper shale (Key P).
9-11	Polygnathus communis communis Branson and Mehl. 9, upper view of UND 2526., x52, upper shale (Key P). 10, lower view of UND 2527., x44, lower shale (Key J). 11, upper view of UND 2528., x53, upper shale (Key P).
12	Bispathodus stabilis (Branson and Mehl). right lateral view of UND 2529., x46, upper shale (Key T).
13, 14, 19, 20	Bispathodus aculeatus aculeatus (Branson and Mehl). 13, oblique upper view of UND 2530., x36, upper shale (Key X). 14, upper view of UND 2531., x36, upper shale (Key W). 19, right lateral view of UND 2537., x19, upper shale (Key Z). 20, right lateral view of UND 2538., x22, upper shale (Key Z).
15	Bispathodus jugosus (Branson and Mehl). upper view of UND 2532., x31, lower shale (Key K).
16, 17	Polygnathus cf. P. nodocostatus Branson and Mehl. 16, upper view of UND 2533., x72, lower shale (Key G). 17, lower view of UND 2534., x80, lower shale (Key G).
18, 23	Palmatolepis gracilis sigmoidalis Ziegler. oblique upper view of UND 2536., x60, lower shale (Key G). 23, oblique lower view of UND 2541., x143, lower shale (Key G).
21	"Spathognathodus" crassidentatus Branson and Mehl. left lateral view of UND 2539., x69, upper shale (Key P).
22	Palmatolepis sp. indet. upper view of UND 2540., x26, lower shale (Key K).


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23

EXPLANATION OF PLATE 3

Figure	
1	"*Neoprioniodus*" cf. "*N.*" *barbatus* (Branson and Mehl). 1, left lateral view UND 2542., x38, upper shale (Key Q).
2	*Ligonodina* sp. A. oblique lateral view of UND 2543., x36, upper shale (Key Q).
3	*Ligonodina* cf. *L.* *panderi* (Hinde). oblique upper view of UND 2544., x39, lower shale (Key K).
4	*Ligonodina* sp. indet. left lateral view of UND 2545., x29, upper shale (Key Q).
5	"*Neoprioniodus*" *alatus* Hinde. right lateral view of UND 2546., x31, upper shale (Key U).
6	*Hibbardella* sp. indet. left lateral view of UND 2547., x19, lower shale (Key J).
7	*Synprioniodina* cf. *S.* *delicatula* Branson and Mehl. left lateral view of UND 2548., x53, upper shale (Key Z).
8	*Dinodus* sp. indet. lateral view of UND 2549., x38, upper shale (Key S).
9	*Ozarkodina* sp. A. left lateral view of UND 2550., x25, upper shale (Key Q).
10	*Metaprioniodus* *biangulatus* Huddle. right lateral view of UND 2551., x24, upper shale (Key X).
11, 16	*Elictognathus* *laceratus* (Branson and Mehl). 11, right lateral view of UND 2552., x37, upper shale (Key Q). 16, right lateral view of UND 2557., x41, upper shale (Key P).
12	*Ozarkodina* sp. B. left lateral view of UND 2553., x25, lower shale (Key H).
13	*Bryantodus* sp. A. right lateral view of UND 2554., x31, upper shale (Key P).
14	*Bryantodus* sp. B. left lateral view of UND 2555., x33, upper shale (Key P).
15	*Bryantodus* cf. *B.* *planus* Branson and Mehl. right lateral view of UND 2556., x29, upper shale (Key W).
17	"*Hindeodella*" cf. "*H.*" *subtilis* Bassler. right lateral view of UND 2558., x41, lower shale (Key W).
18, 19	coniform sp. A. 18, lateral view of UND 2559., x64, lower shale (Key J). 19, oblique posterior view of UND 2560., lower shale (Key J).
20	coniform sp. B. lateral view of UND 2561., x155, lower shale (Key H).


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

APPENDICES

APPENDIX A

NAME AND LOCATION OF CORES USED IN THIS STUDY

NAME AND LOCATION OF CORES USED IN THIS STUDY

Well numbers in the far left column are those of the North Dakota Geological Survey and are listed in numerical order. Locations are based on the standard Land Office Grid System. Under the location heading, QQ stands for first and second quarter of section; S, T, and R stand for section, township, and range, respectively. All townships in North Dakota are north and all ranges are west of the principal baseline and meridian. Well names and operator names are those currently used by the North Dakota Geological Survey.

TABLE 1

CORES USED IN THIS STUDY

Well No.	Well Name	Operator	Location QQ	Location S-T-R	County
105	Walter and Ingerburg Waswick #1	Stanolind Oil and Gas Co.	SWNE	2-153-85	Ward
527	Rough Creek Unit #1	California Oil Co.	NWNE	13-148-98	McKenzie
793	Solomon Bird Bear #1	Mobil Prod. Co.	SENW	22-149-91	Dunn
999	J.M. Donohue #1	Texaco Inc.	SWNE	23-154-100	Williams
1405	Catherine E. Peck #2	Gofor Oil Inc.	NWNE	27-150-96	McKenzie
2618	Jacob Huber #1	Pan American Petroleum Corp.	SWSE	15-145-91	Dunn
2967	A. S. Wisness #2	Texaco Inc.	NWSE	3-152-96	McKenzie
3363	Clarence Pederson (NCT-1) #1	Texaco Inc.	NWSE	19-157-96	Williams
4297	B. E. Hove #1	Pan American Petroleum Corp.	SWNW	2-154-95	Williams
4958	Florence M. Ingerson #2	John B. Hawley Jr. Trust #1	SWNE	2-161-91	Burke
5088	Shell Texel #21-35	Shell Oil Co.	NENW	35-156-93	Mountrail
7579	USA #42-24A	Shell Oil Co.	SENE	24-145-104	McKenzie
7887	Mee USA #3-17	Tenneco Oil Co.	SWNE	17-142-100	Billings
8069	Jensen #12-44	Marathon Oil Co.	SESE	12-154-90	Mountrail
8177	Dobrinski #18-44	Marathon Oil Co.	SESE	18-151-87	Ward
8474	Graham USA #1-15	Tenneco Oil Co.	NESW	15-144-102	Billings
9351	Federal #3	Supron Energy Corp.	NWSE	6-144-101	Billings

APPENDIX B

FORMATION AND MEMBER TOPS

FORMATION AND MEMBER TOPS

Well numbers are those of the North Dakota Geological Survey. Tops are given as feet below the elevation of the Kelly Bushing (KB) and were obtained from geophysical logs. Stratigraphic unit abbreviations are as follows: (B) top of Bakken Formation, (MM) top of middle member of Bakken Formation, (LS) top of lower shale of Bakken Formation, (TF) top of Three Forks Formation. The asterisk indicates the lower shale was absent.

TABLE 2

FORMATION AND MEMBER TOPS

Well No.	KB	B	MM	LS	TF
105	2175	7542	7556	7569	7578
527	2472	11197	11214	11254	11286
793	2092	9994	10014	10046	10076
999	2253	10930	10946	10988	11007
1405	2342	10737	10760	10794	10822
2618	2212	9778	9792	9826	9838
2967	2317	10226	10245	10288	10314
3363	2332	10130	10144	10203	10227
4297	1969	9907	9925	9989	10025
4958	1973	7570	7580	7623	7652
5088	2409	10161	10177	10243	10292
7579	2665	10852	10857	*	10864
7887	2741	10791	10801	10808	10810
8069	2213	9157	9174	9207	9236
8177	2146	8621	8639	8660	8674
8474	2173	10366	10374	10378	10379
9351	2203	10463	10472	10482	10483

APPENDIX C

DISSOLUTION RESULTS

DISSOLUTION RESULTS

Well numbers are those of the North Dakota Geological Survey. Core-box depths are in feet. Members of the Bakken Formation are abbreviated as follows: (U) upper shale, (M) middle member, (L) lower shale. Solution ingredients are explained in the text. Initial weight and dissolved portion weight are in grams. Asterisks mark unrecorded information.

TABLE 3

DISSOLUTION RESULTS

Well No.	Core-Box Depth	Bakken Member	Solution	Weeks in Solution	Initial Weight	Dissolved Portion
105	7583-76	M	Formic	9	142	120
105	7571-68	U	Bleach	8	300	207
105	7571	U	Bleach	8	63	12
105	7568-62	U	Bleach	8	*	*
527	10249-46	M	Formic	*	112	92
793	10018-00	U	Bleach	12	46	10
793	9997-94	U	Bleach	12	42	*
1405	10808.5-806.5	L	Acetic	7	206	18
2967	10297-294	L	Bleach	1	70	3
3363	10221-219	L	Bleach	9	117	66
3363	10219-216	L	Bleach	9	55	15
3363	10219-215	L	Bleach	11	371	99
3363	10215-213	L	Bleach	11	356	139
4297	9910-07	U	Bleach	16	0.9	0.9
4297	9898-95	U	Bleach	12	211	43
5088	10283-277	L	Bleach	8	50	*
5088	10243-240	M	Acetic	8	50	*
5088	10239-238	M	Acetic	4	111	17
5088	10233-230	M	Acetic	4	183	14
5088	10218-215	M	Acetic	4	176	21
5088	10207-204	M	Acetic	4	198	15
5088	10212-209	M	Bleach	8	*	*
5088	10176-173	M	Formic	8	*	*

TABLE 3--Continued

Well No.	Core-Box Depth	Bakken Member	Solution	Weeks in Solution	Initial Weight	Dissolved Portion
5088	10173-169	M	Acetic	4	*	*
5088	10169-167	U	Bleach	10	100	*
5088	10160-156	U	Bleach	10	*	*
7579	10856-855	U	Bleach	7	6	0.5
7887	10800-797	M	Formic	12	212	65
7887	10797-794	M	Formic	12	168	51
7887	10794	M	Formic	12	244	51
7887	10793-792	U	Bleach	12	222	45
7887	10792-790	U	Bleach	12	219	73
7887	10789-786	U	Bleach	12	315	68
8069	9211	L	Formic	10	112	58
8069	9195	M	Formic	10	81	27
8177	8667-65	L	Bleach	8	136	68
8177	8665-60	L	Bleach	8	118	50
8177	8659-57	M	Acetic	4	114	15
5179	8657-54	M	Formic	8	60	51
8177	8654-51	M	Acetic	4	141	63
8177	8643-40	M	Formic	8	65	23
8177	8637-34	U	Bleach	8	46	21
8177	8637	U	Bleach	12	150	*
8177	8634-31	U	Bleach	8	130	40
8474	10374-373	M	Formic	14	193	43
8474	10370-369	M	Formic	14	229	72
8474	10369-367	U	Bleach	14	260	74
8474	10367-365	U	Bleach	14	227	50
8474	10366	U	Bleach	14	289	53
8474	10365-362	U	Bleach	14	255	51
9351	10469.5	L	Bleach	7	160	31
9351	10496.5-460	M	Formic	8	225	30
9351	10460-457	M	Formic	8	146	106
9351	10457-456	U	Formic	8	200	30
9351	10456-454	U	Bleach	8	197	53

TABLE 3--Continued

Well No.	Core-Box Depth	Bakken Member	Solution	Weeks in Solution	Initial Weight	Dissolved Portion
9351	10454-452	U	Bleach	8	200	13
9351	10451-449	U	Bleach	8	200	23
9351	10449	U	Bleach	8	198	22

APPENDIX D

CORE DESCRIPTIONS OF BAKKEN FORMATION AND ADJACENT UNITS

CORE DESCRIPTIONS OF BAKKEN FORMATION AND ADJACENT UNITS
(Only those cores that yielded conodonts are described)

Well numbers are those of the North Dakota Geological Survey and are listed in numerical order. Stratigraphic unit abbreviations are as follows: (Lpl. Fm.) Lodgepole Formation, (U. Shale) upper shale of Bakken Formation, (Mid. Mem.) middle member of Bakken Formation, (L. Shale) lower shale of Bakken Formation, (T. Fks. Fm.) Three Forks Formation. Depths used are in feet and those marked on the exterior of the core boxes. Core-box depths may not correspond directly with depths taken from well logs.

Well No.

105. Stanolind Oil and Gas Co. - Waswick #1, SW¼NE¼ Sec. 2, T. 153 N., R. 85 W., Ward County.

U. Shale

7562-74 Shale, grayish black (N2), non-calcareous, subvertical healed fractures, conodonts concentrated at 7569.

Mid. Mem.

7574-83 Siltstone, light gray (N7) to very light gray (N8) dolomitic, calcareous, wavy bedding, pyrite (locally concentrated), brachiopods (mostly disarticulated), pelmatozoan fragments.

527. California Oil Co. - Rough Creek Unit #1, NW¼NE¼ Sec. 13, T. 148N., R. 98 W., McKenzie County.

Mid. Mem.

11225-61 Siltstone, limestone, medium dark gray (N4) to medium gray (N5), arcuate to wavy bedding; sandy echinoderm brachiopod oolite within 11246-49.

11261-62 Core missing.

L.Shale

11262-71 Shale, grayish black (N2), non-calcareous, fissile, pyritic, calcite filled fractures, platy fracture at 11270, conodonts, core in poor condition.

11271-74 Core missing.

11274-87 Shale, dark gray (N3), as above; silty, flaky and soft (11283-86).

T.Fks.Fm

11287-89 Siltstone, medium dark gray (N4) to medium light gray (N6), argillaceous, dolomitic to calcareous, wavy and planar bedding.

793. Mobil Producing Co. - Solomon Bird Bear #1, SE¼NW¼ Sec. 22, T. 149 N., R. 91 W., Dunn County.

Lpl.Fm.

9991-93 Limestone, light gray (N7) to very light gray (N8), argillaceous.

U.Shale

9993-021 Shale, dark gray (N3), non-calcareous, concentrated conodonts at 9994, pyrite, "dead" oil, core in poor condition.

Mid.Mem.

10021-33 Siltstone, light gray (N7), calcareous, interbedded, irregularly argillaceous; mottled, arcuate to discontinuous wavy bedding.

10033-38 Core missing.

10038-45 Siltstone, mostly light gray (N7), calcareous, small (0.5 cm x 1.0 cm), lenticular, medium bluish gray (5B 5/1) argillaceous blebs.

10045-52 Core missing.

L.Shale

10052-72 Shale, grayish black (N2), non-calcareous, pyritic, argillaceous limestone at 10058-59 and 10071, calcite and pyrite filled fractures, "dead" oil, few conodonts, plant fragments at 10057.

2618. Pan American Petroleum Corp. - Jacob Huber #1, SW¼SE¼ Sec. 15, T. 145 N., R. 91 W., Dunn County.

Mid.Mem.

9794-812 Siltstone, shale, medium dark gray (N4) to medium light gray (N6), calcareous to non-calcareous, mottled, discontinuous planar bedded, fragmentary brachiopods.

9812-22 Siltstone, medium dark gray (N4) to medium light gray (N6), calcareous, wavy discontinuous bedded, irregularly argillaceous, brachiopods, plant (?) fragments.

9822-28 Siltstone, medium light gray (N6) to light gray (N7), calcareous to slightly calcareous, wavy bedded, brachiopods, 2.0 inch (5.0 cm) zone of interlaminated siltstone and grayish black (N2) shale at 9828.

L.Shale

9828-37 Shale, grayish black (N2) to dark gray (N3), non-calcareous, finely laminated, laminated pyrite (some nodular), "dead" oil, siliceous in part, conodonts (uncommonly concentrated), spores.

T.Fks. Fm 9837-42	Siltstone, argillaceous, medium light gray (N6) to medium bluish gray (5B 5/1), non-calcareous.
3363.	Texaco Inc. - Clarence Pederson #1, NW¼SE¼ Sec. 19, T. 157 N., R. 96 W., Williams County.
L.Shale 10213-21	Shale, grayish black (N2), non-calcareous, laminated, nearly conchoidal fracture in part, pyrite commonly in nodules (mostly about 1.0 mm in diameter).
T.Fks.Fm. 10221-23	Shale, greenish gray (5G 6/1), thin wavy bedding (uncommonly discontinuous), possible scour, some pyrite.
4297.	Pan American Petroleum Corp. - B. E. Hove #1, SW¼NW¼ Sec. 2, T. 154 N., R. 95 W., Williams County.
U.Shale 9895-10	Shale, grayish black (N2) to black (N1), mostly non-calcareous, laminated, pyritic, conodonts concentrated at 9908.
5088.	Shell Oil Co. - Shell-Texel #21-35, NE¼NW¼ Sec. 35, T. 156 N., R. 93 W., Mountrail County.
Lpl.Fm 10158-59	Limestone, medium gray (N5), echinoderm fragments, argillaceous.
U.Shale 10159-69	Shale, grayish black (N2), non-calcareous, hard, conchoidal to planar fracture, pyritic, small (1 mm) nodules at 10159, pyritized articulate brachiopods concentrated at 10169, conodonts.
Mid.Mem. 10169-82	Siltstone, shale, very light gray (N7) to greenish gray (5G 6/1), calcareous, interbedded fine sandstone and shale, cross-bedded at 10173, microfaults, soft-sediment deformation, discontinuously bedded, brachiopods and pelmatozoans at top.
10182-90	Sandstone, medium gray (N5), highly calcareous, massive to planar bedded.
10190-08	Siltstone, medium light gray (N6), calcareous, mostly planar bedded, mottled at top.
10208-39	Siltstone, dark gray (N3) to medium gray (N5), calcareous, wispy to mottled bedding, commonly argillaceous, brachiopods.

L.Shale
10239-90 Shale, dark gray (N3) to brownish black (5 YR 2/1), mostly non-calcareous, irregularly silt-rich, calcite and pyrite filled fractures at 10260, pyritized plant spores, pyrite, "dead oil", conodonts, ostracods, fish scales (?) at 10283; thin (about 2.0 inches, 5.0 cm thick) limestone at 10,276; 0.5 inch (1.25 cm) thick zone of interlaminated dark gray shale and greenish gray shale (10290).

T.Fks.Fm.
10290-92 Shale, siltstone, mostly greenish gray (5G 6/1) some light gray (N7), non-calcareous to dolomitic, wavy bedded.

7579. Shell Oil Co. - USA #42-24A, SE¼NE¼ Sec. 24, T. 145 N., R. 104 W., McKenzie County.

Lple.Fm.
10855-55.5 Limestone, medium dark gray (N4), mottled, brachiopod and pelmatozoan fragments.

U.Shale
10855.5-59 Shale, black (N1), non-calcareous, laminated, pyrite, hard, conodonts, abundant broken conodonts, phosphatic debris, pyrite at 10859, contact below abrupt.

Mid.Mem.
10859-66 Siltstone, medium light gray (N6) to light gray (N7), slightly calcareous, argillaceous, mottled, pyritic.

T.Fks.Fm.
10866-69 Siltstone, greenish gray (5G 6/1), mostly non-calcareous, massive to wavy discontinuous bedding, some pyrite.

7887. Tenneco Oil Co. - Mee USA #3-17, SW¼NE¼ Sec. 17, T. 142 N., R. 100W., Billings County.

U.Shale
10786-94 Shale, dark gray (N3), finely laminated, mostly non-calcareous, some calcareous laminae, nearly concoidal fracture in part, pyrite (disseminated), brachiopods at 10794, core in poor condition.

Mid.Mem.
10794-800 Siltstone, medium gray (N5) to medium light gray (N6), calcareous, disrupted bedding, some pyrite, brachiopods, pelmatozoans.

T.Fks.Fm.
10800-02 Siltstone, medium dark gray (N4) to medium light gray (N6), highly calcareous, pyritic, dark clasts at 10800, brachiopods.

8069. Marathon Oil Co. - Jensen #12-44, SE¼SE¼ Sec. 12, T. 154 N., R. 90 W., Mountrail County.

U.Shale
9159-70 Shale, grayish black (N2) to dark gray (N3), non-calcareous, silty, pyritic, finely laminated, nearly conchoidal fracture at 9166, conodonts concentrated at 9164, and 9169.

Mid.Mem.
9170-91 Siltstone, mostly medium dark gray (N4), calcareous, alternating argillaceous and silty beds (siltier beds commonly more calcareous than argillaceous beds) mostly planar bedded, brachiopods irregularly concentrated.

9191-04 Siltstone, medium light gray (N6), calcareous, discontinuous wavy bedded, argillaceous, pyrite, brachiopods, pelmatozoans.

L.Shale
9204-11 Shale, black (N1), non-calcareous, silty, finely laminated, pyritic, conodonts.

9211-11.5 Limestone, medium dark gray (N4), somewhat crystalline.

8177. Marathon Oil Co. - Dobrinski #18-44, SE¼SE¼ Sec. 18, T. 151 N., R. 87 W., Ward County.

U.Shale
8269-39 Shale, grayish black (N2) to brownish black (5 YR 4/1), non-calcareous, finely laminated, conchoidal fracture at 8638, pyrite (disseminated to concentrated), conodont concentration at 8637, woody plant fragment at 8631.

Mid.Mem.
8639-48 Siltstone, sandstone, limestone, medium light gray (N6) to light gray (N7), bioturbated at 8639 and 8642, mostly laminated, scour (?), microfaults, pyrite, brachiopod fragments.

8648-51 Sandstone, light gray (N7), highly calcareous, even bedded to massive, few brachiopods.

8651-61 Siltstone, mostly dark gray (N3) to medium dark gray (N4), highly calcareous, wavy discontinuous to continuous laminae (1 mm), pyrite.

L.Shale
8661-67 Shale, dark gray (N3) to dark greenish gray (5 GY 4/1) non-calcareous, finely laminated, nearly conchoidal fracture common, healed fractures, pyrite (mostly concentrated), conodonts.

8474. Tenneco Oil Co. - Graham USA #1-15, NE¼SW¼ Sec. 15, T. 144 N., R. 102 W., Billings County.

Lple.Fm.	
10159-61	Limestone, medium gray (N5), mottled, pelmatozoans.
U Shale	
10361-69	Shale, grayish black (N2), non-calcareous, finely laminated, pyritic, conodonts, wavy laminae and brachiopods at 10366; blocky fracture, silty, slightly calcareous (10366 to 10367).
Mid.Mem.	
10369-74	Siltstone, medium gray (N4) to medium dark gray (N5), calcareous to non-calcareous, well-laminated beds (0.25 inches, 0.7 cm) in part, mostly weakly bedded, pyrite, well-preserved brachiopods at 10369, gastropods (?); more sandy and calcareous at 10373.
9351.	Supron Energy Corp. - Federal #3, NW¼SE¼ Sec. 6, T. 144 N., R. 101 W., Billings County.
U.Shale	
10449-56	Shale, grayish black (N2) mostly non-calcareous, pyrite (finely disseminated to nodular), conodonts.
Mid.Mem.	
10456-57	Siltstone, shale, grayish black (N2) to medium dark gray (N4), calcareous, gradational to above and below, brachiopod fragments.
10457-69.5	Siltstone, sandstone, medium dark gray (N4) to medium light gray (N6), calcareous, laminated to mottled, some truncated laminae, lighter beds more sandy, pyrite, disarticulated brachiopods common.
L.Shale	
10469.5-70	Shale, black (N1), non-calcareous; abundant conodonts, phosphatic particles, fish parts, pyrite, overlying irregular and abrupt contact with Three Forks Formation at 10470.
T.Fks.Fm.	
10470-72	Shale, siltstone, greenish gray (5 GY 6/1), medium light gray (N5) to medium gray (N6), mostly dolomitic, bioclasts.

REFERENCES CITED

REFERENCES CITED

Achauer, C. W., 1959, Stratigraphy and microfossils of the Sappington Formation in southwestern Montana: Billings Geological Society, 10th Annual Field Conference, Guidebook, p. 41-49.

Anderson, W. L., 1966, Upper Devonian conodonts and the Devonian-Mississippian boundary of north-central Iowa: Journal of Paleontology, v. 40, no. 2, p. 395-415, 5 pls.

Anderson, S. B., and Bluemle, J. P., 1982, Oil exploration and development in the North Dakota Williston Basin: 1981 update: North Dakota Geological Survey Miscellaneous Series no. 62, 22 p.

Austin, R. L., Bergström, S. M., Clark, D. L., Klapper, Gilbert, and Rhodes, F. H. T., 1981, Family unknown, in Robison, R. A., ed., Treatise on invertebrate paleontology, Part W, Miscellanea Supplement 2: Boulder, Colorado and Lawrence, Kansas, The Geological Society of America and The University of Kansas, p. W172-W179.

Austin, R. L., and Rhodes, F. H. T., 1981, Family Elictognathidae, in Robison, R. A., ed., Treatise on invertebrate paleontology, Part W, Miscellanea Supplement 2: Boulder, Colorado, and Lawrence, Kansas, The Geological Society of America and The University of Kansas, p. W170-W172.

Ballard, F. V., 1963, Structural and stratigraphic relationships in the Paleozoic rocks of eastern North Dakata: North Dakota Geological Survey Bulletin 40, 42 p.

Bassler, R. S., 1925, Classification and stratigraphic use of the conodonts: Geological Society of America Bulletin, v. 36, p. 218-220.

Berry, G. W., 1943, Stratigraphy and structure at Three Forks, Montana: Geological Society of America Bulletin, v. 54, no. 1, p. 1-30.

Bjorlie, P. F., 1979, The Carrington Shale facies (Mississippian) and its relationship to the Scallion subinterval in central North Dakota: North Dakota Geological Survey Report of Investigation 67, 46 p.

Bluemle, J. P., Anderson, S. B., and Carlson, C. G., 1980, North Dakota stratigraphic column: North Dakota Geological Survey.

Branson, E. B., and Mehl, M. G., 1933, Conodonts from the Bainbridge (Silurian) of Missouri: University of Missouri Studies, v. 8, no. 1, p. 39-52, 3 pls.

Branson, E. B., and Mehl, M. G., 1933 [1934a], Conodonts from the Grassy Creek shale of Missouri: University of Missouri Studies, v. 8, no. 3, p. 171-259, pls. 13-21.

-----1933[1934b], Conodonts from the Bushburg sandstone and equivalent formations of Missouri: University of Missouri Studies, v. 8, no. 4, p. 265-299, pls. 22-24.

-----1941, New and little known Carboniferous conodont genera: Journal of Paleontology, v. 15, p. 97-106.

-----1944, Conodonts, in Shimer, H. W., and Shrock, R. R., Index fossils of North America: New York, Wiley, p. 235-246.

Branson, E. R., 1933[1934], Conodonts from the Hannibal formation of Missouri: University of Missouri Studies, v. 8, no. 4, p. 301-334, pls. 25-28.

Brindle, J. E., 1960, Mississippian megafaunas in southeastern Saskatchewan: Saskatchewan Department of Mineral Resources Report 45, 107 p., 29 pls.

Christopher, J. E., 1961, Transitional Devonian-Mississippian formations of southern Saskatchewan: Saskatchewan Department of Mineral Resources Report 66, 103 p.

Clarke, D. L., 1981, Paleoecology, in R. A., Robison, ed., Treatise on invertebrate paleontology, Part W, Miscellanea Supplement 2: Boulder, Colorado, and Lawrence, Kansas, The Geological Society of America and The University of Kansas, p. W87-W92.

Conkin, J. E., and Conkin, B. M., 1973, The paracontinuity and determination of the Devonian-Mississippian boundary in the Lower Mississippian type area of North America: University of Louisville Studies in Paleontology and Stratigraphy, no.1, 36 p.

Cooper, C. L., 1939, Conodonts from a Bushberg-Hannibal horizon in Oklahoma: Journal of Paleontology, v. 13, no. 4, p. 379-422, pls. 38-47.

Cooper, C. L., and Sloss, L. L., 1943, Conodont fauna and distribution of a Lower Mississippian black shale in Montana and Alberta: Journal of Paleontology, v. 17, no. 2, p. 168-176, pls. 28, 29.

Crickmay, C. H., 1952, Discrimination of late Upper Devonian: Journal of Paleontology, v. 26, p. 585-609.

Demaison, G. J., and Moore, G. T., 1980, Anoxic environments and oil source bed genesis: American Association of Petroleum Geologists Bulletin, v. 64, no. 8, p. 1179-1209.

Dow, W. G., 1974, Application of oil-correlation and source-rock data to exploration in Williston Basin: American Association of Petroleum Geologists Bulletin, v. 58, no. 7, p. 1253-1262.

Duffield, S. L., and Warshauer, S. M., 1979, Two-step process for extraction of microfossils from indurated organic shales: Journal of Paleontology, v 53, no. 3, p. 747-748.

Epstein, A. G., Epstein, J. B., and Harris, L. D., 1977, Conodont color alteration--an index to organic metamorphism: U. S. Geological Survey Professional Paper 995, 27 p.

Fuller, J. G. C. M., 1956, Mississippian rocks and oilfields in southeastern Saskatchewan: Saskatchewan Department of Mineral Resources Report 19, 42 p.

Gerhard, L. C., Anderson, S. B., LeFever, J.A. , and Carlson, C. G., 1982, Geological development, origin, and mineral resources of Williston Basin, North Dakota: American Association of Petroleum Geologists Bulletin, v. 66, no. 8, p. 989-1020.

Goddard, E. N., Trask, P. D., DeFord, R. K., Rove, O. N., Singewald, J. T., Jr., and Overbeck, R. M., 1948, Rock Color Chart: New York, The Geological Society of America.

Gutshick, R. C., McLane, Michael, and Rodriguez, Joaquin, 1976, Summary of Late Devonian-Early Mississippian biostratigraphic framework in western Montana, in 1976 Field Conference Guidebook: Tobacco Root Geological Society, Special Publication 73, p. 91-124.

Gutshick, R. C., and Moreman, W. L., 1967, Devonian-Mississippian boundary relationships along the cratonic margin of the United States, in Oswald, D. H., ed., International Symposium Devonian System, Calgary, Alberta: Alberta Society of Petroleum Geologists, v. 2, p. 1892-1899.

Gutshick, R. C., Suttner, L. J., and Switek, M. J., 1962, Biostratigraphy of transitional Devonian-Mississippian Sappington Formation of southwest Montana, in The Devonian System of Montana and adjacent areas-- a symposium: Billings Geological Society, 13th Annual Field Conference, Guidebook, p. 79-89.

Gutshick, R. C., and Rodriguez, Joaquin, 1979, Biostratigraphy of the Pilot Shale (Devonian-Mississippian) and contemporaneous strata in Utah, Nevada, and Montana: Brigham Young University Geology Studies, v. 26, pt. 1, p. 37-63.

Harris, A. G., 1981, Color and alteration: an index to organic metamorphism in conodont elements, in Robison, R. A., ed., Treatise on invertebrate paleontology, Part W, Miscellanea Supplement 2: Boulder, Colorado, and Lawrence, Kansas, The Geological Society of America and The University of Kansas, p. W56-W60.

Hass, W. H., 1943, Corrections to the Kinderhook conodont fauna, Little Rocky Mountains, Montana: Journal of Paleontology, v. 17, no. 3, p. 307-308.

-----1959, Conodonts from the Chappel Limestone of Texas: U. S. Geological Survey Professional Paper 294-J, p. 365-369, pls. 46-50.

Heck, T. J., 1979, Depositional environments and diagenesis of the Bottineau interval (Lodgepole) in North Dakota: unpublished M.S. Thesis, University of North Dakota, 227 p.

Heckel, P. H., 1977, Origin of phosphatic black shale facies in Pennsylvanian cyclothems of Mid-Continent North America: American Association of Petroleum Geologists Bulletin, v. 61, no. 7, p. 1045-1068.

Heckel, P. H., and Witzke, B. J., 1979, Devonian world paleogeography determined from distribution of carbonates and related lithic paleoclimatic indicators, in House, M. R., Scrutton, C. T., and Bassett, M. G., eds., The Devonian System: Palaeontological Association Special Papers in Palaeontology, no. 23, p. 99-123.

Hester, T. C., and Schmoker, J. W., 1983, Preliminary log-derived maps of the Bakken Formation, North Dakota and Montana portions of Williston Basin: U. S. Geological Survey Open-file Report 83-717, 125 p.

Hinde, G. J., 1879, On conodonts from the Chazy and Cincinnati Group of the Cambro-Silurian, and from the Hamilton and Genesee-Shale divisions of the Devonian, in Canada and the United States: Geological Society of London, Quarterly Journal, v. 35, p. 351-369.

Holland, F. D., Jr., 1952, Stratigraphic details of Lower Mississippian rocks of northeastern Utah and southwestern Montana: American Association of Petroleum Geologists Bulletin, v. 36, no. 9, p. 1697-1734.

Huddle, J. W., 1934, Conodonts from the New Albany Shale of Indiana: Bulletins of American Paleontology, v. 21, no. 72, p. 186-325, 12 pls.

-----1968, Redescription of Upper Devonian conodont genera and species proposed by Ulrich and Bassler in 1926: U. S. Geological Survey Professional Paper 578, 55 p., 17 pls.

Kents, P., 1959, Three Forks and Bakken stratigraphy in west central Saskatchewan: Saskatchewan Department of Mineral Resources Report 37, 37 p.

Klapper, Gilbert, 1966, Upper Devonian and Lower Mississippian conodont zones in Montana, Wyoming, and South Dakota: The University of Kansas Paleontological Contributions, Paper 3, 43 p., 6 pls.

-----1971, Patrognathus and Siphonodella (Conodonta) from the Kinderhookian (Lower Mississippian) of western Kansas and southwestern Nebraska: Kansas State Geological Survey Bulletin 202, pt. 3, 14 p., pls. 1, 2.

-----1973, Siphonodella, in Ziegler, Willi, ed., Catalogue of conodonts: V. 1, Stuttgart, Schweizerbart'sche, p. 451-470.

-----1975a, Polygnathus, in Ziegler, Willi, ed., Catalogue of conodonts: V. 2, Stuttgart, Schweizerbart'sche, p. 275-328.

-----1975b, Siphonodella, in Ziegler, Willi, ed., Catalogue of conodonts: V. 2, Stuttgart, Schweizerbart'sche, p. 345-358.

-----1981, Pseudopolygnathus, in Ziegler, Willi, ed., Catalogue of conodonts: V. 4, Stuttgart, Schweizerbart'sche, p. 355-408.

Klapper, Gilbert, Austin, R. L., and Rhodes, F. H. T., 1981, Family Polygnathidae, in Robison, R. A., ed., Treatise on invertebrate paleontology, Part W, Miscellanea Supplement 2: Boulder, Colorado, and Lawrence, Kansas, The Geological Society of America and The University of Kansas, p. W162-W166.

Klapper, Gilbert, and Bergstrom, S. M., 1981, Family Hibbardellidae, in Robison, R. A., ed., Treatise on invertebrate paleontology, Part W, Miscellanea Supplement 2: Boulder, Colorado, and Lawrence, Kansas, The Geological Society of America and The University of Kansas, p. W148-W150.

Klapper, Gilbert, and Furnish, W. M., 1962, Devonian-Mississippian Englewood Formation in Black Hills, South Dakota: American Association of Petroleum Geologists Bulletin, v. 46, no. 11, p. 2071-2078.

Klapper, Gilbert, and Phillip, G. M., 1971, Devonian conodont apparatuses and their vicarious skeletal elements: Lethaia, v. 4, p. 429-452.

Knechtel, M. M., and Hass, W. H., 1938, Kinderhook conodonts from Little Rocky Mountains, northern Montana: Journal of Paleontology, v. 12, p. 518-520.

Knechtel, M. M., Smedley, J. E., and Ross, R. J., Jr., 1954, Little Chief Canyon Member of Lodgepole Limestone of Early Mississippian age in Montana: American Association of Petroleum Geologists Bulletin, v. 38, no. 11, p. 2395-2400.

Kume, Jack, 1963, The Bakken and Englewood Formations of North Dakota and northwestern South Dakota: North Dakota Geological Survey Bulletin 39, 87 p.

Laird, W. M., 1956, The Williston Basin--a backward look with a view to the future: North Dakota Geological Society and Saskatchewan Geological Society, 1st International Williston Basin Symposium, p. 14-22.

Lineback, J. A., and Davidson, M. L., 1982, The Williston Basin--Sediment-starved during the Early Mississippian, in Kaldi, J., and Christopher, J. E., eds., Saskatchewan Geological Society and North Dakota Geological Society, 4th International Williston Basin Symposium: Saskatchewan Geological Society Special Publication No. 6, p. 125-130.

MacDonald, G. H., 1956, Subsurface stratigraphy of the Mississippian rocks of Saskatchewan: Geological Survey of Canada Memoir 282, 46 p.

Macqueen, R. W., and Sandberg, C. A., 1970, Stratigraphy, age, and interregional correlation of the Exshaw Formation, Alberta Rocky Mountains: Canadian Petroleum Geology Bulletin, v. 18, no. 1, p. 32-66.

McCabe, H. R., 1959, Mississippian stratigraphy of Manitoba: Manitoba Department of Mines and Natural Resources Publication 58-1, 99 p.

McGugan, Alan, 1965, Occurrence and peristence of thin shelf deposits of uniform lithology: Geological Society of America Bulletin, v. 76, no. 1, p. 125-130.

Meissner, F. F., 1978, Petroleum geology of the Bakken Formation Williston Basin, North Dakota and Montana, in The economic geology of the Williston Basin: Montana Geological Society, 24th Annual Conference, Williston Basin Symposium, p. 207-227.

Müller, K. J., 1962, A conodont fauna from the Banff Formation, western Canada: Journal of Paleontology, v. 36, p. 1387-1391.

Murray, G. H., Jr., 1968, Quantitative fracture study--Sanish pool, McKenzie County, North Dakota: American Association of Petroleum Geologists Bulletin, v. 52, no. 1, p. 57-65.

Nordquist, J. W., 1953, Mississippian stratigraphy of northern Montana: Billings Geological Society, 4th Annual Field Conference, Guidebook, p. 68-82.

Norris, G. E, 1981, Conodonts and biostratigraphy of Mississippian Brazer Dolomite, Crawford Mountains Utah: Journal of Paleontolgy, v. 55, no. 6, p. 1270-1283, 2 pls.

Parrish, J. T., 1982, Upwelling and petroleum source beds with reference to Paleozoic: American Association of Petroleum Geologists Bulletin, v. 66, no. 6, p. 750-774.

Penner, D. G., 1958, Mississippian stratigraphy of southern Alberta Plains, in Goodman, A. J., ed., Jurassic and Carboniferous of western Canada: American Association of Petroleum Geologists, John Andrew Allan Memorial Volume, p. 260-288.

Phillipi, G. T., 1965, On the depth, time, and mechanism of petroleum generation: Geochimica et Cosmochimica Acta, v. 29, no. 9, p. 1021-1049.

Puchkov, V. N., Klapper, Gilbert, and Mashkova, T. V., 1982, Natural assemblages of Palmatolepis from the upper Devonian of the northern Urals: Acta Palaeontologica Polonica, v. 26, no. 314, p. 281-298 (date of imprint 1981).

Raasch, G. O., 1956, Late Devonian and/or Mississippian faunal succession in Stettler area, Alberta: Alberta Society of Petroleum Geologists Journal, v. 4, no. 5, p. 112-118.

Reasoner, M. A., and Hunt, A. D., 1954, Structure of Coleville-Buffalo Coulee area, Saskatchewan: American Association of Petroleum Geologists Bulletin, v. 38, no. 10, p. 1535-1551.

Rexroad, C. B., 1969, Conodonts from the Jacobs Chapel Bed (Mississippian) of the New Albany Shale in southern Indiana: Indiana Geological Survey Bulletin, v. 41, 55 p., 9 pls.

Rexroad, C. B., and Scott, A. J., 1964, Conodont zones in the Rockford Limestone and lower part of the New Providence Shale (Mississippian) in Indiana: Indiana Geological Survey Bulletin no. 30, 54 p., 3 pls.

Rhoads, D. C., and Morse, J. W., 1971, Evolution and ecologic significance of oxygen-deficient marine basins: Lethaia, v. 4, p. 413-428.

Rhodes, F. H. T., and Müller, K. J., 1956, The conodont genus Prioniodus and related forms: Journal of Paleontology, v. 30, no. 3, p. 695-699.

Rich, J. L., 1951, Probable fondo origin of Marcellus-Ohio-New Albany-Chattanooga bituminous shale: American Association of Petroleum Geologists Bulletin, v. 35, p. 2017-2040.

Sandberg, C. A., 1962a, Geology of the Williston Basin, North Dakota, Montana, and South Dakota with reference to subsurface disposal of radioactive waste: U. S. Depatment of the Interior, TEI-809, 148 p.

-----1962b, Stratigraphic section of type Three Forks and Jefferson Formations at Logan, Montana, in Symposium, The Devonian System of Montana and adjacent areas: Billings Geological Society, 13th Annual Field Conference, Guidebook, p. 47-50.

-----1963, Dark shale unit of Devonian and Mississippian age in northern Wyoming and southern Montana: U. S. Geological Survey Professional Paper 475-C, art. 64, p. 17-20.

-----1965, Nomenclature and correlation of lithologic subdivisions of the Jefferson and Three Forks Formations of southern Montana and northern Wyoming: U. S. Geological Survey Bulletin, 1194-N, 18 p.

-----1969, Conodont-rich lag deposits: A tool for dating Late Devonian and Early Mississippian structural movement and oil migration in the northern Rocky Mountains region, in Abstracts for 1968: Geological Society of America Special Paper 121, p. 633.

-----1976, Conodont biofacies of Late Devonian _Polygnathus_ _styriacus_ Zone in western United States, _in_ Barnes, C. R., ed., Conodont Paleoecology: Geological Association of Canada Special Paper 15, p. 171-186.

-----1979, Devonian and Lower Mississippian condont zonation of the Great Basin and Rocky Mountains, _in_ Sandberg, C. A., and Clarke, D. L., eds., Conodont biostratigraphy of the Great Basin and Rocky Mountains: Brigham Young University, Geology Studies, v. 26, pt. 3, p. 87-106.

Sandberg, C. A., and Gutshick, R. C., 1969, Stratigraphy and conodont zonation of type Leatham Formation (Devonian and Mississippian) Bear River Range, Utah: Geologic Society of America, Abstracts with Programs 1969, pt. 5, p. 70-71.

-----1979, Guide to conodont biostratigraphy of Upper Devonian and Mississippian rocks along the Wasatch Front and Cordilleran Hingeline, Utah, _in_ Sandberg, C. A., and Clarke, D. L., eds., Conodont biostratigraphy of the Great Basin and Rocky Mountains: Brigham Young University, Geology Studies, v. 26, pt. 3, p. 107-134.

-----1980, Sedimentation and biostratigraphy of Osagean and Meramecian starved basin and foreslope, western United States, _in_ Fouch, T. D., and Magathan, E. R., eds., Paleozoic paleogeography of the west-central United States: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Rocky Mountain Paleogeography Symposium 1, p. 129-147.

-----1983, Early carboniferous conodont biofacies and paleoecologic models [abs.]: Geological Society of America Abstracts with Programs, North-Central Section, p. 221.

Sandberg, C. A., Gutshick, R. C., Johnson, J. G., Poole, F. G., and Sando, W. J., 1983, Middle Devonian to Late Mississippian geologic history of the Overthrust belt region, western United States: Rocky Mountain Association of Geologists, Geologic Studies of the Cordilleran Thrust Belt, v. 2, p. 691-719.

Sandberg, C. A., and Hammond, C. R., 1958, Devonian system in Williston Basin and central Montana: American Association of Petroleum Geologists Bulletin, v. 42, no. 10, p. 2293-2334.

Sandberg, C. A., and Klapper, Gilbert, 1967, Stratigraphy, age, and paleotectonic significance of the Cottonwood Canyon Member of the Madison Limestone in Wyoming and Montana: U. S. Geological Survey Bulletin 1251-B, 70 p.

Sandberg, C. A., and Mapel, W. J., 1967, Devonian of the Northern Rocky Mountains and Plains, _in_ Oswald, D. H., ed., International Symposium on the Devonian System, Calgary, Alberta: Alberta Society of Petroleum Geologists, v. 1, p.843-877.

Sandberg, C. A., and Poole, F. G., 1977, Conodont biostratigraphy and depositional complexes of Upper Devonian cratonic-platform and continental-shelf rocks in the western United States, in Murphy, M. A., Berry, W. B. N., and Sandberg, C. A., eds., Western North America; Devonian: California University, Riverside, Campus Museum Contributions 4, p. 144-182.

Sandberg, C. A., Poole, F. G., and Gutshick, R. C., 1980, Devonian and Mississippian stratigraphy and conodont zonation of Pilot and Chainman Shales, Confusion Range, Utah, in Fouch, T. D., and Magathan, E. R., eds., Paleozoic paleogeography of the western United States: Rocky Mountain Section, Society of Economic Paleontologists and Mineralogists, Rocky Mountain Paleogeography Symposium 1, p. 71-79.

Sandberg, C. A., Streel, Maurice, Scott, R. A., 1972, Comparison between conodont zonation and spore assemblages at the Devonian-Carboniferous boundary in the western and central United States and in Europe: Congrès International de Stratigraphie et Géologie du Carbonifère, 7th, Krefeld, 1971, Compte Rendu, Maastricht, Ernst van Aelst, p. 179-203, 4 pls.

Sandberg, C. A., and Ziegler, Willi, 1979, Taxonomy and biofacies of important conodonts of Late Devonian styriacus -Zone, United States and Germany: Geologica et Palaeontologica, v. 13, p. 173-212, pls. 1-7.

Sandberg, C. A., Ziegler, Willi, Leuteritz, Klaus, and Brill, S. M., 1978, Phylogeny, speciation, and zonation of Siphonodella (Conodonta, Upper Devonian and Lower Carboniferous): Newsletters on Stratigraphy, v. 7, Stuttgart, Gebrueder Borntraeger, p. 102-120.

Sando, W. J., and Dutro, J. T., Jr., 1974, Type sections of the Madison Group (Mississippian) and its subdivisions in Montana: U. S. Geological Survey Professional Paper 842, 22 p.

Schmoker, J. W., and Hester, T. C., 1983, Organic carbon in Bakken Formation, United States portion of Williston Basin: American Association of Petroleum Geologists Bulletin, v. 67, no. 12, p. 2165-2174.

Shimer, H. W., and Shrock, R. R., 1944, Index fossils of North America: Cambridge, Massachusetts, The Massachusetts Institute of Technology Press, 837 p.

Spencer, A. C., 1917, The geology and ore deposits of Ely, Nevada: U. S. Geological Survey Professional Paper 96, p. 1-189.

Sweet, W. C., 1981a, Macromorphology of elements and apparatuses, in Robison, R. A., ed., Treatise on invertebrate paleontology, Part W, Miscellanea Supplement 2: Boulder, Colorado, and Lawrence, Kansas, The Geological Society of America and The University of Kansas, p. W5-W20.

-----1981b, Glossary of morphological and structural terms for conodont elements and apparatuses, in Robison, R. A., ed., Treatise on invertebrate paleontology, Part W, Miscellanea Supplement 2: Boulder, Colorado, and Lawrence, Kansas, The Geological Society of America and The University of Kansas, p. W60-W67.

Thode, H. G., 1981, Sulfur isotope ratios in petroleum research and exploration: Williston Basin: American Association of Petroleum Geologists Bulletin, v. 65, no. 9, p. 1527-1335.

Thomas, L. A., 1949, Devonian-Mississippian formations of southeast Iowa: Geological Society of America Bulletin, v. 60, p. 403-438, 4 pls.

Thompson, T. L., and Fellows, L. D., 1969[1970], Stratigraphy and biostratigraphy of Kinderhookian and Osagean (Lower Mississippian) rocks of southeastern Missouri and adjacent areas: Missouri Geological Survey and Water Resources, Report of Investigations no. 45, 263 p., 8 pls.

Thrasher, L. C., 1983, oral communication, University of North Dakota, Grand Forks, North Dakota.

Twenhofel, W. H., 1936, Marine unconformities, marine conglomerates, and thickness of strata: American Association of Petroleum Geologists Bulletin, v. 20, no. 6, p. 677-703.

Ulrich, E. O., and Bassler, R. S., 1926, A classification of toothlike fossils, conodonts, with descriptions of American Devonian and Mississippian species: United States National Museum Proceedings, v. 68, art. 12, 63 p., 11 pls.

Wang, C. Y., and Ziegler, Willi, 1982, On the Devonian-Carboniferous boundary in South China based on conodonts: Geologica et Palaeontologica, v. 16, p. 151-162, 2 pls.

Warren, P. S., 1937, Age of the Exshaw Shale in the Canadian Rockies: American Journal of Science, 5th Series, v. 33, p. 454-457.

Webster, R. L., 1982, Analysis of petroleum source rocks of the Bakken Formation (Devonian and Mississippian) in North Dakota: unpublished M.S. Thesis, University of North Dakota, 150 p.

Williams, J. A., 1974, Characterization of oil types in Williston Basin: American Association of Petroleum Geologists Bulletin, v. 58, no. 7, p. 1242-1252.

Ziegler, Willi, 1962, Taxonomie und phylogenie oberdevonischer Conodonten und ihre stratigraphische Bedeutung: Weisbadden, Landesamt Bodenforsch., heft 38, 166 p., 14 pls.

Ziegler, Willi, 1973, Palmatolepis, in Ziegler, Willi, ed., Catalogue of conodonts: V. 1, Stuttgart, Schweizerbart'sche, p. 255-314.

-----1975, Bispathodus, in Ziegler, Willi, ed., Catalogue of conodonts: V. 2, Stuttgart, Schweizerbart'sche, p. 13-56.

-----1977, Palmatolepis, in Ziegler, Willi, ed., Catalogue of conodonts: V. 2, Stuttgart, Schweizerbart'sche, p. 289-414.

Ziegler, Willi, Sandberg, C. A., and Austin, R. L., 1974, Revision of the Bispathodus group (Conodonta) in the Upper Devonian and Lower Carboniferous: Geologica et Palaeontologica, v. 8, p. 97-112, 3 pls.