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Stratigraphy of the Inyan Kara Formation (Lower Cretaceous) in the vicinity of the Nesson Anticline, northwestern North Dakota

Brad L. Wartman
University of North Dakota

STRATIGRAPHY OF THE INYAN KARA FORMATION (LOWER CRETACEOUS) IN THE VICINITY OF THE NESSON ANTICLINE, NORTHWESTERN NORTH DAKOTA

by

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Bachelor of Science, University of Kansas

A Thesis

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of the

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This thesis submitted by Brad L. Wartman in partial fulfillment of [th]e requirements for the degree of Master of Science from the University [o]f North Dakota is hereby approved by the Faculty Advisory Committee [u]nder whom the work was done.

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

A. William Johnson
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Permission

Title Stratigraphy of the Inyan Kara Formation (Lower Cretaceous) in the vicinity of the Nesson Anticline, northwestern North Dakota

Department Geology

Degree Master of Science

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Signature Brad L. Wartman

Date March 3, 1983

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ABSTRACT

The Lower Cretaceous Inyan Kara Formation, at the base of the Dakota Group, consists of sandstone, siltstone, shale, and coal. The stratigraphy of the Inyan Kara and facies relationships within the formation and with the underlying Swift and overlying Skull Creek Formations in the vicinity of the Nesson Anticline, northwestern North Dakota, were evaluated using 11 cross-sections, 163 borehole geophysical logs, and 1 well core.

The Inyan Kara can be differentiated on well logs into three members. The basal member,"A", consists of sandstone, siltstone, shale, and coal. It is about 200 feet (60 m) to 400 feet (122 m) thick in the study area. The member is characterized by abrupt facies changes of sandstone units. Log patterns in "A" suggest that the lower portion of the member was deposited in a dominantly deltaic environment whereas the upper portion of "A" was deposited in a dominantly fluvial environment. The member is approximately equivalent to the Lakota Formation in the Black Hills of South Dakota.

The middle member,"B", consists of sandstone, siltstone, and shale. It is about 20 feet (6 m) to 150 feet (46 m) thick in the study area. The member is characterized by gradual facies changes. Log patterns suggest that member "B" was deposited in a marginal-marine environment. The member is approximately equivalent to the Fall River Formation in the Black Hills.

The upper member,"C", consists of interbedded siltstone and shale. It is about 15 feet (4.5m) to 40 feet (12 m) thick in the study area. The member is characterized by a lack of facies changes. The extent, continuity, and lithologies in "C" suggest that the member was deposited in a shallow marine environment. The member is approximately equivalent to the lower portion of the Skull Creek Formation in the Black Hills.

Facies relationships suggest that the upper portion of the Swift Formation and the lower portion of member "A" represent a regressional sequence in the study area whereas the upper portion of member "A", members "B" and "C", and the Skull Creek Formation represent a transgressional sequence in the study area.

Thickness trends of members "A", "B", and "C" suggest that the Williston Basin and the Little Knife Anticline were active structures during the deposition of the Inyan Kara, that the direction of regression was from east to west, and that the direction of transgression was from west to east in the study area.

Evidence for an unconformity between the Swift and Inyan Kara Formations, as proposed by previous workers, in the study area is possibly ambiguous and inconclusive. Additional evidence suggests that both conformable and unconformable contacts exist between the Swift and the Inyan Kara.

INTRODUCTION

In 1979, the North Dakota Geological Survey, in a co-operative effort with the Department of Energy, Division of Geothermal Energy, began a multi-year study to assess the hydrothermal potential of regional aquifers in the state. Preliminary results of regional studies indicated that the Inyan Kara Formation was one of the most promising aquifers, with good potential for development as a low-temperature hydrothermal resource (Harris and others 1981). The present study was undertaken to provide a more detailed understanding of the formation in the northwestern part of the state.

Purpose of Study

In this study, work on the Inyan Kara was directed towards five purposes:

(1) To determine the lithology and thickness of the Inyan Kara Formation in northwestern North Dakota.

(2) To evaluate the presence and extent of members within the Inyan Kara in northwestern North Dakota.

(3) To interpret possible facies relationships of these members.

(4) To evaluate the equivalence of members of the Inyan Kara in northwestern North Dakota to rock-stratigraphic units in the type area, the Black Hills of South Dakota.

(5) To interpret possible depositional environments of members within the Inyan Kara in northwestern North Dakota.

Geologic Setting

Stratigraphy

In North Dakota, the Inyan Kara Formation is the basal unit in a series of clastics that form the Lower Cretaceous Dakota Group (Fig. 1). The formation is generally regarded to be unconformable with the underlying Swift Formation (Upper Jurassic) and in transitional contact with the overlying Skull Creek Formation (Hansen 1955, Anderson 1982).

The Inyan Kara consists of sandstone, shale, siltstone, and coal (Hansen 1955). Deposition of the formation is generally regarded to have been in environments varying from non-marine to marine (Butler 1981, Anderson 1982).

Regional Structures

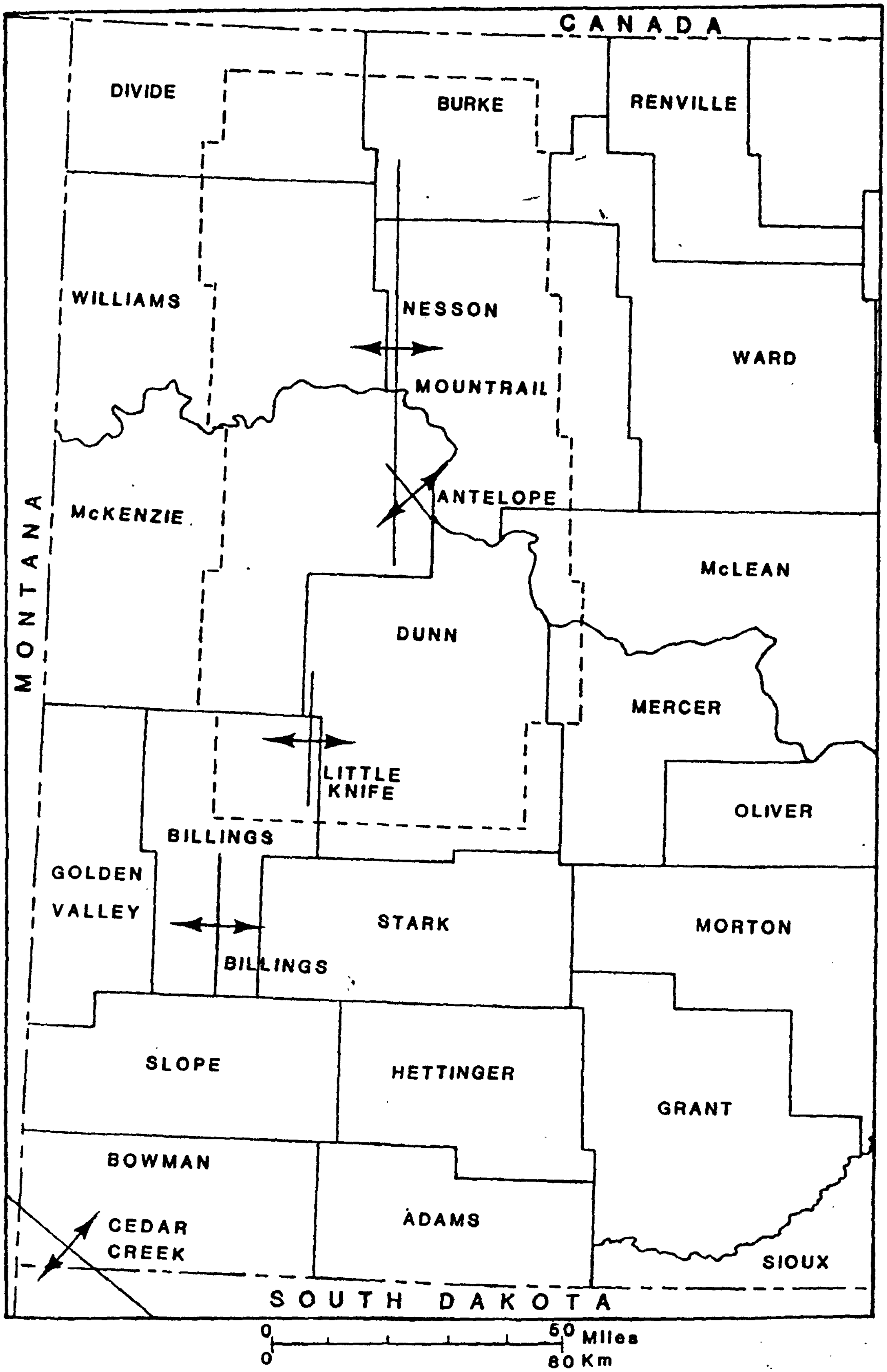
Structures in North Dakota are largely restricted to the western two-thirds of the state. The largest structure is the Williston Basin, which covers North Dakota and extends into South Dakota, Montana, Saskatchewan, and Manitoba (Gerhard and others, 1982). Regional dips in the Basin are towards the west-central portion of North Dakota.

Five major anticlines are present in the Williston Basin. The Billings Anticline, Little Knife Anticline, and Nesson Anticline trend north-south. The Cedar Creek Anticline and Antelope Anticline trend northwest-southeast (Fig. 2).

Figure 1. Stratigraphic column of the Dakota Group (modified from Bluemle and others 1981).

Series	Group	Formation
U. Cretaceous	Colorado	Belle Fourche
L. Cretaceous	Dakota	Mowry
		Newcastle
		Skull Creek
		Inyan Kara
U. Jurassic		Swift

Figure 2. Location of major anticlinal features in western North Dakota (modified from Gerhard and others 1982). Study area is shown by dashed line.


CANADA
DIVIDE
BURKE
RENVILLE
WILLIAMS
NESSON
MOUNTRAIL
WARD
MONTANA
McKENZIE
ANTELOPE
McLEAN
DUNN
MERCER
LITTLE
KNIFE
OLIVER
BILLINGS
GOLDEN
VALLEY
STARK
MORTON
BILLINGS
SLOPE
HETTINGER
GRANT
BOWMAN
ADAMS
CEDAR
CREEK
SIOUX
SOUTH DAKOTA
0
50 Miles
0
80 Km

Location of Study Area

The area of study for this project covers approximately 7,524 square miles (19,487 square kilometers) in northwestern North Dakota (Figs. 2 and 3). The study area was chosen for two reasons:

(1) The density of oil and gas wells drilled in the region is high, allowing for detailed formation correlation, by relatively close well spacing, on the order of a few miles.

(2) The area contains several structures, including the Nesson, Little Knife, and Antelope Anticlines and the central portion of the Williston Basin, which may have had an influence on the deposition of the Inyan Kara.

Previous Work

The stratigraphic nomenclature of the Inyan Kara and its lateral equivalents has undergone considerable change since its inception in the mid-1800s. The review of nomenclature in this study will concentrate on the work done in South Dakota, primarily in the Black Hills, and in North Dakota. Figure 4 is a summary of the units currently accepted as equivalent to the Inyan Kara in South Dakota, Montana, Saskatchewan, and Manitoba. Figure 5 summarizes stratigraphic terminology for units equivalent to the Inyan Kara in South Dakota, and Figure 6 shows stratigraphic terminology for the Inyan Kara in North Dakota.

Figure 3. Location of study area in northwestern North Dakota.

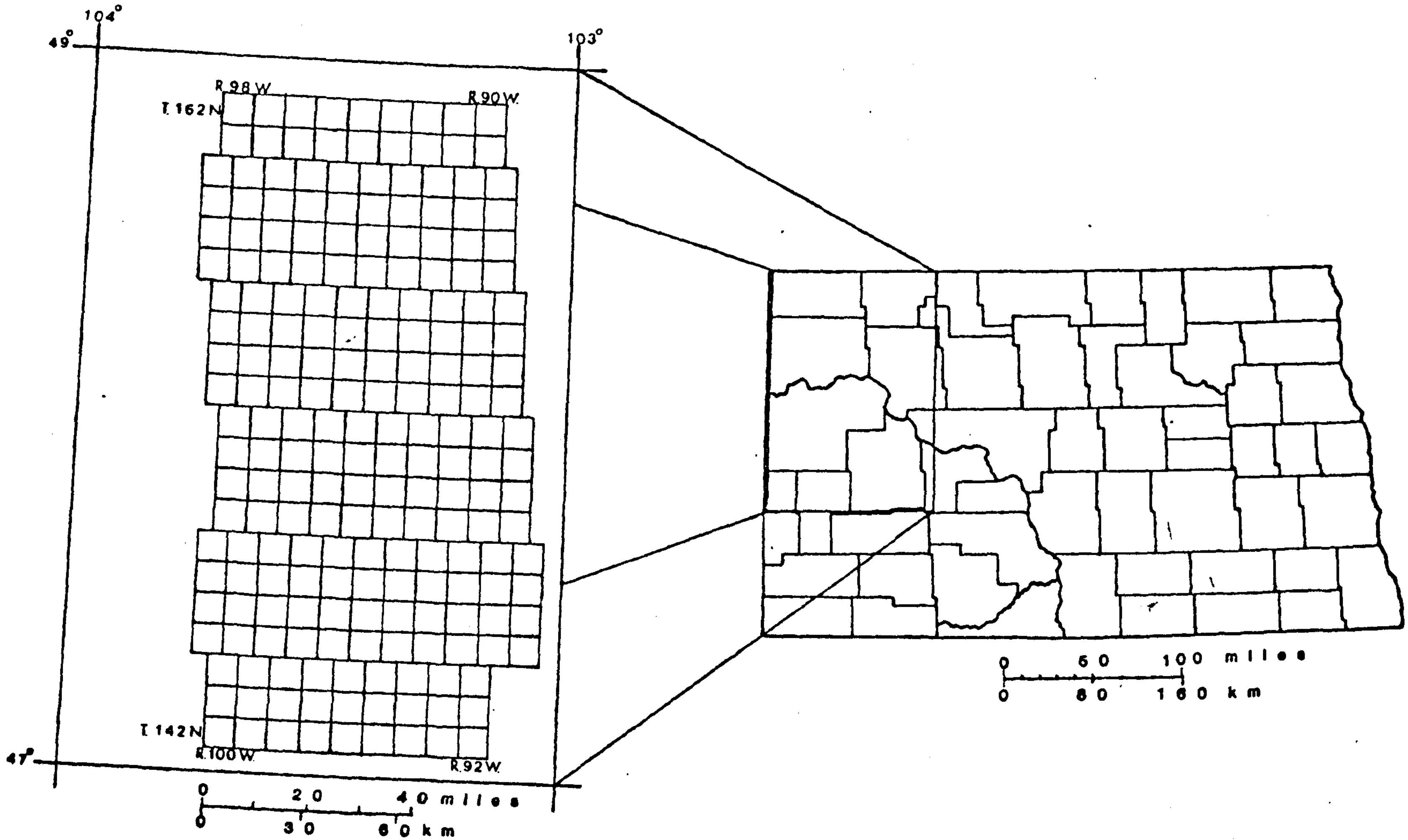

104°
49°
103°
R.98 W.
R.90 W.
T. 162 N.
T. 142 N.
R.100 W.
R.92 W.
47°
0 20 40 miles
0 30 60 km
0 50 100 miles
0 80 160 km

Figure 4. Stratigraphic units equivalent to the Inyan Kara Formation in areas surrounding North Dakota (modified from Bluemle and others 1981).

<table>
<tr><th>Montana</th><th>South Dakota</th><th colspan="2">North Dakota</th><th>Manitoba</th><th>Saskatchewan</th></tr>
<tr><td>Skull Creek</td><td>Skull Creek</td><td rowspan="5">Dakota Group (in part)</td><td>Skull Creek</td><td>Ashville</td><td>Joli Fou</td></tr>
<tr><td>"Basal Colorado Silt"</td><td rowspan="2">Fall River</td><td rowspan="4">Inyan Kara</td><td rowspan="4">Swan River</td><td rowspan="4">Cantuar</td></tr>
<tr><td>Dakota</td></tr>
<tr><td>Kootenai</td><td rowspan="2">Lakota</td></tr>
<tr><td>Lakota</td></tr>
<tr><td>Morrison</td><td>Morrison</td><td colspan="2">Swift</td><td>Waskada</td><td>Vanguard</td></tr>
</table>

Figure 5. Summary of nomenclatural history of units equivalent to the Inyan Kara Formation in South Dakota.

<table>
<tr><th>Meek and Hayden (1858)</th><th>Darton (1901,1909)</th><th>Russel (1928)</th><th colspan="2">Rubey (1930)</th><th colspan="2">Gries (1954)</th><th colspan="2">Waage (1959)</th><th>Rice (1976)</th><th>Bluemle and others (1981)</th></tr>
<tr><td>Unit no. 2 (Ft. Benton Gp.)</td><td>Ft. Benton Gp.</td><td>Graneros Shale</td><td colspan="2">Skull Creek</td><td rowspan="4">Dakota Gp. (in part)</td><td>Skull Creek</td><td colspan="2">Skull Creek</td><td>Skull Creek
"Basal silt"</td><td>Skull Creek</td></tr>
<tr><td rowspan="3">Basal no. 1 sand (Dakota)</td><td>Dakota</td><td>Fall River</td><td rowspan="3">Inyan Kara Gp.</td><td>Fall River</td><td>Fall River</td><td rowspan="3">Inyan Kara Gp.</td><td>Fall River</td><td>Fall River</td><td>Fall River</td></tr>
<tr><td>Fuson</td><td>Fuson</td><td>Fuson</td><td>Fuson</td><td rowspan="2">Lakota</td><td>Fuson</td><td rowspan="2">Lakota</td></tr>
<tr><td>Lakota</td><td>Lakota</td><td>Lakota</td><td>Lakota</td><td>Lakota</td></tr>
<tr><td>Beulah Shale</td><td>Beulah Shale</td><td>Morrison</td><td colspan="2">Morrison</td><td colspan="2">Morrison</td><td colspan="2">Morrison</td><td>Morrison</td><td>Morrison</td></tr>
</table>

Figure 6. Summary of nomenclatural history of the Inyan Kara Formation in North Dakota.

<table>
<tr><th>Kline (1942)</th><th colspan="2">Hansen (1955)</th><th colspan="2">Anderson and Carlson (1966)</th><th>Rice (1976)</th><th colspan="2">Bluemle and others (1981)</th><th colspan="3">This study</th></tr>
<tr><td rowspan="2">Ft. Benton Gp.</td><td rowspan="5">Dakota Gp. (in part)</td><td rowspan="2">Skull Creek</td><td rowspan="5">Dakota Gp. (in part)</td><td rowspan="2">Skull Creek</td><td>Skull Creek</td><td rowspan="5">Dakota Gp. (in part)</td><td rowspan="2">Skull Creek</td><td rowspan="5">Dakota Gp. (in part)</td><td colspan="2">Skull Creek</td></tr>
<tr><td>"Basal silt"</td><td rowspan="4">Inyan Kara Fm.</td><td>"C"</td></tr>
<tr><td>Dakota</td><td>Fall River</td><td>Fall River</td><td>Fall River</td><td rowspan="3">Inyan Kara</td><td>"B"</td></tr>
<tr><td>Fuson</td><td>Fuson</td><td rowspan="2">Lakota</td><td>Fuson</td><td rowspan="2">"A"</td></tr>
<tr><td>Lakota</td><td>Lakota</td><td>Lakota</td></tr>
<tr><td>Beulah Shale</td><td colspan="2">Morrison</td><td colspan="2">Swift</td><td>Swift</td><td colspan="2">Swift</td><td colspan="3">?
Swift</td></tr>
</table>

South Dakota.-- The first recorded reference to Cretaceous rocks in the Upper Midwest was made by Lewis and Clark in 1805 during their expedition to the Pacific Northwest (Schoon 1971). Near a campsite on the Missouri River, in what is now northeastern Nebraska, the expedition record described a cliff of buff-colored, massively-bedded sandstone that is now recognized as a part of the Dakota Formation.

In South Dakota, the first description of Cretaceous rocks was made by Meek and Hayden (1858), who were naturalists accompanying an Army expedition to the Black Hills, then a part of the Nebraska Territory. They described a sequence of light brown sandstones, variously colored shales, and beds of coal that they recognized as the basal Cretaceous strata in the Black Hills. Meek and Hayden correlated these strata to the "Basal Number One Sand" (Dakota Formation) that, earlier in the expedition, they had described and named in what is now northeastern Nebraska, near the town of Dakota City.

Newton and Jenny (1880) studied and described cycadophytes from the lower part of the Dakota Formation (of Meek and Hayden) and ascribed an age of Early Cretaceous to the strata.

Ward (1894, 1899) restudied the cycadophytes of the Dakota of the Black Hills. He concluded that the Dakota (of Meek and Hayden) could be divided into a lower member of Early Cretaceous age and an upper member--equivalent to the true "Dakota"--of Late Cretaceous age.

Darton (1901, 1909) correlated rock units from the Front Range of the Rocky Mountains to the Black Hills. He considered Meek and Hayden's Dakota Formation as consisting of three formations. He named his basal formation the Lakota, a sequence of coarse-grained, massive, and cross-bedded sandstones, with local conglomerates, 200-300 feet (60-91 m) thick. He noted the presence of fossils (cycadophytes and saurian bones), and stated that, on the basis of sedimentary structures, such as local channeling, the basal contact of the Lakota with the underlying Morrison Formation was unconformable. Darton named his middle formation, a sequence of nonfossiliferous clay and fine-grained sandstone averaging 100 feet (30 m) thick, the Fuson. He named the uppermost unit, a sequence of nonfossiliferous, fine-grained sandstones averaging 100 feet (30 m) thick, the Dakota. Darton concluded that the contact between the Dakota and Fuson represented a time-stratigraphic boundary separating the rocks of Early Cretaceous age (Lakota and Fuson) from rocks of Late Cretaceous age (Dakota) in the Black Hills.

Russel (1928) described fossils, mostly cycadophytes, that had been discovered recently in Darton's Dakota Formation, and concluded that Darton's Dakota was actually of Early Cretaceous age. To help alleviate the confusion that was arising in the use of the term "Dakota", Russel suggested that the name "Fall River Formation" be substituted for Darton's Dakota Formation.

Rubey (1930) measured and described several sections of the Lakota-Fall River interval in and around the Black Hills. He concluded that Darton's Fuson Formation did not extend outside of the area directly surrounding the Black Hills, and that the Lakota-Fall River interval should be combined together into the Inyan Kara Group.

Gries (1954) published the first subsurface correlations of Lower Cretaceous rocks in South Dakota using borehole geophysical logs. He correlated units from the Black Hills to the eastern part of the state nd southward into northeastern Nebraska. Gries said that the Dakota ormation in eastern Nebraska and South Dakota was represented in the stern part of the state by the Newcastle Formation. He said that the ocks of the Lakota-Fall River interval were not an extension of the kota Formation, but instead represented a separate period of position, with the sediments of the Dakota directly overlying the Fall ver in the eastern part of the state. Gries proposed that the term akota Group" be used to include all the strata of the Lakota-Newcastle terval.

Waage (1959) measured and described several sections of the Inyan a Group, including a few of Darton's original sections, in the Black ls. Waage concurred with Rubey's conclusion that Darton's Fuson ation was not correlatable outside of the Black Hills area. He her suggested that the term "Fuson" be dropped altogether, and that strata of Darton's Fuson be included in the Lakota Formation. Waage luded that the boundary between his Lakota and Fall River Formations esented a "transgressive disconformity" marked by a zone of abundant rite pellets.

Rice (1976, 1977) constructed cross-sections and correlation charts retaceous and Paleocene rocks in South Dakota. He correlated the s of the Lakota-Fall River interval, including the Fuson Formation, odified Russel's classification by dropping the term "Inyan Kara p". Rice recognized the Lakota Formation as the basal Cretaceous stone unconformably overlying rocks of Jurassic age, the Fall River e first sandstone directly underlying the Skull Creek Formation, he intervening strata as within the Fuson Formation.

Schoon (1971) and Bluemle and others (1981) have published stratigraphic charts that have modified Waage's classification by dropping the term "Inyan Kara Group" and retaining the Lakota and Fall River.

North Dakota.-- The nomenclatural history of Lower Cretaceous rocks in the state has generally paralleled the work done in South Dakota. The earliest classification in the state is that of Kline (1942), who in a general stratigraphic column of rock units in the Williston Basin, correlated Darton's Lakota, Fuson, and Dakota Formations with the basal Cretaceous sandstones and shales in the Basin.

Hansen (1955) modified Gries' Dakota Group to include the Mowry Formation, and renamed Kline's Dakota Formation the Fall River Formation. He constructed subsurface cross-sections of the Lakota-Greenhorn interval in the state using borehole geophysical logs, and included descriptions of drilling samples for the Lakota, Fuson, and Fall River Formations. Hansen described the Lakota Formation as a white to light gray, coarse to medium-grained sandstone with "shale streaks", and reaching a maximum thickness of 110 feet (34 m). He concluded that the Lakota was deposited as a sheet sandstone in a littoral environment and formed the basal facies of a transgressive sequence. Hansen described the Fuson Formation as a medium-gray to gray-black shale with lenses of very fine-grained, quartzose sandstone. Thickness of the Fuson was described as highly variable, with a maximum thickness of 80 feet (24 m) in the western part of the state. He concluded that the Fuson was deposited in an epineritic environment to the south and west of the transgressive Lakota Formation. The uppermost unit, the Fall

River Formation, was described by Hansen as an interbedded sequence of light gray, coarse to fine-grained, quartzose sandstone and gray, massively bedded, silty shale. Thickness of the Fall River was given as 30-210 feet (9-64 m), with the thickest part of the formation occurring in the west and thinning to the east. Hansen separated the depositional environments of the Fall River into two areas:

(1) In the southern part of the state, the Fall River was deposited under unstable shelf conditions varying from neritic to littoral and fluvial.

(2) In the northern part of the state, the Fall River was deposited in either a platform or deltaic environment, with transgression of the epicontinental Cretaceous sea from southwest to northeast in the state.

Anderson and Carlson (1966) followed Waage's classification by including the Fuson as a part of the Lakota Formation.

Rice (1976, 1977) published cross-sections and correlation charts of Cretaceous and Paleocene rocks extending across North Dakota, central and western South Dakota, and eastern Montana. He correlated the Lakota-Fall River interval, including the Fuson Formation, and modified Fussel's classification by dropping the term "Inyan Kara Group". Rice recognized the Lakota Formation as the basal sandstone unconformably overlying rocks of Jurassic age, the Fall River Formation as the first sandstone directly underlying the Skull Creek Formation, and the intervening strata as within the Fuson Formation.

The North Dakota Geological Survey, after examination of hundreds of well logs, concluded that the Lakota-Fuson-Fall River subdivision was ot applicable, and grouped all three formations into the Inyan Kara ormation (Bluemle and others 1981).

MATERIALS AND METHODS

Introduction

In the study area, information on the Inyan Kara was obtained from borehole geophysical logs (also known as well logs, wireline logs, or simply logs) and well core.

Interpretations of the extent and depositional environments of the Inyan Kara and its members were made from cross-sections, contour maps, and lithologic descriptions.

Borehole Geophysical Logs

Borehole geophysical logs were the most abundant data source available in the study area. Interpretations made from well logs were used to identify and correlate rock-stratigraphic boundaries and make qualitative assessments of lithology and depositional environments. In this study three types of well logs, the Gamma-Ray, Spontaneous Potential, and Focusing-Electrode (Laterolog), were used.

For each well log type, a short description of the parameters measured and applications of the log are given below. A more detailed description of each log type can be found in training manuals published by various logging companies (Schlumberger 1972, Dresser Atlas 1974, Welex 1978).

Gamma-Ray Log

The Gamma-Ray log measures the natural gamma-ray emissions produced by the decay of unstable isotopes of uranium, potassium, and thorium, which occur naturally in sediments. In this study, the Gamma-Ray log was used for two purposes:

(1) To correlate rock-stratigraphic units.

(2) To qualitatively estimate lithology for lithologic units greater than five feet (1.5 m) in thickness.

Spontaneous Potential Log

The Spontaneous Potential log measures the response of a formation to cation-anion movement along formation boundaries from an induced electrical current. In this study, The Spontaneous Potential log was used to aid the Gamma-Ray log in identifying and correlating sandstone units.

Focusing-Electrode Logs

The Focusing-Electrode logs are a suite of log types that measure formation resistivity at various distances into the formation by the projection of a current "beam". One type, the Laterolog, was chosen for use in this study because of its ability to resolve shallow and deep formation resistivities in thin beds (less than five feet (1.5 m) thick). In this study, two types of Laterologs were used:

(1) The Shallow Laterolog, used on the Dual Laterolog, measures the formation resistivity less than 6 feet (1.8 m) into the formation (invaded and flushed zones).

(2) The Deep Laterolog, used on the Dual Laterolog, Laterolog-3, and Laterolog-7, measures the resistivity at 9 to 15 feet (2.7 to 4.5 m) into the formation (true formation resistivity).

The Laterolog was used in this study for three purposes:

(1) To correlate rock-stratigraphic units.

(2) As a qualitative indicator of formation lithology.

(3) To provide a qualitative indication of formation permeability (Dual Laterolog only).

Lithologic Identification

Identification of lithologies on borehole geophysical logs is a matter of interpretation based on the response of a given lithology to the logging devices. In the Inyan Kara, a combination of the Gamma-Ray log and Dual Laterolog provided the best recognition of these lithologic types (Fig. 7):

(1) Sandstone

(a) Gamma-Ray log

(i) Low radioactivity level. Sandstones with a low shale content are called "clean"; those with a relatively high shale content are called "dirty".

(b) Spontaneous Potential log

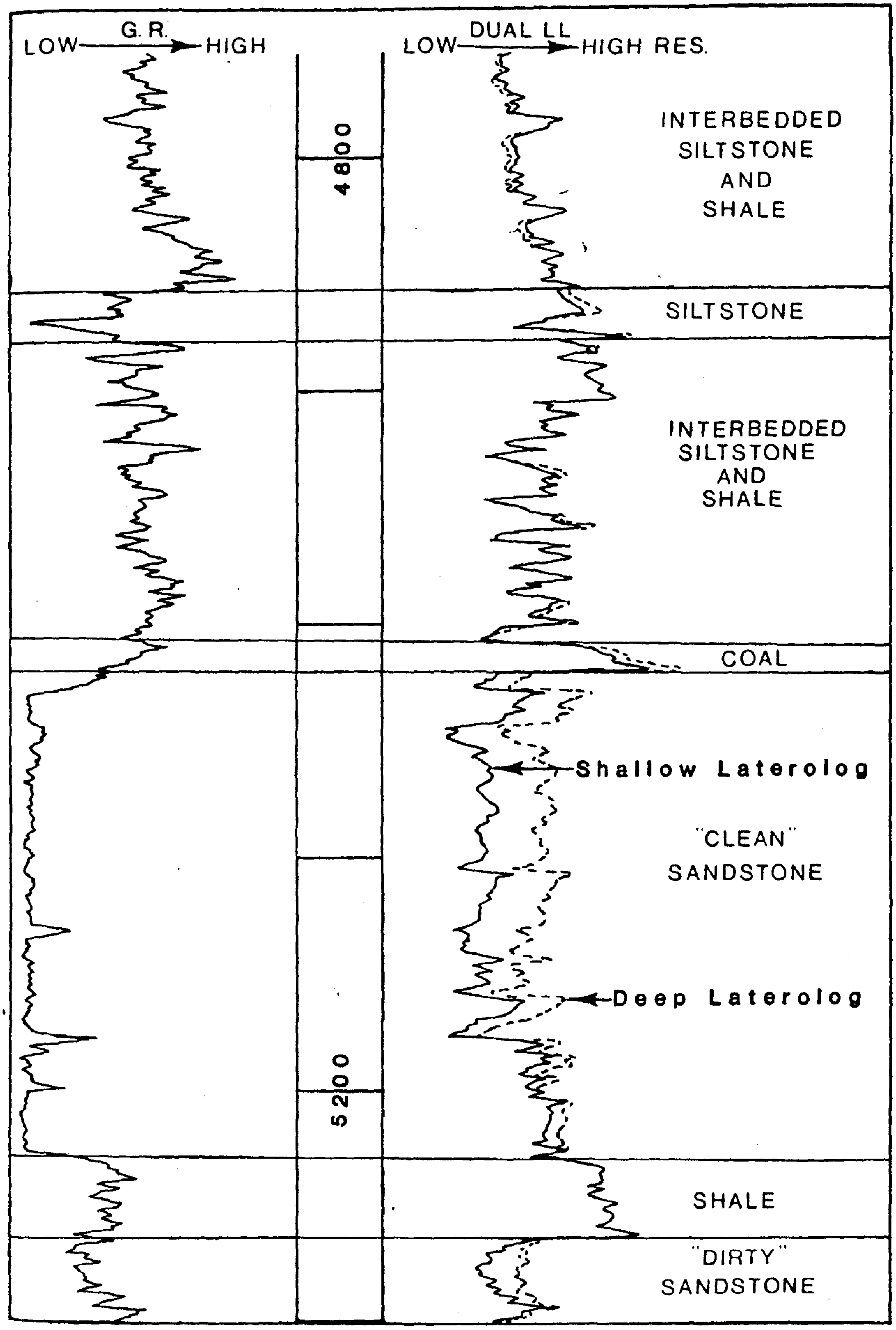
(i) Positive deflection of curve.

(c) Dual Laterolog

(i) Deep Laterolog resistivity is greater than the Shallow Laterolog. Separation of the Laterolog curves is generally wide.

(ii) Deep Laterolog resistivity tends to be low.

Figure 7. Gamma-Ray log and Dual Laterolog of the Inyan Kara Formation showing interpreted lithologies (NDGS 7226, Sec. 21, T. 155 N., R. 90 W.).


G.R.
LOW HIGH
DUAL LL
LOW HIGH RES.
4800
5200
INTERBEDDED SILTSTONE AND SHALE
SILTSTONE
INTERBEDDED SILTSTONE AND SHALE
COAL
Shallow Laterolog
"CLEAN" SANDSTONE
Deep Laterolog
SHALE
"DIRTY" SANDSTONE

(2) Siltstone

(a) Gamma-Ray log

(i) Low radioactivity (not diagnostic).

(b) Dual Laterolog

(i) Resistivity level variable, depending upon permeability, with values generally between those of sandstone and shale.

(ii) Narrow to moderate separation of shallow and deep resistivity values.

(3) Shale

(a) Gamma-Ray log

(i) Relatively high radioactivity level.

(b) Dual Laterolog

(i) High, generally uniform resistivity.

(ii) Little or no separation of shallow and deep resistivity values.

(4) Coal

(a) Gamma-Ray log

(i) Radioactivity level variable, with levels ranging from intermediary between sandstone and shale to greater than shale.

(b) Dual Laterolog

(i) Resistivity level is greater than or equal to shale.

(ii) Separation of shallow and deep resistivity values highly variable, depending upon the amount of fracturing (not diagnostic).

Well Core

Only one well in the study area, the Matthew Iverson 1 (Sec. 1, T. 155 N., R. 95 W.), NDGS 165, had recovered core from the Inyan Kara. Two intervals of the formation were cored (Fig. 8):

(1) Interval 1: 4980 to 4930 feet (1517 to 1502 m).

(2) Interval 2: 4647 to 4590 feet (1416 to 1399 m).

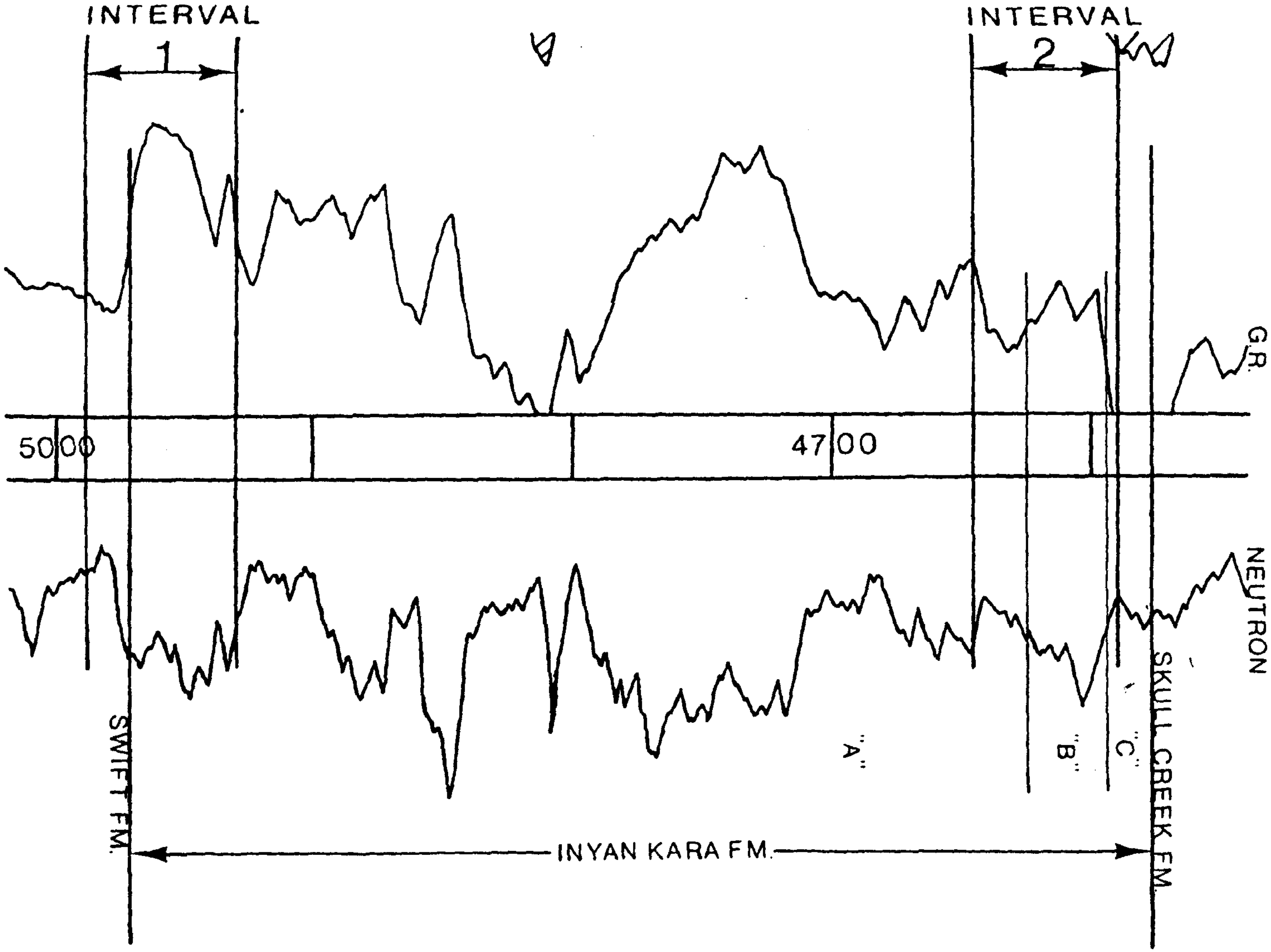
Drilling Samples

Although drilling samples were available for the Inyan Kara in the study area, the quality of these samples is questionable. Conversations with the personnel of oil and gas drilling rigs and wellsite geologists indicate that depth control and sample quality for formations younger than Jurassic are generally poor. Because of these discussions, it was decided not to include a description of any drilling samples in this study.

Cross-Sections

Correlation of the Inyan Kara Formation and its members in the study area was made from nine cross-sections, using logs from 94 wells (Plate I). Six cross-sections were oriented east-west with a spacing between sections of approximately four townships (Plates II-IV). The remaining three cross-sections were oriented north-south (Plates V and VI). Additional wells were used, where available, between logs in a given section to aid in correlation. The top of the Mowry Formation,

Figure 8. Well log of NDGS 165 (Sec. 1, T. 155 N., R. 95 W.) showing cored interval of the Inyan Kara Formation in relationship to members "A", "B", and "C".


INTERVAL
1
INTERVAL
2
G.R.
5000
4700
NEUTRON
SWIFT FM.
"A"
"B"
"C"
SKULL CREEK FM.
INYAN KARA FM.

which has a characteristic radioactivity pattern in the study area, was used as a stratigraphic datum.

Logs for the cross-sections were chosen using the following criteria:

(1) One well per township along the line of section, with a minimum well spacing of 2 miles (3.2 km).

(2) Resolution of log character as compared to other logs in the township.

In addition, two cross-sections were constructed for the Lone Butte and Stanley oil fields for detailed correlation of members and sandstone units of the Inyan Kara (Plate VII). Well spacing for these sections was less than one mile (1.6 km).

For both the regional and detailed cross-sections, correlation of stratigraphic units was based upon two criteria:

(1) Similar stratigraphic position between wells.

(2) Continuity of log character between wells.

The legal description of wells used in the cross-sections is given in Appendix A.

Contour Maps

Logs from 583 wells in the western one-third of the state were used to provide data for regional structure contour and isopach maps of the Inyan Kara (Plates VIII and IX) using a combination of equal spacing and interpretive contouring techniques (Bishop 1960). Wells (Appendix B) were chosen on the basis of one well per township.

Isopach maps of each member (Plates X-XII) of the Inyan Kara in the study area were made with logs from 163 wells. Wells (Appendix C) were chosen on the basis of one well per township.

Lithologic Descriptions

Lithologic descriptions of the Inyan Kara and its members were based on:

(1) Interpretations from well logs that provided qualitative information on general lithology.

(2) Hand sample descriptions of well core that provided information on lithology and sedimentary structures.

A description of well core is given in Appendix D.

RESULTS

Inyan Kara Formation

Identification of formation boundaries

Lower contact.-- In the study area, four types of contacts mark the base of the Inyan Kara:

(1) Abrupt transition from shale (Swift) to "clean" sandstone (Inyan Kara) (Well 45, Section E-E', Plate IV).

(2) Abrupt transition from a relatively low-resistivity shale (Swift) to a high-resistivity shale (Inyan Kara) (Well 83, Section H-H', Plate V).

(3) A gradational contact of interbedded sandstone and shale grading upwards into sandstone (Well 15, Section B--B', Plate II).

(4) A "clean" sandstone (Inyan Kara) overlying a "dirty" sandstone (Swift) (Well 23, Section H-H', Plate V).

In most parts of the study area, the contact is of type (1). Contacts of types (1) and (2) are relatively simple to identify and correlate. In the few areas where types (3) and (4) are present, the contact is recognized by correlating log markers in the Swift Formation from the log in question with log markers in logs from nearby wells. Correlation of log markers is continued upsection until units can no longer be correlated; the contact is then chosen at the boundary between the correlatable (Swift) and non-correlatable (Inyan Kara) units.

<u>Upper contact</u>.-- The upper contact of the Inyan Kara with the Skull Creek Formation is a gradational zone of interbedded siltstone and shale grading upwards into shale in all parts of the study area. In this zone the contact was chosen at the point where a distinctive "sawtooth" pattern of alternating high and low resistivity values appears on the Laterolog (Fig. 7) going down section.

Structure

The surface of the Inyan Kara varies from -2000 feet (-610 m) below sea level in the north-central portion of the study area to -3386 feet (-1032 m) in the west-central portion (Plate VIII).

The largest structure in the study area is the Williston Basin, which provides a regional dip towards the west-central portion. The Williston Basin extends outside of the study area to eastern North Dakota, southwestern Manitoba, southeastern Saskatchewan, eastern Montana, and northwestern South Dakota (Gerhard and others 1982).

The most prominent structure in the study area is the Nesson Anticline, which reaches a maximum elevation of -2190 feet (-667 m) in southeastern Williams County. The Nesson plunges southward from the northern border of the study area, covering an area of approximately 750 square miles (1942 square kilometers). The western flank of the Nesson is steep, with a dip of approximately 900 feet/mile (170 m/km).

The Little Knife Anticline, in the southwestern portion of the study area, trends north-south but produces little structural relief.

The Antelope Anticline trends northwest-southeast and intersects the southeastern corner of the Nesson Anticline.

There are three unnamed structures in the study area that occur in Dunn County. In the northwestern portion of the county, two depressions trend northeast-southwest. In the southeastern portion of the county, a positive structure trends northwest-southeast, plunging to the northwest.

Thickness

The Inyan Kara reaches a maximum thickness in the study area of 495 feet (151 m) in south-central Williams County and a minimum of 226 feet (69 m) in south-central Dunn County (Plate VIII).

The central and western portions of the study area are part of a broad region of sediment greater than 400 feet (122 m) thick that extends westward out of the state. Areas of formation thickness greater than 450 feet (137 m), in the central portion of the study area, occur west of the approximate axis of the Nesson Anticline. Two long, narrow extensions of sediment greater than 400 feet (122 m) thick project out of this region. One extends to the north along the axis of the Nesson Anticline. The other extends into the south-central portion of the study area.

The northeastern and southeastern portions of the study area are dominated by linear zones of thick sediment (greater than 350 feet (107 m) thick). These zones are roughly oriented towards the west-central portion of the study area.

In the southwestern portion of the study area are two anomalous regions of sediment less than 350 feet (107 m) thick. These regions are separated by a narrow area of sediment greater than 400 feet (122 m) thick, trend north-south, and lie to the west of the approximate axis of the Little Knife Anticline.

Subdivisions of the Inyan Kara Formation

Three members of the Inyan Kara were identified and correlated using borehole geophysical logs. Each member was given an informal name.

Member "A"

Identification of member.-- The lowermost member is present in all parts of the study area, and is characterized by sandstone units that are difficult to correlate. As shown in the detailed cross-sections J-J' and K-K' (Plate VII), an individual, well-developed, relatively "clean" sandstone exhibits abrupt lateral change in log character on both the Gamma-Ray log and Dual Laterolog and abruptly pinches out (Interval 5695-5760, Well 103 to Interval 5690-5770, Well 102).

Boundary contacts.-- The basal contact of member "A" is equivalent to the basal contact of the Inyan Kara Formation, which has been described earlier.

The upper contact was chosen at the point where lithologic units become correlatable. The contact is generally abrupt and marked by an abrupt transition from shale (member "A") to a "clean" sandstone or siltstone (member "B") (Well 32, Section H-H', Plate V). In a few cases, the contact is marked by a gradational zone of interbedded siltstone and shale (Well 40, Section E-E', Plate IV), requiring comparison with logs from nearby wells to locate the contact.

Thickness.-- The thickness of member "A" varies from less than 200 feet (61 m) in the extreme southern portion of the study area to over 400 feet (122 m) in the west-central portion, and constitutes up to 90% of the total formation thickness. The member thins to the east, north, and southeast, except for an anomalously thin area less than 200 feet (61 m) thick on the northwestern flank of the Little Knife Anticline in the southwestern portion of the study area (T. 144-149 N., R. 98-100 W.).

Linear, oriented bodies of thick and thin sediment dominate the isopach map of the member (Plate X). Orientation of these bodies is east-west in the southern and central portions of the study area and north-south in the northern portion. Bifurcation of relatively thick bodies is towards the north and east.

Log lithology.-- Using well logs, four basic lithologies were recognized: sandstone, shale, siltstone, and coal.

Sandstone occurs in the study area as units from a few feet (less than 1 m) to greater than 200 feet (61 m) in thickness. On the Gamma-Ray log, four types of sandstone units were recognized:

(1) Upper and lower contacts are sharp with overlying and underlying lithologies; sandstone is relatively homogeneous (Interval 4720-4840 feet, Well 53, Section F-F', Plate IV).

(2) Basal contact is sharp, upper contact is gradational with a general decrease in grain size upsection (Interval 5390-5425 feet, Well 36, Section D-D', Plate III).

(3) Basal contact is gradational; grain size increases upsection with a sharp upper contact (Interval 5130-5200 feet, Well 7, Section A-A', Plate II).

(4) Both upper and lower contacts are gradational (Interval 4620-4710 feet, Well 48, Section F-F', Plate IV).

Units of type (1) tend to occur at the base of the member, whereas units of types (2), (3), and (4) tend to occur in the upper portion of "A". The relatively wide separation of the Shallow and Deep Laterolog curves indicates that permeability of these sandstones is relatively high (Fig. 7).

Siltstone occurs in beds less than 5 feet (1.5 m) thick interbedded with shale, either in a gradational zone between sandstone and shale units (Interval 5210-5240, Well 74, Section H-H', Plate V) or in intervals composed dominantly of shale (Interval 4890-4930, Well 81, Section H-H', Plate V).

Shale is present in beds varying from a few feet (less than 1 m) to over 150 feet (46 m) thick. The lower contact is generally gradational with sandstone, whereas the upper contact may either be gradational with or truncated by an overlying sandstone unit. In a few cases, shale is overlain by coal.

Coal occurs in beds less than 10 feet (3 m) thick, and generally overlies sandstone units that coarsen upward.

Core lithology.-- Of the well core in the study area, approximately 55 feet of member "A" was retrieved. Approximately 40 feet (12 m) of core came from Interval 1 and 15 feet (4.5 m) from Interval 2 (Fig. 8).

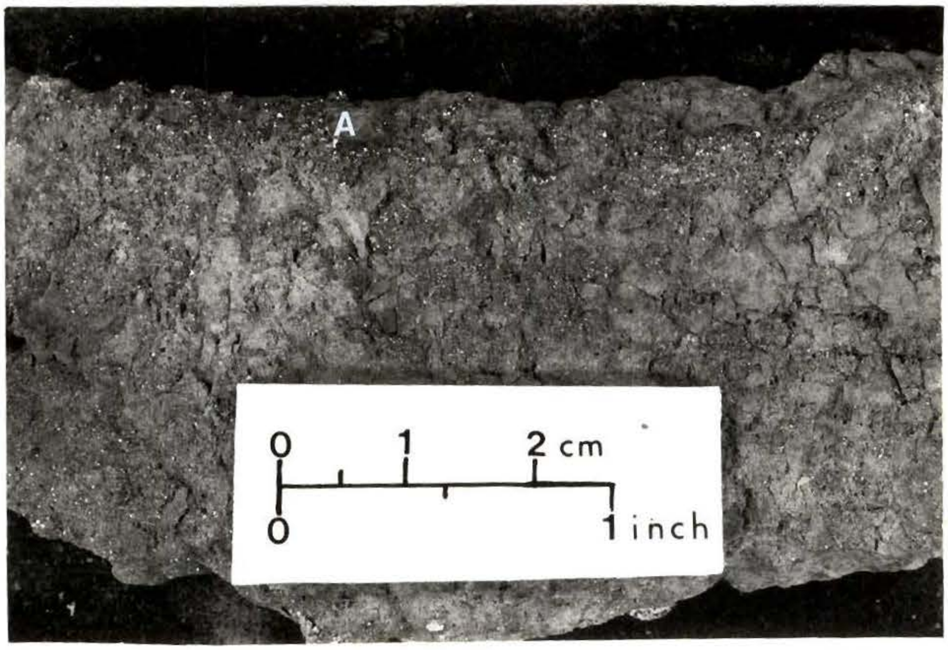
The basal cored interval of the member includes a generalized vertical sequence of sandstone, siltstone, shale, and coal. The upper cored interval of the member contains shale.

The contact between the Swift Formation and the overlying Inyan Kara is very sharp, with an abrupt transition from black, calcareous, pyritic shale (Swift) (Fig. 9) to a coarse-grained sandstone (Inyan Kara) (Fig. 10).

Sandstone is present in the lower 35 feet (10.6 m) of the member as a sequence of individual units 1-17 feet (0.3-5.2 m) thick. The lower 8 feet (2.4 m) of the sandstone is coarse- to medium-grained, with the exception of a shale-pebble conglomerate 1 foot (0.3 m) above the basal contact of the member (Fig. 11). The upper section of the sandstone decreases in grain size upwards from medium to very fine. The dominant constituent of the sandstone is quartz, which occurs as subangular grains with a dusty gray coating (possibly clay). Other constituents noted, in decreasing abundance, are shale fragments, "white specks" (possibly altered feldspar), and discontinuous laminae of dark, possibly organic, material. The sandstone is moderately friable and does not react to acid, suggesting a weak cement. Sedimentary structures include cross-bedding in the coarse- to medium-grained portion (Fig. 12) and ripple cross-lamination (Fig. 13) and climbing ripples (Fig. 14) in the upper, finer-grained, portion. Except for a few plant fragments in the uppermost portion of the sandstone, no fossils were found.

Figure 9. Shale of the Swift Formation with pyrite crystals (light specks at A). Fig. 8, 4973 feet (1515.8 m).

Figure 10. Contact of the Swift Formation (shale in lower portion of photo) with coarse-grained sandstone of member "A". Fig. 8, 4972 feet (1515.4 m).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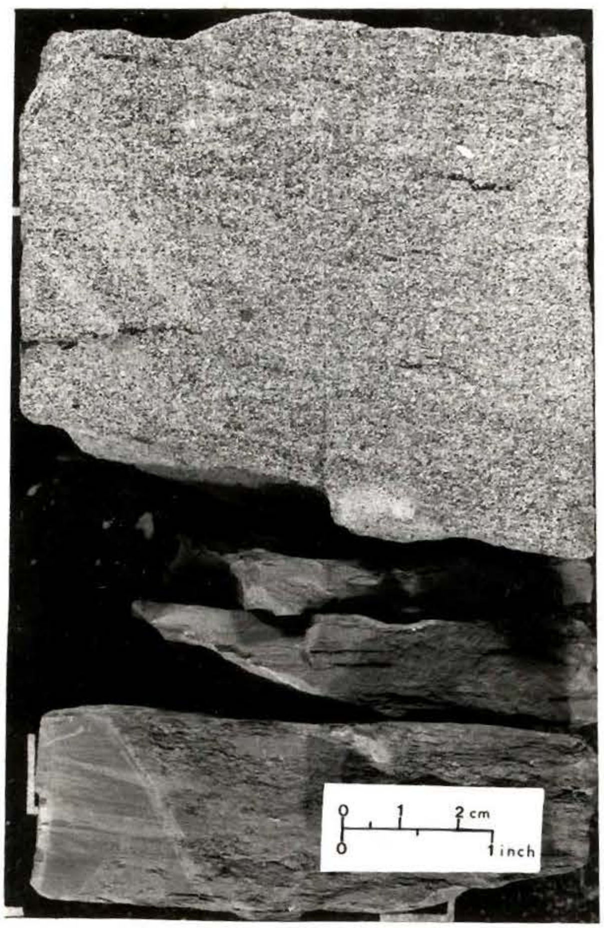
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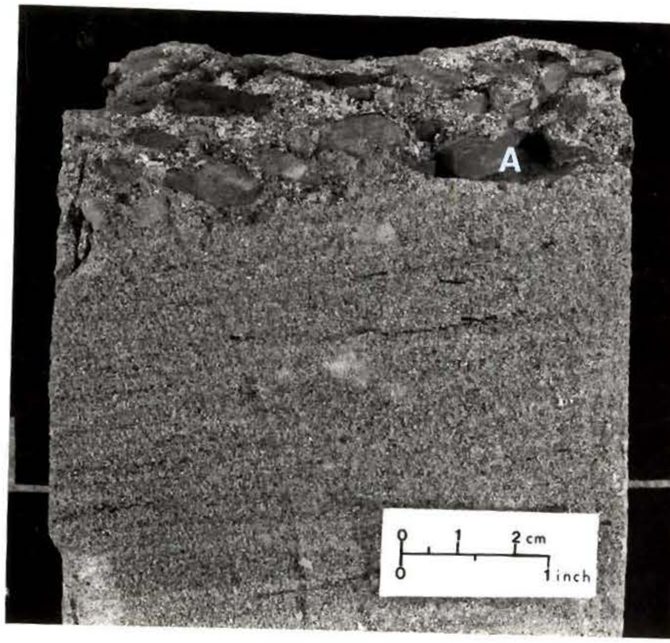
Figure 11. Shale-pebble conglomerate (A) overlying cross-bedded, coarse-grained sandstone in member "A". Fig. 8, 4971 feet (1515.2 m).

Figure 12. Medium-grained, cross-bedded sandstone, with over- and underlying medium-grained, massively bedded sandstone in member "A". Fig. 8, 4957 feet (1510.8 m).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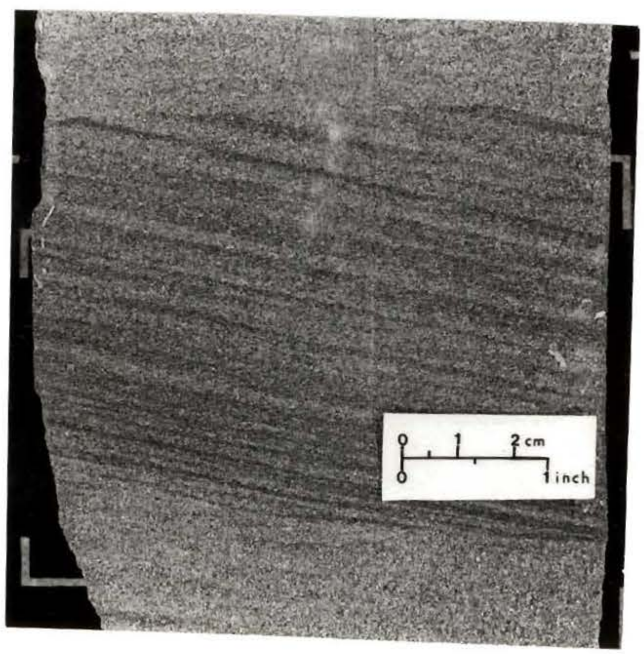
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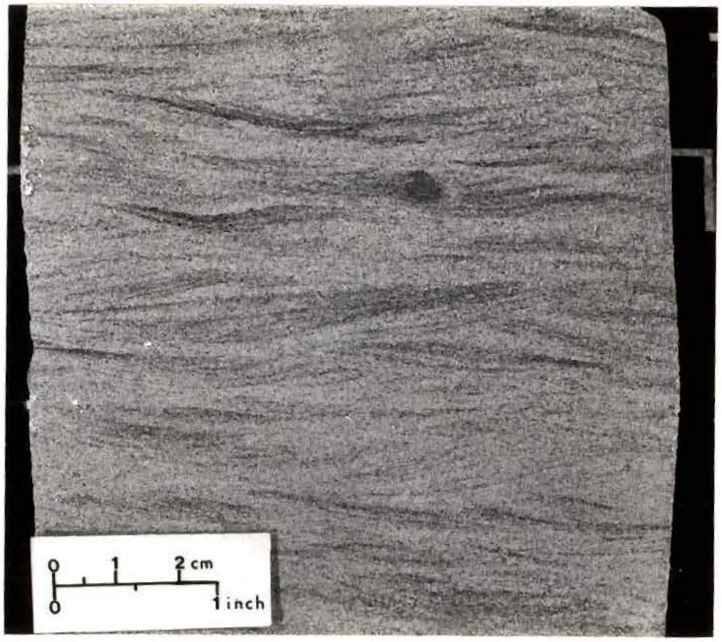
Figure 13. Ripple cross-lamination in fine-grained sandstone in the upper portion of member "A". Fig. 8, 4938 feet (1505.1 m).

Figure 14. Climbing ripples in fine-grained sandstone in the upper portion of member "A". Fig. 8, 4937 feet (1504.7 m).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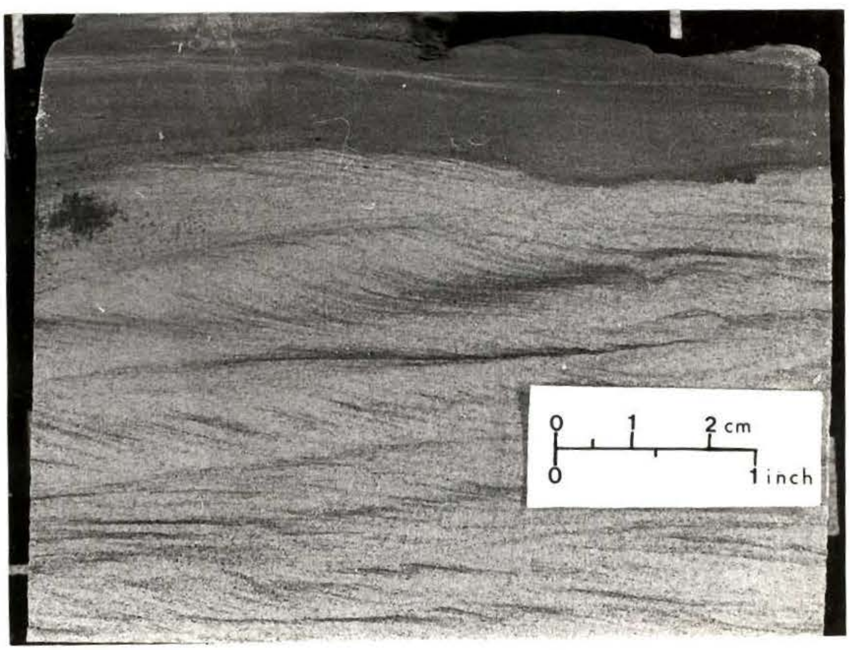
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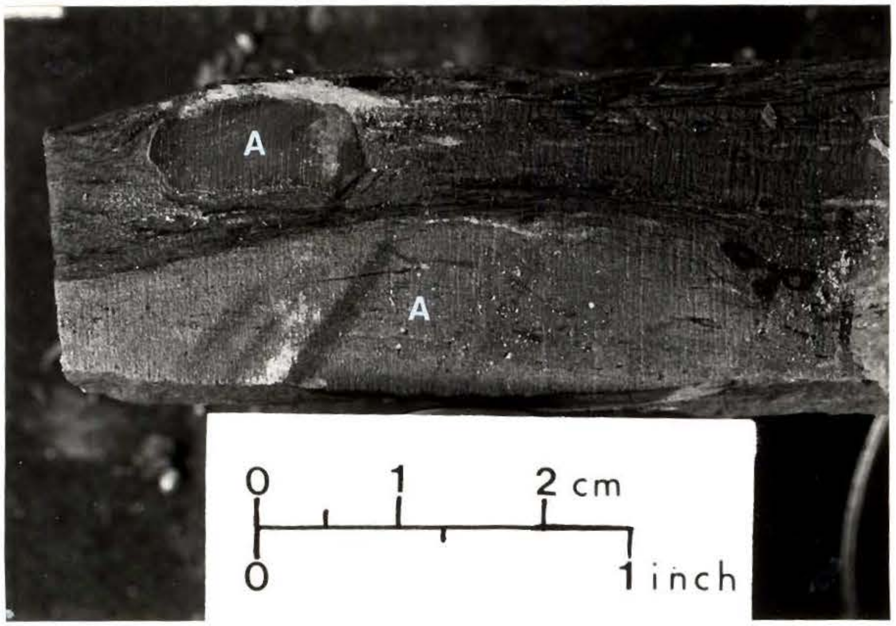
Figure 15. Ironstone nodules (A) in the uppermost portion of member "A". Note deformation of shale laminae around the nodules. Fig. 8, 4632 feet (1411.8 m).

Figure 16. Lignitic fragment (A) in coarse-grained sandstone with filled pores (B) in member "A". Fig. 8, 4939-4930 feet (1505.6-1502.6 m).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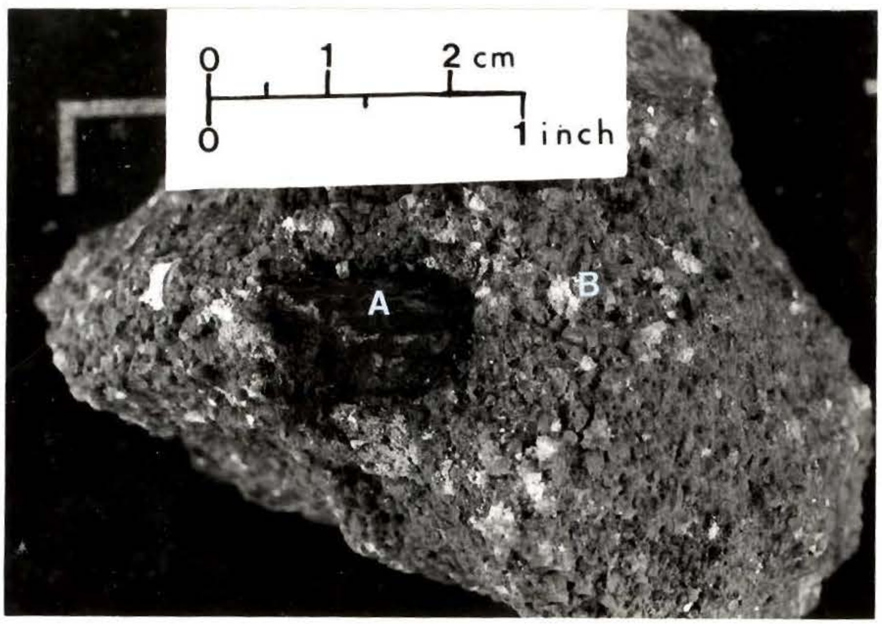
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Two types of shale are found in the member:

(1) A black, calcareous shale, similar to shale found in the Swift Formation, occurs as sand- to pebble-sized grains or clasts in the lower portion of the sandstone (Fig. 11).

(2) A medium- to dark-gray, thinly laminated shale is present in both the upper and lower portions of the member (Fig. 14). In the upper portion, both iron-oxide staining and ironstone nodules are present (Fig. 15).

Siltstone occurs as quartzose laminae interbedded with shale in the uppermost part of the core.

The uppermost 9 feet (2.7 m) of Interval 1 are missing, but abundant fragments of lignitic coal are found in the core box, indicating that a coal bed approximately 9 feet (2.7 m) thick was cored but not recovered. Some of the lignitic fragments are imbedded in a coarse-grained sandstone that is partially cemented with gypsum (Fig. 16).

Member "B"

Identification of member.-- The middle member is present in all parts of the study area, and is characterized by units that are correlatable at distances on the order of several miles.

Boundaries.-- The basal contact of member "B" is generally abrupt, with a moderately thick bed of sandstone or siltstone (10-30 feet (3-9 m) thick) overlying a shale unit of member "A" (Well 6, Section A-A', Plate II). In a few cases the contact is within a gradational zone of interbedded siltstone and shale (Well 20, Section C-C', Plate III).

The upper contact of the member is generally within a gradational zone of siltstone and shale grading upwards into shale (Well 63, Section H-H', Plate V). In a few cases the upper contact is marked by a sharp transition from siltstone or sandstone to shale (Well 43, Section H-H', Plate V).

Thickness.-- Member "B" varies in thickness from less than 20 feet (6 m) in the eastern and southeastern portions of the study area to over 150 feet (46 m) in the east-central portion.

An isopach map of the member (Plate XI) shows two distinct depositional patterns in the study area. In the eastern and southern portions of the study area, the member forms a series of roughly parallel, linear bodies of relatively thick sediment that are oriented northeast-southwest. In the northwestern portion of the study area bodies of relatively thick sediment, which trend either east-west or north-south, are flanked by bodies of thinner sediment that bifurcate towards the east and north. An anomalous area of thin sediment less than 50 feet (15 m) thick occurs in the southwestern portion of the study area west of the axis of the Little Knife Anticline.

Log lithology.-- On logs, the member consists of three sedimentary units, each with a distinctive log character. Between two units, there is a transitional zone that shares log characteristics of both units (Wells 41-43, Section E-E', Plate IV). The presence of these transitional zones distinguishes member "B" from the underlying member "A" and permits moderately good identification and correlation of it in the study area.

Three general types of units were recognized:

(1) A basal unit of sandstone or thick siltstone in abrupt contact with member "A" overlain by thinly interbedded siltstone and shale grading upwards into shale (Well 11, Section B-B', Plate II).

(2) Interbedded siltstone and shale in gradational contact with member "A" grading upwards into shale (Well 65, Section G-G', Plate V).

(3) Interbedded siltstone and shale in gradational contact with "A", coarsening upward, with a sharp upper contact with "C" (Well 42, Section E-E', Plate IV).

Sandstone units in member "B" are relatively "clean" and less than 30 feet (9 m) thick. An exception is in the southeastern portion of the study area, where sandstone units up to 60 feet (18 m) thick are present (Well 16, Section B-B', Plate II). The basal contact of all sandstone units is generally abrupt whereas the upper contact generally grades upward into interbedded siltstone and shale.

Siltstone occurs in beds that are generally less than 5 feet (1.5 m) thick and are usually interbedded with shale

Shale occurs in beds less than 5 feet (1.5 m) thick and are commonly interbedded with siltstone. Radioactivity of the shales generally increases up section.

Core lithology.-- A complete section of member "B" was retrieved in Interval 2 (Fig. 8). The section consists of interbedded laminae of siltstone and shale.

Siltstone laminae vary in thickness from 3-4 inches (7-10 cm) to less than 0.04 inches (1 mm). Laminae are generally homogeneous and appear to be composed almost totally of quartz.

Shale occurs in laminae generally less than 1 inch (2.5 cm) thick. Laminae are gray to black, with layers of abundant plant fragments (Fig. 17).

Contacts between laminae are generally sharp (Fig. 18). Sedimentary structures include rip-up clasts (Fig. 19), micro-dikes of siltstone intruding shale (Fig. 20), convoluted bedding (Fig. 21), burrows (Figs. 19 and 20), and truncated bedding surfaces (Fig. 22). In places, bioturbation was extensive enough to destroy most of the original bedding (Fig. 23).

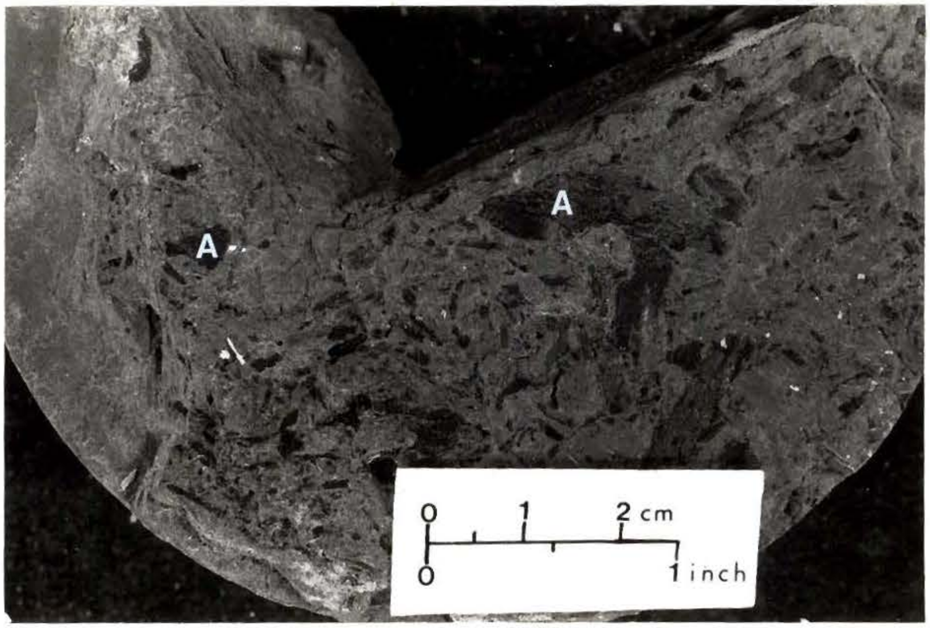
Member "C"

Identification of member.--- The upper member is shale interbedded with siltstone. The member, on the Laterolog, forms a distinct "sawtooth" pattern of alternating high and low resistivity values (Fig. 8).

Boundaries.-- Both the upper and lower contact of the member are generally gradational. The lower contact, with member "B", occurs within a generally gradational zone of siltstone and shale grading upwards into shale, with the contact chosen at the point where the "sawtooth" pattern of the member begins on the Laterolog. The upper contact is equivalent to the contact of the Inyan Kara and Skull Creek Formations, which has been described previously.

Figure 17. Plant fragments (dark spots at A) in shale of member "B". Viewed from horizontal cross-section of core. Fig. 8, 4625 feet (1409.7 m).

Figure 18. Regular and irregular lamination of siltstone and shale in member "B". Fig. 8, 4615 feet (1406.6 m).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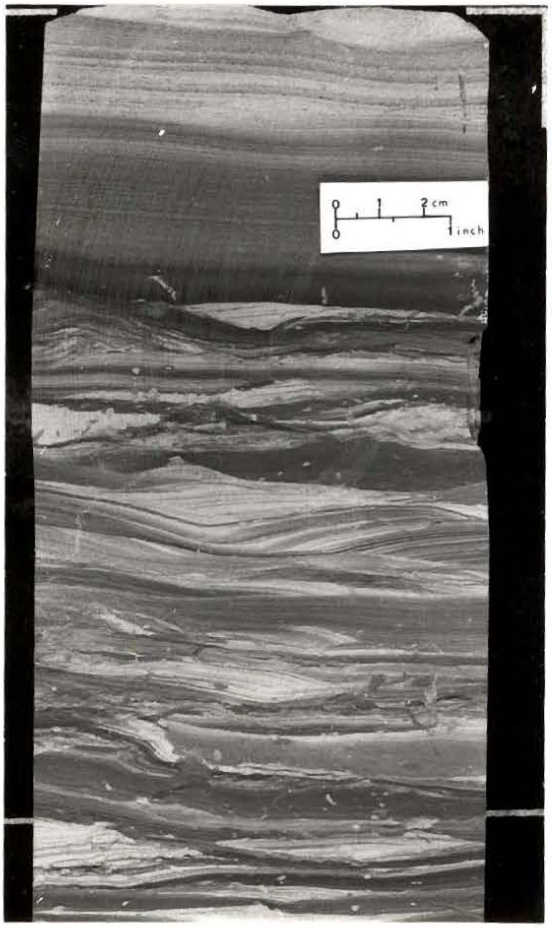
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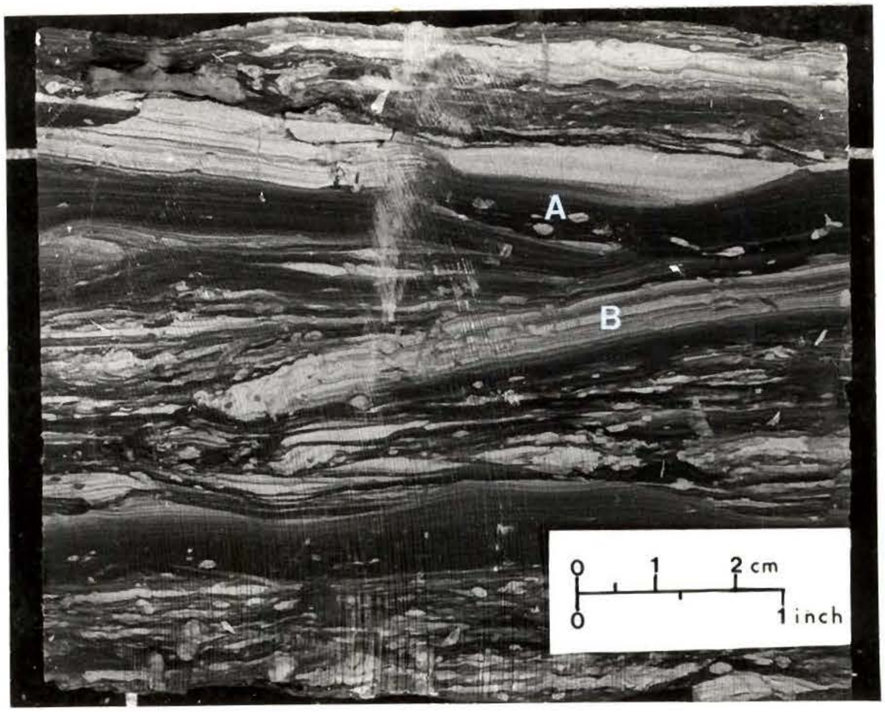
Figure 19. Horizontal burrows (A) and rip-up clasts (B) in member "B". Fig. 8, 4629 feet (1410.9 m).

Figure 20. Micro-dike of siltstone intruding shale (A) and vertical burrows (B). Fig. 8, 4615 feet (1406.6 m).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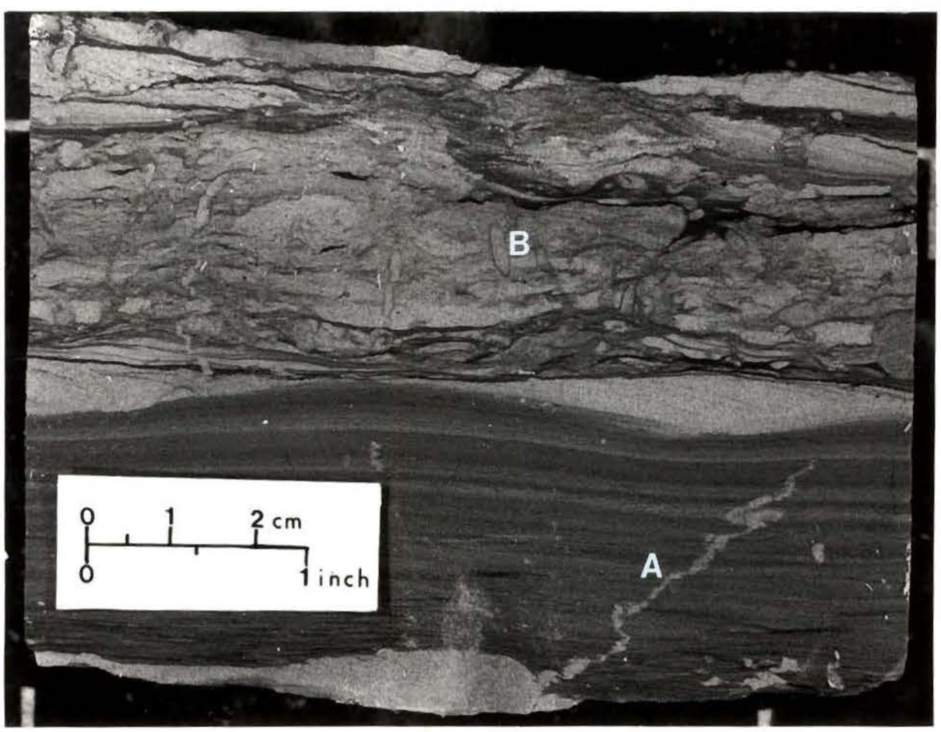
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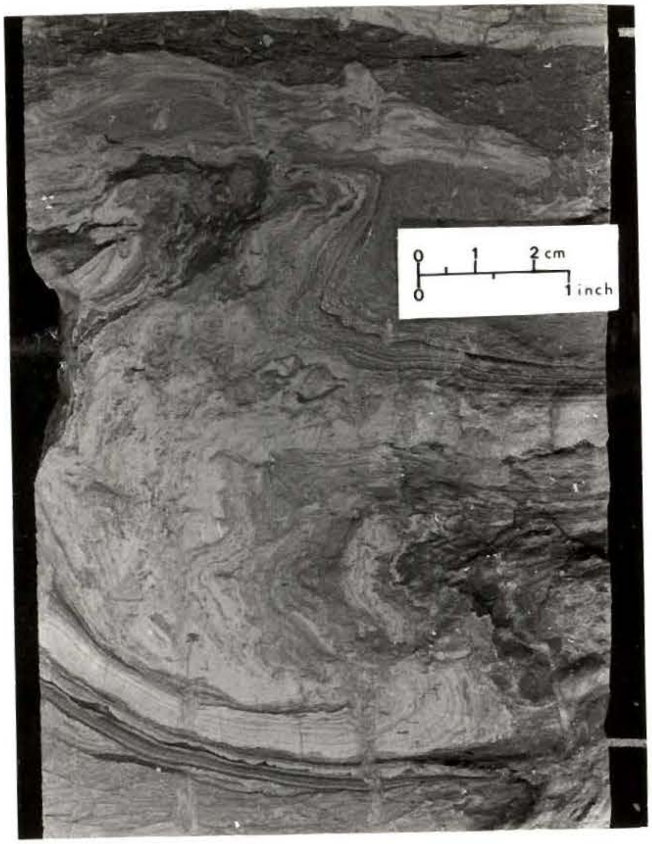
Figure 21. Convoluted bedding in member "B". Fig. 8, 4628 feet (1410.6 m).

Figure 22. Erosional truncation (along A-B) of beds in member "B". Fig. 8, 4629 feet (1410.9 m).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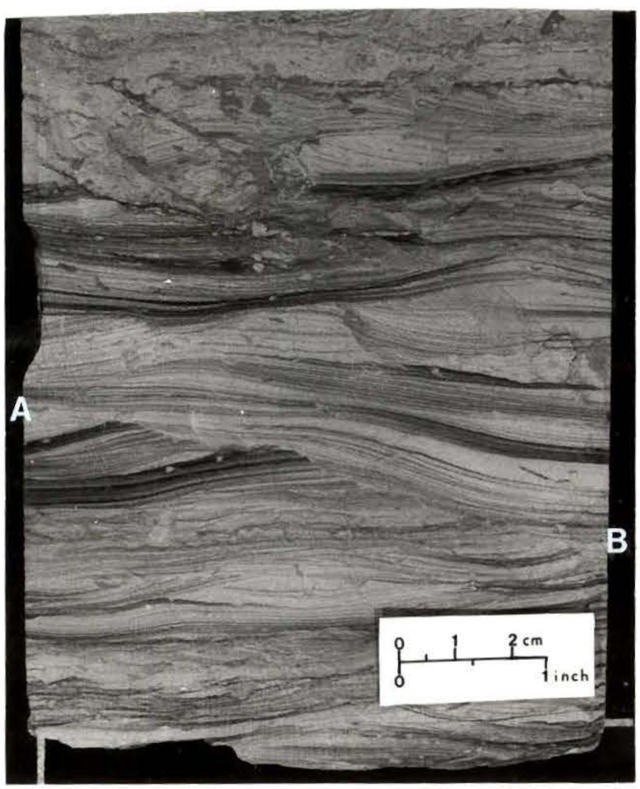
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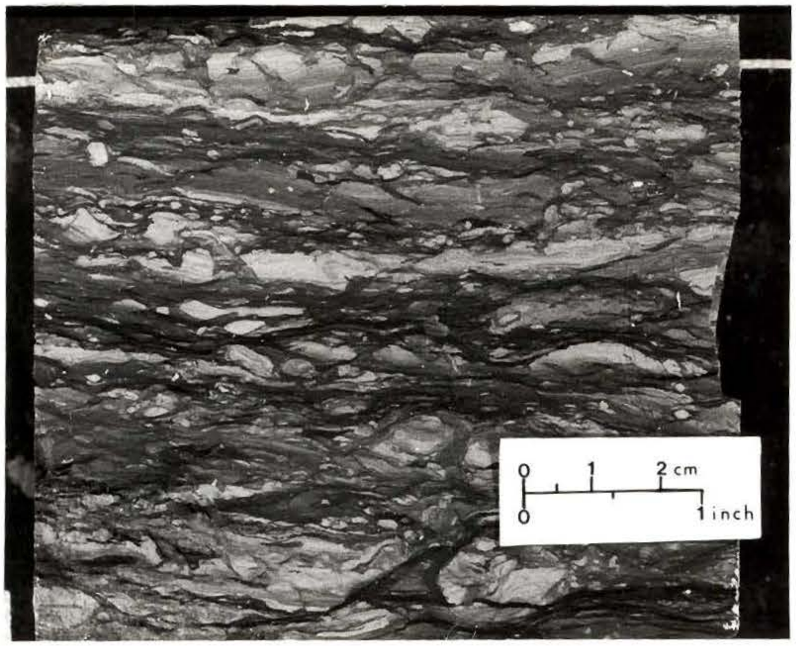
Figure 23. Heavily reworked sediments, possibly from burrowing, in member "B". Fig. 8, 4593 feet (1399.9 m).

Figure 24. Laminated shale with laminae and lenses of siltstone in member "C". Fig. 8, 4590 feet (1399 m).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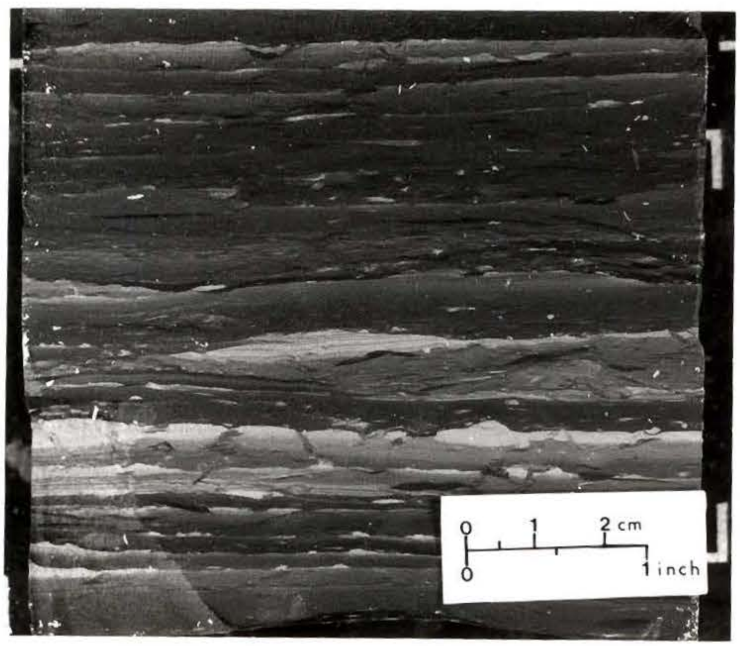
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Thickness.-- Member "C" varies in thickness from approximately 45 feet (14 m) in the southwestern portion of the study area to less than 15 feet (4.5 m) in the eastern portion (Plate XII).

In comparison with members "A" and "B", deposition of "C" was relatively uniform, with a general thinning trend from southwest to the northeast. An anomalous thick area is in the southwestern portion of the study area (T. 148-149 N., R. 94-96 W.).

Log lithology.-- On logs, member "C" forms a distinct, uniform pattern in all parts of the study area. On the Gamma-Ray log, the member is composed of high-radioactivity shales interbedded with thin beds of siltstone less than 5 feet (1.5 m) thick. Radioactivity of the shales is generally highest in the middle of the member and decreases in intensity both up and down section.

On the Laterolog, the member forms a distinct "sawtooth" pattern of alternating high and low resistivity values in response to the interbedded lithologies (Well 1, Section A-A', Plate I). This pattern varies consistently with the thickness of the member, with the number of "teeth" decreasing from west to east (Wells 1 to 9, Section A-A', Plate I).

Core lithology.-- Approximately 2 feet (0.6 m) of member "C" was recovered from the uppermost portion of Interval 2 (Fig. 8). The member is composed almost entirely of thin laminae of black shale, with occasional laminae or lenses of quartzose siltstone (Fig. 24). No fossils or sedimentary structures were recognized.

DISCUSSION

Facies Analysis

Introduction

Most of the interpretations regarding facies and facies relationships in this study were made using borehole geophysical logs. This was necessary due to the limited amount of core available and lack of outcrops in the study area. The interpretations of lithologies from logs were generalized; the interpretations of facies and facies environments were, therefore, also generalized.

Member Facies

Member "A".-- As shown in cross-sections J-J' and K-K', member "A" is composed of laterally discontinuous sandstone units that are difficult to correlate over distances of more than a few miles. The discontinuity of these units suggests that abrupt facies changes are characteristic of the member. Halle (1981) described four Gamma-Ray log patterns, similar to those recognized in member "A", that represented units of nonmarine facies (Fig. 25):

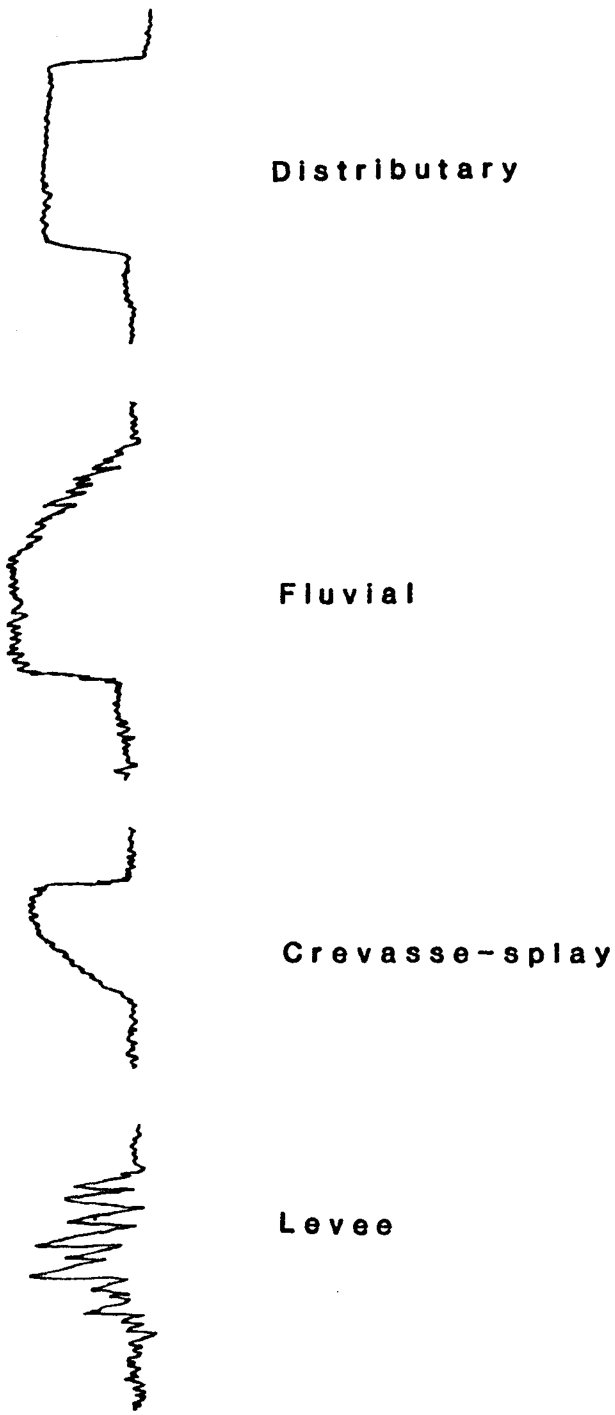
(1) Distributary channel: Blocky, squared-off pattern with sharp upper and lower contacts (Type 1 in member "A").

(2) Fluvial channel: Fining-upward, "Christmas tree", pattern (Type 2 in member "A").

(3) Crevasse-splay: Coarsening-upward, "inverted Christmas tree" pattern, often capped by a coal (Type 3 in member "A").

(4) Levee: Sawtooth-shaped pattern (Type 4 in member "A").

Figure 25. Sketches of Gamma-Ray log patterns recognized by Halle (1981) as representing nonmarine facies.


Distributary
Fluvial
Crevasse-splay
Levee

Pettijohn, Potter, and Siever (1973) compiled a list of physical characteristics of fluvial sandstone units that are similar to those recognized on logs and in well core of member "A":

(1) Petrology

(a) Abundant shale pebbles and shale-pebble conglomerates.

(b) Carbonaceous debris commonly present.

(c) Faunal content low to absent.

(2) Sedimentary Structures

(a) Asymmetrical ripple marks.

(b) Abundant, well-oriented cross-bedding.

(3) Size, Shape, and Orientation

(a) Commonly elongate, with widths ranging from a few tens of feet to composites of 30 miles.

(b) Dendritic, anastomosing, and bifurcating patterns present.

(4) Associated Lithologic Types

(a) Vertical

(i) Overlying silty shales, commonly of fluvial origin. Peat or coal commonly present.

(ii) Basal contact sharply disconformable.

(iii) Multistory sandstone bodies.

(b) Lateral

(i) Silty shale and siltstone, commonly with abundant carbonaceous material.

(ii) Multilateral sandstone bodies, with correlation being generally difficult.

The similarity of characteristics of member "A" and those of nonmarine facies described by Halle and Pettijohn, Potter, and Siever suggests that "A" represents a nonmarine facies of the Inyan Kara Formation. The dominant occurrence of presumed distributary-type deposits at the base of "A" suggests that the lower portion of the member represents a predominately deltaic facies. Log patterns indicating fluvial channel, crevasse-splay, and levee deposits imply that the upper portion of "A" is a fluvial facies.

Member "B".-- Based upon comparisons in log character the units described in member "B" are similar in shape to the fluvial channel, crevasse-splay, and levee facies of member "A". The units in member "B", however, differ from those in "A" with respect to continuity; the units in "B" are correlatable with relatively high reliability over fairly large distances. The continuity of the units in "B" and the gradational "transition zones" between units suggests that facies in the member are fewer and reflect conditions of more uniform deposition.

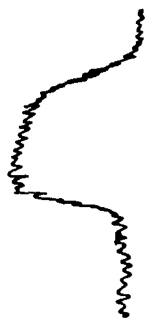
Serra and Sulpice (1975) described three Gamma-Ray log patterns, similar to those in member "B", that were interpreted to correspond to units representative of marginal-marine facies (Fig. 26):

(1) Transgressive sand: Sharp basal contact with a fining-upward pattern (Type 1 of member "B").

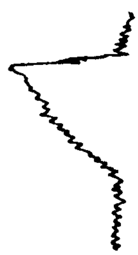
(2) Barrier-bar: Transitional lower contact, coarsening upward, with a sharp upper contact (Type 3 of member "B")

(3) Tidal channel or tidal flat: Jagged, sawtooth-shaped pattern with gradational upper and lower contacts (Type 2 of member "B").

Figure 26. Sketches of Gamma-Ray log patterns recognized by Serra and Sulpice (1975) as representing marginal-marine facies.



Transgressive



Barrier-bar

Tidal channel or Tidal-flat

Evidence for marginal-marine deposition of member "B" is supplemented by the cored interval of the member. The laminated siltstone and shale units in the core are similar to sediments representative of tidal flat facies described by Reineck and Singh (1980). Although the Gamma-Ray log that accompanies the well core is not of good quality (Fig. 8), the log does resemble the jagged, sawtooth-shaped pattern ascribed to tidal flat or tidal channel facies.

The units recognized in member "B" and the described core of "B" are similar to the trangressive, barrier-bar, and tidal flat or tidal channel facies described by Serra and Sulpice and Reineck and Singh. The similarity of these units implies that member "B" represents a marginal-marine facies of the Inyan Kara Formation.

Member "C".-- Member "C" differs from members "A" and "B" in that "C" maintains a consistent log character throughout the study area, suggesting that the member represents a single facies. Persistent lateral continuity of units over large areas is generally considered to reflect rocks of a marine facies (Serra and Sulpice 1975). The presence of thin beds of siltstone interbedded with marine shales in the member suggests that periodic influxes of terrigenous material entered the marine environment. The widespread nature and continuity of the siltstone beds in "C" suggest that the siltstone beds were being distributed at a relatively shallow depth, implying that the member was deposited under shallow marine conditions.

Facies Relationships

Due to a lack of outcrops and well core in the study area, no direct evidence of facies relationships between the Swift Formation, members of the Inyan Kara, and the Skull Creek Formation was observed. Indirect evidence for facies relationships between these units is implied, however, by sequences of the interpreted facies of members "A", "B", and "C".

The suggestion of a deltaic facies for portions of the lower part of "A", plus the presence of transitional lower boundary contacts, suggest that the upper portion of the Swift Formation, which has been interpreted to represent a marine facies (Gerhard and others 1982), and the lower portion of member "A" may be facies of a regressive sequence, as illustrated in Fig. 27.

The interpretation of a sequence of fluvial (member "A"), marginal-marine (member "B"), nearshore marine (member "C"), and open marine (lower Skull Creek) facies suggests that the three members and the Skull Creek may be facies of a transgressive sequence, as illustrated in Fig. 28.

Figure 27. Diagrammatic sketch showing suggested conformable relationship between member "A" and the Swift Formation.

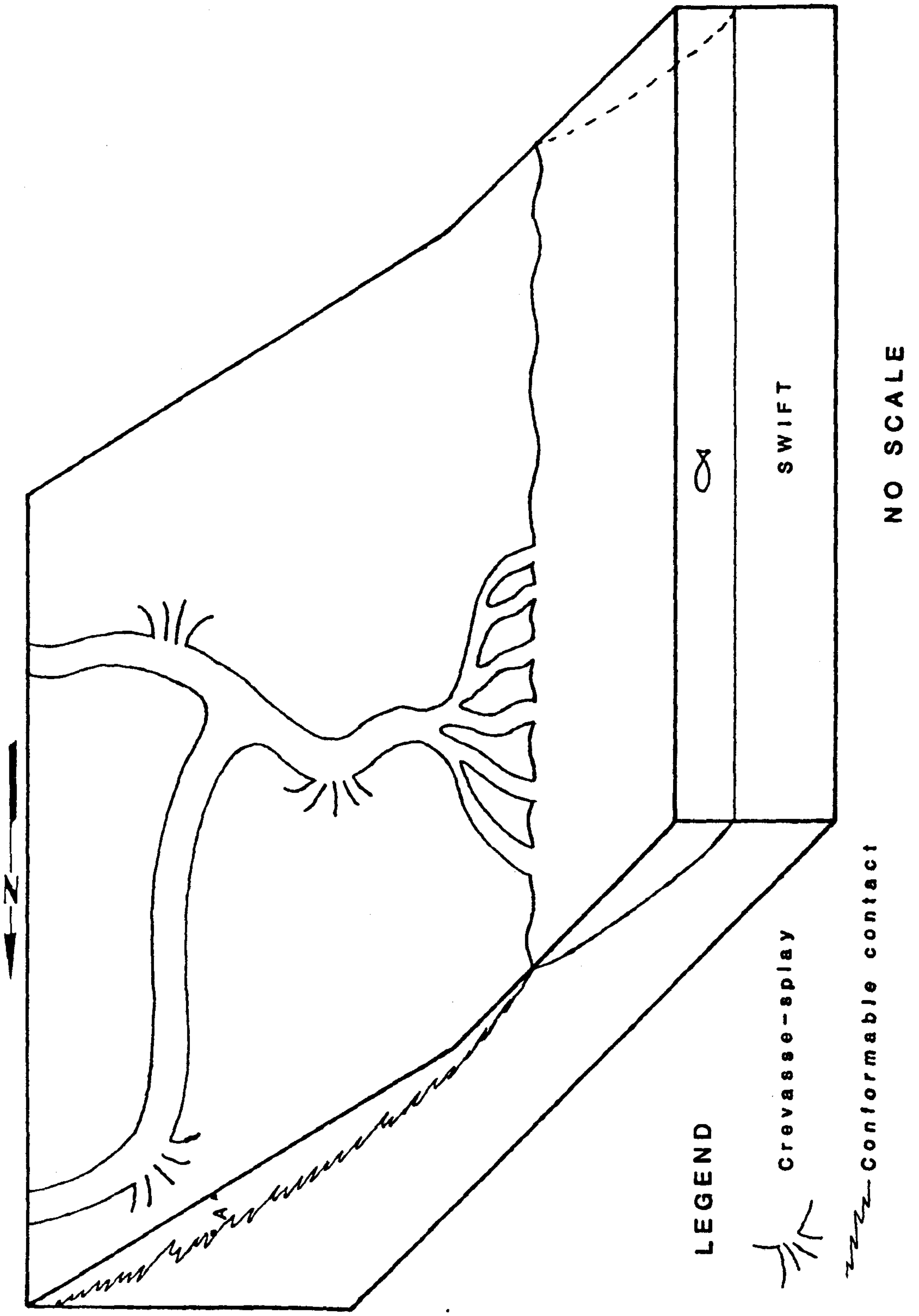
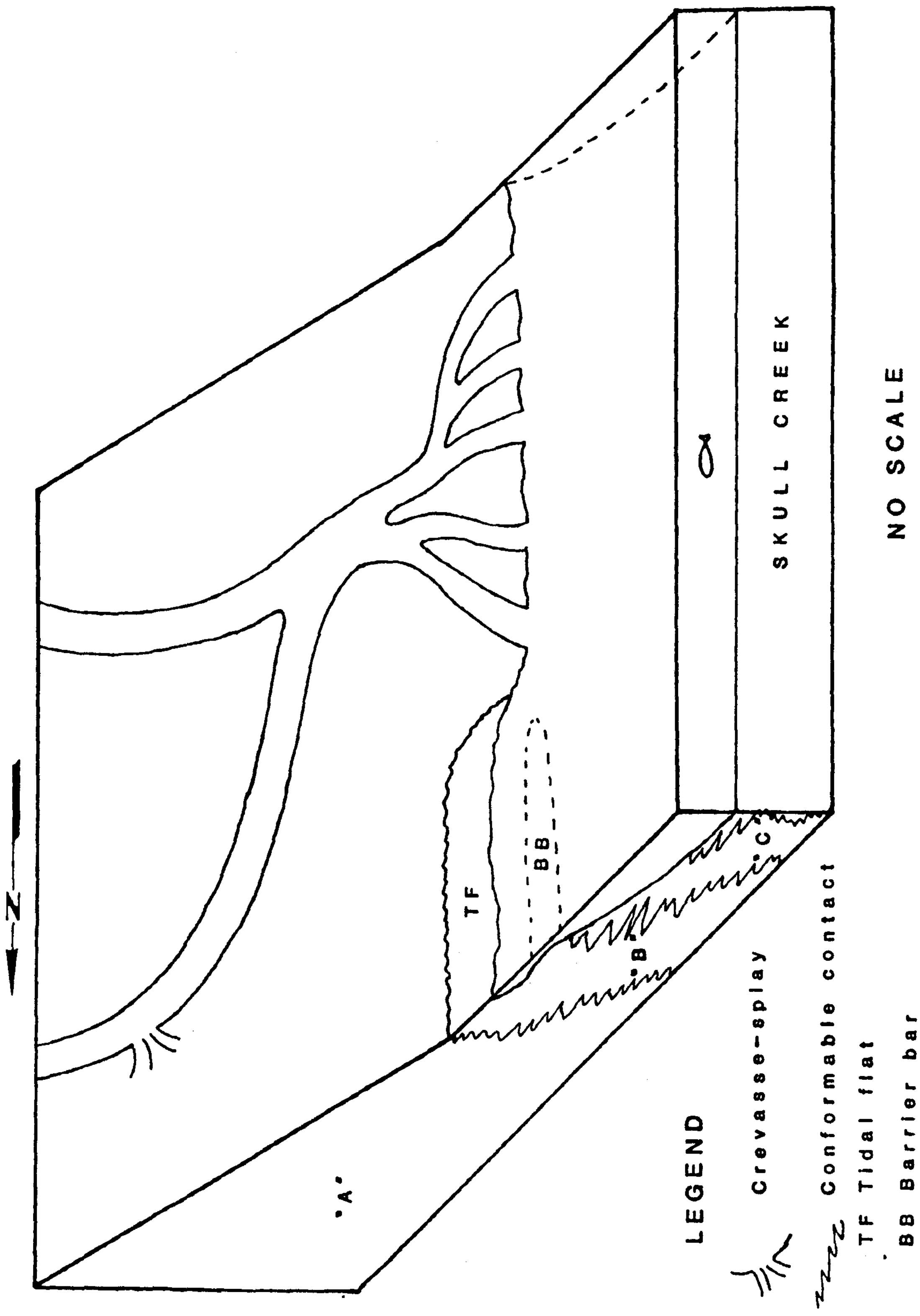

N
SWIFT
NO SCALE
LEGEND
Crevasse-splay
Conformable contact

Figure 28. Diagrammatic sketch showing suggested conformable relationships between members "A", "B", "C", and the Swift Formation.


N
"A"
"B"
"C"
TF
BB
SKULL CREEK
NO SCALE
LEGEND
Crevasse-splay
Conformable contact
TF Tidal flat
BB Barrier bar

Environments of Deposition

Environments of members "A", "B", and "C"

Member "A".-- The deltaic and fluvial facies of member "A" suggest that the member was deposited in two separate phases. In the lower portion of the member, where log patterns indicative of distributary-type deposits tended to occur, the deltaic facies implies that the lower portion of "A" was probably deposited in a deltaic environment where distributary channels were dominant. No specific deltaic type was recognized. In the upper portion of the member, where log patterns from fluvial channel, levee, and crevasse-splay deposits tended to occur, the upper portion of "A" was probably deposited in a fluvial environment.

The interpretation of a facies relationship between the deltaic facies of the lower part of member "A" and the marine facies of the Swift Formation implies that the lower portion of "A" was deposited during regression of the epicontinental sea. The relationship between the fluvial facies of the upper portion of member "A" and the marginal-marine facies of member "B" implies that the upper portion of "A" and member "B" are part of a transgressional sequence. No boundary between the regressive and transgressive phases of member "A" was recognized.

Structural and possible paleotopographic influences on the deposition of member "A" in the study area are reflected in an isopach map of the member (Plate X). Two trends of relatively thick sediment, greater than 300 feet (91 m) thick, bifurcate towards the east and north. The thickness and bifurcation patterns of these areas, along with a general thinning trend of the member to the east, suggest that they may have been major drainage patterns, with sediment transport from the north and east towards the west in the study area. The anomalously thin area on the northwestern flank of the Little Knife Anticline implies that the Little Knife was a slightly positive feature during the deposition of "A", tending to deflect stream flow north and south of the anticline. The Nesson Anticline appears to have not been a significantly positive feature during the deposition of member "A".

Member "B".-- The interpretation of member "B" is that the member was deposited in a marginal-marine environment. The three recognized facies from well logs (transgressive, tidal flat or tidal channel, and barrier-bar) indicate a lack of deltaic sediments either because the influx of sediments was relatively low or because transgression occurred relatively rapidly. The "transitional zones" noted between the facies suggest that simultaneous deposition of all three facies was occurring during the deposition of "B". The interpreted sequence of nonmarine (member "A"), marginal-marine (member "B"), and shallow marine (member "C") facies implies that "B" is part of a transgressive sequence.

The isopach map of member "B" (Plate XI) reflects the structural and possible paleotopographic controls that influenced the deposition of the member in the study area. In the northwestern portion of the study area, a region of relatively thick sediment, greater than 60 feet (18 m) thick, trends north-south and occurs in the same general area as the drainage system described for member "A". Log patterns in this area (Wells 29 and 30, Section D-D'; Well 41, Section E-E' and Wells 50, 51, 52, and 53, Section F-F', Plate IV) imply that it was a tidal channel or tidal flat; the shape and orientation of the area imply that it may have been a former river valley. Elsewhere in the study area, log patterns suggest that transgressive sands were dominant in the study area, followed by tidal flat and barrier bar deposits. In the southern portion of the study area the northeast-southwest-trending areas of relatively thick sediment contain log patterns that imply all three facies were present. Possible explanations for the thick accumulation of sediments in these areas is that they either represent a stillstand or a period of high sediment influx which, coupled with subsidence of the Williston Basin, would allow sediments to accumulate. The general thinning trend of the member to the east suggests that transgression of the Cretaceous sea was from west to east in the study area, which is in agreement with previous work (McGookey and others 1972).

Structurally, the interpreted direction of transgression suggests that the Williston Basin was a negative feature during the deposition of member "B". The north-south-trending, anomalously thin area west of the axis of the Little Knife Anticline suggests that the Little Knife was a slightly positive feature during deposition of the member. The Nesson Anticline appears not to have had a significant effect on the deposition of member "B".

Member "C".-- The interpreted marine facies of member "C" suggests that the member was deposited in an offshore environment. The relatively high radioactivity response of the shales in "C" suggests that the shales have a high organic content.

The correlation of a decrease in the number of siltstone beds on the Laterolog with a decrease in thickness suggests that the beds reflect the progression of the depositional environment of "C" across the study area. The widespread extent of the siltstone units in the member suggests that the depositional environment of "C" was shallow and covered a wide area.

The interpreted sequence of marginal-marine (member "B"), shallow marine (member "C"), and deeper marine (Skull Creek) facies, plus the interpreted gradational contacts between member "C" and the Skull Creek Formation, imply that "C" is also part of a transgressional sequence.

The isopach map of member "C" (Plate XII) reflects structural and possible paleotopographic influences on the deposition of the member. For the most part, the deposition of "C" was relatively uniform in the study area. The member thins to the east and northeast, suggesting that transgression in the study area was from west to east. The irregular shape of some of the contours may be the result of paleotopographic influences that are accentuated by the small contour interval. The irregular contours may also be due, in part, to differential compaction in the member. The general thinning trend from west to east suggests that the Williston Basin was a negative feature during the deposition of "C". The anomalously thick area northeast of the Little Knife Anticline in the southwestern portion of the study area implies that the Little Knife continued to be a slightly positive feature during the deposition of member "C". The Nesson Anticline appears to have had no significant effect upon deposition.

Depositional History of the Inyan Kara

As a general regression of the epicontinental sea progressed across the study area from east to west in Late Jurassic-Early Cretaceous time, deposition of the Swift Formation ceased. Fluvial systems developed, transporting sediment from the east and north into the study area and depositing the sediments of member "A". The relatively high frequency of distributary-type log patterns in the lower portion of the member suggests that, during regression, deltas may have been present.

With the transgression of the epicontinental sea from west to east in the Early Cretaceous in the study area deposition of member "A" was succeeded by that of member "B". Log patterns of transgressive, tidal channel or tidal flat, and barrier-bar deposits suggest that member "B" was deposited in a marginal-marine environment. Temporary halts in the transgression of the Cretaceous sea or increased influx of sediments and subsidence of the Williston Basin are suggested by the thick accumulation of sediments in the southern portion of the study area.

As further transgression of the Cretaceous sea moved the shoreline eastward, deposition of member "B" ceased and was gradually replaced by member "C". Regular occurrences of siltstone beds in "C" suggest that periodic influxes of terrigenous material occurred over most of the study area. Further transgression gradually replaced the deposition of "C" with deposition of the Skull Creek.

Structurally, deposition of the members of the Inyan Kara were controlled mainly by the Williston Basin, which was a negative feature that oriented stream flow for member "A" to the west and controlled transgression of the Cretaceous sea from west to east during the deposition of "B" and "C". The only recognized positive structural feature in the study area was the Little Knife Anticline, which caused a slight thinning of each member over or near its axis.

Correlations of the Inyan Kara

Correlations from the study area to the Black Hills

One question that arises in a stratigraphic problem is the lateral extent of a stratigraphic unit. No direct correlation of the Inyan Kara from the Black Hills to the study area was possible due to the lack of available well logs between the Black Hills and the southwestern border of North Dakota. Indirect interpretations were made, however, from comparison of the rocks of the Lakota-Fall River interval in the Black Hills to the members in the study area and from an indirect cross-section from the Black Hills to the study area.

Darton (1901, 1909) first named and described the Lakota-Fuson-Dakota section in the Black Hills. He described the Lakota Formation as a unit of coarse-grained and cross-bedded sandstone with local beds of coal and "partings of shale of no great thickness" lying unconformably upon the "Beulah Shale" (Morrison) or the Unkpapa sandstone. Darton described the Fuson Formation as a nonfossiliferous sequence of fine sand and clay. He described the Dakota Formation as a sandstone with both thin and massive bedding.

Waage (1959) and Robinson and others (1964) provided more detailed descriptions of rocks in the Lakota-Fall River interval. The Lakota Formation (Darton's Lakota and Fuson) was described as sandstone, siltstone, shale, and coal. Sandstone units in the Lakota were conglomeratic, coarse-, medium-, and fine-grained with cross-bedding, cross-lamination, and massive bedding. The Fall River Formation (Darton's Dakota) was described as a dominantly sandy unit, generally fine-grained, with trails, burrows, casts, and abundant laminated, cross-laminated, and ripple-marked bedding. Above the Fall River, in the lower portion of the Skull Creek Formation, was a sequence of interbedded siltstone and shale.

Rice (1977) constructed cross-sections from the Black Hills to south-central South Dakota and from south-central South Dakota to the study area, providing an indirect cross-section from the Black Hills to the study area. He recognized the Lakota Formation as the lowermost sandstone unit resting unconformably upon Jurassic rocks, the Fall River (Darton's Dakota) as the uppermost sandstone unit lying below the Skull Creek Formation, with the intervening strata designated as the Fuson Formation. Above the Fall River, Rice named and correlated a sequence of interbedded siltstone and shale in the lower Skull Creek Formation as the "basal silt".

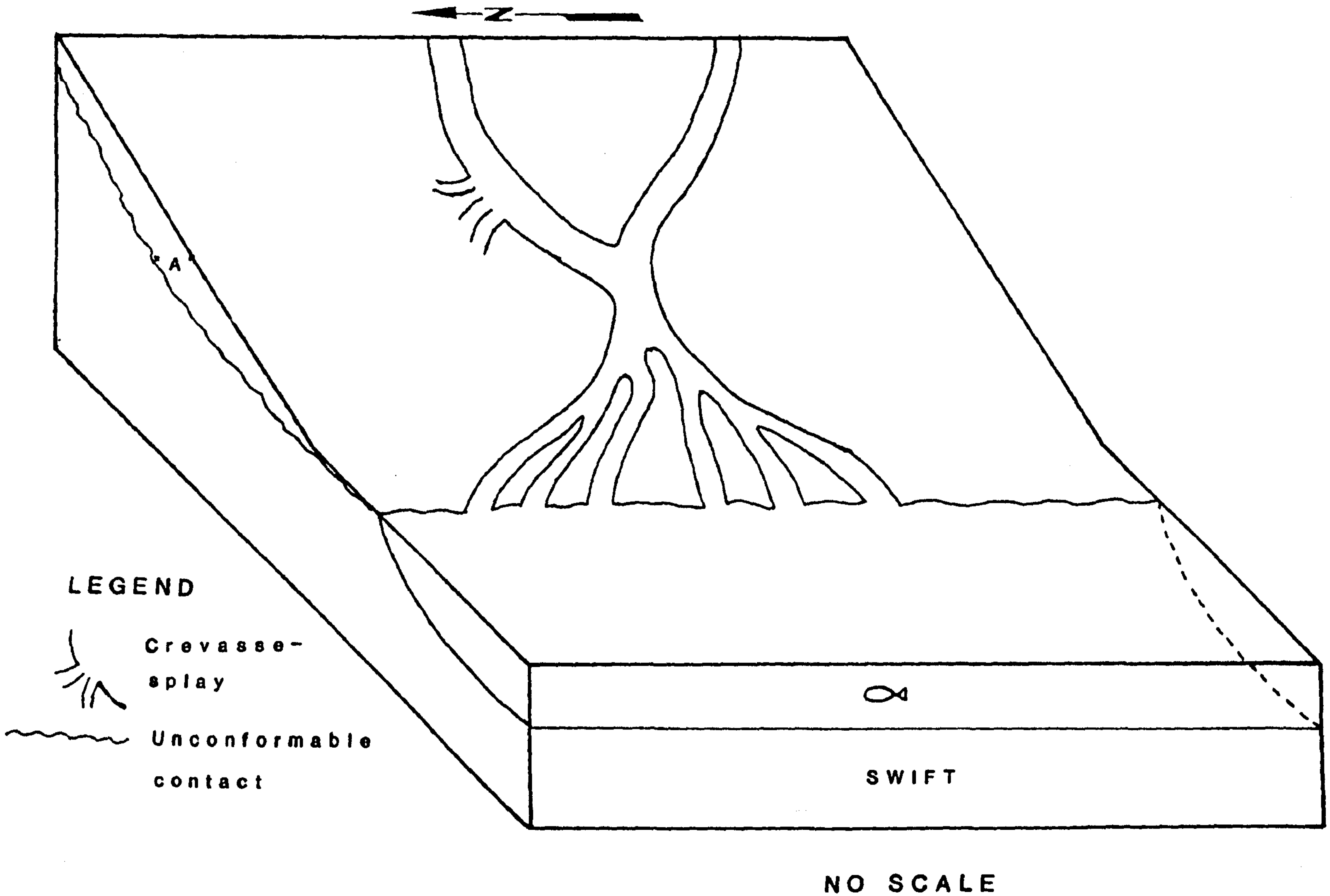
Comparisons of stratigraphic position and depositional sequence between the Lakota-"basal silt" interval (of Rice) in the Black Hills and members of the Inyan Kara Formation in the study area suggest that equivalent units may exist in the two areas.

The Lakota Formation of Waage (Darton's and Rice's Lakota-Fuson interval) and member "A" in the study area lie at the bottom of the basal Cretaceous clastic sequence and contain sedimentary features that suggest deposition in a nonmarine environment. The similarity between these units suggests that the Lakota Formation (of Waage) and member "A" may be approximately equivalent.

The Fall River Formation and member "B" lie above units interpreted to have been deposited in a nonmarine environment (the Lakota Formation and member "A", respectively) and have sedimentary features that suggest the units were deposited in a marginal-marine environment. The similarity betweeen these units suggests that the Fall River Formation and member "B" may be approximately equivalent units.

The "basal silt" (of Rice) and member "C" both lie, in conformable contact, above units interpreted to have been deposited in a marginal-marine environment (the Fall River Formation and member "B", respectively). Both units are composed of interbedded siltstone and shale that suggest deposition in a nearshore marine environment, although Rice has included all siltstone units in the Skull Creek as part of the "basal silt"; member "C" contains only the interbedded siltstone and shale that form the distinctive "sawtooth" pattern on the Laterolog, which occurs in the lower portion of Rice's "basal silt". The similarities between the lower portion of the "basal silt" and member "C" suggest that the units may be approximately equivalent.

Figure 29. Diagrammatic sketch showing the unconformable relationship of member "A" with the Swift Formation as suggested by Anderson and Carlson (1966) and Gerhard and others (1982).


N
A
LEGEND
Crevasse-splay
Unconformable contact
SWIFT
NO SCALE

Analysis of the Swift-Inyan Kara contact

An unconformity in clastic sequences is, by definition, a substantial break in the geologic record that represents an interruption in the depositional sequence (Krumbein and Sloss 1963). Previous work on the Inyan Kara in North Dakota has suggested that the Swift-Inyan Kara contact represents a regional unconformity (Hansen 1955, Rice 1977, Gerhard and others 1982), as illustrated in Fig. 29. In this study, no conclusive evidence was found for a regional unconformity in the study area.

Previous works have cited the pinching out of units in the Swift, such as the one shown in Section C-C', and abrupt changes in lithology from shale (Swift) to sandstone (Inyan Kara) as evidence of an unconformity. In this study, the suggestion of a facies relationship between the Swift and the Inyan Kara offers an alternate interpretation to this cited evidence. The pinching out of units in the Swift, instead of representing erosional truncation, may represent the lateral extent of the units. The abrupt change in lithologies, in which the overlying sandstone units have log patterns that suggest a distributary-channel facies, may not represent an erosional contact; instead, it may represent an abrupt facies change in a marine-deltaic facies sequence.

Evidence for an unconformity in portions of the study area is based upon the observed lithologic changes in well core. The Swift-Inyan Kara contact in the core (Fig. 8) is marked by an abrupt change from shale to coarse-grained sandstone. In the lower portion of the sandstone the presence of sand- to pebble-sized grains of shale, which resemble the lithology of the shales in the Swift, suggests that erosion of the Swift was occurring nearby, which would imply the presence of a nearby unconformable contact. Unfortunately, the log that accompanies the well core (Fig. 8) is of poor resolution and is not suitable for comparison with other logs.

Evidence for a conformable contact is based on the gradational contacts recognized in the study area (formation contact type 3), which suggests a gradual facies change from marine (Swift) to nonmarine (Inyan Kara), as illustrated in Fig. 25.

CONCLUSIONS

(1) The Inyan Kara Formation is a clastic unit of sandstone, siltstone, shale, and coal. It varies in thickness from approximately 225 feet (69 m) to 500 feet (152 m) in the study area.

(2) Using well logs, the Inyan Kara can be separated into three members that are correlatable throughout the study area.

(3) The lowermost member, "A", is a unit of sandstone, siltstone, shale, and coal. It varies in thickness from approximately 200 feet (61 m) to 400 feet (122 m) in the study area.

(4) Log patterns of sandstone units in the lower portion of "A" suggest that the lower portion of the member was deposited in a dominantly deltaic environment. Log patterns and the discontinuity of sandstone units in the upper portion of "A" suggest that the upper portion of the member was deposited in a dominantly fluvial environment.

(5) The middle member, "B", is a unit of sandstone, siltstone, and shale. It varies in thickness from approximately 20 feet (6 m) to 150 feet (46 m) in the study area.

(6) Log patterns in member "B" suggest that the member was deposited in a marginal-marine environment.

(7) The upper member, "C", is a unit of interbedded siltstone and shale. It varies in thickness from approximately 15 feet (4.5 m) to 45 feet (14 m).

(8) The presence and lateral continuity of widespread, thin siltstone beds interbedded with marine shale in "C" suggests that the member was deposited in a shallow marine environment.

(9) Thickness trends in members "A", "B", and "C" suggest that the Williston Basin and the Little Knife Anticline were active structural features during the depostion of the Inyan Kara Formation in the study area.

(10) Thickness trends in members "A", "B", and "C" suggest that regression of the epicontinental sea in Late Jurassic-Early Cretaceous time was from east to west and that the initial transgression of the Cretaceous sea was from west to east in the study area.

(11) The upper portion of the Swift Formation and the lower portion of member "A" are suggested to be facies of a regressional sequence.

(12) The upper portion of member "A", members "B" and "C", and the lower portion of the Skull Creek Formation are suggested to be facies of a transgressional sequence.

(13) Comparison and indirect correlation of the Lakota-"basal silt" interval (of Rice) in the Black Hills with members "A", "B", and "C" in the study area suggest that the Lakota (or Lakota-Fuson) Formation is approximately equivalent to member "A", the Fall River Formation is approximately equivalent to member "B", and the lower portion of the "basal silt" is approximately equivalent to member "C".

(14) Analysis of evidence used to suggest a regional unconformity between the Swift and Inyan Kara Formations in the Black Hills suggests that such evidence is ambiguous and, therefore, not conclusive. Some evidence does suggest, however, that locally both conformable and unconformable contacts are present in the study area.

APPENDICES

APPENDIX A

LEGAL DESCRIPTIONS OF WELLS USED IN CROSS-SECTIONS

Legal descriptions of wells used in cross-sections

Appendix A consists of the legal descriptions of the wells used in cross-sections A-A' to K-K'. Each description consists of two lines. The first line contains, in order, the cross-section reference number, North Dakota Geological Survey well number, well owner or operator, and well name. The second line contains, in order, well location (1/4 1/4 section-township-range) and elevation of the Kelly Bushing.

1. 7361, Amoco Production Company, Stevens Federal C1-29
SW/NE 29-142-100, KB=2757.

2. 8947, Amarex Incorporated, Kanski A 5-1
SE/SE 7-142-99, KB=2708.

3. 7384, Crystal Exploration and Production Co., Kuntz no. 11-23
NW/NW 23-142-98, KB=2648.

4. 8754, Vanderbilt Resources Corp., Rodrmas 1-25
NE/SE 25-142-97, KB=2636.

5. 8403, Supron Energy Corp., F.V. Buresch 1
NE/NE 32-142-96, KB=2602.

6. 6477, Amoco Production Co., Fisek 1
SE/SW 2-14SE/SW 2-95, KB=2287.

7. 5155, Shar-Alan Oil Corp., Mackey 1
SW/SW 13-143-94, KB=2133.

8. 7700, Shar-Alan Oil Corp., Walter Benz 1
SW/SW 32-143-93, KB=2221.

9. 8115, Keldon Oil Co., Dressler 1
NE/SW 24-142-92, KB=2277.

10. 7313, Bello Petroleum Corp., Sheep Creek BN 10-33
NE/SW 33-146-100, KB=2574.

11. 7611, Penzoil Exploration and Prod., Grassy Butte 21-21 Federal
NE/NW 21-146-99, KB=2629.

12. 8535, W.H. Hunt Trust Estate, Brockmier 1
SE/SE 3-146-98, KB=2552.

13. 6335, Amoco Production Co., Roquette 1
SW/SE 8-146-97, KB=2509.

14. 4611, Helmerich and Payne, Inc., North Dakota State 1
SW/SW 36-146-96, KB=2435.

15. 6887, Amoco Production Co., Richardson 1
SW/NE 35-146-95, KB=2325.

16. 6448, Smokey Oil Co., O'Neill 11-24
NW/NW 24-146-94, KB=2256.

17. 7885, American Natural Gas, F.L.B. Askew 1-14
SE/SE 14-146-93, KB=2406.

18. 5532, Cities Service Oil Co., Goetz A-1
NE/NE 33-146-91, KB=2146.

19. 8020, Alpha Resources, Inc., Rogness 1-34
SW/NE 34-150-99, KB=2114.

20. 7704, Gulf Oil Expl. and Prod., Shafer State 1-23-3B
NE/SE 23-150-98, KB=2021.

21. 8343, Consolidated Crude Oil, Skjelvik 4-35
NW/NW 35-150-97, KB=2365.

22. 7136, Tenneco Oil Co., Lucking 1-27
NW/SE 27-150-96, KB=2329.

23. 8083, Texaco, Inc., Mosholder 4
SW/NE 7-150-95, KB=2381.

24. 7673, Helmerich and Payne, Inc., Matthew 1-20
SW/SW 20-150-94, KB=2231.

25. 4113, Texaco, Inc.--Skelly Oil Co., Fort Berthold Allottees 1-A
SE/NW 4-150-93, KB=2198.

26. 7457, Apache Corp., Apache-Grace 1-20
NW/NE 20-150-92, KB=2141.

27. 4386, Empire State Oil Co. et al, Vowerk 1
SE/SE 28-151-90, KB=2216.

28. 8265, Northwest Exploration Co., 3 Long Creek
SW/SE 36-154-99, KB=2252.

29. 7915, Brent Exploration, Inc., Seaton 14-30
SE/SW 30-155-98, KB=2278.

30. 7931, Mapco, Inc., MCGA 14-33
SE/SW 33-155-97, KB=2124.

31. 1266, Amerada Petroleum Co., Woodrow Sven 1
SE/SW 1-154-96, KB=1955.

32. 6687, Amerada Hess Corp., State E 32-6-1
SW/NE 16-154-95, KB=2300.

33. 3227, Amerada Petroleum Corp. et al, N.D. "N" 1
SE/SE 16-155-94, KB=2030.

34. 2273, Stewart Petroleum Co., Cvancara 1
NW/SW 15-155-93, KB=2360.

35. 2816, Davis Oil Co., Len Corkuff 1
SW/SE 12-154-92, KB=2389.

36. 6695, Donald C. Slawson, Hill 5-1
NE/NW 5-154-91, KB=2305.

37. 8069, Marathon Oil Co., Jensen 12-44
SE/SE 12-154-90, KB=2213.

38. 3252, Hunt Oil Co., Annie S. Hoover et al 1
NE/NW 3-158-99, KB=2150.

39. 3274, H.L. Hunt, Carl T. Solem 1
NW/SE 2-159-98, KB=2306.

40. 8239, Lear Petroleum, Oase 1
SW/SW 17-158-97, KB=2298.

41. 8979, Ranger Oil Co., Herfindahl 11-22
NE/SW 22-158-96, KB=2420.

42. 5935, Amerada Heess Corp., NDCA Deep Unit 1
NW/NE 21-158-95, KB=2513.

43. 5350, Amerada Hess Corp., TMU L146X
NE/SW 7-158-94, KB=2368.

44. 4335, I.J. Wilwhite, Calkota, and Assoc., Honrud 1
NW/NE 10-159-93, KB=2290.

45. 6047, Apache Corp., Edwards 1-9
SE/SE 9-159-92, KB=2467.

46. 5786, Bralorne Intl., Inc., Bralorne et al 15-19 Lumley
SW/SE 19-158-91, KB=2379.

47. 6677, True Oil Co., Halvorson 43-14
NE/SE 14-157-90, KB=2305.

48. 8888, Lear Petroleum, Gordon Hall 1
NW/NE 30-161-98, KB=2117.

49. 4394, Texaco, Inc., R.W. Redlin (NCT-1) 1
SW/SW 20-161-97, KB=2157.

50. 6798, Shell Oil Co., State Rindel 43-16
NW/SE 16-162-96, KB=2141.

51. 7989, Keba Oil and Gas Co., Vande Walle 41X-5
NE/NE 5-162-95, KB=1955.

52. 8139, Bills and St. Clair, State Ahre 1
SE/NW 16-162-94, KB=2016.

53. 8831, Texakota, Inc., Ulsrud 2
SW/NE 11-161-93, KB=2297.

54. 8364, Texaco Oil and Gas Corp., Hermanson 1
NW/SE 13-162-92, KB=1954.

55. 7859, Crown Central Petroleum, Arthur M. Johnson 1-A
NW/NW 34-161-91, KB=1975.

56. 4599, The Anshutz Corp., Inc., Ormiston 1
SW/SE 25-162-90, KB=1957.

57. 3044, Amerada Petroleum Corp., Marie Selle Tract 1-1
NE/NE 27-143-92, KB=2200.

58. 8235, Santa Fe Energy Corp., State Coyote Creek 1-36
SE/SE 36-144-92, KB=2258.

59. 7978, Terra Resources, Inc., Tozier 1-17
NW/SE 17-145-91, KB=2223.

60. 4375, Empire State Oil Co., Youngbear-Sanderson 1
NW/NE 1-149-90, KB=2064.

61. 793, Mobil Producing Co., Solomon Birdbear et al 1
SE/SW 22-149-91, KB=2052.

62. 7783, Home Petroleum Co., Tribal 1-1
SE/NW 1-150-90, KB=2212.

63. 4747, Miami Oil Producers et al, Stolpman 1
NW/NW 30-152-90, KB=1881.

64. 6834, Marathon Oil Co., Croft 1
NW/SE 27-155-91, KB=2315.

65. 6515, Brownlie, Wallace, Armstrong, and Bander, Jaha 17-11
NW/NW 17-156-91, KB=2340.

66. 4433, Union Oil Co. of Calif., Dave Linburg 1
SE/NE 24-159-91, KB=2385.

67. 6028, Apache Corp., Apache 1-30 Masters
SE/SE 30-160-90, KB=2336.

68. 1082, Calvert Drilling, Inc., Jepsen 1
NE/NE 30-161-90, KB=2075.

69. 5157, Shar-Alan Oil Corp., Heiser 1
NE/SE 36-143-96, KB=2112.

70. 8374, Abode Oil and Gas Corp., Federal Killdeer 41-4
NE/NE 4-144-96, KB=2435.

71. 8431, Amoco Production Co., Sahaydak 1
SW/SW 21-145-96, KB=2573.

72. 8077, Mesa Petroleum Co., Pelton 1-10
10-147-96, KB=2417.

73. 8448, Samedan Oil Corp., Lost Bridge State 1-16
NE/NE 16-148-96, KB=2394.

74. 5936, Ashland Exploration Co., Nelson 1-29
NW/NE 29-149-95, KB=2294.

75. 8631, Texaco, Inc., A.M. Nelson (NCT-1) 2
SE/NW 5-151-95, KB=2386.

76. 8100, Energetics, Inc., Hazen 42-3
SE/NE 3-152-95, KB=2308.

77. 6433, Edward Mike Davis-DBA-Tiger Oil Co., Siguardson 33-23
NW/SE 23-153-95, KB=2344.

78. 6362, Amerada Hess Corp., Marvin Iverson 23-18
SW/SW 18-155-95, KB=2305.

79. 379, Amerada Petroleum Corp., Dena Svor Unit 3
SW/SE 9-156-95, KB=2319.

80. 7832, Dome Petroleum Corp., Neset 1-28
SW/SW 28-157-94, KB=2203.

81. 5411, Hunt Oil Co., NTMU 1-19
SW/NE 6-159-94, KB=2364.

82. 4101, Geochemical Surveys, Smith 1
SW/SE 5-160-94, KB=2379.

83. 6607, North Central Oil Corp., Priebe State 1
NE/NE 5-161-95, KB=2405.

84. 6418, Tenneco Oil Co., B-N 2-29
SE/NW 29-143-100, KB=2647.

85. 6395, Apache Corp., Federal 33-31
NW/SE 31-144-100, KB=2403.

86. 7501, Amoco Production Co., Federal "B" 1
NE/SE 25-145-100, KB=2556.

87. 8341, Tenneco Oil Co., Meinhart USA 1-34
NE/SW 34-147-100, KB=2129.

88. 7700, Texas Oil and Gas Corp., Sperati Federal 1-31
SW/NE 31-148-100, KB=2402.

89. 7943, Amoco Production Co., Hamre 1
NE/NW 23-149-99, KB=2380.

90. 8092, Texaco, Inc., R.T. Lattin 1
SW/NE 27-151-99, KB=2278.

91. 2849, Lyda Hunt-Herbert Trusts et al, Henry C. Hystad 1
NE/SW 31-152-99, KB=2316.

92. 3406, Hunt Petroleum Corp., Emilia Erickson et al 1
NE/NE 10-156-99, KB=2281.

93. 3449, Hunt Petroleum Corp., Chester J. Hamers 1
SE/NW 20-157-98, KB=2213.

94. 3491, Hunt Petrolum Corp., Joseph Thvedt 1
NW/SE 13-160-98, KB=2345.

95. 8915, Amoco Production Co., Lone Butte Federal Amoco A-1
NE/SW 19-147-97, KB=2113.

96. 8414, Gulf Oil Expl. and Prod. Co., Carus Federal 1-30-2C
SE/NW 30-147-97, KB=2385.

97. 8545, Gulf Expl. and Prod. Co., Mormon Butte Federal 1-25-4B
NE/SW 30-147-97, KB=2490.

98. 8215, Gulf Oil and Expl. Co., Mormon Butte Federal 1-25-36
SE/SE 25-147-98, KB=2512.

99. 8624, Gulf Oil Expl. and Prod. Co., Mormon Butte Federal 4-25-4D
SW/SW 25-147-98, KB=2439.

100. 7234, Marathon Oil Co., Armour 18-14
SW/SW 18-155-90, KB=2286.

101. 7369, Marathon Oil Co., Fenborg 19-32
SW/NE 19-155-90, KB=2281.

102. 6974, Brownlie, Wallace, Armstrong, and Bander, State 19-43
NE/SE 19-155-90, KB=2284.

103. 8157, BWAB, Inc., Harsrad 29-21
NE/NW 29-155-90, KB=2327.

APPENDIX B

VALUES OF THICKNESS AND ELEVATION FOR THE INYAN KARA FORMATION

Values of thickness and elevation for the Inyan Kara Formation

Appendix B consists of Table 1, which is a list of the wells used in preparing the regional isopach and structure contour maps of the Inyan Kara (Plates VIII and IX). The wells are listed by township (TWN), range (RNG), and section (SEC) and include the elevation of the Kelly Bushing (KB), depth to the top of the Inyan Kara (DKIK) and Swift (DJSW) Formations, elevation of the top of the Inyan Kara (EKIK), thickness of the Inyan Kara (TKIK), and the North Dakota Geological Survey well number (NDGS). The asterisks (*) indicate that the wells were used in preparing the isopach maps of members "A", "B", and "C" (Plates X-XII), a listing of which is included in Appendix C.

TABLE 1

VALUES OF THICKNESS AND ELEVATION FOR THE INYAN KARA FORMATION

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
129	84	28		2338	3328	3447	-990	119	7930
	85	27		2331	3400	3518	-1069	122	6654
	94	7		2648	4482	4725	-1834	243	8091
	98	30		2695	4562	4852	-1867	290	6050
	100	21		2787	4659	5090	-1872	431	6370
	101	6		2925	4682	5065	-1757	383	5619
	102	2		2857	4590	5018	-1733	428	6074
	103	23		2964	4602	4995	-1638	393	5822
	104	28		3039	4575	4965	-1536	390	6600
	105	13		3149	4445	4800	-1296	355	6176
	106	23		3061	4038	4460	-977	422	6203
130	86	1		1995	3190	3290	-1195	100	4969
	88	23		2206	3450	3612	-1244	162	5118
	91	7		2453	4152	4350	-1699	198	6322
	95	28		2804	4675	4870	-1871	195	7642
	100	17		2867	4865	5290	-1998	425	4545
	102	7		2951	4745	5030	-1794	285	6398
	103	3		3030	4822	5050	-1792	228	5951
	104	15		3179	4845	5180	-1666	335	4143
	107	2		2940	3840	4185	-900	345	3735
131	85	17		2105	3312	3450	-1207	138	4968
	86	9		2009	3238	3390	-1229	152	4953
	87	31		2451	3710	3875	-1259	165	4935
	88	27		2531	3858	4000	-1327	142	5097
	98	32		2805	4790	5228	-1985	438	7939
	100	5		2892	4945	5228	-2053	283	5772
	101	19		2932	4908	5268	-1976	360	4449
	102	6		3007	4950	5175	-1943	225	4542
	103	34		3043	4892	5116	-1849	224	5904
	104	23		3260	5020	5362	-1760	342	5838
	105	33		3002	4418	4808	-1416	390	8119
	106	4		2889	4128	4419	-1239	291	8365
132	84	7		2066	3212	3350	-1146	138	4966
	85	29		2257	3475	3575	-1218	100	5113
	86	7		2285	3610	3768	-1325	158	6420
	93	16		2556	4483	4702	-1927	219	8206
	104	15		3167	5000	5340	-1833	340	5888
	106	27		2921	4353	4662	-1432	309	4452
133	83	26		1997	3068	3230	-1071	162	232
	89	19		2437	4115	4328	-1678	213	4701
	90	1		2350	4115	4355	-1765	240	3636
	92	21		2508	4452	4710	-1944	258	6413
	93	26		2517	4575	4792	-2058	217	7075

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
134	97	24		2669	4870	5238	-2201	368	7453
	98	5		2776	5035	5350	-2259	315	5881
	100	23		2879	5085	5435	-2206	350	7016
	101	33		2976	5175	5500	-2199	325	4749
	102	9		2897	5032	5310	-2135	278	5933
	106	15		2872	4420	4820	-1548	400	7787
134	83	26		2145	3369	3535	-1224	166	4967
	90	5		2408	4280	4538	-1872	258	5496
	92	3		2442	4495	4780	-2053	285	8143
	93	22		2367	4567	4832	-2200	265	7231
	95	30		2602	4926	5190	-2324	264	5689
	96	31		2829	5135	5415	-2306	280	7965
	98	11		2745	5202	5388	-2457	186	4568
	100	23		2955	5276	5568	-2321	292	7890
	105	21		2907	4840	5245	-1933	405	6355
135	82	11		2101	3244	3328	-1143	84	4989
	83	34		2124	3334	3472	-1210	138	3859
	92	12		2524	4585	4930	-2061	345	4984
	96	35		2544	4943	5310	-2399	367	8312
	98	2		2655	5131	5426	-2473	295	5049
	100	16		2807	5195	5535	-2388	330	1464
	101	10		2776	5210	5520	-2434	310	5929
	103	18		2971	5270	5618	-2299	348	4280
136	81	18		1907	3038	3178	-1131	150	5979
	92	15		2429	4528	4865	-2099	337	5447
	93	35		2548	4739	5020	-2182	290	5783
	96	14		2738	5288	5600	-2550	312	7876
	97	19		2680	5250	5552	-2570	302	6795
	99	7		2784	5418	5745	-2634	327	5245
	100	3		2847	5495	5860	-2648	365	5896
	101	23		2810	5292	5635	-2482	343	6048
	102	4		2633	5160	5510	-2527	350	6855
	105	22		2694	4879	5232	-2185	353	6319
	106	23		2937	5015	5320	-2078	305	7784
137	82	17		1736	3125	3278	-1389	153	5018
	83	34		2281	3620	3720	-1339	100	3978
	87	25		2190	3945	4155	-1755	210	5011
	88	5		2342	4248	4448	-1906	200	7020
	92	9		2326	4504	4968	-2178	464	5142
	95	22		2717	5320	5708	-2603	388	5255
	97	9		2688	5455	5740	-2767	285	5143
	98	2		2749	5542	5936	-2793	394	5482
	99	14		2749	5550	5940	-2801	390	6438
	100	2		2800	5515	5822	-2715	307	5195
	102	20		2719	5382	5742	-2663	360	2357
	103	28		2728	5220	5572	-2492	352	7842

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
137	104	9		2696	5218	5549	-2522	331	6361
	106	22		3032	5058	5482	-2026	424	6272
138	82	21		1896	3178	3451	-1282	273	5019
	83	5		1980	3364	3690	-1384	326	5379
	85	6		2076	3755	4075	-1679	320	7770
	86	19		1965	3780	3963	-1815	183	7937
	92	9		2407	4698	5072	-2291	374	6476
	94	23		2554	5062	5405	-2508	343	5203
	97	18		2726	5800	6097	-3074	297	2496
	98	26		2756	5895	6208	-3139	313	7007
	99	21		2696	5485	5863	-2789	378	6307
	100	29		2842	5560	5895	-2718	335	6601
	101	36		2888	5580	5975	-2692	395	6485
	102	1		2737	5370	5742	-2633	372	5243
	103	29		2765	5239	5600	-2474	361	4490
	104	27		2725	5262	5169	-2537	357	5832
	105	9		2867	5240	5656	-2373	416	4130
139	82	11		1861	3225	3338	-1364	113	2185
	86	30		2204	4038	4234	-1834	196	133
	90	27		2426	4525	4860	-2099	335	1620
	92	16		2494	4830	5180	-2336	350	6797
	93	11		2456	4888	5173	-2432	285	4446
	94	3		2450	5242	5570	-2792	328	5754
	95	21		2453	5292	5542	-2839	250	7076
	96	29		2530	5548	5802	-3018	254	5464
	97	8		2496	5275	5572	-2779	297	6447
	98	15		2544	5418	5785	-2874	367	6369
	99	9		2629	5614	5972	-2985	358	5014
	100	6		2805	5636	6010	-2831	374	5342
	101	1		2753	5568	5920	-2815	352	5869
	102	11		2523	5210	5562	-2687	352	3573
	103	17		2898	5500	6009	-2602	509	4999
	104	13		2766	5336	5790	-2570	454	4308
	105	4		2808	5368	5770	-2560	402	6563
	106	10		2836	5218	5680	-2382	462	6861
140	86	36		2204	3958	4211	-1754	253	5017
	88	26		2230	4270	4588	-2040	318	7340
	89	5		2284	4512	4888	-2228	368	7818
	93	11		2293	4908	5234	-2615	326	5415
	94	27		2395	5128	5486	-2733	358	6691
	95	13		2474	5400	5738	-2926	338	5361
	96	14		2456	5631	5941	-3085	310	5526
	97	9		2590	5536	5895	-2946	359	5440
	98	19		2572	5506	5832	-2834	376	5683
	99	31		2668	5582	5884	-2914	302	6820
	100	22		2767	5745	6068	-2978	323	4497
	102	19		2413	5138	5546	-2725	408	6106

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
140	103	10		2662	5365	5874	-2703	509	6331
	105	33		2814	5378	5763	-2564	385	5738
141	82	15		1973	3435	3695	-1462	260	8144
	85	34		2173	3980	4160	-1807	180	6894
	91	8		2113	4715	5040	-2602	325	824
	93	17		2227	5060	5335	-2833	275	5470
	94	24		2255	5156	5464	-2901	308	5274
	95	18		2595	5443	5702	-2848	259	6530
	96	30		2591	5464	5852	-2873	388	5399
	97	7		2598	5570	5920	-2972	350	6396
	98	8		2581	5550	5838	-2969	288	6512
	99	16		2628	5628	5975	-3000	247	6788
	100	26		2556	5429	5790	-2873	361	5861
	101	22		2333	5181	5645	-2848	464	6659
	102	9		2470	5290	5730	-2820	440	7527
	103	31		2726	5485	5985	-2759	500	8460
	104	7		2759	5435	5812	-2676	377	7753
	105	27		2710	5532	5750	-2622	418	5438
142	84	7		2138	3996	4162	-1858	166	4941
	85	14		2193	4018	4224	-1825	206	3227
	91	6		2000	4760	5076	-2760	316	4727
	92	24	*	2155	4888	5213	-2733	325	5131
	93	1	*	2061	5080	5398	-3019	318	9096
	95	2	*	2287	5124	5417	-2837	293	6477
	96	31	*	2618	5600	5920	-2982	320	7360
	97	23	*	2583	5546	5870	-2963	324	5621
	98	36	*	2676	5632	5941	-2956	309	6140
	99	3	*	2728	5754	6078	-3026	324	7618
	100	22	*	2720	5591	5869	-2871	278	6914
	101	13		2535	5360	5755	-2825	395	7452
	102	7		2414	5280	5722	-2866	442	5842
	103	3		2595	5845	5905	-2890	420	7255
	104	22		2595	5380	5805	-2785	425	4466
	105	32		2692	5312	5745	-2620	433	7969
143	83	10		1951	3605	3745	-1654	140	4938
	84	33		2139	3955	4125	-1816	170	4939
	86	34		2217	4268	4438	-2051	170	4942
	92	16	*	2221	4949	5324	-2728	375	9106
	93	23	*	2248	5022	5348	-2774	326	1787
	94	13	*	2133	5000	5355	-2867	355	5155
	95	31	*	2214	5221	5567	-2998	346	8275
	96	36	*	2211	5218	5570	-3007	352	5157
	97	17	*	2575.	5569	5852	-3015	283	8202
	98	28	*	2649	5718	6045	-3019	327	6647
	99	2	*	2722	5760	6090	-3038	330	7348

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
143	100	29	*	2647	5560	5906	-2913	346	6418
	101	4		2428	5308	5670	-2880	362	6724
	102	1		2285	5198	5552	-2913	354	5711
	103	25		2579	5445	5882	-2866	437	6821
	105	17		2669	5509	5885	-2840	376	4735
144	85	34		1958	3888	4110	-1930	222	4823
	88	10		2059	4385	4795	-2326	410	377
	89	11		1968	4395	4730	-2427	335	4808
	90	29		2080	4812	5197	-2732	385	7616
	91	16		2121	4810	5160	-2689	350	5233
	92	7	*	2261	4946	5317	-2685	371	7346
	93	4	*	2240	5073	5418	-2833	345	7460
	94	28	*	2121	5122	5480	-3001	358	4748
	95	30	*	2343	5425	5864	-3082	439	8153
	96	30	*	2310	5377	5767	-3067	390	6489
	97	6	*	2508	5583	6010	-3075	427	7426
	98	3	*	2532	5575	5935	-3043	360	6228
	99	14	*	2750	5800	6078	-3050	278	6214
	100	30	*	2597	5578	5881	-2981	303	4035
	101	6		2198	5145	5479	-2947	334	6310
	102	14		2341	5292	5660	-2951	368	4419
	103	18		2531	5504	5884	-2973	380	6947
	104	1		2451	5413	5815	-2962	402	6508
	105	23		2569	5455	5868	-2886	413	6562
145	80	21		1944	3344	3560	-1400	216	4814
	81	8		2013	3515	3758	-1502	243	4815
	82	10		1875	3478	3746	-1603	268	4810
	83	28		2008	3748	3995	-1740	247	4812
	84	29		1699	3560	3846	-1861	286	4824
	85	17		1948	3996	3246	-2048	300	4796
	86	31		1854	4020	4380	-2166	360	4795
	87	15		1924	4162	4582	-2238	420	4798
	88	17		2203	4662	5148	-2459	486	4177
	90	34	*	2085	4898	5220	-2813	322	6674
	91	17	*	2223	4914	5249	-2691	335	7978
	92	28	*	2141	4847	5180	-2706	333	4488
	93	32	*	2221	5156	5555	-2431	399	5162
	94	7	*	2327	5378	5730	-3051	352	6086
	95	1	*	2359	5422	5792	-3063	370	6348
	96	21	*	2573	5727	6118	-3154	391	8431
	97	18	*	2517	5593	6009	-3076	416	6082
	98	13	*	2614	5679	6095	-3065	416	6230
	99	11	*	2680	5815	6250	-3135	435	5422
	100	7	*	2346	5318	5761	-2972	443	6552
	101	29		2118	5074	5520	-2956	446	5268
	102	17		2432	5538	5948	-3106	410	7746

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
145	103	19		2590	5654	6120	-3064	466	6014
	104	12		2558	5625	6038	-3067	413	6655
	105	24		2379	5330	5804	-2951	474	3645
146	81	34		1932	3412	3645	-1480	233	4813
	82	32		2022	3645	3910	-1623	265	1516
	86	32		2186	4325	4663	-2139	338	4797
	90	25	*	2309	5052	5418	-2743	366	3492
	91	33	*	2146	4962	5335	-2816	373	5532
	93	14	*	2396	5260	5639	-2864	379	7885
	94	21	*	2186	5284	5645	-3098	361	6182
	95	35	*	2325	5356	5743	-3055	430	6887
	96	10	*	2658	5713	6117	-3055	404	7477
	97	8	*	2509	5601	5986	-3092	385	6335
	98	36	*	2262	5368	5666	-3106	298	6324
	99	11	*	2628	5791	6169	-3163	378	7611
	100	21	*	2590	5718	6072	-3128	354	6786
	101	15		2494	5560	5950	-3066	390	7495
	102	11		2210	5372	5760	-3162	388	6716
	103	5		2291	5365	5832	-3074	467	7726
	104	10		2391	5438	5870	-3047	432	7549
	105	15		2280	5290	5730	-3010	440	6382
147	80	11		1880	3203	3452	-1323	249	5261
	92	10	*	2048	4903	5312	-2855	409	7745
	93	8		2297	5196	5612	-2899	416	2848
	95	23	*	2379	5510	5910	-3131	400	7576
	96	22	*	2525	5703	6066	-3078	363	6623
	97	18	*	2055	5120	5452	-3065	332	8486
	98	36	*	2513	5586	5940	-3073	354	6345
	99	27	*	2587	5729	6080	-3142	351	7636
	100	34	*	2129	5274	5568	-3146	294	8341
	101	21		2196	5380	5684	-3184	304	6718
	102	27		2222	5382	5765	-3160	383	7850
	103	17		2216	5356	5770	-3140	414	6443
	104	29		2327	5401	5824	-3074	423	6848
	105	1		2090	5168	5690	-3078	522	6456
148	89	30		2058	4765	5105	-2707	340	5352
	90	1	*	2064	4773	5160	-2728	387	4375
	95	18	*	2441	5478	5848	-3039	370	2352
	96	10	*	2095	5072	5428	-2977	356	7614
	97	20	*	2443	5552	5900	-3109	348	3178
	98	36	*	2206	5327	5675	-3121	348	6597
	100	9	*	2311	5594	5924	-3283	330	6524
	102	4		2433	5675	6110	-3242	435	7580
	103	24		2474	5700	6120	-3226	420	7648
	104	7		2321	5512	6007	-3191	495	6387
	105	2		2081	5202	5690	-3121	488	6383

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
149	86	16		2227	4376	4769	-2149	393	5126
	90	5	*	1989	4800	5168	-2811	368	1194
	91	22	*	2102	4942	5322	-2840	380	793
	92	33	*	2363	5187	5595	-2824	408	7214
	93	24	*	2149	5047	5422	-2898	375	607
	95	16	*	2294	5210	5576	-2916	366	5936
	96	24	*	2499	5372	5750	-2873	378	6368
	97	2	*	2212	5253	5625	-3041	372	4085
	98	11	*	2232	5538	5828	-3306	290	3157
	99	10	*	2127	5495	5868	-3368	373	6493
	100	22	*	2207	5528	5870	-3321	342	7879
	102	35		2397	5658	6030	-3261	372	7478
	103	28		2212	5488	5895	-3276	407	7640
	104	18		2122	5242	5790	-3120	548	6807
150	80	14		2006	3330	3604	-1324	274	3089
	86	27		2162	4282	4662	-2120	380	8310
	88	29		1999	4545	4916	-2546	371	5826
	89	12		2019	4550	4947	-2531	397	6766
	90	1	*	2190	4981	5360	-2791	379	7783
	92	20	*	2143	5000	5357	-2857	357	7457
	93	4	*	2198	5147	5522	-2949	375	4113
	94	33	*	2334	5163	5560	-2829	397	3731
	95	19	*	2342	5100	5484	-2758	384	6608
	96	20	*	2327	5152	5532	-2825	380	6849
	97	3	*	2244	5147	5571	-2903	424	7743
	98	23	*	2022	5293	5708	-3271	475	7704
	99	15	*	2141	5522	5960	-3381	438	7873
	100	29		2335	5675	6115	-3340	440	5774
	101	20		2308	5622	6087	-3314	465	7796
	102	31		2262	5580	5998	-3318	418	7650
	103	3		2127	5477	5915	-3350	438	7422
	104	25		2170	5384	5866	-3214	482	5655
151	81	19		2146	3642	3972	-1478	348	5401
	86	23		2150	4221	4648	-2071	427	5096
	88	20		2147	4655	5020	-2508	365	5731
	89	34		2139	4685	5090	-2546	405	8447
	90	1	*	2115	4761	5171	-2646	410	4392
	94	10	*	1956	4744	5152	-2788	408	4594
	95	13	*	2107	4734	5130	-2627	396	3056
	96	34	*	2432	5081	5457	-2649	376	4095
	97	11	*	2291	5093	5478	-2802	385	7008
	99	27	*	2278	5629	6055	-3351	426	8092
	101	23		2048	5375	5785	-3327	410	4723
	102	1		2086	5385	5895	-3299	510	7142
	103	8		2200	5508	5910	-3308	402	1642

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
152	82	33		2086	3605	4005	-1519	400	588
	83	13		2110	3673	4092	-1563	419	3080
	85	7		2122	4170	4525	-2048	355	7554
	86	28		2120	4285	4635	-2165	350	5105
	87	28		2092	4336	4710	-2244	374	5313
	88	19		2086	4538	4903	-2452	365	2779
	90	30	*	1881	4568	4942	-2687	374	4747
	93	16	*	2020	5004	5427	-2984	424	4061
	94	7	*	2190	4803	5190	-2613	387	3387
	95	7	*	2363	4865	5249	-2502	384	4013
	96	14	*	2451	4957	5348	-2506	391	6323
	99	31	*	2316	5648	6063	-3332	415	2849
	101	5		2198	5492	5960	-3294	468	6946
	102	35		2276	5575	6085	-3299	510	6799
	104	2		2169	5435	5969	-3266	534	8178
153	80	14		1636	2858	3158	-1222	300	5344
	82	15		1795	3286	3658	-1491	372	5519
	83	7		2067	3855	4226	-1788	371	3314
	84	30		2123	4115	4472	-1992	357	8270
	85	13		2117	4002	4386	-1885	384	5158
	87	24		2098	4268	4620	-2170	352	6637
	89	10		1979	4455	4845	-2476	390	7471
	92	25	*	2307	5222	5636	-2915	414	3317
	94	32	*	2260	4816	5245	-2556	429	4239
	95	36	*	2379	4927	5345	-2548	418	6617
	96	10	*	2097	4475	4933	-2378	458	4494
	97	16	*	2052	5338	5810	-3286	472	7233
	99	1	*	2342	5702	6168	-3360	460	7470
	100	1		2313	5650	6125	-3337	475	8441
	101	26		2100	5309	5800	-3209	491	6616
	103	31		2222	5500	6050	-3278	550	7602
	104	25		2172	5440	5972	-3268	532	7632
154	81	19		1566	2970	3250	-1404	280	3237
	82	31		1797	3378	3664	-1581	286	4891
	83	8		1845	3511	3918	-1666	407	2930
	84	32		2132	4010	4420	-1878	410	6653
	85	6		2219	4245	4460	-2026	215	5389
	86	22		2121	4253	4475	-2132	222	4223
	88	5		2132	4455	4792	-2323	337	7238
	89	29		2162	4705	5070	-2543	365	7918
	90	22	*	2235	4823	5221	-2588	398	7414
	91	5	*	2305	5106	5484	-2801	378	6695
	92	12	*	2389	5222	5630	-2833	408	2816
	95	18	*	2052	4297	4750	-2245	453	6184
	96	1	*	1955	4240	4702	-2285	462	1266
	99	36	*	2256	5630	6125	-3374	495	7074

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
154	100	20		1880	5208	5700	-3328	492	2476
	102	9		2155	5412	5900	-3257	488	8423
	103	4		2305	5459	5976	-3154	517	5992
155	81	21		1593	2902	3230	-1309	328	5531
	82	25		1659	3015	3380	-1356	365	6100
	84	8		1884	3650	3932	-1766	282	6725
	85	32		2206	4160	4428	-1954	268	6610
	86	16		2234	4305	4618	-2071	313	5468
	87	15		2219	4362	4671	-2143	309	7612
	88	35		2135	4414	4776	-2279	362	6179
	89	19		2034	4501	4861	-2467	360	7368
	90	21	*	2317	4835	4854	-2518	377	7220
	91	27	*	2315	5032	5450	-2717	418	6834
	93	15	*	2360	5313	5732	-2953	419	2273
	94	16	*	2030	4739	5130	-2709	391	3227
	95	18	*	2305	4524	4972	-2219	448	6362
	96	35		2032	4222	4680	-2190	458	6388
	97	14	*	2253	4938	5362	-2685	424	7089
	98	21	*	2248	5502	5900	-3254	398	7712
	99	8	*	2116	5365	5826	-3249	461	7405
	100	30		1898	5175	5618	-3277	443	7004
	101	8		2192	5425	5938	-3233	513	6806
	102	24		2192	5462	5935	-3270	473	7692
156	80	8		1526	2594	2904	-1068	310	4112
	81	8		1580	2848	3160	-1268	312	5563
	82	5		1638	2980	3335	-1342	355	5360
	83	22		1678	3199	3550	-1521	351	4805
	84	10		1730	3295	3715	-1565	420	4400
	85	19		1982	3910	4220	-1928	310	3984
	86	30		2206	4357	4625	-2151	268	7695
	87	12		2146	4293	4583	-2147	290	7042
	90	31	*	2280	4865	5253	-2585	388	7847
	91	17	*	2340	4984	5397	-2544	413	6515
	92	14	*	2322	5021	5417	-2699	396	592
	93	26	*	2376	5238	5640	-2862	402	5333
	94	28	*	2331	5000	5351	-2669	351	7741
	95	2	*	2264	4628	5069	-2364	441	7699
	96	36	*	2335	4585	5015	-2250	430	5427
	97	27	*	2272	5045	5500	-2773	465	547
	99	10	*	2281	5475	5904	-3194	429	3406
	101	16		2168	5340	5773	-3172	433	3235
	102	14		2151	5246	5717	-3095	471	7054
	103	23		2389	5405	5870	-3016	465	6789
	104	12		2437	5370	5859	-2933	489	7356

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
157	79	12		1487	2306	2636	-819	330	5078
	80	2		1506	2466	2795	-960	329	5982
	81	24		1535	2640	2961	-1105	321	4409
	82	36		1622	2912	3308	-1290	396	6486
	83	1		1631	2961	3280	-1330	319	5539
	84	2		1770	3312	3692	-1542	380	6502
	85	24		1829	3550	3962	-1721	412	6032
	86	3		1887	3754	4170	-1867	416	5809
	87	1		2053	4155	4470	-2102	315	6978
	88	12		2301	4435	4755	-2134	320	3673
	89	20		2222	4550	4945	-2328	395	4194
	90	19		2384	4930	5305	-2546	375	1406
	91	4	*	2372	4946	5340	-2574	394	4682
	94	10		2290	4815	5203	-2525	388	1270
	95	33	*	2271	4580	5022	-2309	442	6111
	96	30		2324	4955	5357	-2631	394	8296
	97	2	*	2296	5111	5506	-2815	395	7789
	98	20	*	2213	5323	5717	-3110	394	3449
	101	17		2191	5180	5702	-2989	522	7834
	103	10		2358	5512	5742	-2854	530	5271
158	79	7		1480	2354	2694	-874	340	5076
	80	7		1511	2543	2840	-1032	297	7609
	81	12		1516	2602	2879	-1086	277	6380
	82	1		1562	2690	3042	-1128	352	7279
	83	28		1673	3042	3387	-1369	345	7709
	84	18		1755	3410	3784	-1655	374	6409
	85	22		1819	3537	3840	-1718	303	5585
	86	31		1975	3968	4278	-1993	310	6553
	87	24		1769	3820	4195	-2051	375	6041
	88	30		2259	4485	4817	-2226	332	3540
	89	9		2342	4620	5022	-2278	402	3005
	91	19	*	2379	5017	5370	-2638	353	5786
	92	9		2288	4942	5300	-2654	358	1315
	94	7	*	2368	4888	5283	-2520	395	5350
	95	21	*	2513	4909	5329	-2396	420	5935
	96	26	*	2354	4882	5245	-2528	363	7565
	97	17	*	2276	5126	5533	-2850	407	8239
	99	3	*	2150	4942	5328	-2792	386	3252
	100	1		2133	4920	5375	-2787	455	8180
	101	10		2087	4896	5355	-2809	459	7164
	103	6		2035	4642	5022	-2607	380	5054
159	79	29		1457	2374	2648	-917	274	6700
	80	29		1495	2445	2780	-950	335	7804
	81	33		1521	2626	2934	-1105	308	6379
	82	32		1587	2750	3170	-1163	420	5692
	83	33		1646	2928	3287	-1282	349	7057

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
159	84	8		1697	3146	3496	-1449	350	6328
	85	31		1828	3566	3882	-1738	316	5615
	86	26		1863	3688	4030	-1825	342	5851
	87	3		1921	3872	4188	-1951	316	2134
	88	32		2141	4344	4663	-2203	319	1843
	90	17		2398	4785	5165	-2387	380	3604
	91	24	*	2381	4814	5171	-2433	357	4433
	92	9	*	2467	4910	5282	-2443	372	6047
	93	10	*	2290	4808	5200	-2518	392	4335
	94	6	*	2364	4750	5147	-2386	397	5411
	95	30	*	2370	4862	5236	-2492	374	3126
	96	12	*	2317	4813	5173	-2496	360	3392
	97	10	*	2301	4984	5377	-2683	393	8039
	98	2	*	2306	4963	5308	-2657	345	3274
	99	2	*	2273	4938	5312	-2665	374	6017
	101	2		2160	4760	5418	-2600	388	5509
	102	15		2295	4895	5330	-2600	435	6162
	103	24		2206	4786	5110	-2580	324	4663
160	79	16		1464	2224	2518	-760	294	4915
	80	19		1511	2402	2732	-891	330	2596
	81	5		1516	2472	2800	-956	328	4192
	82	5		1549	2585	3000	-1036	415	4431
	83	27		1600	2797	3128	-1197	331	4997
	84	21		1687	3028	3400	-1341	372	6001
	85	27		1743	3325	3653	-1582	328	6446
	86	4		1821	3535	3840	-1714	305	7716
	87	16		1893	3768	4105	-1875	337	6482
	88	36		1952	3962	4363	-2010	401	4097
	89	19		2062	4173	4495	-2111	322	1005
	90	30	*	2336	4631	4978	-2295	347	6028
	91	5	*	2414	4658	4999	-2244	341	5721
	92	21	*	2358	4750	5132	-2392	382	7917
	93	23	*	2371	4805	4895	-2434	359	2684
	94	5	*	2379	4816	5198	-2437	382	4101
	95	3	*	2373	4662	5078	-2289	416	5192
	96	35	*	2290	4745	5083	-2455	338	5009
	97	19	*	2307	4865	5228	-2558	363	5547
	98	10	*	2243	4722	5040	-2479	318	5248
	99	24	*	2236	4775	5070	-2539	295	7116
	100	12		2212	4583	4978	-2471	395	4837
	101	32		2257	4792	5168	-2535	376	3374
	102	26		2263	4735	5148	-2472	413	4962
	103	33		2006	4436	4869	-2430	433	7658
161	79	1		1470	2140	2392	-670	252	6259
	80	9		1500	2312	2512	-812	200	5943
	81	10		1514	2450	2740	-936	290	5358

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
161	82	33		1561	2648	3058	-1087	410	4918
	83	17		1611	2785	3168	-1174	383	5455
	84	10		1666	2955	3355	-1285	404	3987
	85	14		1754	3190	3538	-1436	348	6166
	86	22		1829	3486	3786	-1657	300	6507
	87	4		1881	3588	3960	-1707	372	5796
	89	32		1994	4075	4400	-2081	325	1842
	90	15	*	1983	4068	4373	-2085	305	5850
	91	2	*	1973	4084	4395	-2111	311	4958
	92	15	*	2422	4658	5060	-2236	402	4317
	93	2	*	2244	4515	4886	-2271	371	7575
	94	5	*	2364	4612	4990	-2248	378	5246
	96	25	*	2364	4720	5065	-2356	345	2996
	97	20	*	2157	4603	4937	-2446	334	4394
	98	13	*	2060	4462	4816	-2402	354	2722
	100	15		2242	4587	4892	-2345	305	2721
	101	3		2244	4542	4957	-2298	415	6751
	102	19		2102	4385	4805	-2283	420	4487
	103	25		2075	4330	4770	-2255	440	6900
162	79	35		1470	2125	2362	-655	237	7270
	80	11		1496	2210	2530	-714	320	5038
	81	32		1520	2415	2760	-895	345	3034
	82	26		1538	2440	2790	-902	350	4726
	83	32		1603	2750	3102	-1147	352	7799
	84	14		1626	2800	3135	-1174	335	5574
	85	3		1699	2965	3280	-1266	315	5779
	86	30		1837	3445	3765	-1608	320	6442
	87	1		1716	3246	3590	-1530	344	6504
	89	14		1923	3770	4105	-1847	335	3365
	90	32	*	1964	3996	4303	-2032	307	7664
	91	34	*	1975	4103	4410	-2128	307	7859
	92	15	*	1948	4039	4413	-2091	374	6081
	93	36	*	2096	4364	4726	-2268	362	6460
	94	21		2050	4302	4675	-2252	373	7528
	95	20	*	2136	4303	4668	-2167	365	4074
	96	16	*	2141	4388	4728	-2247	340	6798
	98	5	*	2221	4482	4853	-2261	371	1900
	100	13		2349	4593	4950	-2244	357	6541
	101	27		2201	4535	4920	-2334	390	6652
	102	3		2244	4373	4621	-2129	255	3441
	103	26		2145	4330	4730	-2185	400	6429
163	79	8		1480	2065	2395	-585	330	7151
	80	36		1499	2172	2498	-673	326	6126
	81	23		1512	2220	2575	-708	355	7298
	82	24		1530	2334	2684	-804	350	7147
	83	23		1594	2578	2900	-984	322	7176

TABLE 1--CONTINUED

TWN	RNG	SEC	*	KB	DKIK	DJSW	EKIK	TKIK	NDGS
163	84	27		1620	2700	3072	-1080	372	7491
	85	30		1736	2989	3393	-1253	404	5649
	86	11		1752	3060	3500	-1308	440	7473
	87	3		1645	3085	3480	-1440	395	6749
	89	23		1907	3565	3850	-1658	315	6877
	90	7		1943	3742	4092	-1799	350	7540
	91	7		1957	3820	4200	-1863	380	5950
	92	7		1941	3927	4235	-1986	345	7837
	93	15		1933	4008	4410	-2075	402	5782
	94	6		1921	3967	4323	-2046	356	7773
	95	29		1926	4055	4420	-2129	365	4691
	96	32		1932	4195	4484	-2193	359	7515
	97	26		1957	4145	4516	-2188	371	3903
	98	30		2119	4469	4785	-2350	316	6061
	99	23		2209	4400	4705	-2191	305	5404
	100	27		2170	4310	4630	-2140	320	7095
	101	14		2180	4305	4603	-2125	298	6110
	102	14		2128	4203	4470	-2075	263	6062
	103	35		2154	4175	4420	-2021	245	3596
164	79	32		1492	2048	2320	-556	272	3775
	80	33		1508	2125	2470	-617	355	6874
	81	33		1519	2212	2576	-693	364	4780
	82	35		1534	2332	2670	-798	338	3706
	83	33		1603	2555	2877	-952	355	3051
	84	30		1643	2685	3098	-1042	413	7684
	85	33		1680	2790	3155	-1110	365	5388
	86	36		1737	2990	3360	-1253	370	3906
	87	34		1636	3055	3395	-1419	340	6349
	89	32		1852	3452	3748	-1600	306	5332
	90	33		1901	3665	4017	-1764	352	5908
	91	31		1959	3775	4130	-1816	355	1707
	92	34		1978	3830	4195	-1852	365	2856
	93	31		1911	3915	4282	-2004	367	1153
	95	31		1903	3878	4248	-1975	370	5989
	96	32		1898	3982	4320	-2084	338	4149
	103	34		2177	4110	4315	-1933	205	3982

APPENDIX C

VALUES OF THICKNESS FOR MEMBERS "A", "B", AND "C"

Values of thickness for members "A", "B", and "C"

Appendix C consists of Table 2, which is a list of the wells used in the isopach maps of members "A", "B", and "C" (Plates X-XII). The wells are arranged by township (TWN), range (RNG), and section (SEC) and include elevation of the Kelly Bushing (KB), depth to the tops of members "C" (DC), "B" (DB), "A" (DA), and Swift Formation (DJSW), thicknesses of "C" (TC), "B" (TB), and "A" (TA), and the North Dakota Geological Survey well number (NDGS).

TABLE 2

VALUES OF THICKNESS FOR MEMBERS "A", "B", AND "C"

TWN	RNG	SEC	KB	DC	DB	DA	DJSW	TC	TB	TA	NDGS
142	92	24	2155	4888	4912	4930	5213	24	18	283	5131
	93	1	2061	5080	5106	5166	5398	26	60	232	9096
	95	2	2287	5124	5152	5209	5417	28	57	208	6477
	96	31	2618	5600	5633	5687	5920	33	54	233	7360
	97	23	2583	5546	5581	5643	5870	35	62	217	5621
	98	36	2676	5632	5664	5721	5941	32	57	220	6140
	99	3	2728	5754	5788	5848	6078	34	60	230	7618
	100	22	2720	5591	5625	5689	5869	34	64	189	6914
143	92	16	2221	4949	4973	5024	5324	24	51	300	9106
	93	23	2248	5022	5050	5114	5348	28	64	234	1787
	94	13	2133	5000	5028	5080	5355	28	52	275	5155
	95	31	2214	5221	5251	5318	5567	30	67	249	8275
	96	36	2211	5218	5250	5300	5570	32	50	270	5157
	97	17	2575	5569	5600	5628	5852	31	28	224	8202
	98	28	2699	5718	5750	5790	6045	32	40	255	6647
	99	2	2722	5760	5793	5850	6090	33	57	240	7348
	100	29	2647	5560	5594	5677	5906	34	83	229	6418
144	92	7	2261	4946	4972	5050	5317	26	78	267	7346
	93	4	2240	5073	5100	5160	5418	27	60	258	7460
	94	28	2121	5122	5151	5210	5480	29	59	270	4748
	95	30	2343	5425	5455	5505	5864	30	50	359	8153
	96	30	2310	5377	5408	5454	5767	31	46	313	6489
	97	6	2508	5583	5615	5670	6010	32	55	340	7426
	98	3	2532	5575	5608	5678	5935	33	70	257	6228
	99	14	2750	5800	5833	5903	6078	33	70	175	6214
	100	36	2597	5578	5612	5682	5881	34	70	199	4035
145	90	34	2085	4898	4926	4985	5220	28	49	235	6674
	91	17	2223	4914	4938	4972	5249	24	34	277	7978
	92	28	2141	4847	4876	4920	5180	29	44	260	4488
	93	32	2221	5156	5186	5247	5555	30	61	308	5162
	94	7	2327	5378	5408	5465	5730	30	57	265	6086
	95	1	2359	5422	5452	5512	5792	30	60	280	6348
	96	21	2573	5727	5758	5825	6118	31	69	293	8431
	97	18	2517	5593	5625	5706	6009	32	81	303	6082
	98	13	2614	5679	5713	5775	6095	34	62	320	6230
	99	11	2680	5815	5850	5920	6250	35	70	330	5422
	100	7	2346	5318	5362	5409	5761	44	47	352	6552
146	90	25	2309	5052	5073	5127	5418	21	54	291	3492
	91	33	2146	4962	4985	5053	5335	23	68	282	5532
	93	14	2396	5260	5288	5307	5639	27	19	332	7885
	94	21	2186	5284	5311	5379	5645	27	68	266	6182
	95	35	2300	4593	4622	4696	5023	29	74	327	6687

TABLE 2--CONTINUED

TWN	RNG	SEC	KB	DC	DB	DA	DJSW	TC	TB	TA	NDGS
146	96	10	2658	5713	5743	5824	6117	30	81	293	7477
	97	8	2509	5601	5634	5725	5986	33	91	261	6335
	98	36	2262	5368	5399	5454	5666	31	55	212	6324
	99	11	2628	5791	5836	5931	6169	45	95	238	7611
	100	21	2590	5718	5765	5830	6072	47	65	242	6786
147	92	10	2048	4903	4930	4982	5312	27	52	330	7745
	93	8	2212	5072	5100	5219	5483	28	119	264	4957
	95	23	2379	5510	5542	5653	5910	32	111	257	7576
	96	22	2625	5703	5735	5823	6066	32	88	243	6623
	97	18	2055	5120	5152	5219	5452	32	67	233	8486
	98	36	2513	5586	5618	5676	5940	32	58	264	6345
	99	27	2587	5729	5765	5827	6080	36	62	253	7636
	100	34	2525	5274	5320	5364	5568	46	44	204	8341
148	90	1	2064	4773	4792	4820	5160	19	28	340	4375
	95	18	2441	5478	5515	5556	5848	37	41	292	2352
	96	10	2095	5072	5104	5166	5428	42	62	262	7614
	97	20	2443	5552	5585	5638	5900	33	53	262	3178
	98	36	2206	5327	5361	5405	5675	34	44	270	6597
	100	9	2311	5594	5636	5702	5924	42	66	222	6524
149	90	5	1989	4800	4817	4857	5168	17	40	311	1194
	91	22	2102	4942	4959	5020	5322	17	61	302	793
	92	33	2363	5187	5215	5347	5595	28	132	248	7214
	93	24	2149	5047	5072	5160	5422	25	88	262	607
	95	16	2294	5210	5242	5278	5576	32	36	298	5936
	96	24	2499	5372	5402	5446	5750	30	44	304	6368
	97	2	2212	5253	5285	5350	5625	32	65	275	4085
	98	11	2232	5538	5570	5657	5828	32	87	171	3157
	99	10	2127	5495	5529	5590	5868	34	61	278	6493
150	90	1	2190	4981	5000	5084	5360	19	84	276	7783
	92	20	2143	5000	5028	5097	5357	28	69	260	7457
	93	4	2198	5147	5175	5229	5522	28	54	293	4113
	94	33	2334	5163	5200	5264	5560	37	64	296	3731
	95	19	2342	5100	5130	5175	5484	30	45	309	6608
	96	20	2327	5152	5185	5228	5532	33	43	304	6849
	97	3	2244	5147	5180	5243	5571	33	63	318	7743
	98	23	2022	5293	5326	5400	5708	33	74	308	7704
	99	15	2141	5522	5558	5643	5960	36	85	317	7873
151	90	13	2115	4761	4781	4934	5171	20	153	237	4392
	94	10	1956	4744	4775	4833	5152	31	58	319	4594
	95	13	2107	4734	4762	4806	5130	28	44	324	3056
	96	34	2432	5081	5113	5160	5457	32	47	297	4095
	97	11	2291	5093	5127	5181	5478	34	54	297	7008
	99	27	2278	5629	5662	5701	6055	33	46	347	8092
152	90	30	1881	4568	4581	4737	4942	13	156	205	4747

TABLE 2--CONTINUED

TWN	RNG	SEC	KB	DC	DB	DA	DJSW	TC	TB	TA	NDGS
152	93	16	2020	5004	5030	5098	5427	26	68	329	4061
	94	7	2190	4803	4833	4885	5190	30	52	305	3387
	95	7	2363	4865	4896	4961	5249	31	65	288	4013
	96	14	2451	4957	4989	5041	5348	32	53	307	6323
	99	31	2316	5648	5681	5773	6063	33	96	290	2849
153	92	25	2307	5222	5248	5330	5636	26	82	306	3317
	94	32	2260	4816	4845	4910	5245	29	65	335	4239
	95	36	2379	4927	4957	5008	5345	30	51	337	6617
	96	10	2097	4475	4505	4570	4933	30	65	363	4494
	97	16	2052	5338	5372	5406	5810	34	34	404	7233
	99	1	2342	5702	5739	5768	6168	37	29	404	7233
154	90	22	2235	4823	4846	4896	5221	23	50	325	7414
	91	5	2305	5106	5129	5147	5484	23	18	337	6695
	92	12	2389	5222	5347	5282	5630	25	35	348	2816
	95	18	2052	4297	4328	4368	4750	31	40	382	6184
	96	1	1955	4240	4270	4330	4702	30	60	372	1266
	99	36	2256	5630	5664	5712	6125	34	48	413	7074
155	90	21	2317	4835	4854	4880	5212	19	26	332	7220
	91	27	2315	5032	5052	5080	5450	20	28	370	6834
	93	15	2360	5313	5341	5404	5732	28	63	328	2273
	94	16	2030	4739	4764	4814	5130	25	50	316	3227
	95	18	2305	4524	4556	4587	4972	32	31	385	6362
	97	14	2253	4938	4970	5037	5362	32	67	325	7089
	98	21	2248	5502	5537	5636	5900	35	99	264	7712
	99	8	2116	5365	5402	5482	5826	37	80	344	7405
156	90	31	2280	4865	4890	4955	5253	25	65	298	7847
	91	17	2340	4984	5008	5058	5397	24	50	339	6515
	92	14	2322	5021	5052	5090	5417	31	38	327	592
	93	26	2376	5238	5266	5308	5640	28	42	332	5333
	94	28	2331	5000	5028	5071	5351	28	43	280	7741
	95	2	2264	4628	4655	4699	5069	27	44	370	7699
	96	36	2335	4585	4618	4681	5015	33	63	334	5427
	97	27	2272	5045	5082	5145	5500	37	73	355	547
	99	10	2281	5475	5511	5560	5904	36	49	344	3406
157	91	4	2372	4946	4965	5015	5340	19	50	325	4682
	93	33	2271	4580	4608	4662	5022	28	54	360	6111
	96	2	2423	4886	4919	4977	5280	33	58	303	6723
	97	2	2296	5111	5148	5187	5506	37	39	319	7789
	98	20	2213	5323	5358	5408	5717	35	50	309	3449
158	91	19	2379	5017	5040	5105	5370	23	65	265	5786
	94	7	2368	4888	4917	4988	5283	29	71	295	5350
	95	21	2513	4909	4941	5014	5329	32	73	315	5935
	96	26	2354	4882	4912	4985	5245	30	73	260	7565
	97	17	2276	5126	5160	5218	5533	34	58	315	8239

TABLE 2--CONTINUED

TWN	RNG	SEC	KB	DC	DB	DA	DJSW	TC	TB	TA	NDGS
158	99	3	2150	4942	4974	5012	5328	32	38	316	3252
159	91	24	2381	4814	4835	4878	5171	21	43	293	4433
	92	9	2467	4910	4933	4990	5282	23	57	292	6047
	93	10	2290	4808	4833	4874	5200	25	41	326	4335
	94	6	2364	4750	4778	4837	5147	28	59	310	5411
	95	30	2370	4862	4893	4960	5236	31	67	276	3126
	96	12	2317	4813	4842	4900	5173	29	58	273	3392
	97	10	2301	4984	5016	5071	5377	32	55	306	8039
	98	2	2306	4963	4998	5061	5308	35	63	247	3274
	99	2	2273	4938	4970	5037	5312	32	67	275	6017
160	90	30	2336	4631	4655	4725	4978	24	70	253	6028
	91	5	2414	4658	4680	4741	4999	22	57	258	5721
	92	21	2358	4750	4772	4820	5132	22	48	312	7917
	93	23	2371	4805	4831	4895	5163	26	64	268	2684
	94	5	2379	4816	4841	4898	5198	25	57	300	4101
	95	3	2372	4662	4690	4772	5078	28	82	306	5192
	96	35	2290	4745	4770	4835	5083	25	65	248	5009
	97	19	2307	4865	4894	4948	5228	29	54	280	5547
	98	10	2243	4722	4753	4809	5040	31	56	231	5248
	99	24	2236	4775	4810	4865	5070	35	55	205	7116
161	90	15	1983	4068	4090	4139	4373	22	49	234	5850
	91	2	1973	4084	4107	4147	4395	23	40	248	4958
	92	15	2422	4658	4682	4738	5060	24	56	322	4317
	93	2	2244	4515	4538	4602	4886	23	64	284	7575
	94	5	2364	4612	4640	4716	4990	28	76	274	5246
	96	25	2364	4720	4745	4785	5065	25	40	280	2996
	97	20	2157	4603	4635	4682	4937	29	47	255	4394
	98	13	2060	4462	4493	4540	4816	31	47	276	2722
162	90	32	1964	3996	4010	4044	4303	14	34	259	7664
	91	34	1975	4103	4121	4168	4410	18	47	242	7859
	92	15	1948	4039	4051	4105	4413	12	54	308	6081
	93	36	2096	4364	4390	4454	4726	26	64	282	6460
	95	20	2136	4303	4329	4402	4668	26	73	266	4074
	96	16	2141	4388	4410	4476	4728	22	66	252	6798
	98	5	2221	4482	4503	4562	4853	21	59	291	1900

APPENDIX D

CORE DESCRIPTION

APPENDIX D

Core description

Description of core from the Matthew Iverson 1, NDGS 165, Sec. 1, Twn. 155 N., Rng. 96 W. was arranged as follows: rock lithology; rock color; rock constituents; sedimentary structures; miscellaneous. Terminology used in the descriptions are from Pettijohn, Potter, and Siever (1973) and Reineck and Singh (1980). Depths in feet (m) were taken from core-box labels as filed with the Core and Sample Library of the North Dakota Geological Survey, Grand Forks, North Dakota.

APPENDIX D

CORE DESCRIPTION

NDGS 165

Core Depth	Core Description
INYAN KARA FORMATION	
Member "C" (in part):	
4590-4592 (1399-1399.6)	Interbedded shale and siltstone; shale is black; thinly laminated; siltstone is light gray; thinly laminated to lensoidal.
Member "B":	
4592-4632 (1399.6-1411.8)	Interbedded siltstone and shale; shale is black; thinly laminated; with abundant plant fragments near the base that decrease in abundance up section; siltstone is light gray; quartzose; in thin to thick laminae that decrease in abundance up section; structures include load structures (throughout core), erosional truncation (Fig. 22), micro-dikes (Fig. 20), convoluted bedding (Fig. 21), rip-up clasts (Fig. 19), and both horizontal and vertical burrows (Figs. 19 and 20); bedding is predominantly wavy and parallel but may be either even and parallel or wavy and nonparallel.
Member "A":	
4632-4647 (1411.8-1416.4)	Siltstone and shale; shale is light to dark gray; thinly laminated; with ironstone nodules (Fig. 15), iron-oxide staining, and abundant plant fragments; siltstone is light gray; quartzose; occurs as burrow infilling or thin laminae.
4648-4929 (1416.7-1502.3)	Missing section (not cored)

Core Depth	Core Description
4930-4939 (1502.7-1505.4)	Coal, sandstone, siltstone and shale; core broken into fragments; sandstone is quartzose, coarse-grained, with a dusty red-brown coating (possibly iron-oxide), with infilling of a few pores with a soft, white mineral (possibly gypsum), well indurated, often containing fragments of coal (Fig. 16); siltstone is quartzose and occurs as laminae interbedded with gray shale.
4940-4943 (1505.7-1506.6)	Sandstone; light gray; quartzose, fine-grained, friable; no bedding evident, but mottling suggests some bioturbation.
4943-4964 (1506.9-1514.2)	Sandstone; medium gray; medium-grained, dominantly quartz plus black shale fragments with laminae to thin beds of light gray shale, friable; ripple cross-lamination and climbing ripples (Figs. 13 and 14).
4964-4968 (1513-1514.2)	Sandstone; medium gray; medium-grained, dominantly quartz plus black shale fragments with thin beds of quartzose sandstone, friable; cross-bedded.
4968-4971 (1514.2-1515.1)	Sandstone; medium gray; coarse- to medium-grained, dominantly quartz and black shale fragments, "white specks" (possibly altered feldspar), and stringers of dark, possibly carbonaceous, material, friable; fining-upwards sequence with cross-bedding.
4971 (1515.1)	Shale-pebble conglomerate; black; pebbles are rounded, calcareous, with a matrix of coarse-grained, quartzose sandstone.
4971-4972 (1515.1-1515.4)	Sandstone; dark gray; coarse-grained, dominantly quartz and black shale fragments with "white specks" (possibly altered feldspar), friable; cross-bedded.

Swift Formation (in part):

4972-4980 (1515.4-1518)	Shale; black; calcareous with crystals of pyrite; thinly laminated; upper contact is abrupt.

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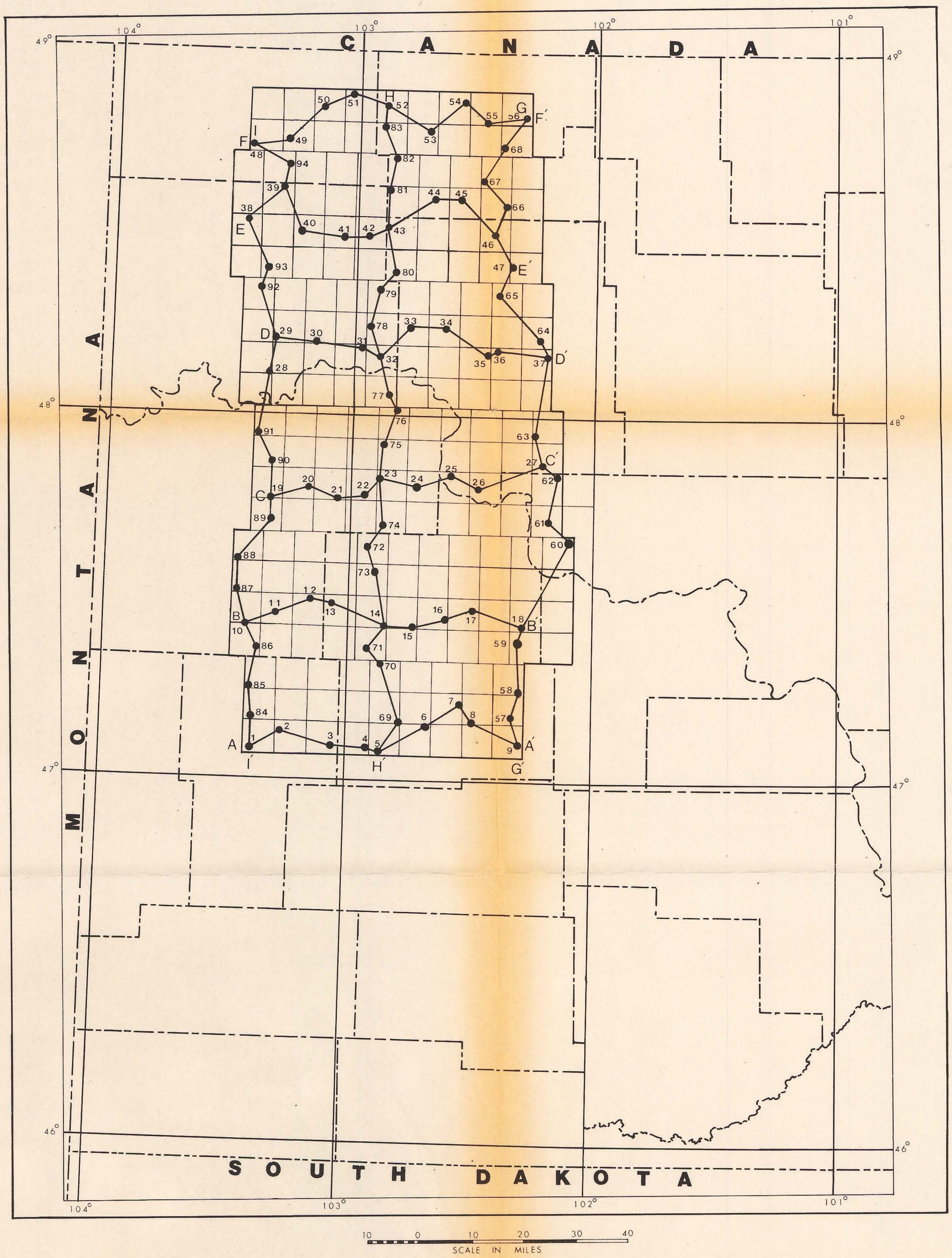

PLATE I

LOCATION OF CROSS-SECTIONS A-A' TO I-I'

WITH WELL REFERENCE NUMBERS

T1983
W266
plate I

PLATE I

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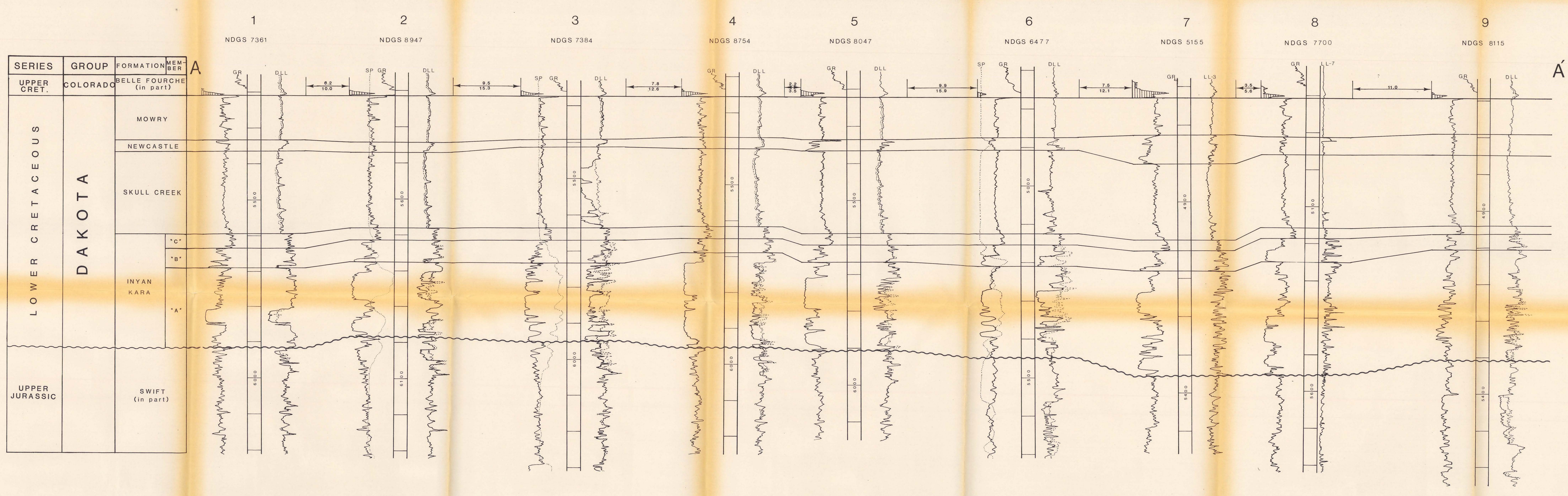

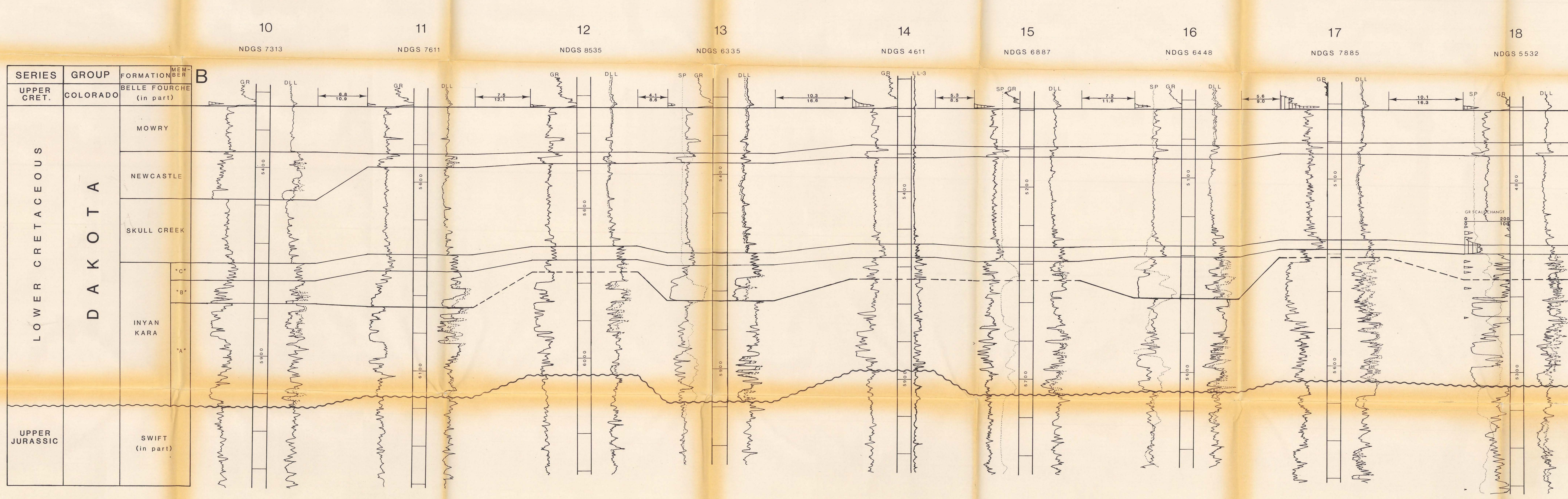

LEGEND

LOG TYPES

GR Gamma-Ray

SP Spontaneous Potential

DLL Dual Laterolog

LL-3 Laterolog-3

LL-7 Laterolog-7

Back-up curve

10 Well reference no.

NDGS 6687 NDGS well no.

Conformable formation contact(s)

Unconformable(?) Formation Contact

Footage from kelly bushing

(Miles) / (Kilometers) Distance between wells

PLATE II
CORRELATIONS OF THE MOWRY-INYAN KARA INTERVAL IN WESTERN NORTH DAKOTA

(For cross-section location see Plate I)

Stratigraphic Datum: Top of Mowry Fm.

(FEET) 100 50 0 (METERS)

(MILES)

(KILOMETERS)

PLATE II

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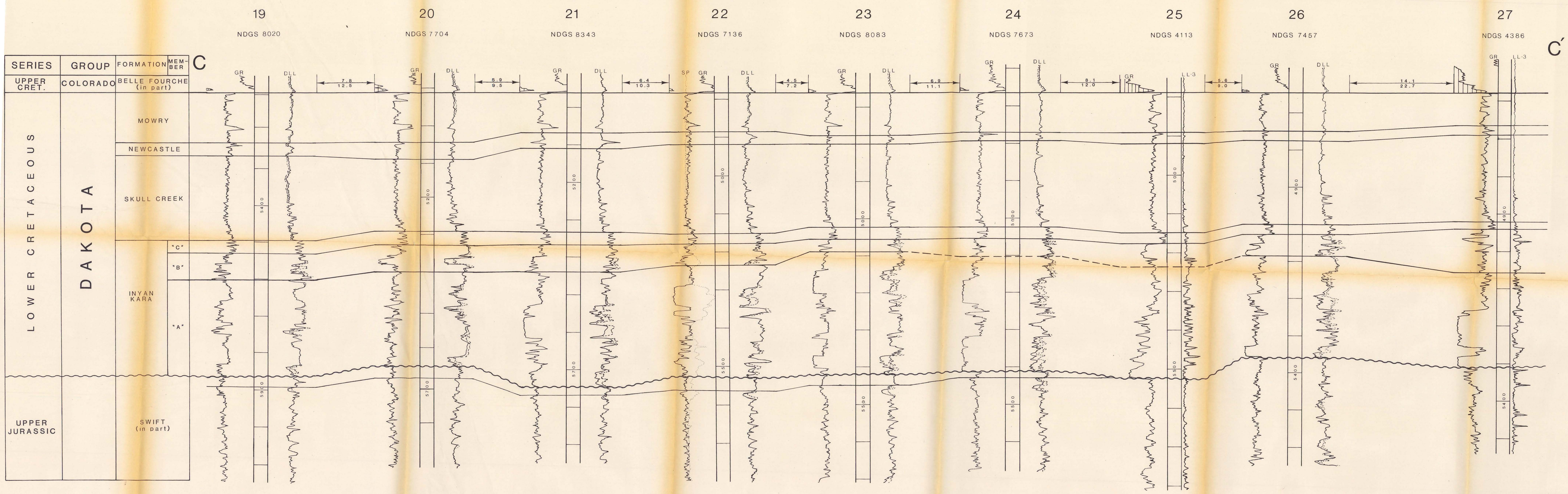

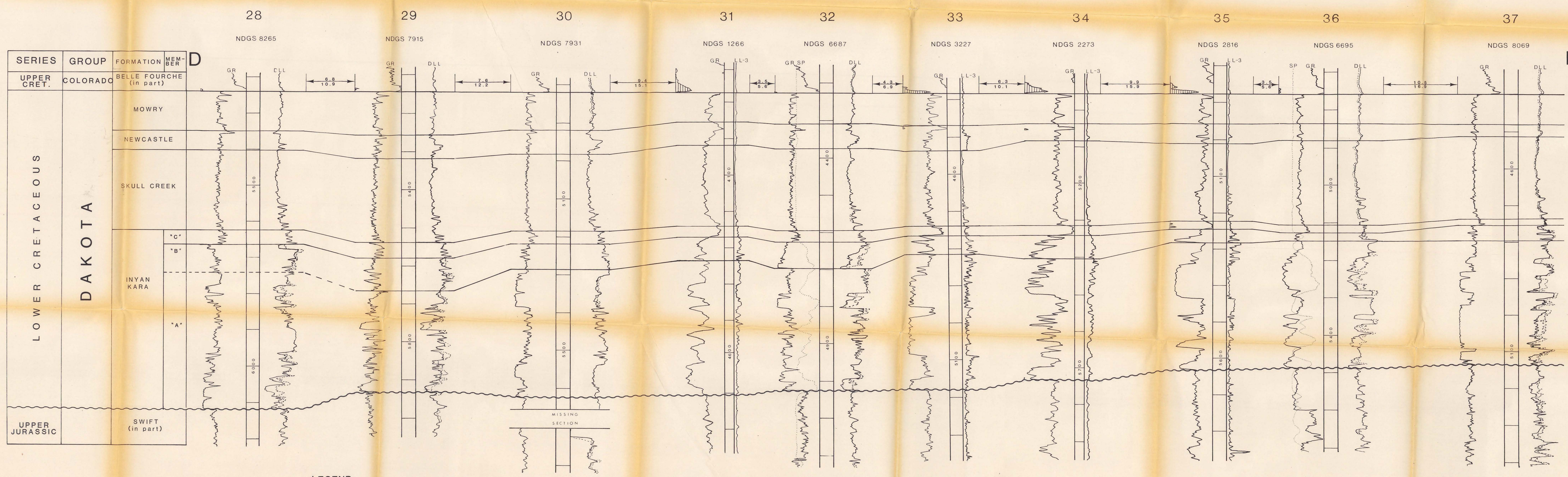

LEGEND

GR Gamma Ray

SP Spontaneous Potential

LL-3 Laterolog-3

DLL Dual Laterolog

Back-up curve

28 Well reference no.

NDGS 6687 NDGS Well no.

Conformable formation contact(s)

Unconformable(?) formation contact

(miles) (kilometers) Distance between wells

Footage from kelly bushing

PLATE III
CORRELATIONS OF THE MOWRY-INYAN KARA INTERVAL IN WESTERN NORTH DAKOTA

(For cross-section location see Plate I)

Stratigraphic Datum: Top of Mowry Fm.

(FEET) (METERS) (MILES) (KILOMETERS)

PLATE III

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PLATE IV

CORRELATIONS OF THE MOWRY–INYAN KARA INTERVAL IN WESTERN NORTH DAKOTA

(For cross-section location see Plate I)

Stratigraphic Datum: Top of Mowry Fm.

LOG TYPES

GR Gamma Ray

SP Spontaneous Potential

DLL Dual Laterolog

LL-3 Laterolog-3

LL-7 Laterolog-7

LEGEND

Back-up curve

56 Well reference no.

NDGS 6687 NDGS well no.

Conformable formation contact(s)

Unconformable(?) formation contact

Footage from kelly bushing

(miles) (kilometers) Distance between wells

(FEET) 100 50 0 (METERS) 30

(MILES) (KILOMETERS)

PLATE IV

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G
G′
H
H′
SERIES
GROUP
FORMATION
MEMBER
UPPER CRET.
COLORADO
BELLE FOURCHE (in part)
MOWRY
NEWCASTLE
SKULL CREEK
LOWER CRETACEOUS
DAKOTA
INYAN KARA
"C"
"B"
"A"
UPPER JURASSIC
SWIFT (in part)
56 NDGS 4599
68 NDGS 1082
67 NDGS 6028
66 NDGS 4433
46 NDGS 5786
47 NDGS 6677
65 NDGS 6515
64 NDGS 6834
37 NDGS 8069
63 NDGS 4747
27 NDGS 4386
62 NDGS 7783
61 NDGS 793
60 NDGS 4375
18 NDGS 5532
59 NDGS 7978
58 NDGS 8235
57 NDGS 3044
9 NDGS 8115
52 NDGS 8139
83 NDGS 6607
82 NDGS 4101
81 NDGS 5411
43 NDGS 5350
80 NDGS 7832
79 NDGS 379
78 NDGS 6362
32 NDGS 6687
77 NDGS 8433
76 NDGS 8100
75 NDGS 8631
23 NDGS 8083
74 NDGS 5938
73 NDGS 8448
72 NDGS 8077
14 NDGS 4611
71 NDGS 8431
70 NDGS 8374
69 NDGS 5157
5 NDGS 8403
LOG TYPES
GR Gamma Ray
SP Spontaneous Potential
DLL Dual Laterolog
LL-3 Laterolog-3
LL-7 Laterolog-7
BHC Borehole Compensated Sonic
LEGEND
Back-up curve
77 Well reference no.
NDGS 8631 NDGS well no.
Conformable formation contact(s)
Unconformable (?) formation contact
Footage from kelly bushing
(MILES) (KILOMETERS) Distance between wells
(FEET) (METERS)
(MILES) (KILOMETERS)
PLATE V
CORRELATIONS OF THE MOWRY-INYAN KARA INTERVAL
IN WESTERN NORTH DAKOTA
(For cross-section location see Plate I)
Stratigraphic datum: Top of Mowry Fm.
PLATE V
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PLATE VI
CORRELATIONS OF THE MOWRY–INYAN KARA INTERVAL IN WESTERN NORTH DAKOTA

(For cross-section location see Plate I)

Stratigraphic datum: Top of Mowry Fm.

(FEET) 100, 50, 0 (METERS)

(MILES)

(KILOMETERS)

LOG TYPES

GR GAMMA RAY

SP SPONTANEOUS POTENTIAL

DLL DUAL LATEROLOG

LL-3 LATEROLOG-3

LEGEND

Back-up curve

91 Well reference no.

NDGS 3274 NDGS well no.

Conformable formation contact(s)

Unconformable(?) formation contact

Footage from Kelly Bushing

(MILES) (KILOMETERS) Distance between wells

PLATE VI

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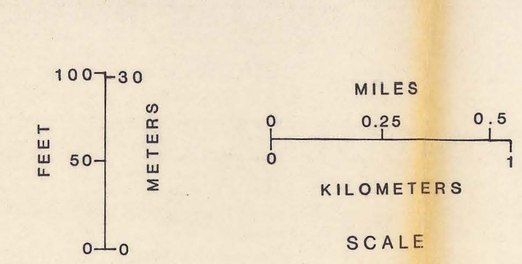
LEGEND

- CONFORMABLE FORMATION CONTACTS
- UNCONFORMABLE FORMATION CONTACT
- 100 WELL REFERENCE NUMBER
- (Miles) (Kilometers) DISTANCE BETWEEN WELLS

LOG TYPES

- GR GAMMA-RAY
- DLL DUAL LATEROLOG
- SP Spontaneous Potential

PLATE VII
CORRELATION OF MEMBERS "A", "B", AND "C" OF THE INYAN KARA FORMATION
(INCLUDING CORRELATION OF SANDSTONE UNITS IN MEMBER "C")



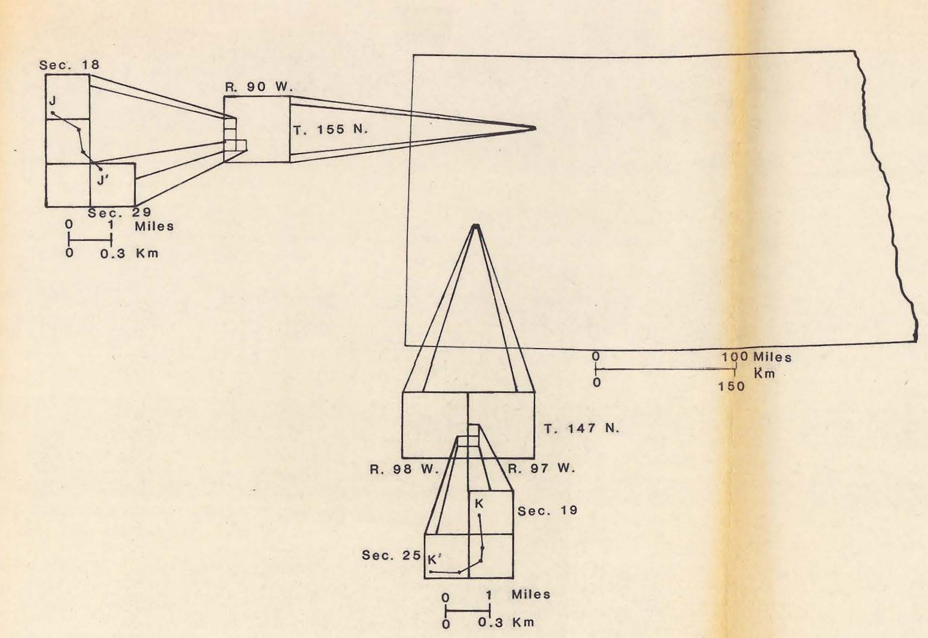


PLATE VII
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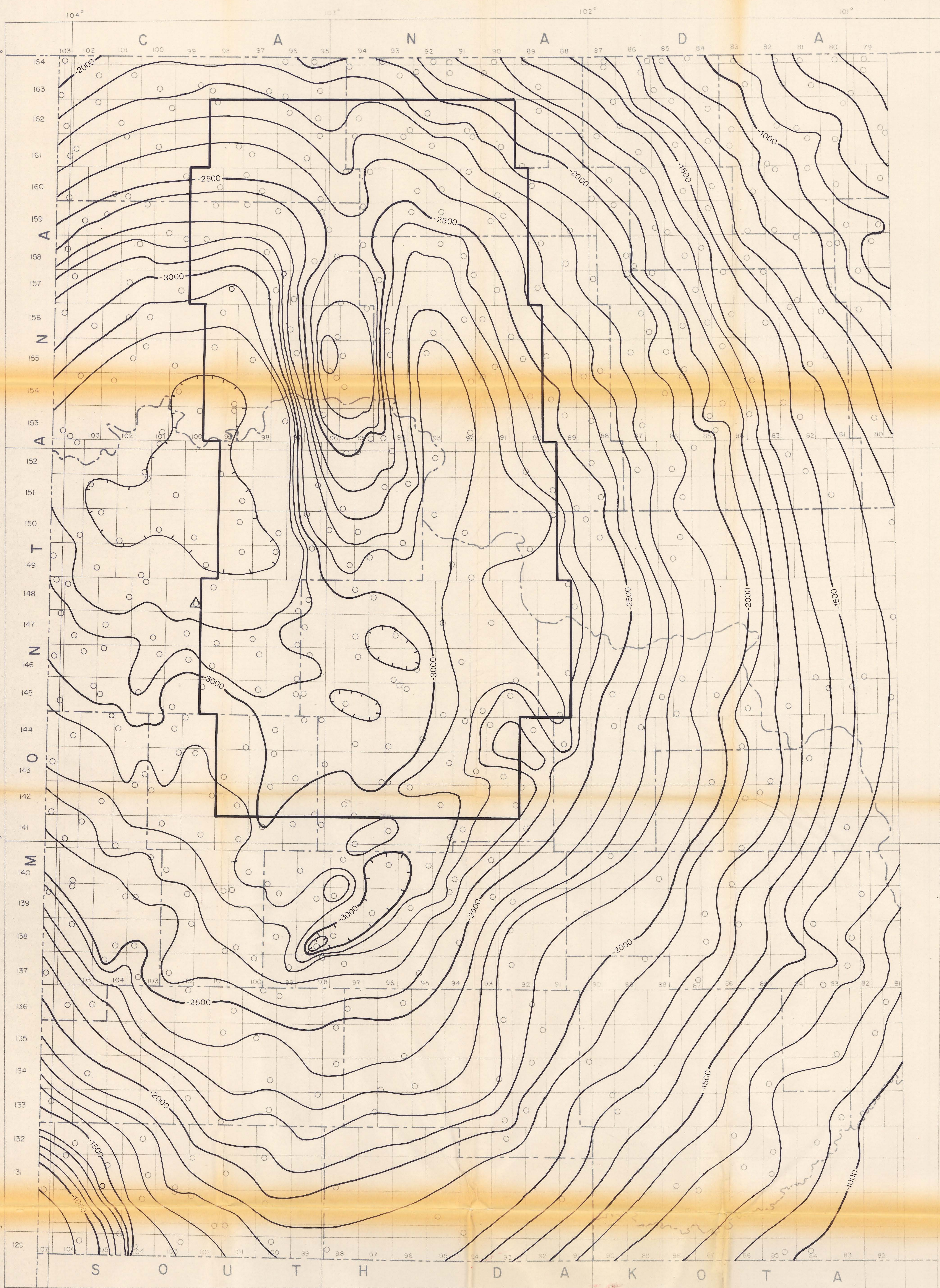

PLATE VIII

STRUCTURE CONTOUR MAP OF THE TOP OF THE INYAN KARA FORMATION

C.I.=100 feet

Datum is mean sea level

0 — 20 Miles
0 — 30 Km

LEGEND

- -1400— CONTOURS
- OUTLINE OF STUDY AREA
- ○ CONTROL POINT
- DEPRESSION
- △ LOCAL COMPLEX STRUCTURE (Red Wing Creek)

PLATE VIII
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PLATE IX
ISOPACH MAP OF THE INYAN KARA FORMATION

C.I.=50 feet

LEGEND

—400— CONTOUR

FORMATION THICKNESS GREATER THAN 400 FEET

OUTLINE OF STUDY AREA

○ CONTROL POINT

0 — 20 Miles
0 — 30 Km

PLATE IX
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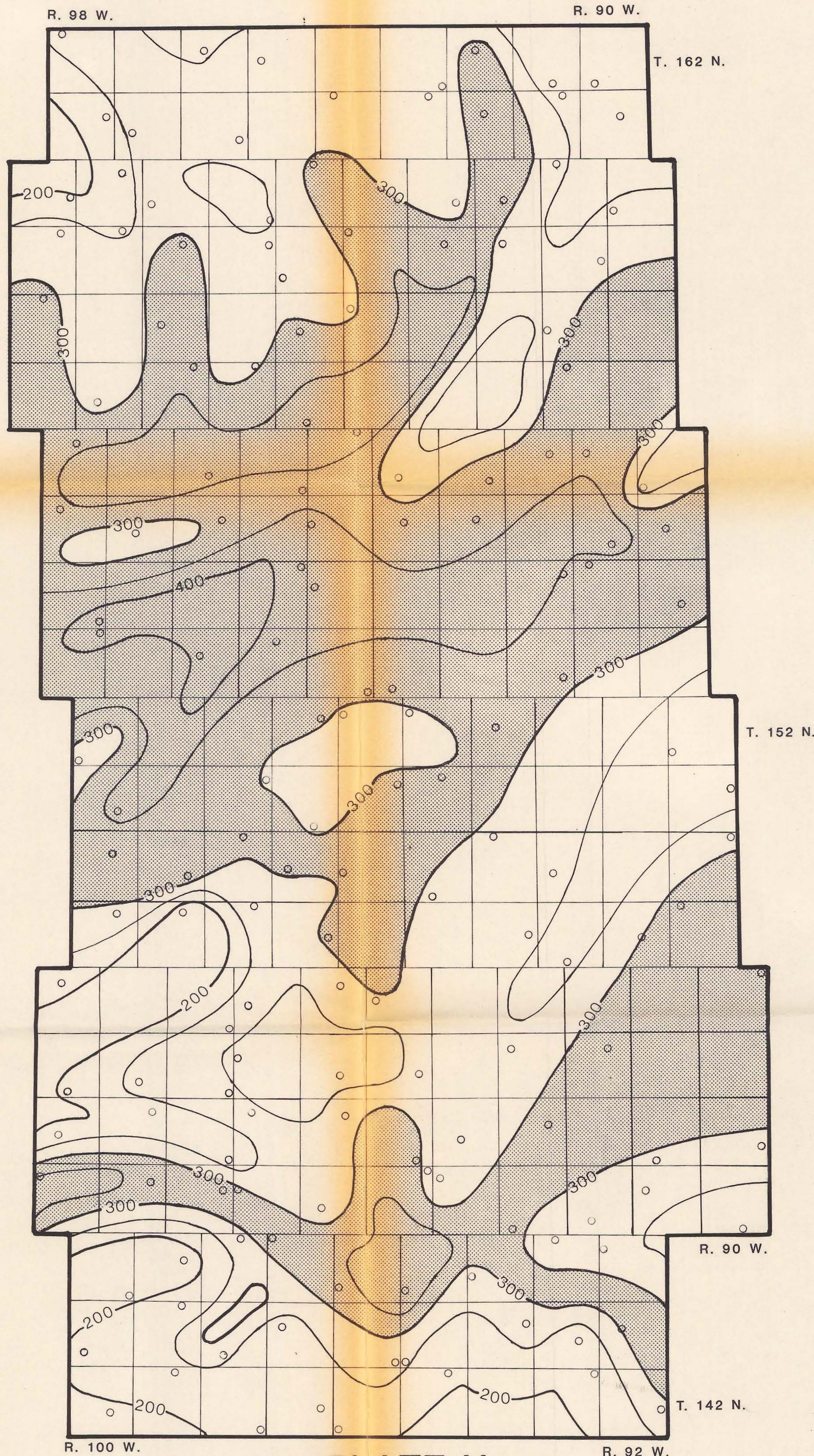

PLATE X

ISOPACH MAP OF MEMBER "A"

(For location of study area see Plate I)

C. I. = 50 feet

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plate 10

LEGEND

—200— CONTOUR

MEMBER THICKNESS GREATER THAN 300 FEET

○ CONTROL POINT

0 — 20 Miles
0 — 30 Km

PLATE X

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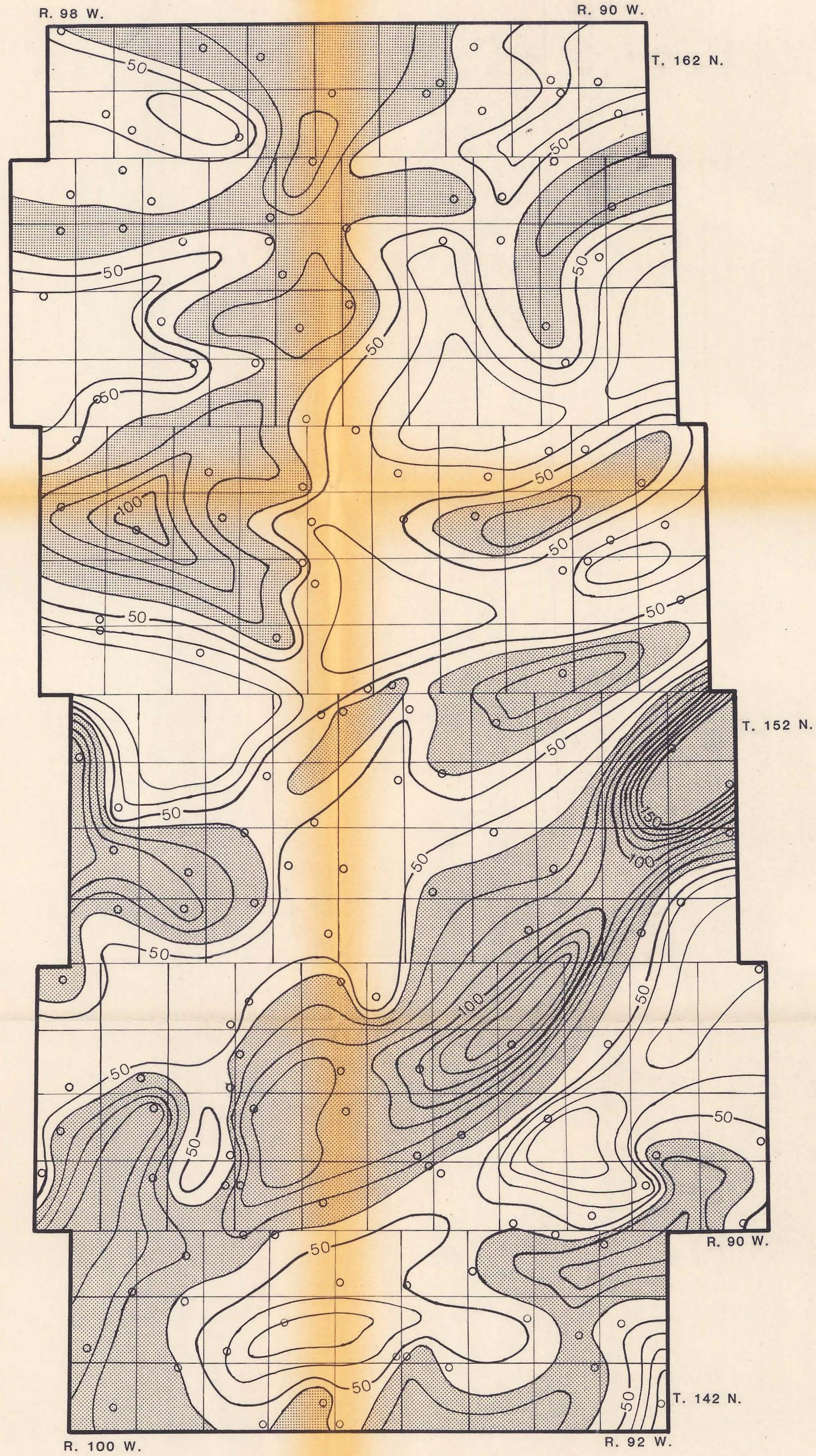

PLATE XI

ISOPACH MAP OF MEMBER "B"

(For location of study area see Plate I)

C.I.=10 feet

T1983
W266
plate 11

LEGEND

—60— CONTOUR

MEMBER THICKNESS GREATER THAN 60 FEET

○ CONTROL POINT

0 20 Miles
0 30 Km

PLATE XI
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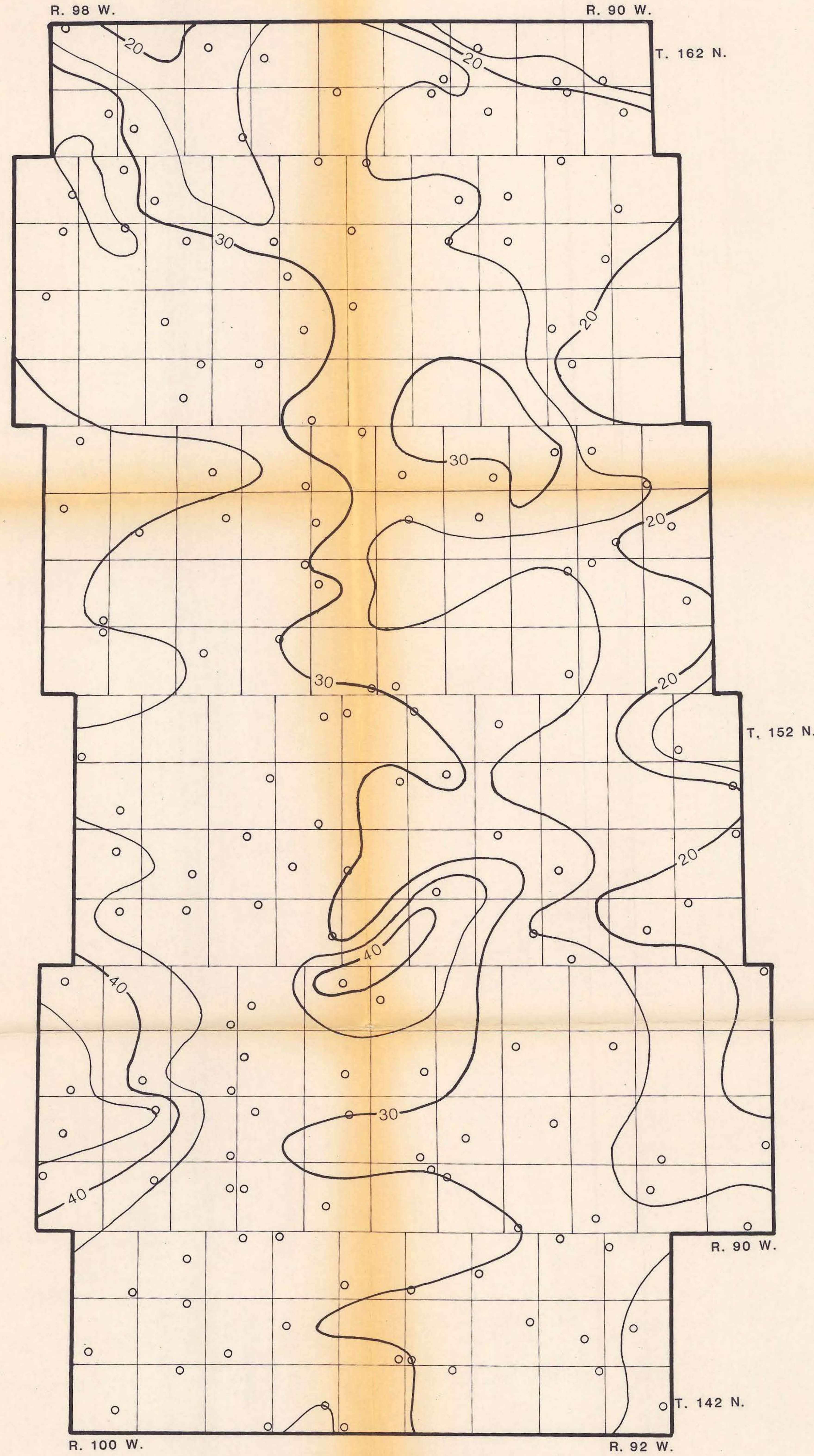

PLATE XII

ISOPACH MAP OF MEMBER "C"

(For location of study area see Plate I)

C.I.=5 feet

T1983
W266
plate 12

LEGEND

—40— CONTOUR
o CONTROL POINT

0 20 Miles
0 30 Km

PLATE XII
BRAD L. WARTMAN
1983