Cliffs Minerals, Inc.

CLIFFS MINERALS, INC.
EASTERN GAS SHALES PROJECT
DOW CHEMICAL CORES #100, #103, AND #205
SANILAC COUNTY, MICHIGAN

PHASE II REPORT
PRELIMINARY LABORATORY RESULTS
MAY 1981

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1.0 INTRODUCTION

The U.S. Department of Energy is funding a research and development program entitled the Eastern Gas Shales Project designed to increase commercial production of natural gas in the eastern United States from Middle and Upper Devonian Shales. The program's objectives are as follows:

1. To evaluate recoverable reserves of gas contained in the shales.
2. To enhance recovery technology for production from shale gas reservoirs.
3. To stimulate interest among commercial gas suppliers in the concept of producing large quantities of gas from low-yield, shallow Devonian Shale wells.

During the summer of 1980, Cliffs Minerals, Inc. acquired portions of three cores that were cut under a Dow Chemical/ERDA project during 1978. Cliffs' purpose in analyzing the cores is to characterize the Antrim Shale of the Michigan Basin under the DOE funded Eastern Gas Shales Project. The three cores were cut from Dow Chemical #100, #103 and #205 wells of Sanilac County, Michigan. This report summarizes the procedures and results of core characterization work performed on these cores at the Eastern Gas Shales Core Laboratory.

2.0 SCOPE OF WORK

The objective of work performed at the Eastern Gas Shales Project's Core Laboratory is to provide a detailed characterization of the Dow Chemical cores. Data were acquired from several sources for analysis. Many geophysical logs were available for inspection, which included the following:

Geophysical Logs

Dow Chemical Core #100	Dow Chemical Core #103
Borehole Compensated Neutron	Borehole Compensated Density
Borehole Compensated Density	Borehole Compensated Neutron
Gamma Ray	Gamma Ray
Caliper	Caliper
3-D Velocity	3-D Velocity
Induction Electric Log	Core - Gamma Correlation (Core Lab)
Spontaneous Potential	Spinner Survey

Dow Chemical Core #205

Borehole Compensated Density

Gamma Ray

Borehole Compensated Neutron

3-D Velocity

Four-Arm Caliper

Core - Gamma Correlation (Core Lab)

At the EGSP Core Laboratory, the Dow Chemical cores were laid out, washed, measured, oriented (when possible), and photographed prior to description and sampling. Characterization work performed included photographic logs, detailed lithologic logs, fracture logs (both natural and induced types), core color variation, and stratigraphic interpretation of the cored intervals. In addition, physical property samples from the #103 core (the only oriented core) were prepared. These samples

were tested by Michigan Technological University under subcontract. Physical properties data obtained from specimen tests include:

- Directional Ultrasonic Velocity
- Directional Tensile Strength
- Strength in Point Load
- Microfracture Trends

3.0 LABORATORY PROCEDURES

3.1 Review of Geophysical Logs:

One of the first laboratory procedures performed on the Dow Chemical cores was the examination of the geophysical logs and comparison of them with published reference sections. Using the gamma ray and density logs, a preliminary stratigraphic section was prepared for the cored interval. These two logs have proven to be the most useful tools within the Devonian Shale sequence. Much of the development of existing formation nomenclature for the Devonian Shales is based on the recognition of characteristic features on these logs. Consequently, formation boundaries and thicknesses were, in some cases, more readily determined from gamma ray and density logs than from visual examination of the core itself. The interpretation of prominent features on the geophysical logs in advance of core description is a means to assure that these features will receive adequate recognition.

3.2 Photographic Log:

After the Dow Chemical cores had been laid out, washed, and oriented (when possible) on a group of laboratory tables, a series of photographs was taken to record the "as received" condition. A photo-

graphic log was then compiled for subsequent documentation. One copy of each log is to be forwarded to the Morgantown Energy Technology Center, under separate cover, together with this report.

3.3 Detailed Lithologic Log:

After detailed visual examination, the Dow Chemical cores were described in intervals which vary from about 10 to 15 feet in length. The first sentence of the description contains a brief summary of lithology, color, and sedimentary structure. Additional remarks were recorded to describe unique features observed within the interval. These remarks may concern any (or all) of the following:

1. Coarse clastic interbeds with scour surfaces, sole marks, cross-stratification, ripple lamination, etc.

2. Macroscopic fossils such as carbonaceous and pyritized vegetal constituents, conodonts, invertebrate shell fragments and casts, fish scales and teeth, etc.

3. Bioturbation, as discrete burrows or as mottled stratification, with emphasis on distribution and association with other rock fabric features.

4. Concretions, slump features, clasts and rip-up structures, gas pits, and other inorganic structures.

5. Modes of pyritization: as disseminated occurrences, nodules, coatings on shell fragments or plant tissue fragments; as accessory mineralization with concretions or clastic interbeds; and as primary irregular lenses or laminae in euxinic black shales.

6. Occurrence of fissility and friability.

7. Carbonate content.

Lithologic terminology applied to the shales is summarized in Figure 1. The classification scheme in use at the Core Laboratory for describing limestones is that of Dunham (1962), shown in Figure 2. Core colors were described using the Rock Color Chart published by the Geological Society of America (1948).

3.4 Stratigraphic Section:

A stratigraphic section for the cored intervals was prepared after the gamma ray and density logs were examined and the detailed lithologic log had been completed. Formation thicknesses were measured, contacts located as precisely as possible, and age relationships determined from published sources.

The locations of certain formation boundaries in the Devonian Shales are difficult to establish with precision. In some cases a contact between two units is gradational, or the nature of a contact may be problematical.

3.5 Color Histogram:

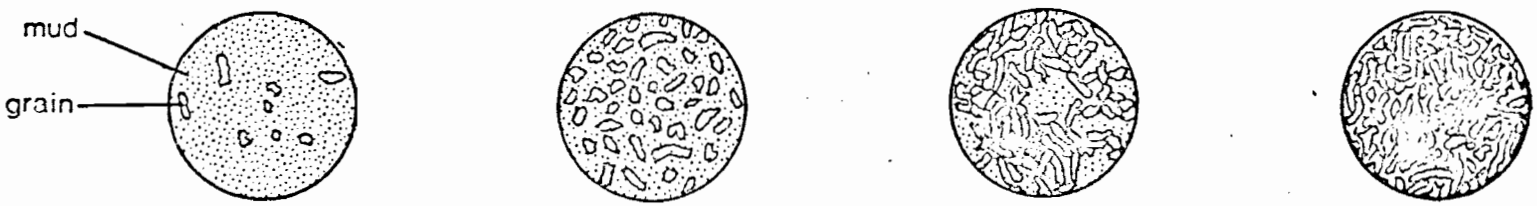
A color histogram for the Dow Chemical cores was compiled to provide a relative measure of the distribution of light and dark shales throughout the cored interval. Studies by Hosterman (1980) have shown a direct relationship between color and the amount of organic matter present. The amount of organic matter is important, because it is the primary source of natural gas. Using the G.S.A. Rock Color Chart, the net length of each color present within each 5-foot interval was recorded. Colors with values darker than dark gray (N3) were grouped together for each segment to determine the percentage of dark shale, and colors with values lighter than or equal to dark gray (N3) were combined

	INCREASING SILT CONTENT →		
NON-FISSILE	MUDSTONE	SILTY MUDSTONE	SILTSTONE
FISSILE	SHALY MUDSTONE	SILTY SHALE	SHALY SILTSTONE

FIGURE 1

TEXTURAL CLASSIFICATION OF FINE CLASTIC SEDIMENTARY ROCKS

MUD SUPPORTED (Sand-size carbonate grains suspended in carbonate mud)		GRAIN SUPPORTED (Sand-size carbonate grains with interstitial carbonate mud)	
< 10% SAND-SIZE GRAINS	> 10% SAND-SIZE GRAINS	MUD PRESENT	NO MUD
Lime Mudstone	Wackestone	Packstone	Grainstone



BIOLOGICALLY CEMENTED GRAINS: Boundstone

NO RECOGNIZABLE TEXTURE: Crystalline Limestone

FIGURE 2

TEXTURAL CLASSIFICATION OF LIMESTONES (AFTER DUNHAM, 1962)

to determine the precentage of light shale. Use of the term "value" refers to the Munsell system of color identification, wherein a specific color is defined by a unique hue, value, and chroma designation.

3.6 Fracture Logs:

Methods of fracture analysis employed at the EGSP Core Laboratory are similar to those described by Kulander, et al., (1977). A standardized logging procedure has been developed by the Morgantown Energy Technology Center. Abbreviations and symbols used in conjunction with the EGSP Standard Core Fracture Logging Format are listed and defined in Appendix D. Because the #100 and #205 cores are not oriented cores, fracture orientation data could not be collected.

Determination of the number, location, orientation, and character of natural fractures intercepted in the cored interval is of vital interest for the selection of appropriate well completion and stimulation techniques. Criteria applied to distinguish natural fractures from fractures induced during coring and handling are listed below (quoted from Evans, 1978):

CORING-INDUCED FRACTURES EXHIBIT THE FOLLOWING CHARACTERISTICS

1. Fracture origin within the core or on the core margin.
2. Hackle plumes diverging from the origin to intersect the core margin or preexisting fracture surface orthogonally.
3. Hackle marks becoming progressively coarser in the vicinity of the core margin or preexisting fracture surface.
4. Twist hackle originating near the core margin or preexisting fracture surface.

5. Hackle plumes diverging in a spiral pattern from the central part of the core on a subhorizontal fracture surface; indicative of torsional stress.

6. Closely spaced arrest lines on a vertical or near-vertical planar fracture; arrest lines are convex downcore and exhibit approximate bilateral symmetry.

7. Hackle marks on a vertical or near-vertical planar fracture diverging downcore from the center of the plane toward the margins.

8. An abrupt change in the direction of fracture propagation (hook) near the core margin or preexisting fracture surface.

NATURAL FRACTURES EXHIBIT THE FOLLOWING CHARACTERISTICS

1. Smooth, polished planar fracture faces, with or without slickensides.

2. Mineralization coating fracture surfaces or filling a closed fracture.

3. A smooth fracture extending across the core against which later fractures terminate.

4. Small conchoidal chips or hook features at the intersection of an inclined fracture plane and the core margin; the chips hook to meet the inclined fractures orthogonally.

Coring- and handling-induced fractures were logged in detail. This information provides additional documentation regarding the condition of the core as received from the field, and it is useful for assessing the effect of problems encountered during drilling. The frequency of disc fractures (generally the most prevalent and least diagnostic type of induced fracture) was recorded in the form of a histogram.

4.0 REPORTING OF RESULTS

A correlation chart has been compiled which provides a visual display of the following data recorded for the Dow Chemical cores:

1. Stratigraphic Column
2. Lithology
3. Color Histogram
4. Gamma Ray Log
5. Compensated Bulk Density Log
6. Conductivity Log
7. Borehole Compensated Neutron
8. Orientation/Distribution of Natural Fractures
9. Disc Fracture Frequency

Discussions of core stratigraphy, lithology, and the occurrence of fractures are provided in Section 5.0. Appendices A, B, and C contain detailed lithologic descriptions of the cores. Terminology applied in describing natural and induced fractures are provided in Appendix D, and the fracture data are presented in Appendices E, F, and G.

One copy of each photographic log was submitted as a separate document to the Morgantown Energy Technology Center. A second copy is available for inspection at the EGSP Core Laboratory.

When physical properties testing of samples from the Dow Chemical #103 core has been concluded, a final (Phase III) report will be issued containing an analysis of those data together with a summary of the information already compiled at the Core Laboratory.

After characterization was completed, the cores were sealed in a moisture barrier and packaged in 3-foot boxes for temporary archiving at the EGSP Core Laboratory. Following a 90-day period, the Dow Chemical cores will be transferred to the Michigan Geological Survey.

5.0 DISCUSSION OF RESULTS

5.1 General:

Dow Chemical's experimental test site (Figure 3) is located in southern Sanilac County in eastern Michigan.

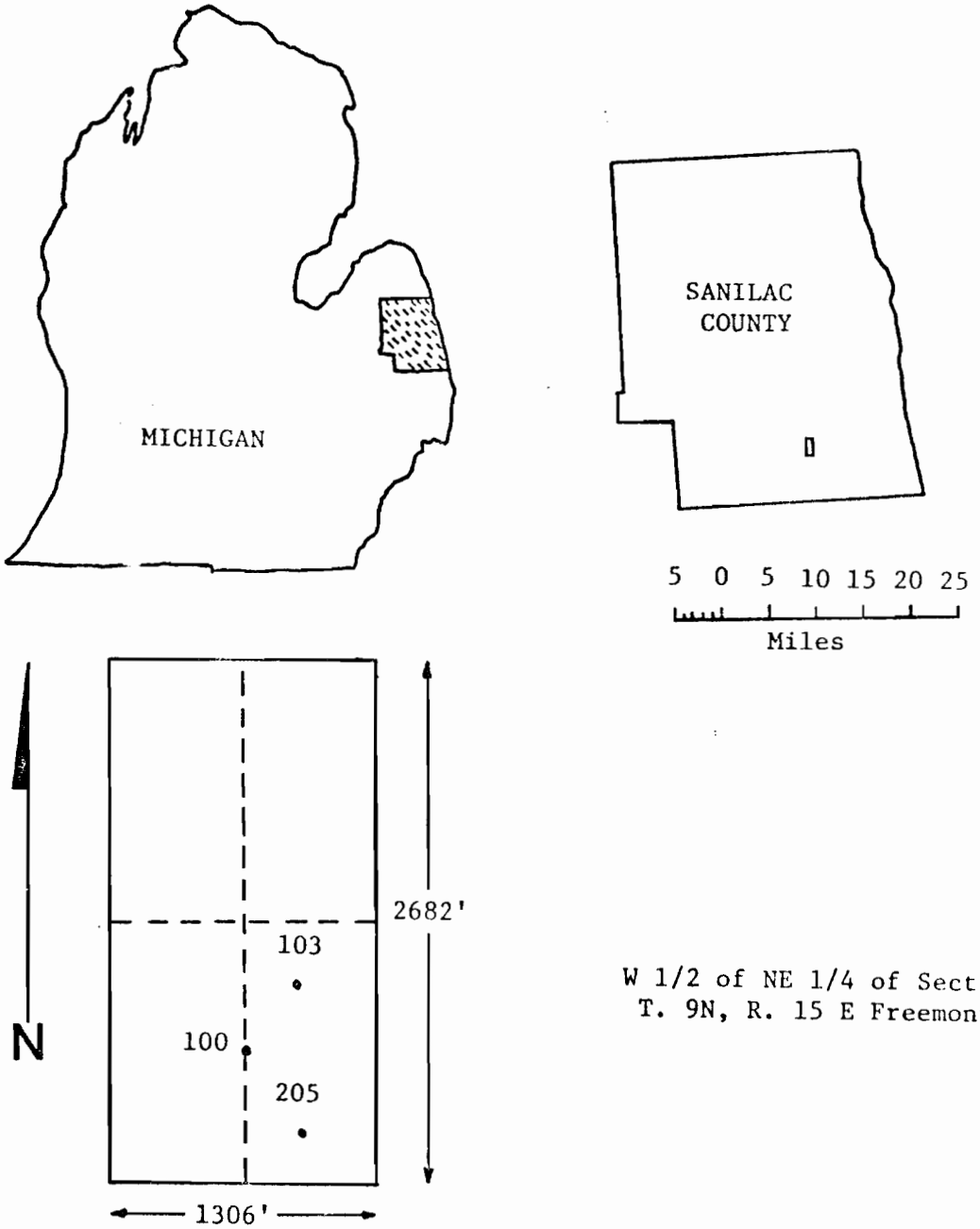
In late 1976, the Dow Chemical Company entered into a contract with ERDA to investigate the feasibility of extracting oil from Michigan's Antrim Shale by an in situ process (Young, 1978). Twenty-seven wells were drilled on the 80-acre test site. Cores were taken from nine of these wells for shale characterization and fracture assessment.

In 1980, Cliffs Minerals, Inc. received portions from three cores, #100, #103, and #205 to characterize the Antrim Shale for the Eastern Gas Shales Project.

5.2 Geologic Setting:

The Dow Chemical well sites are located in southeastern Sanilac County on the eastern side of the Michigan Basin. The surface is covered by glacial drift which is approximately 225 feet thick. These sediments are predominantly sand and gravel with some clay. Directly underlying these Quaternary sediments are the shales of the Mississippian Coldwater Formation. This formation overlies the stratigraphic units that were cored.

Strike and dip estimations, based on three point projection of the three wells, suggest that the subsurface strata are essentially horizontal.



W 1/2 of NE 1/4 of Section 8,
T. 9N, R. 15 E Freemont Twp.

FIGURE 3

LOCATION OF DOW CHEMICAL #100, #103, AND #205 WELLS
SANILAC COUNTY, MICHIGAN

The topography of the area is typically glacial, rolling hills with marshes and meandering streams in low lying areas.

5.3 Stratigraphy:

Intervals of 337, 171 and 109 feet of core were obtained for analysis from the Dow Chemical #100, #103, and #205 cores, respectively. Stratigraphy, formation depths, intervals cored, and cored intervals received at Cliffs Minerals, Inc. are listed in Tables 1-3.

Due to the proximity of the wells, it is possible to assemble from the three cores a nearly complete stratigraphic section of the following formations from youngest to oldest: Sunbury Shale, Berea Sandstone, Bedford Shale, "False Antrim" Shale, Antrim Shale, Traverse Formation, Dundee Limestone and Detroit River Group. Portions of the Sunbury Shale, Berea Sandstone and Bedford Shale are contained in the upper portion of the Dow Chemical #100 core. The Dow Chemical #103 core contains parts of the False Antrim Shale and Units 6 through 1A of the Antrim Shale. Units 1B and 1C of the Antrim Shale and the upper part of the Traverse Formation are represented in the Dow Chemical #205 core. The remaining and lower portion of the Dow Chemical #100 core is composed of portions of the Dundee Limestone and Detroit River Groups. A summary description of each unit follows Tables 1-3. Because the Dow Chemical #100 well intersected all of the stratigraphic units described, geophysical logs from this well will be used for describing all contacts.

The stratigraphic nomenclature used in this report is patterned after that used by Ells, (1978).

TABLE 1

FORMATION THICKNESSES, DOW CHEMICAL WELL #100

Formation	Depths	Depths Cored	Cored Intervals Received
Sunbury Shale	818'- 946'	820'- 946'	820'- 862' 880'- 894' 915'- 946'
Berea Sandstone	946'-1030'	946'-1030'	946'-1030'
Bedford Shale	1030'-1170'	1030'-1150' 1160'-1170'	1030'-1146' ----
False Antrim Shale	1170'-1209'	1170'-1209'	----
Antrim Shale:			
Unit 6	1209'-1240'	1209'-1240'	----
Unit 5	1240'-1268'	1240'-1268'	----
Unit 4	1268'-1303'	1268'-1303'	----
Unit 3	1303'-1340'	1303'-1340'	----
Unit 2	1340'-1358'	1340'-1358'	----
Unit 1A	1358'-1394'	1358'-1394'	----
Unit 1B	1394'-1410'	1394'-1410'	----
Unit 1C	1410'-1429'	1410'-1429'	----
Traverse Formation	1429'-1850'	1429'-1476'	----
Dundee Limestone	1850'-2055'	2000'-2055'	2000'-2015' 2022'-2055'
Detroit River Group	2055'-T.D.	2055'-2059'	2055'-2057'

TABLE 2

FORMATION THICKNESSES, DOW CHEMICAL WELL #103

Formation	Depths	Depths Cored	Cored Intervals Received
False Antrim Shale	1155'-1194'	1177'-1194'	1177'-1186' 1191'-1194'
Antrim Shale:			
Unit 6	1194'-1220'	1194'-1220'	1194'-1200' 1202'-1203' 1204'-1211' 1216'-1218' 1219'-1220'
Unit 5	1220'-1251'	1220'-1251'	1220'-1238' 1241'-1251'
Unit 4	1251'-1284'	1251'-1284'	1251'-1284'
Unit 3	1284'-1322'	1284'-1322'	1284'-1316' 1318'-1322'
Unit 2	1322'-1344'	1322'-1344'	1322'-1344'
Unit 1A	1344'-T.D.	1344'-1368'	1344'-1364' 1365'-1368'

TABLE 3

FORMATION THICKNESSES, DOW CHEMICAL WELL #205

Formation	Depths	Depths Cored	Cored Intervals Received
Antrim Shale:			
Unit 1B	1376'-1394'	1383'-1394'	1383'-1394'
Unit 1C	1394'-1420'	1394'-1420'	1394'-1396' 1401'-1420'
Traverse Formation	1420'-T.D.	1420'-1497'	1420'-1497'

Sunbury Shale

The Sunbury Shale occurs between 818 and 946 feet from surface in the Dow Chemical #100 well. The cored interval extends from 820 feet to the base of the shale. Cored intervals received at Cliffs Minerals, Inc. include: 820 to 862 feet, 880 to 894 feet, and 915 to 946 feet.

Lithologically, the Sunbury Shale is composed of olive black (5Y 2/1), thick bedded shaly mudstone. Most of the core contains disseminated mica and occasional micaceous partings. Pyrite occurs throughout as nodules, lenses, and burrow fillings. At several locations in the interval, the pyrite has been partially oxidized to limonite. Fossils are relatively abundant throughout, consisting of carbonaceous plant fragments, vitrinite fragments, inarticulate brachiopod shells (Lingula sp. and Orbiculoidea sp.), fish scales, conodonts, algal spore bodies (Tasmanites sp.), and lumpy concentrations of scales, teeth, bony fragments and carbonaceous fragments, possibly fecal deposits.

On geophysical logs, the upper contact of the Sunbury Shale is depicted by a sharp increase in gamma radiation from 175 to over 210 API units. This contact was not cored. The contact between the Sunbury Shale and the underlying Berea Sandstone is displayed on geophysical logs by an overall increase in gamma radiation from a consistent 200 API units to a fluctuating range of 50 to 150 API units. This contact occurs on the logs at 954 feet, while in the Dow #100 core the lithologic contact is present at 946 feet.

The Sunbury-Berea contact is marked in the core by a distinct change from olive black (5Y 2/1) shaly mudstone to pale yellowish brown (10YR 6/2) sandstone. A thin pyrite lamination is present between the two lithologic units at 946 feet. The top of the Berea consists of an irregular, truncated surface, possibly erosional in origin.

Berea Sandstone

The Berea Sandstone is present in the Dow Chemical #100 well between 946 and 1030 feet from surface. The entire interval was cored and was received by Cliffs Minerals, Inc.

The Berea Sandstone is composed of medium to fine grained (2 to 3ϕ), subangular quartz sand with minor amounts of mica (muscovite) and accessory minerals (hornblende, zircon). Thin beds of siltstone and silty shale are common at the top and bottom of the formation, although the central portion is composed of relatively well sorted, thick bedded, clean sandstone. Well developed cross bedding and micaceous laminae are locally abundant throughout most of the interval. Carbonaceous plant material (both bituminous and vitrinitic) is common throughout, occurring as coaly lenses, individual woody fragments, carbonaceous partings, and thin dendritic laminae referred to as "rootlet horizons". Nodules of limonite and pyrite are present throughout, and much of the core contains a yellowish brown (10YR 5/4) limonite staining. The unstained sandstone is a uniform, medium light gray (N6) color. The basal portion of the Berea Sandstone (1003.7 to 1030.0 feet) is a transition zone with the underlying Bedford Shale. This zone consists of interbedded sandstone, siltstone and silty shale with cross lamination, ripple lamination, distorted bedding planes, and small-scale ball and pillow structures.

The contact (1030 ft.) in the Dow #100 core between the Berea Sandstone and the underlying Bedford Shale is gradational over a distance of 50.3 feet (1003.7 to 1054.0 ft.). The contact comprises a gradual transition from predominantly sandstone, with interbedded siltstone and

mudstone, to predominantly mudstone, with interbedded sandstone and siltstone. Bedding planes in this transition zone are distorted and irregular, and cross lamination, ripple lamination, sand clasts and mud lumps are common. Because of the subtle gradational nature of the Berea-Bedford contact in the core, the boundary could not be determined from lithological information alone. Additional interpretation was provided by geophysical logs, wherein the contact can be identified by a change from a fluctuating gamma radiation curve, 50 to 150 API units, to a nearly stable curve, ∿160 API units. This occurs in the Dow #100 well at 1030 feet, although no marked lithologic boundary is visible at this depth in the Dow #100 core.

Bedford Shale

The Bedford Shale appears in the Dow Chemical #100 core between the depths of 1030 and 1170 feet. The intervals from 1030 to 1150 and from 1160 to 1170 feet were cored, but only the interval from 1030 to 1146 feet was available for analysis by Cliffs Minerals, Inc.

The Bedford Shale is mainly composed of greenish black (5G 2/1), thick bedded shaly mudstone and silty shale. Numerous siltstone and silty sandstone units are present, varying in thickness from thin laminae to thin beds. These coarser units are abundant in, but not restricted to, zones at the top of the formation near the contact with the overlying Berea Sandstone, and zones in the basal 50 feet of the Bedford. Bedding surfaces are irregular throughout; scour surfaces with associated sand/silt clasts are common. Cross- and ripple-laminations, and micaceous/carbonaceous partings occur throughout the

formation. Dipped beds and microfaults located between 1084 and 1094 feet suggest the lateral proximity of a large concretion or sand lens to the core. The Bedford is nearly barren of fossils; a few carbonaceous plant fragments and occasional resinous spores are present. The contact (1170 ft.) between the Bedford Shale and the underlying False Antrim Shale was not cored within any of the three Dow Chemical wells. On geophysical logs, this contact is displayed as a very slight increase in gamma radiation from 160 to 180 API units.

False Antrim Shale

The False Antrim Shale occurs from 1170 to 1209 feet in Dow Chemical Well #100 and from 1155 to 1194 feet in Dow Chemical Well #103. The entire interval within the Dow Chemical #100 well was cored; however, none of this core was available for inspection by Cliffs Minerals, Inc. Within the Dow Chemical #103 well, the interval from 1177 to 1194 feet was cored. Except for the interval from 1186 to 1191 feet, the core was received for analysis.

Within the Dow Chemical #103 core, the False Antrim Shale is composed of olive gray (5Y 3/2) and grayish olive (10Y 4/2), thinly laminated to thick bedded silty shales and shaly mudstones. The upper 10 feet of the cored interval contain numerous slump features with associated curviplanar slickensided fractures. The lowermost 2 cm of the False Antrim is mottled due to bioturbation. Resinous spore bodies are sparse. The lower two feet contain several poorly preserved, partially pyritized brachiopod casts.

In the core, the contact (1194 ft.) between the False Antrim Shale and the underlying Antrim Shale can be identified by a distinct change from olive gray (5Y 2/1) and olive brown (5Y 4/4) shaly mudstones to black (N1) shaly mudstone. The contact is marked by a 2-cm thick bioturbated zone.

On the geophysical logs, the False Antrim Shale's basal contact is displayed as a very noticeable increase in gamma radiation from 180 to 320 API units.

Antrim Shale

The Antrim Shale is divided on the basis of gamma ray log signatures into six units, designated as Units 1-6. Unit 1, the lowermost unit, is further divided into three subunits; Units 1A, 1B, and 1C.

Portions of the Antrim Shale were cored in all three of the Dow Chemical wells. The entire Antrim Shale was cored in the Dow Chemical #100 well; however, this cored interval was not available for inspection by Cliffs Minerals, Inc. The Dow Chemical #103 core contains core cut from Units 6 - 1A of the Antrim Shale. A list of cored intervals received is available in Table 2. Units 1B and 1C are represented fairly well in the Dow Chemical #205 core (Table 3). A summary description of each unit follows.

Unit 6:

Unit 6, the uppermost member of the Antrim Shale, occurs in the Dow Chemical #103 core between 1194 and 1220 feet and is composed of black (N1), thick bedded shaly mudstones. Resinous spore bodies are abundant. Fish scales occur frequently; several fossil fish jaws are

also present. Several zones containing conodonts are present. Small (1 to 2 mm) carbonaceous fragments occur throughout. Pyrite occurs as disseminated grains and small (5 to 10 mm in diam.) nodules.

The contact in the core between Unit 6 and the underlying Unit 5 is not marked by a distinct change. Black (N1), thick bedded, shaly mudstones continue across the contact. Pyrite, in its various forms, gradually becomes weakly calcareous over the contact.

On the geophysical logs, the contact between Unit 6 and Unit 5 is depicted as a noticeable depression in gamma radiation to 240 API units.

Unit 5:

Unit 5 is present within the Dow Chemical #103 core from 1220 to 1251 feet. This unit is made up of black (N1), brownish black (5YR 2/1), and olive black (5Y 2/1), thick bedded, shaly mudstones. Fish scales, fish teeth, and fossil fish jaws occur frequently throughout the unit. Resinous spore bodies and carbonaceous fragments are abundant. Pyrite is present as disseminated grains, in thin lenses and laminae, and in nodules up to 3 cm in diameter. The pyrite occurrences are slightly calcareous.

In the #103 core, the contact between Units 5 and 4 occurs at 1251 feet and can be distinguished by a gradational change over several feet in the core from brownish black (5YR 2/1), thick bedded, shaly mudstones to olive black (5Y 2/1) and olive gray (5Y 4/1) laminated shaly mudstones and mudstones.

On the geophysical logs the basal contact of Unit 5 is displayed as a change from a fluctuating gamma radiation curve, 240 to 260 API units, to a stable curve, 220 API units.

Unit 4:

Unit 4 occurs in the Dow Chemical #103 core between 1251 and 1284 feet and contains olive black (5Y 2/1) and grayish olive (10Y 4/2), thinly laminated to thick bedded shaly mudstones and mudstones. The upper 1/2 of the unit contains several bioturbated zones with subhorizontal burrow structures. Fossils which are present in this interval include: brachiopod casts, fossil fish jaws, teeth and scales, vitrinite and woody fragments, resinous spore bodies, and carbonaceous fragments. Pyrite nodules averaging 1 cm in diameter are common throughout the unit. The pyrite nodules are weakly calcareous. The lower 1/2 of the unit contains numerous, thin (<1 mm), calcareous laminae.

The contact between Units 4 and 3 occurs at 1284 feet and can be distinguished in the core by a gradual darkening of the core from laminated olive black (5Y 2/1) and grayish olive (10Y 4/2) shaly mudstones and mudstones to olive black shaly mudstone.

On the gamma ray log this contact is depicted as a slight increase from 220 to 240 API units.

Unit 3:

Unit 3 is present in the Dow Chemical #103 core between the depths of 1284 and 1322 feet. It is made up of olive black (5Y 2/1) and brownish black (5YR 2/1), thinly laminated to thin bedded, shaly mudstones. The upper 1/2 of the unit is predominantly olive black grading

to brownish black in the lower 1/2. Fossils which occur in this unit include: resinous spore bodies, fish scales, and vitrinite and carbonaceous fragments. Pyrite occurs as nodules throughout, and as disseminated grains in lenses and laminae in the lower 1/2 of the unit. Pyrite occurrences become less calcareous and are eventually noncalcareous in the lower 1/2.

The contact (1322 ft.) between Units 3 and 2 can be identified in the core as a gradational change from brownish black (5YR 2/1) to olive black (5Y 2/1) shaly mudstones.

On the geophysical logs this contact is displayed as a depression in gamma radiation to approximately 210 API units.

Unit 2:

Unit 2 of the Antrim Shale occurs between the depths of 1322 and 1344 feet in the Dow Chemical #103 core. Lithologically, it is composed of olive black (5Y 2/1) and dusky yellow green (5GY 5/2), thinly laminated to thick bedded shaly mudstones and mudstones. A zone of Foerstia sp. extends from 1326.4 to 1336.3 feet. Resinous spore bodies are common throughout, and occasional fish scales occur in the lower 5 feet. A bioturbated zone is present at 1335.3 feet. Pyrite exists in thin laminae and small nodules, which are weakly calcareous.

The contact (1344 ft.) between Unit 2 and Unit 1 is present in the core as a change from olive black (5Y 2/1), thick bedded, shaly mudstone to sequences of dusky yellow green (5GY 5/2) and light olive gray (5Y 5/2) bioturbated mudstones, which eventually grade downcore into olive black shaly mudstones.

On the gamma ray log the contact between Units 2 and 1A is depicted as a very sharp depression to 180 API units.

Unit 1:

Unit 1, which is subdivided into subunits 1A, 1B and 1C, was analyzed in the Dow Chemical #103 and #205 cores. The Dow Chemical #103 core contains the upper 24 feet of Unit 1A. The lower 11 feet of Unit 1B and almost the entire Unit 1C are contained in the Dow Chemical #205 core.

Unit 1A:

Unit 1A is present in the Dow Chemical #103 well between 1344 feet and the base of the well. The interval from 1344 to 1368 feet was cored. Lithologically, the interval consists of olive black (5Y 2/1), dusky yellow green (5GY 5/2), and light olive gray (5Y 5/2), thinly laminated to thick bedded shaly mudstones and mudstones. The shaly mudstones and mudstones occur in sequences of dusky yellow green mudstone grading to bioturbated light olive gray mudstone, and then to olive black shaly mudstone. Resinous spore bodies are common and have been altered to pyrite in the dusky yellow green zones. Several conodonts are present in the lower 8 feet of the cored interval. Pyrite occurs as small nodules in the olive black zones. Both calcite and dolomite form the mineralization on several natural fractures in the interval.

The contact between Units 1A and 1B was not cored in either the Dow Chemical #103 or #205 wells. This contact was cored in the Dow Chemical #100 well. However, this portion of the core was not available for analysis. On the geophysical logs this contact is displayed as a change in gamma radiation from over 240 to 200 API units.

Unit 1B:

Unit 1B of the Antrim Shale occurs in the Dow Chemical #205 well between the depths of 1376 and 1394 feet. The lower 11 feet of this interval was cored. The core is predominantly composed of calcareous mudstones and mudstones, thinly laminated to thin bedded. Argillaceous limestones and siltstones are present in the upper 1/2, but in minor amounts. The dominant rock colors are light olive gray (5Y 6/1) in the upper 1/2 and olive black (5Y 2/1) in the lower 1/2; olive gray (5Y 4/1 and 5Y 3/2) are present throughout, but to a lesser degree. Resinous spores, inarticulate and articulate brachiopods, vitrinite and carbonaceous fragments, and biogenic structures occur within Unit 1B. Biogenic structures are present as discrete burrows or as mottled stratification. Pyrite is present as lenses, nodules and as mineralization of burrows and vitrinite fragments. The contact (1394 ft.) between Unit 1B and Unit 1C is present in the Dow Chemical #205 core and is described as a gradual increase in the proportion of dark mudstones.

On the gamma ray log Unit 1B is displayed as a very noticeable depression in the curve to 140 API units.

Unit 1C:

Unit 1C is present in the Dow Chemical #205 well between the depths of 1394 and 1420 feet. The intervals from 1394 to 1396 and from 1401 to 1420 feet were available for analysis. These intervals are composed predominantly of olive black (5Y 2/1) mudstone in the upper 2/3 and dusky yellowish brown (10YR 2/2) mudstone in the lower 1/3. Silty mudstones and a few thin, calcareous, siltstone laminae occur in the lower 2/3. Rock colors which are present, but in lesser amounts, include

olive gray (5Y 3/2 and 5Y 4/1) and dusky yellow green (5GY 5/2). Stratification ranges from thinly laminated to thin bedded. Resinous spores, inarticulate brachiopods (Lingula sp.), carbonaceous and vitrinite fragments, and burrows are present. The burrows are either mud- or silt-filled, or mineralized with pyrite. Pyrite is also noted as nodules, lenses and disseminated grains.

The contact (1420 ft.) between Unit 1C and the underlying Traverse Formation is evident as an abrupt change from olive gray (5Y 3/2) pyritic mudstone to a light olive gray (5Y 6/1) shaly mudstone. On the geophysical logs this contact is expressed as a decrease in gamma radiation from over 320 API units to a curve which fluctuates between 160 and 40 API units.

Traverse Formation

The upper 77 feet (1420 - 1497 ft.) of the Traverse Formation was cored in the Dow Chemical #205 well. This interval consists of a variety of rock types and colors such as shaly mudstones, calcareous shaly mudstones, argillaceous limestones, dolostones, argillaceous dolostones and cherts. Cherty lenses and fragments can be found throughout the upper 1/3, and are predominant between 1438 and 1444 feet. Rock colors that typify the Traverse Formation include: olive gray (5Y 3/2 and 5Y 4/1), light olive gray (5Y 5/2 and 5Y 6/1), yellowish gray (5Y 8/1), pinkish gray (5YR 8/1), greenish gray (5GY 6/1), dark greenish gray (5GY 4/1), dark gray (N3), very light gray (N8), and pale yellowish brown (10YR 6/2). Fossils are common to abundant throughout the cored portion of the formation, except within the cherty intervals where fossils are not present. These fossils include: articulate and inartic-

late brachiopods, carbonaceous fragments, crinoid fragments and columnals, bryozoa fragments, a single trilobite (?) fragment, and mud- and silt-filled or pyritized burrows. Lenses, nodules and disseminated grains of pyrite are present, but are restricted to the upper 10 feet. Calcareous concretions and several thin oolitic limestones occur in the lower 1/2. Dolomitic laminae containing crystals of calcite spar are present between 1438 and 1444 feet.

Core containing the contact between the Traverse Formation and the underlying Dundee Limestone was not available for description. On geophysical logs from the Dow Chemical #100 well this contact is displayed as a change from a fluctuating gamma radiation curve, 40 to 160 API units, to a fairly consistent curve, 40 to 60 API units.

Dundee Limestone

The lower 55 feet of the Dundee Limestone are present in the Dow Chemical #100 core from 2000 to 2055 feet. This interval is composed of interbedded lime mudstones, wackestones, and argillaceous limestones in the upper part (2000 to 2037 ft.), and crystalline (lithographic) limestones in the remainder. Core colors range from pinkish gray (5YR 8/1) and yellowish gray (5Y 8/1) to olive gray (5Y 3/2) and dark greenish gray (5GY 4/1); bedding ranges from thinly laminated to thick bedded. The upper three feet of the interval consist of a pure, microcrystalline lime mudstone containing numerous small vugs (1 to 2 mm) partially filled with tiny calcite crystals. A single bed of grainstone occurs from 2009 to 2010 feet; a dolostone bed is present between 2025.7 and 2026.8 feet.

The overall appearance of the core consists of light-colored beds of relatively pure limestone alternating with dark-colored beds of organic-rich, argillaceous limestone. The organic-rich beds and laminae are more abundant in the upper 1/2. Fresh surfaces smell of kerogen.

Pressure-solution features are abundant throughout the interval. These include stylolites, distorted and truncated fossils, interrupted bedding planes, and recrystallized (neomorphic) calcite. Most of the stylolitic surfaces are fairly rich in carbonaceous material and clay.

The lower-central portion of the interval (2037 to 2048 ft.) contains eleven distinct beds of light-colored, powdery, friable limestone, irregularly distributed within the darker crystalline limestones. These powdery beds appear to be caliche horizons; together with their associated carbonaceous laminae they seem to represent episodes of subaerial exposure. The basal portion of the core contains zones of large (3 x 6 cm), dark brown platy crystals, possibly organic-rich celestite.

Fossils in this interval are very poorly preserved and consist of articulate brachiopod shells, bryozoa fragments, and segments of crinoid stems.

The contact (2055 ft.) between the Dundee Limestone and the underlying Detroit River Group is marked by a stylolite separating the crystalline limestones of the Dundee from the lime mudstones and argillaceous limestones of the Detroit River. The Detroit River Group limestones show a distinct lack of large, brown, platy celestite crystals that are common in the basal portion of the Dundee. On the geophysical logs this contact could not be readily distinguished.

Detroit River Group

The Dow Chemical #100 well was terminated four feet into the Detroit River Group (2055 to 2059 ft.), possibly within the Anderdon Limestone. Of this interval, only the upper two feet of core were available for analysis. It consists of lime mudstones and argillaceous limestones, dark yellowish brown (10YR 4/2) and dusky yellowish brown (10YR 2/2) in color, and ranging from thinly to thickly laminated. Intense bioturbation occurs at 2056.1 feet. Occasional stylolites are present; this interval is barren of fossils.

5.4 Fracture Analysis:

Both natural and induced fractures present in the #100, #103 and #205 Dow Chemical cores were examined in detail. Because the Dow Chemical #100 and #205 cores were not oriented cores, strike and dip directions of fractures contained in these cores could not be measured. The resulting fracture logs are included in Appendices E-G of this report. Terminology and abbreviations used in fracture log compilation are summarized in Appendix D.

Natural Fractures

A total of thirty-one natural fractures were observed in the Dow Chemical #103 core. Of these, fifteen are microfaults, twelve are simple joints, three are compound joints and one is a fault. The distribution of fractures throughout the interval is shown in Table 4.

TABLE 4

DISTRIBUTION OF NATURAL FRACTURES, DOW CHEMICAL #103 CORE

Formation	Cored Intervals Received	Core Length	Number of Fractures	Frequency/ Foot
False Antrim	1177'-1186'	9'	14	1.56
	1191'-1194'	3'	1	0.33
Antrim Shale:				
Unit 6	1194'-1200'	6'	1	0.17
	1202'-1203'	1'	0	0.00
	1204'-1211'	7'	1	0.14
	1216'-1218'	2'	0	0.00
	1219'-1220'	1'	0	0.00
Unit 5	1220'-1238'	18'	0	0.00
	1241'-1251'	10'	0	0.00
Unit 4	1251'-1284'	33'	3	0.09
Unit 3	1284'-1316'	32'	0	0.00
	1318'-1322'	4'	1	0.25
Unit 2	1322'-1344'	22'	7	0.32
Unit 1A	1344'-1364'	20'	3	0.15
	1365'-1368'	3'	0	0.00

All planar natural fractures in the Dow Chemical #103 core were analyzed to identify common structural trends. Figure 4 is a graphic representation of the data plotted in polar form on a Schmidt (Equal Area) stereonet. The data have been contoured to determine locations of maximum pole density using the method described by Ragan (1968).

The strike of the planar natural fractures ranges from N24°E to N76°E with a concentration at N65°E. Dips are generally vertical to near vertical.

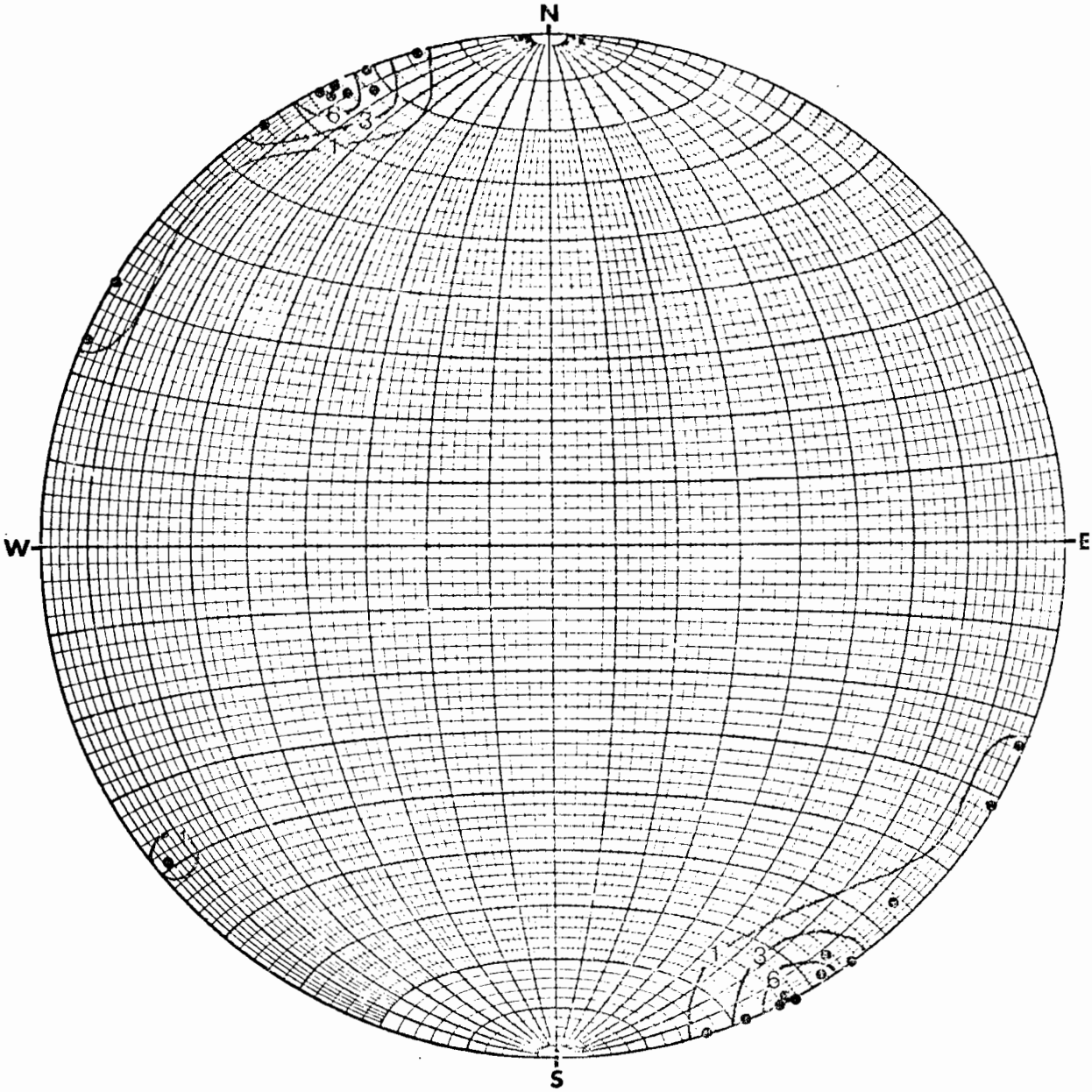


FIGURE 4

CONTOURED DIAGRAM OF POLES TO NATURAL FRACTURES
DOW CHEMICAL #103 CORE

All curviplanar natural fractures (microfaults) in the Dow Chemical #103 core occur in a section that could not be oriented. No plottable data are available.

The occurrence and type of natural fractures contained within each formation from this core were also analyzed. Criteria examined include: location of fracture concentrations, or conversely, the lack of fractures within the stratigraphic unit and any predominance of fracture strike trends.

False Antrim:

The False Antrim contains 15 natural fractures, all of which are classified as microfaults. These fractures are probably a result of slumping and soft sediment deformation. All of these fractures appear to strike in the same general direction and dip approximately 30°. The exact orientation of these fractures is unknown because this section of the core could not be oriented and strike and dip data could not be measured.

Antrim Shale:

The Antrim Shale (Core #103) contains sixteen natural fractures. Of these, twelve are simple joints, three are compound joints, and one is a fault. Fractures in Units 6, 5 and 4 appear to be nonmineralized. Two small fractures at the base of Unit 3 are mineralized with pyrite. Calcite, and possibly dolomite, form the mineralization on approximately 1/2 of the fractures from Units 2 and 1A. The fault plane in Unit 6 is horizontal, with slickenlines oriented at N70°E. The general strike of the joints and compound joints is N60°E to N70°E, dipping

near vertical to vertical. The strike and frequency of natural fractures is presented in Figure 5.

Three natural fractures are present in the 109 feet of core analyzed from the Dow Chemical #205 well. The upper fracture is a vertical simple joint and occurs in Unit 1B of the Antrim Shale at a depth of 1386 feet. A horizontal fault occurs at 1405 feet in Unit 1C, also of the Antrim Shale. The Traverse Formation contains a calcite mineralized simple joint at 1471 feet. Distribution of natural fractures throughout the cored interval is summarized in Table 5.

TABLE 5

DISTRIBUTION OF NATURAL FRACTURES, DOW CHEMICAL #205 CORE

Formation	Cored Intervals Received	Number of Fractures	Frequency/ Foot
Antrim Shale:			
Unit 1B	1383'-1394'	1	0.09
Unit 1C	1394'-1396'	0	0.00
	1401'-1420'	1	0.05
Traverse Formation	1420'-1497'	1	0.01

Of the 23 natural fractures contained in the received portion of the Dow Chemical #100 core, ten are simple joints, two are compound joints, six are microfaults and five are faults. Distribution of these fractures throughout the cored interval is shown in Table 6. This core was not an oriented core; hence, strike and dip direction data for the fractures could not be measured.

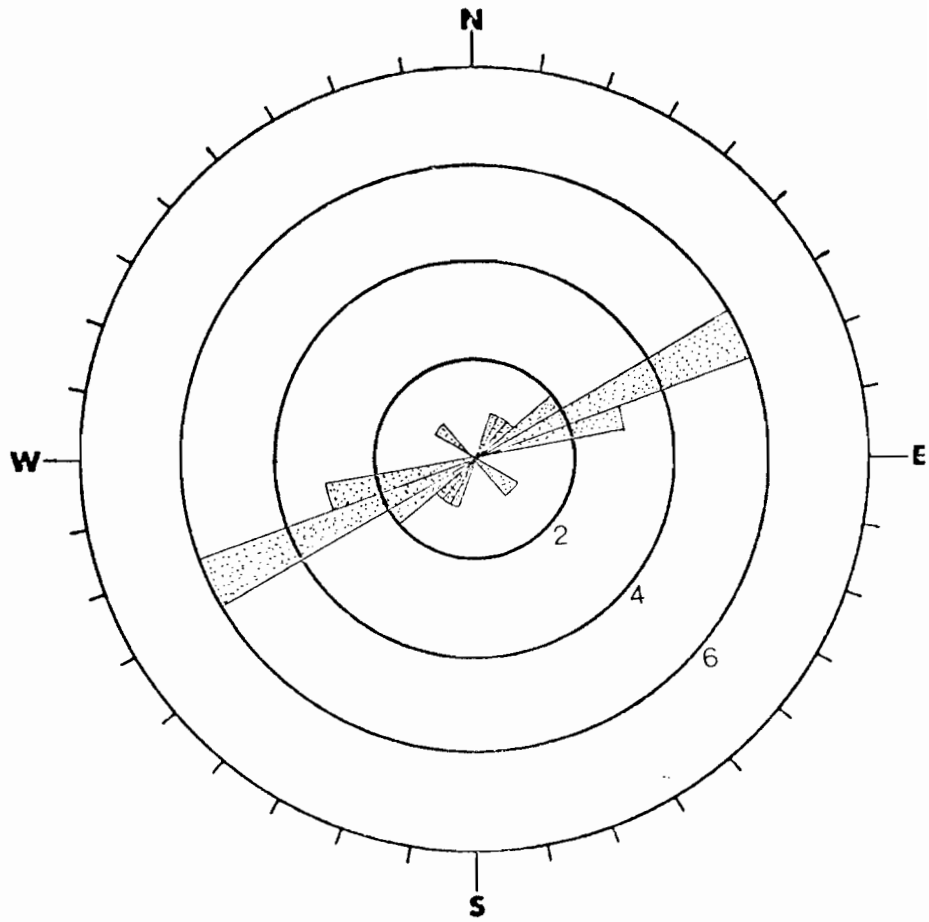


FIGURE 5

STRIKE AND FREQUENCY OF NATURAL FRACTURES IN THE ANTRIM SHALE

Fractures within the Sunbury Shale, Berea Sandstone and Bedford Shale are, for the most part, faults and microfaults associated with slumping and soft sediment compaction. The remainder of the fractures in the Dow #100 core are joints and compound joints that occur in the Dundee Limestone. None of these appear to be mineralized, and all are limited in extent.

TABLE 6

DISTRIBUTION OF NATURAL FRACTURES, DOW CHEMICAL #100 CORE

Formation	Cored Intervals Received	Number of Fractures	Frequency/ Foot
Sunbury Shale	820'- 862'	4	0.10
	880'- 894'	1	0.07
	915'- 946'	1	0.03
Berea Sandstone	946'-1030'	3	0.04
Bedford Shale	1030'-1146'	5	0.04
False Antrim Shale	-----	-	----
Antrim Shale	-----	-	----
Traverse Formation	-----	-	----
Dundee Limestone	2000'-2015'	4	0.27
	2022'-2055'	5	0.15
Detroit River Group	2055'-2057'	0	0.00

Induced Fractures

More than 95% of the fractures examined in the Dow Chemical #100, #103, and #205 cores were interpreted to be coring- or handling-induced. Disc fractures were the most common type observed. Torsional, petal, petal-centerline fractures and disc fractures with circular slickenlines were identified and individually logged. Several of the

centerline fractures appear to be induced extensions of natural fractures. A rosette of the strike and frequency of induced fractures in the Dow Chemical #103 core is presented in Figure 6.

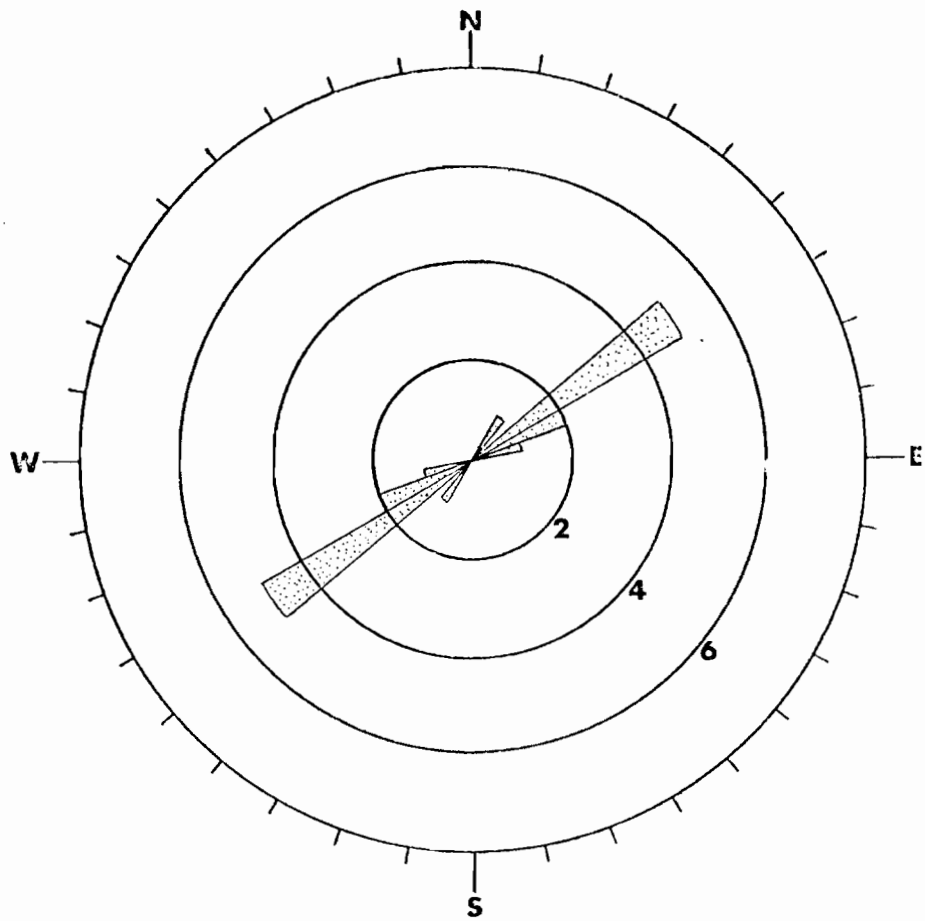


FIGURE 6

STRIKE AND FREQUENCY OF INDUCED FRACTURES IN THE ANTRIM SHALE

A P P E N D I X A

DETAILED LITHOLOGIC DESCRIPTION
DOW CHEMICAL #100 CORE, SANILAC COUNTY, MICHIGAN

INTERVAL	DESCRIPTION
820.0' - 830.0' (10.0')	Shaly mudstones, olive black (5Y 2/1), thick bedded. Occasional micaceous partings are present; disseminated mica occurs sparsely throughout. Pyrite nodules up to 5 mm in diameter are contained within the core. Fossils occurring in this interval include fish scales and carbonaceous plant fragments. Carbonaceous fragments are more common in the lower 1/2.
830.0' - 840.0' (10.0')	Shaly mudstones, olive black (5Y 2/1), thick bedded. Disseminated mica occurs sparsely throughout. Pyrite nodules averaging 5 mm in diameter are present; slickensides occur around the circumference of a larger (10 mm) nodule at 835.9 feet. Carbonaceous plant fragments are common throughout. A large vitrinite fragment (1 x 3 cm), apparently a plant stem, occurs at 834.1 feet.
840.0' - 850.0' (10.0')	Shaly mudstones, olive black (5Y 2/1), thick bedded. Disseminated mica and micaceous partings occur throughout; occasional pyrite nodules up to 5 mm in diameter are present in the upper 1/3. A few subhorizontal, pyrite filled burrow structures occur in the core; the pyrite in several of these burrow structures has been partially oxidized to limonite. This interval is moderately fossiliferous throughout, containing carbonaceous plant fragments, vitrinite fragments (840.9 and 846.4 ft.), inarticulate brachiopod shells (Lingula sp. and Orbiculoidea sp.), and a few fish scales.
850.0' - 856.5' (6.5')	Shaly mudstones, olive black (5Y 2/1), thick bedded. Disseminated mica and occasional carbonaceous plant fragments occur throughout. A vitrinite fragment, apparently a plant stem (1 x 7 cm), is present at 853.9 feet. A single, large inarticulate brachiopod shell (Lingula sp.), approximately 1 cm in length, occurs at 850.3 feet.
856.5' - 863.0' (6.5')	Shaly mudstones, olive black (5Y 2/1), thick bedded. Disseminated mica and occasional carbonaceous plant fragments occur throughout. Pyrite nodules, possibly fecal in origin and up to 1.5 cm in diameter, are present in the core.

INTERVAL	DESCRIPTION
863.0' - 880.0' (17.0')	Core from this interval was not received for analysis.
880.0' - 887.0' (7.0')	Shaly mudstones, olive black (5Y 2/1), thick bedded. Disseminated mica occurs throughout. A few lenses of crystalline pyrite, 1 mm thick by 10 mm in length, are present in the upper one foot. This interval is barren of fossils.
887.0' - 894.0' (7.0')	Shaly mudstones, olive black (5Y 2/1), thick bedded. Disseminated mica occurs throughout. This interval is barren of fossils.
894.0' - 915.0' (21.0')	Core from this interval was not received for analysis.
915.0' - 925.0' (10.0')	Shaly mudstones, olive black (5Y 2/1), thick bedded. Disseminated mica occurs sparsely throughout. Pyrite is present as nodules (∿2 mm diam.) and thin lenses (∿ 1 mm thick). Fossils present in this interval include carbonaceous plant fragments, fish scales and conodonts. A vitrinite fragment occurs at 922.5 feet; resinous algal spores (Tasmanites sp.) are present on a parting at 924.9 feet.
925.0' - 935.0' (10.0')	Shaly mudstones, olive black (5Y 2/1), thick bedded. Disseminated mica and silty grains occur throughout. A few 1-mm thick pyrite lenses are scattered in the core. Fossils present in this interval include carbonaceous and vitrinitic plant fragments, algal spore bodies (Tasmanites sp.), and a single fish scale.
935.0' - 946.0' (11.0')	Shaly mudstones and silty shales, olive black (5Y 2/1), thin to thick bedded. Silt and mica content increase near the base of the interval. Fossils are relatively abundant and consist of carbonaceous plant fragments, algal spore bodies (Tasmanites sp.), conodonts and conodont fragments, fish scales, fish teeth and bone fragments, and inarticulate brachiopod shells (Orbiculoidea sp.). Most of the fossils in this interval, with the exception of Orbiculoidea, occur in localized clumps or clusters associated with carbonaceous material. Two of these clumps are present at 942.7 and 945.5 feet and probably originated as fecal deposits. Orbiculoidea sp. occurs extensively on partings in the lower 7 feet of the interval.

INTERVAL	DESCRIPTION
946.0' - 954.0' (8.0')	Fine sandstones and silty shales, pale yellowish brown (10YR 6/2), medium gray (N5), and medium dark gray (N4), thinly laminated to thin bedded. The sandstone consists predominantly of fine, subangular quartz grains with moderate amounts of mica and rare amounts of glauconite. Friability and silt content increase in the lower 1/2 of the interval. Sand clasts are present between 951.8 and 952.1 feet, above a scour surface. Pyrite occurs throughout in subhorizontal burrow structures and as disseminated grains; much of the pyrite is oxidized to limonite. Carbonaceous partings are present throughout and a minor amount of carbonaceous plant fragments are scattered in the core. A few resinous and pyrite-coated spores (Tasmanites sp.) occur throughout.
954.0' - 957.4' (3.4')	Silty shales with numerous thin laminae of sandy siltstone, dark gray (N3) and medium gray (N5), thick bedded. A micaceous zone located at 954.3 feet appears to be a possible ash bed. Limonite nodules and stains occur throughout; the limonite probably represents oxidized pyrite. A few carbonaceous fragments are present in the core.
957.4' - 961.3' (3.9')	Siltstones with numerous thin laminae of silty shale, medium gray (N5) and dark gray (N3), thick bedded. The core is highly micaceous, and contains carbonaceous partings and carbonaceous plant fragments throughout. Limonite staining is present throughout the entire interval, but is especially predominant in the lower 1/2.
961.3' - 970.3' (9.0')	Fine sandstones and silty shales, medium light gray (N6), thinly laminated to thick bedded. The sandstone consists of medium to fine, subangular quartz grains and disseminated mica with a few micaceous and carbonaceous partings. Minor cross and ripple laminations are present in the sandstone units. Silty shale beds in the upper 1/2 contain carbonaceous lenses between 961.5 and 962.5 feet. These lenses consist of the coaly remains of stemmed plants, and the stems in each lens appear to be oriented along a unique (current ?) flow direction. Many of these lenses are surrounded by microfaults.

INTERVAL	DESCRIPTION
970.3' - 979.6' (9.3')	Fine sandstones, medium light gray (N6), thin bedded. Numerous thin carbonaceous and shaly laminae occur throughout. The sandstone consists of medium to fine, subangular quartz with some mica and minor amounts of accessory minerals (hornblende, zircon). A 5 x 2 mm vug (gas pit ?) occurs at 974.95 feet. Pyrite nodules occur throughout, but are more common below 978 feet. Most of the nodules are partially weathered to limonite.
979.6' - 990.0' (10.4')	Sandstones, medium light gray (N6), thick bedded. Much of this interval is cross bedded; the cross beds are separated by very thin (∿1 mm) clay-rich laminae, and range in thickness from 1.0 to 1.5 cm. The cross beds exhibit an apparent dip of approximately 20°. Thin, dendritic laminae of bituminous material, referred to as "rootlet horizons" are common between 985.0 and 986.0 feet. A large vitrinite fragment (1 x 3 cm) occurs at 989.4 feet.
990.0' - 1,000.0' (10.0')	Sandstones, medium light gray (N6), thick bedded. Most of the core is cross bedded; the cross beds dip approximately 18°. A bituminous rootlet horizon occurs at 990.2 feet. Limonite nodules up to 2.5 cm in diameter, are fairly common in the upper 1/2, especially at 992.85 and 993.0 feet. A few carbonaceous plant fragments and disseminated mica flakes occur throughout.
1,000.0' - 1,003.7' (3.7')	Sandstones, medium light gray (N6), thick bedded. The interval is cross bedded (20° dip), and contains occasional micaceous partings. A vitrinite fragment is present at 1,007.0 feet. Bituminous rootlet horizons and a few mud lumps occur throughout.
1,003.7' - 1,011.7' (8.0')	Silty shales and very fine sandstones, olive gray (5Y 3/2) and light gray (N7), thinly laminated to thin bedded. Cross lamination, ripple lamination, and occasional basal scour surfaces are associated with the sandstone units. A large, distorted sand clast, possibly part of a ball and pillow structure, is present between 1,004.7 and 1,005.0 feet. Several micaceous/carbonaceous partings occur in the core from 1,005.9 to 1,006.2 feet; disseminated mica is common in the silty shale below 1,006.2 feet.

INTERVAL	DESCRIPTION
1,011.7' - 1,016.0' (4.3')	Silty mudstones and very fine sandstones, olive black (5Y 2/1) and light gray (N7), thinly laminated to thin bedded. The sandstone consists of very fine quartz grains and minor mica flakes. A thin sandstone bed located between 1,013.5 and 1,013.65 feet contains prominent cross lamination; horizontal, micaceous/carbonaceous partings occur in the sandstone between 1,013.9 and 1,015.0 feet. Two zones of limonite-stained silty mudstone clasts are present between 1,015.0 and 1,016.0 feet. These clasts are gravel sized, well rounded, and oval shaped, with their long axes oriented parallel to bedding planes in the core. They appear to be an intraformational edgewise conglomerate.
1,016.0' - 1,021.7' (5.7')	Silty mudstones and silty sandstones, medium dark gray (N4), olive gray (5Y 4/1), and light gray (N7), thin to thick bedded. Sedimentary structures are abundant throughout in both lithologic units, including: truncated, small-scale ball and pillow structures; cross lamination; ripple lamination; scour surfaces with associated sand clasts; rip-up structures; edgewise conglomerate; and contorted, distorted bedding planes. A large sand clast, surrounded by microfaults, occurs between 1,019.7 and 1,020.2 feet.
1,021.7' - 1,030.0' (8.3')	Silty sandstones and silty mudstones, light gray (N7) and dark gray (N3), thinly laminated to thin bedded. Contorted and wavy bedding, ripple lamination, cross lamination, and scour surfaces with associated sand clasts occur throughout. A large sand clast with internal mudstone laminae, possibly a portion of a ball and pillow structure, is present between 1,025.3 and 1,025.8 feet. Shaly partings and micaceous/carbonaceous partings (some slightly resinous) are common throughout.
1,030.0' - 1,032.3' (2.3')	Silty mudstones and very fine sandstones, dark gray (N3) and light gray (N7), thinly laminated to thin bedded. Cross lamination, contorted bedding, ripple lamination, and scour surfaces with associated sand clasts are present in the interval. Shaly partings and micaceous/carbonaceous partings occur throughout.
1,032.3' - 1,034.0' (1.7')	Core from this interval was not received for analysis.

INTERVAL	DESCRIPTION
1,034.0' - 1,040.0' (6.0')	Silty mudstones and very fine sandstones, dark gray (N3), olive gray (5Y 3/2), and light gray (N7), thinly laminated to thin bedded. Contorted bedding, ripple lamination and scour surfaces are present throughout. Zones containing small sand clasts (up to 3 mm in diam.) occur sparsely within the thicker mudstone units. Micaceous/carbonaceous partings are distributed throughout.
1,040.0' - 1,047.0' (7.0')	Silty mudstones and very fine sandstones, olive gray (5Y 4/1) and medium light gray (N6), thinly laminated to thin bedded. Contorted bedding, minor ripple and cross laminations, scour surfaces with associated sand clasts, shaly partings and micaceous/carbonaceous partings occur throughout.
1,047.0' - 1,054.0' (7.0')	Silty mudstones and silty sandstones, olive gray (5Y 4/1) and medium light gray (N6), thinly laminated to thin bedded. The silty sandstone units contain cross and ripple lamination; occasional scour surfaces with associated sand clasts are present in the core. A few shaly partings and micaceous/carbonaceous partings occur throughout. Several of the micaceous partings contain yellowish-brown deposits of resinous material, possibly derived from compacted masses of resinous spores. The basal two feet of the interval is dominated by silty mudstones.
1,054.0' - 1,064.0' (10.0')	Shaly mudstones, greenish black (5G 2/1), thick bedded. Disseminated mica and micaceous partings are present in the core. Small, carbonaceous plant fragments occur sparsely throughout.
1,064.0' - 1,074.0' (10.0')	Shaly mudstones, greenish black (5G 2/1), thick bedded. The interval is slightly to moderately micaceous, and two thin siltstone lenses are present at 1,072.4 and 1,073.4 feet. The lower of these contains minor cross lamination and rests on a scour surface.

INTERVAL	DESCRIPTION
1,074.0' - 1,084.0' (10.0')	Shaly mudstones and silty shales, greenish black (5G 2/1), thick bedded. A few thin, ripple-marked siltstone lenses occur throughout. Disseminated mica and occasional micaceous/carbonaceous partings are present in the core. Small pyrite nodules (∿1 mm diam.) and carbonaceous plant fragments are distributed sparsely throughout.
1,084.0' - 1,094.0' (10.0')	Shaly mudstones and silty shales, greenish black (5G 2/1), thick bedded. Disseminated mica occurs throughout. The bedding in this interval dips 10° to 20°, and a rubble zone occurs from 1,086.0 to 1,091.0 feet. Numerous slickensided microfaults are present between 1,084.0 and 1,085.0 feet. This fracture evidence suggests the lateral proximity of the core to a large concretion or sand lens centered between 1,086.0 and 1,091.0 feet.
1,094.0' - 1,104.0' (10.0')	Silty shales with numerous thin siltstone laminations, greenish black (5G 2/1) and light olive gray (5Y 5/2), thinly laminated to thin bedded. The frequency and thickness of the siltstone units increase downcore; the siltstone to silty shale ratio in the lower 1/2 of the interval is nearly 1 to 1. The siltstone units vary in thickness from very thin laminae to very thin beds (<1 mm to ∿2 cm). Several of the siltstones rest on scour surfaces and most contain cross lamination and ripple lamination.
1,104.0' - 1,114.0' (10.0')	Silty shales and siltstones, greenish black (5G 2/1) and light olive gray (5Y 5/2), thinly laminated to thin bedded. Many of the siltstone units rest on scour surfaces; bedding planes are irregular and cross lamination occurs throughout. Carbonaceous partings are present in a siltstone bed located between 1,106.6 and 1,106.7 feet.
1,114.0' - 1,124.0' (10.0')	Silty shales and siltstones, greenish black (5G 2/1) and light olive gray (5Y 5/2), thinly laminated to thin bedded. Disseminated mica and micaceous/carbonaceous partings are moderately abundant in the core. Ripple and cross laminations occur within many of the siltstone units. Scour surfaces with associated siltstone clasts are present throughout the interval. Much of the core is stained with limonite.

INTERVAL	DESCRIPTION
1,124.0' - 1,134.0' (10.0')	Silty shales and siltstones, greenish black (5G 2/1), dark gray (N3), and light olive gray (5Y 5/2), thinly laminated to thin bedded. Ripple laminations and scour surfaces occur in the siltstone units. A small-scale ball and pillow structure is present at the base of a siltstone bed between 1,125.3 and 1,125.5 feet.
1,134.0' - 1,140.0' (6.0')	Silty shales and siltstones, greenish black (5G 2/1) and light olive gray (5Y 6/1), thinly laminated to thick bedded. The siltstone units contain cross lamination, rippled laminae and occasional sand clasts. Micaceous/carbonaceous partings occur throughout.
1,140.0' - 1,146.4' (6.4')	Silty shales and siltstones, dark greenish gray (5GY 4/1) and light olive gray (5Y 6/1), thinly laminated to thin bedded. The siltstone units contain rippled laminae, cross laminations, and occasional scour surfaces. A few micaceous/ carbonaceous partings occur throughout.
1,146.4' - 2,000.0' (853.6')	Core from this interval was not received for analysis.
2,000.0' - 2,015.1' (15.1')	Lime mudstones, wackestones, and argillaceous limestones, pinkish gray (5YR 8/1), light olive gray (5Y 6/1) and dark greenish gray (5GY 4/1), thinly laminated to thick bedded. The core consists of light-colored beds of relatively pure limestone alternating with dark-colored beds of organic-rich, argillaceous limestone. Most of the beds contain smaller scale, alternating light and dark laminae. The upper 3 feet of the interval consist of a pure, hard, microcrystalline lime mudstone (micrite) containing very abundant, small (1 to 2 mm) vugs partially filled with thin calcite crystals. A single thin bed of grainstone is present between 2,009.0 and 2,010.0 feet. Stylolites and other pressure-solution features, such as distorted fossils and neomorphic (recrystallized) calcite are abundant throughout. Most of the stylolitic surfaces are fairly rich in carbonaceous matter and clay. Fossils in this interval are poorly preserved, and consist of articulate brachiopods, bryozoa (?) and crinoid stems.

INTERVAL	DESCRIPTION
2,015.1' - 2,022.2' (7.1')	Core from this interval was not received for analysis.
2,022.2' - 2,036.9' (14.7')	Argillaceous limestones, lime mudstones, wackestones and dolostone, pinkish gray (5YR 8/1), yellowish gray (5Y 8/1), light olive gray (5Y 6/1), moderate yellowish brown (10YR 5/4), light olive brown (5Y 5/6) and olive grays (5Y 4/1 and 5Y 3/2), thinly laminated to thin bedded. The dolostone occurs in a single thin bed located between 2,025.7 and 2,026.8 feet; a dolostone nodule (pebble ?) is present at 2,022.3 feet. Much of the core contains thin carbonaceous laminae with somewhat uneven bedding planes occurring at irregular spacing. Stylolites occur frequently throughout. The stylolitic surfaces are coated with organic matter; a stylolite at 2,023.2 feet encloses a layer of organic material 4 mm thick. Other pressure-solution features in the interval include recrystallized calcite and truncated bedding planes. Brown, platy crystals (celestite ?) up to 4 cm in length are scattered throughout the lower 1/4. Fossils in this interval consist of articulate brachiopod, bryozoa and crinoid fragments in the wackestone units.
2,036.9' - 2,048.0' (11.9')	Crystalline limestones, pale yellowish brown (10YR 6/2) and very pale orange (10YR 8/2), thin to thick bedded. Most of the interval consists of very fine grained, featureless, lithographic limestones (micrite). Eleven thin beds of dark, organic-rich limestone with associated pale orange limestones (caliche ?) occur throughout. These beds generally exhibit a relatively smooth top and an irregular basal surface, and appear to represent episodes of subaerial exposure and erosion. A few organic-rich layers and nodules (algal deposits ?) occur within the micritic limestone units. Occasional stylolites are present; this interval is barren of fossils.

INTERVAL	DESCRIPTION
2,048.0' - 2,055.3' (7.3')	Crystalline limestones, pale yellowish brown (10YR 6/2) and dusky yellowish brown (10YR 2/2), thinly laminated to thin bedded. Abundant, thin laminae of dark, organic-rich limestone occur within the lighter beds. Dark brown, platy crystals (celestite ?) are present throughout, but are especially common in the lower 1/2. Numerous stylolites are present; this interval is barren of fossils.
2,055.3' - 2,056.4' (1.1')	Lime mudstones and argillaceous limestones, dark yellowish brown (10YR 4/2), and dusky yellowish brown (10YR 2/2), thinly to thickly laminated. Intense bioturbation occurs at 2,056.1 feet. Occasional stylolites are present; this interval is barren of fossils.

A P P E N D I X B

DETAILED LITHOLOGIC DESCRIPTION
DOW CHEMICAL #103 CORE, SANILAC COUNTY, MICHIGAN

INTERVAL	DESCRIPTION
1,177.0' - 1,185.7' (8.7')	Silty shales, olive gray (5Y 3/2), thick bedded. The core is extremely fissile, has a waxy luster, and contains numerous slump features with associated curviplanar slickensided fractures. The strikes of these fractures are generally parallel with dips of ∿30°. Spore bodies are present, but sparse. Most of the spore bodies are resinous, but some occur on slickensided fractures and have been partially pyritized. The interval is noncalcareous.
1,185.7' - 1,191.3' (5.6')	Core from this interval was not received for analysis.
1,191.3' - 1,194.5' (3.2')	Shaly mudstones, olive gray (5Y 4/1), grayish olive (10Y 4/2), light brown (5YR 5/6), and moderate olive brown (5Y 4/4), thinly laminated to thin bedded. The upper foot contains thin to thick laminae of olive black, light brown, and moderate olive brown shaly mudstones. The remainder of the interval grades from olive gray to grayish olive shaly mudstones. The lower 2 cm are slightly mottled by bioturbation. Small (<5 mm) carbonaceous plant fragments and resinous spore bodies occur, but are sparse. Poorly preserved, partially pyritized fossil brachiopod fragments occur at 1,193.0, 1,193.3, and 1,193.9 feet.
1,194.5' - 1,199.5' (5.0')	Shaly mudstones, black (N1) and grayish black (N2), thin to thick bedded. The upper 1/2 foot consists of grayish black shaly mudstone which quickly grades into black shaly mudstone. The interval is dominated by a large natural fracture ∿2 feet in length which starts just below the bioturbated zone of the preceding interval. Resinous spore bodies and small (1 mm) carbonaceous plant fragments occur frequently. Several fish scales also were observed in the interval. Pyrite occurs throughout in small nodules (up to 2 mm in diam.) and as disseminated grains.
1,199.5' - 1,202.4' (2.9')	Core from this interval was not received for analysis.

INTERVAL	DESCRIPTION
1,202.4' - 1,210.8' (8.4')	Shaly mudstones, black (N1), thick bedded. The interval has core missing from 1,203.3 to 1,203.9 feet and at 1,206.1 feet. A poorly preserved fossil fish jaw is present at 1,202.5 feet. Fish scales, carbonaceous plant fragments and resinous spore bodies occur frequently. Two zones of fossil hash, which include conodonts, fish scales, fish teeth, and carbonaceous fragments, occur at 1,208.1 and 1,209.6 feet. Pyrite occurs as disseminated grains and as replacement in some of the spore bodies.
1,210.8' - 1,216.4' (5.6')	Core from this interval was not received for analysis.
1,216.4' - 1,220.0' (3.6')	Shaly mudstones, black (N1), thick bedded. The interval has core missing from 1,218.3 to 1,219.0 feet. Resinous spore bodies, fish scales and small (1-2 mm) carbonaceous plant fragments occur throughout. Fossil fish jaws occur at 1,216.4 and 1,220.0 feet. Several conodonts are present at 1,219.0 feet. Pyrite occurs as disseminated grains throughout, and as nodules contained within a zone from 1,217.5 to 1,218.0 feet. The largest nodule is approximately 15 mm in diameter.
1,220.0' - 1,230.0' (10.0')	Shaly mudstones, black (N1), thick bedded. A poorly preserved, partially pyritized, brachiopod cast occurs at 1,229.0 feet. Fossil fish jaws are present at 1,225.2, 1,228.9, 1,229.7, and 1,229.8 feet. A carbonaceous fragment that could be the remains of a fish fin (4 mm x 14 mm) is present at 1,229.3 feet. This fragment is surrounded by a mineralized halo, approximately 5 mm thick. Resinous spore bodies, fish scales, and small (1 to 2 mm) carbonaceous fragments occur frequently throughout the interval. Pyrite occurs in disseminated grains throughout, in nodules (up to 3 cm in diam.) at 1,221.8 and 1,224.7 feet, and in thin lenses (<1 mm thick), that are weakly calcareous.

INTERVAL	DESCRIPTION
1,230.0' - 1,238.4' (8.4')	Shaly mudstones, black (N1) and brownish black (5YR 2/1), thick bedded. There is a gradational change from black to brownish black in the lower 1/2 of the interval. Fossil fish jaws occur at 1,230.5, 1,231.1, 1,233.0, and 1,236.6 feet. A zone containing numerous conodonts exists at 1,236.2 feet. Resinous spore bodies are numerous, and in some zones are so concentrated that they impart an orange color to the core. Fish scales and small carbonaceous fragments occur frequently throughout the interval. Pyrite occurs as disseminated grains throughout, in occasional thin (<1 mm), weakly calcareous laminae, and in a large (2 x 3 cm) nodule at 1,231.6 feet.
1,238.4' - 1,247.5' (9.1')	This interval contains five zones of missing core; therefore, depths of fossils and sedimentary structures have not been assigned. Shaly mudstones, brownish black (5YR 2/1), thick bedded. A thin bed of medium dark gray (N4) carbonate (2 cm thick) occurs approximately 18 inches above the bottom of the interval. This carbonate contains numerous distorted, thin mud laminae, and rests on a solution surface. Several fossil fish jaws are present in the interval. Resinous spore bodies and carbonaceous fragments occur frequently throughout the interval. Pyrite occurs in both large and small nodules (5 mm to 2 cm in diam.); thin calcareous laminae are associated with some of these nodules.
1,247.5' - 1,251.0' (3.5')	Shaly mudstones, brownish black (5YR 2/1) and olive black (5Y 2/1), thick bedded. The change from brownish black to olive black is gradational over the length of the interval. Fossil fish jaws are present at 1,248.0 and 1,248.4 feet. Occasional fish scales and teeth also occur in the interval. Resinous spore bodies are numerous throughout. Pyrite occurs in slightly calcareous nodules that average about 1 cm in diameter.

INTERVAL	DESCRIPTION
1,251.0' - 1,260.0' (9.0')	Shaly mudstones and mudstones, olive black (5Y 2/1) and olive gray (5Y 4/1), thickly laminated to thin bedded. A strongly bioturbated zone containing numerous subhorizontal burrow structures (5 to 10 mm in diam.) exists from 1,253.1 to 1,253.4 feet. Brachiopod casts occur at 1,251.2 and 1,253.8 feet. A fossil fish jaw is present at 1,251.9 feet. Resinous spore bodies are abundant, and in several zones extremely abundant. A thin, weakly calcareous, convoluted pyrite lamina occurs at 1,258.3 feet. Pyrite nodules are common, ranging in size from 2 mm to 10 mm in diameter, and are weakly calcareous.
1,260.0' - 1,269.9' (9.9')	Shaly mudstones and mudstones, olive black (5Y 2/1) and grayish olive (10Y 4/2), thin to thick bedded. Zones of strongly bioturbated grayish olive mudstone occur from 1,261.5 to 1,262.2 feet and from 1,266.4 to 1,266.9 feet. These zones contain subhorizontal burrow structures, from 2 to 10 mm in diameter. Brachiopod casts occur from 1,262.0 to 1,262.2 feet, and at 1,265.8 and 1,267.0 feet. A fossil fish jaw is present at 1,265.0 feet. Fish scales and resinous spore bodies are numerous throughout the interval. A large (5 x 40 mm) vitrinite fragment occurs at 1,267.8 feet, and several woody fragments of similar size occur at 1,269.0 and 1,269.9 feet. Weakly calcareous pyrite nodules, 5 to 10 mm in diameter, are common in the interval.
1,269.9' - 1,278.0' (8.1')	Shaly mudstones, olive black (5Y 2/1) and grayish olive (10Y 4/2), thinly laminated to thin bedded. A grayish olive zone from 1,274.5 to 1,274.6 feet contains numerous thin (<1 mm) calcareous laminae. These laminae also occur frequently throughout the lower 1/2 of the interval. Resinous spore bodies, fish scales, and fish teeth are present throughout. Pyrite occurs throughout the interval in nodules (2 to 15 mm in diam.) that are weakly calcareous.

INTERVAL	DESCRIPTION
1,278.0' - 1,284.2' (6.2')	Shaly mudstones, olive black (5Y 2/1), thinly laminated to thin bedded. The interval contains numerous thin (<1 mm), weakly calcareous laminae. A 3-mm thick lamina of moderately yellowish brown (10YR 5/4) dolomite containing numerous small (<1 mm) carbonaceous fragments occurs at 1,280.4 feet. A large (10 x 40 mm) woody fragment is present at 1,282.6 feet. Resinous spore bodies and small (<1 mm) carbonaceous fragments are frequent. Pyrite is present as several small nodules, 5 to 10 mm in diameter.
1,284.2' - 1,293.0' (8.8')	Shaly mudstones and mudstones, olive black (5Y 2/1) and olive gray (5Y 4/1), thinly laminated to thin bedded. Thin (<1 mm), calcareous laminae are present throughout but with decreasing frequency toward the bottom of the interval. A fossil hash which contains fish teeth and scales, conodonts, and resinous spore bodies is present at 1,287.4 feet. Resinous spore bodies and fish scales are common throughout the interval. Small, moderately calcareous pyrite nodules (5 mm in diam.), occur with increasing frequency toward the bottom of the interval.
1,293.0' - 1,303.0' (10.0')	Shaly mudstones, olive black (5Y 2/1), thinly laminated to thin bedded. A fossil fish jaw is present at 1,297.6 feet. A woody fragment (4 x 45 mm) occurs at 1,302.7 feet. Resinous spore bodies and fish scales are common throughout. Pyrite occurs in nodules up to 1 cm in diameter and as disseminated grains in common, thin (<1 mm), calcareous laminae.
1,303.0' - 1,312.2' (9.2')	Shaly mudstones, olive black (5Y 2/1) and brownish black (5YR 2/1), thinly laminated to thin bedded. The change from olive black to brownish black mudstone is gradational. Resinous spore bodies are abundant, and in some zones extremely abundant. Fish scales and carbonaceous fragments are less frequent than in previous intervals. A large (4 x 6 cm) pyrite nodule is present at 1,308.3 feet. The pyrite nodules are noncalcareous.

INTERVAL	DESCRIPTION
1,312.2' - 1,315.5' (3.3')	Shaly mudstones, brownish black (5YR 2/1), thick bedded. Resinous spore bodies are common throughout. Several fish scales and small (1 to 2 mm), carbonaceous fragments are present. A large vitrinite fragment (2 x 4 cm) occurring at 1,313.7 feet is oriented in a NE-SW direction. Pyrite occurs as several small (3-5 mm) nodules.
1,315.5' - 1,318.1' (2.6')	Core from this interval was not received for analysis.
1,318.1' - 1,322.2' (4.1')	Shaly mudstones, brownish black (5YR 2/1), thick bedded. Resinous spore bodies occur throughout; several small (2-3 mm) carbonaceous fragments are present in the interval. A 3-mm long vertical fracture mineralized with pyrite and associated with a disseminated pyrite lamina occurs at 1,321.1 feet. Pyrite also occurs as small (3-5 mm) nodules throughout, and as a large nodule (13 x 40 mm) at 1,320.1 feet. The latter nodule is associated with a 1-mm thick lamina of disseminated pyrite.
1,322.2' - 1,329.9' (7.7')	Shaly mudstones, brownish black (5YR 2/1) and olive black (5Y 2/1), thinly laminated to thick bedded. The change from brownish black to olive black is gradational. Resinous spore bodies are common throughout; a 2-mm thick, dark yellowish brown (10YR 4/2) lamina at 1,322.4 feet contains very abundant spores. A zone of Foerstia sp. is first noticed at 1,326.4 feet. Foerstia sp. range from 3 to 5 mm in diameter, and the size remains uniform throughout the lower part of the interval. Vertical fractures, 2 to 3 mm in length and mineralized with pyrite, are present at 1,323.5 and 1,326.7 feet. A lamina of disseminated pyrite 5-mm thick occurs at 1,326.7 feet. Pyrite also exists as small (5 to 10 mm) nodules which are slightly calcareous.

INTERVAL	DESCRIPTION
1,329.9' - 1,339.2' (9.3')	Shaly mudstones and mudstones, olive black (5Y 2/1) and dusky yellow green (5GY 5/2), thinly laminated to thick bedded. The dusky yellow green mudstones are bioturbated and occur in a zone (5 mm thick) at 1,335.3 feet. A 1-mm thick lamina of dolomite is present at 1,336.4 feet. The Foerstia sp. zone that begins in the previous interval ends at 1,336.3 feet. Resinous spore bodies are common throughout. Pyrite occurs as small (5 mm in diam.) nodules and in several thin (<1 mm) lamina. Pyrite occurrences are weakly calcareous.
1,339.2' - 1,344.0' (4.8')	Shaly mudstones, olive black (5Y 2/1), thick bedded. A large vitrinite fragment (6 x 7 cm) is present at 1,343.8 feet. Resinous spore bodies are common throughout; fish scales are occasionally present. The interval contains several laminae of disseminated pyrite that range from 1 mm to 1 cm in thickness. Small pyrite nodules (3 to 5 mm in diam.) are also common.
1,344.0' - 1,351.1' (7.1')	Shaly mudstones, olive black (5Y 2/1), thick bedded. Resinous spore bodies are common throughout. Several thin (<1 mm) laminae of disseminated pyrite, usually associated with pyrite nodules are present in the interval. A zone that extends from 1,349.3 to 1,349.5 feet contains several thin (<1 mm) dolomitic laminae. Dolomite and calcite form the mineralization on several natural fractures in the interval.
1,351.1' - 1,360.1' (9.0')	Shaly mudstones and mudstones, olive black (5Y 2/1), dusky yellow green (5GY 5/2), and light olive gray (5Y 5/2), thickly laminated to thin bedded. The interval consists of sequences of dusky yellow green mudstone grading to bioturbated light olive gray mudstone to olive black shaly mudstone. Spore bodies are generally altered to pyrite in the dusky yellow green zones. Resinous spore bodies are common in the olive black zones. A large pyrite nodule (15 mm in diam.) is present at 1,359.6 feet. Calcite is present as mineralization in a natural fracture.

INTERVAL	DESCRIPTION
1,360.1' - 1,368.0' (7.9')	Shaly mudstones and mudstones, olive black (5Y 2/1), light olive gray (5Y 5/2), and dusky yellow green (5GY 5/2), thinly laminated to thin bedded. The interval consists of sequences of dusky yellow gray mudstone grading to bioturbated light olive gray mudstone, and then to olive black shaly mudstone. Resinous spore bodies are common in the olive black zones, and are altered to pyrite in the dusky yellow green zones. Conodonts are present in both the light and dark zones. Pyrite also occurs as small (1 to 3 mm in diam.) nodules in the olive black zones. The bottom two feet of the interval contain numerous thin (<1 mm) dolomitic laminae. A natural fracture in the interval contains some calcite mineralization.

A P P E N D I X C

DETAILED LITHOLOGIC DESCRIPTION
DOW CHEMICAL #205 CORE, SANILAC COUNTY, MICHIGAN

INTERVAL	DESCRIPTION
1,383.0' - 1,390.3' (7.3')	Mudstones, calcareous mudstones, and argillaceous limestones, light olive gray (5Y 6/1), olive grays (5Y 4/1 and 5Y 3/2), olive black (5Y 2/1), and medium light gray (N6), thickly laminated to thin bedded. A few thin laminae of calcareous siltstone occur throughout. The argillaceous limestone is present as thin, irregular beds and isolated concretions. Bioturbation is intense between 1,384.3 and 1,386.4 feet; mud and pyrite filled burrow structures occur throughout. Pyrite is also present as nodules and occasional thin laminae. Several fossils are preserved in the mudstones, including carbonaceous plant fragments, resinous spores, and inarticulate brachiopods (Lingula sp.). A few bedding planes in the limestone units contain casts of articulate brachiopod shells.
1,390.3' - 1,396.2' (5.9')	Mudstones, olive black (5Y 2/1), olive gray (5Y 4/1), and light olive gray (5Y 6/1), thickly laminated to thin bedded. Alternating light and dark zones give the core a banded appearance; small (2 mm diam.), subhorizontal burrow structures filled with mud and pyrite are common at the base of the lighter units. A single, thin pyrite lamina is present at 1,392.4 feet. Fossils contained within the interval include carbonaceous plant fragments, pyrite-coated vitrinite (1,393.8 and 1,395.7 ft.), resinous spores, and inarticulate brachiopods (Lingula sp.).
1,396.2' - 1,401.6' (5.4')	This interval was sent to Wayne State University, Detroit, Michigan for porosity and permeability analysis.
1,401.6' - 1,409.5' (7.9')	Mudstones, olive black (5Y 2/1) and olive grays (5Y 3/2 and 5Y 4/1), thin bedded. Alternating light and dark zones give the core a banded appearance; numerous mud and pyrite filled burrow structures occur at the base of the lighter units. Nodules, laminae, and disseminated crystals of pyrite are common throughout the darker zones. Thin, calcareous laminae are frequently present at the contacts between the light and dark zones. A vitrinite lamina occurs at 1,407.5 feet; carbonaceous plant fragments and resinous spores are present throughout.

INTERVAL	DESCRIPTION
1,409.5' - 1,413.6' (4.1')	Mudstones and silty mudstones, olive black (5Y 2/1), olive gray (5Y 4/1), and dusky yellow green (5GY 5/2), thinly laminated to thin bedded. Dark mudstones predominate throughout; a few thin, irregular siltstone laminae are present in the upper 3/4 of the interval. The lower 1/4 is composed of alternating thin beds of dark mudstone and light silty mudstone. Subhorizontal, silty-mud filled burrow structures are present at the base of the lighter units. Pyrite is common throughout, occurring as nodules, lenses, and irregular, thin laminae. Pyritic laminae and crystals occur in association with the siltstone laminae. A lens shaped, calcareous concretion is present at 1,412.4 feet. Inarticulate brachiopod casts (Lingula sp.), carbonaceous plant fragments, and resinous spores occur throughout.
1,413.6' - 1,420.1' (6.5')	Mudstones, silty mudstones, and siltstones, dusky yellowish brown (10YR 2/2), olive black (5Y 2/1), olive grays (5Y 3/2 and 5Y 4/1), and light olive gray (5Y 5/2), thinly laminated to thin bedded. The upper two feet consist of mottled olive gray mudstones and silty mudstones. The remainder is composed of dark silty mudstones containing abundant, irregular laminae of calcareous siltstone. Bioturbation is moderate to intense throughout. Subhorizontal, mud filled burrow structures are abundant in the mottled zones, and many pyrite filled burrow structures are present in the lower 1/2. Carbonaceous plant fragments and resinous spores occur on bedding planes throughout the interval. Casts of inarticulate brachiopods (Lingula sp.) are present between 1,417.0 and 1,420.0 feet.
1,420.1' - 1,429.1' (9.0')	Shaly mudstones, olive gray (5Y 4/1) and light olive gray (5Y 6/1), thick bedded. The interval is slightly to moderately calcareous throughout; the higher carbonate content occurs in irregular zones, generally less than one-foot thick. Pyrite is abundant and occurs as nodules, lenses and disseminated crystals. Occasional pyrite-filled burrows are also present. Small, articulate brachiopod casts are common throughout, and are locally abundant on several partings.

INTERVAL	DESCRIPTION
1,429.1' - 1,438.4' (9.3')	Calcareous mudstones and argillaceous limestones, olive grays (5Y 3/2 and 5Y 4/1), and dark gray (N3), thinly laminated to thin bedded. The upper two feet of the interval are shaly; calcareous mudstone is the dominant lithology in the upper 1/2. The argillaceous limestone content increases downcore. The limestones consist of wackestones, and lime mudstones; crinoid fragments are the major grain component. A large, irregular chert nodule occurs at 1,434.0 feet; smaller chert fragments are present at 1,435.8 and 1,435.9 feet. Bioturbation is intense in this interval; the core displays a mottled fabric and most of the bedding features have been destroyed. Fossils are abundant and consist of crinoid fragments, articulate brachiopods, bryozoa, and carbonaceous plant fragments. A parting covered with crinoid, articulate brachiopod, and bryozoa fragments occurs at 1,433.4 feet.
1,438.4' - 1,444.1' (5.7')	Dolostones, argillaceous dolostones and cherts, pinkish gray (5YR 8/1), olive gray (5Y 4/1), light olive gray (5Y 6/1), and very light gray (N8), thinly laminated to thin bedded. The dolostones are very finely crystalline, and contain numerous spar-filled vugs. Chert is abundant in this interval, occurring as irregular lenses, nodules, and occasional uneven beds. Much of the chert is highly fractured; most of the fractures are stained with a yellowish brown mineral (limonite ?). Thin, argillaceous laminae occur throughout. This interval is barren of fossils.
1,444.1' - 1,451.0' (6.9')	Calcareous shaly mudstones, olive gray (5Y 4/1), thinly laminated to thin bedded. The interval is highly fossiliferous; shells and shell fragments are common throughout. Many of the fossils are concentrated in discrete laminae ranging in thickness from 1 to 2 cm. Fossils which are present include articulate brachiopods, bryozoa, and crinoid fragments.

INTERVAL	DESCRIPTION
1,451.0' - 1,458.4' (7.4')	Mudstones and calcareous mudstones, olive grays (5Y 3/2 and 5Y 4/1), thin bedded. The interval is highly fossiliferous; shells and shell fragments are abundant throughout. Numerous fossiliferous laminae, 2 to 20 mm thick, are present in the interval. Fossils which are present include articulate brachiopods, bryozoa, and crinoid fragments.
1,458.4' - 1,464.8' (6.4')	Calcareous mudstones and argillaceous limestones, olive gray (5Y 4/1) and light olive gray (5Y 6/1), thin to thick bedded. The argillaceous limestone beds are confined to the upper two feet; they consist of wackestone. The grain fraction of the wackestone is composed of crinoid, brachiopod and bryozoa fragments. A few lime filled burrow structures are present at the base of the limestone units. Calcareous mudstones dominate the lower portion of the interval. It contains abundant fossils, including carbonaceous plant fragments, articulate brachiopod shells and spines, crinoid segments, and bryozoa fragments. Subhorizontal, pyrite filled burrow structures are common within the lower 1/2.
1,464.8' - 1,469.9' (5.1')	Calcareous mudstones, argillaceous limestones, and wackestones, olive gray (5Y 4/1) and light olive grays (5Y 5/2 and 5Y 6/1), thin bedded. Calcareous mudstones predominate; they contain abundant shells and shell fragments of articulate brachiopods, bryozoa and crinoids. Fragments of these three fossil types comprise the grain fraction of the wackestone beds. Limestone content is greater in the lower portion of the interval; several calcareous concretions occur in the basal one foot. Abundant, pyrite filled, subhorizontal burrow structures, and occasional carbonaceous plant fragments are present throughout.

INTERVAL	DESCRIPTION
1,469.9' - 1,476.6' (6.7')	Packstones, wackestones, argillaceous limestones, and calcareous mudstones, pale yellowish brown (10YR 6/2), pinkish gray (5YR 8/1), yellowish gray (5Y 8/1), greenish gray (5GY 6/1), and olive gray (5Y 3/2), thinly laminated to thick bedded. Packstones and wackestones predominate throughout the interval; the grain fraction of these units consists primarily of crinoid, bryozoa, and brachiopod fragments. A bed of oolitic packstone occurs between 1,473.0 and 1,476.0 feet. Many of the carbonate units in the upper 1/2 are interlaminated with dark, calcareous mudstone. Calcareous concretions occur from 1,470.0 to 1,470.5 feet and at 1,471.3 feet. Occasional lime and mud filled burrow structures are present throughout. Fossils occurring in this interval include articulate brachiopods, crinoids, bryozoa, carbonaceous plant fragments and occasional pelecypods.
1,476.0' - 1,482.0' (6.4')	Calcareous shaly mudstones, dark greenish gray (5GY 4/1), thick bedded. Small, subhorizontal, pyrite filled burrow structures occur abundantly throughout. Pyrite is also present as occasional small nodules. Fossils occurring in this interval include numerous carbonaceous plant fragments (many coated with pyrite), articulate brachiopod casts, and a trilobite carapace (?) at 1,477.2 feet.
1,482.0' - 1,488.7' (6.7')	Calcareous shaly mudstones, dark greenish gray (5GY 4/1) and olive gray (5Y 4/1), thick bedded. Small, subhorizontal, pyrite filled burrow structures are abundant throughout. Fossils occurring in this interval include numerous carbonaceous plant fragments (many coated with pyrite), bryozoa, and occasional articulate brachiopod casts. An unusual, oblong, bullet-shaped fossil preserved with pyrite is present at 1,485.5 feet.
1,488.7' - 1,494.3' (5.6')	Calcareous shaly mudstones and argillaceous limestones, dark greenish gray (5GY 4/1) and light olive gray (5Y 6/1), thin bedded. The mudstones contain numerous, small, subhorizontal, pyrite filled burrow structures. The limestones contain concretions and are very fossiliferous; fragments of crinoids, bryozoa and articulate brachiopods are abundant in these units. Pyrite coated plant fragments occur throughout.

INTERVAL	DESCRIPTION
1,494.3' - 1,497.5' (3.2')	Argillaceous limestones, calcareous mudstones, and packstones, dark greenish gray (5GY 4/1), olive gray (5Y 6/1), and pinkish gray (5YR 8/1), thickly laminated to thin bedded. Calcareous concretions occur in the upper 1/2. The packstones are oolitic, and contain several microfaults. Fossils are common in the argillaceous limestones; crinoid, bryozoa, and articulate brachiopod fragments are present.

A P P E N D I X D

SYMBOLS, TERMS, AND ABBREVIATIONS USED IN FRACTURE LOGGING

DOW CHEMICAL WELLS #100, #103, and #205 SANILAC COUNTY, MICHIGAN

Appendix D

1. CHARACTER: Specifically, the character of the fracture plane.

   (P): Planar
   (CP): Curviplanar

2. FRACTURE TYPE: These terms are used to classify the different types of fractures into genetic groups.

   (N): Natural

Spl. Jt.	(Simple Joint): One discrete fracture plane, no displacement.
Cpd. Jt.	(Compound Joint): Two or more parallel, closely spaced (approximately 1 cm or less) fracture planes, no displacement.
Flt.	(Fault): A shear fracture with demonstrable displacement indicated by displaced primary features or slickensides.
Mcr. Flt.	(Micro-Fault): A small-scale shear fracture, generally curviplanar; of the same order of size as the core diameter.

   (CI): Coring Induced

PF	(Petal Fracture): An oblique fracture, usually planar or slightly curviplanar, which originates at the core margin and terminates against bedding within the core.
PFC	(Petal-Centerline Fracture): A fracture originating as a petal fracture which curves downcore and bisects the core as a vertical planar fracture. The strike of the vertical fracture and the petal fracture is identical. The face of the vertical fracture is characterized by regularly spaced arrest lines, convex downcore and symmetrical about the core axis.
DF	(Disc Fracture): A subhorizontal fracture originating within the core and displaying hackle plumes radiating from the fracture origin to meet the core margin orthogonally.

TF	(Torsional Fracture): A spiraling or irregular fracture developed when a couple is applied to the core.
DCS	(Disc Fracture with Circular Slickensides): A feature induced by coupling of the inner and outer core barrels, causing core in the barrel to rotate against a stationary core stump.
KES	(Knife Edge Spall): A fracture, typically conchoidal, formed by scribe knives cutting orientation grooves into the core. This fracture type can be used to determine the downcore direction and the relative age of induced fractures.
CBS	(Core Bit Spall): A tiny conchoidal fracture caused by a diamond from the core bit plucking a chip off the edge of a preexisting fracture. When the face of the preexisting fracture is viewed with the core in normal position the spalls should appear along the right-hand margin. This fracture type is useful in inferring fracture chronology.

3. FRACTOGRAPHIC FEATURES:

Org.	(Fracture Origin): A discrete fracture surface irregularity from which hackles originate. Fractures may originate at the boundaries of fossils, concretions, preexisting fractures, etc.
Hkl.	(Hackle): A linear marking on a fracture face, similar to a striation, which trends in the direction of fracture propagation. Hackles radiate away from the origin, are perpendicular to arrest lines, and will curve to meet preexisting surfaces orthogonally.
Fn. Hkl. Plm.	(Fine Hackle Plume): A very fine, wispy plumose structure on an otherwise featureless fracture face.
Incl. Hkl.	(Inclusion Hackle): A hackle trailing an inclusion or obstacle on the fracture plane.
Cs. Tw. Hkl.	(Coarse Twist Hackle): A hackle composed of discrete steps generally appearing as a fringe near the edge of a fracture face.

Ar. In. (Arrest Line): A crescentic feature with a cusp-like profile which marks the still stand of the fracture front. Two types are noted:

Term. Ar. In.: Terminal Arrest Lines.
Int. Ar. In.: Intermediate Arrest Lines.

Hk. (Hook): The curving of a fracture plane to adjust to a change in the stress field orientation. Fractures hook to meet preexisting free surfaces orthogonally and in the vicinity of the neutral axis developed in bending.

4. TERMINATIONS: These terms are used to describe how a fracture terminates. The upper entry depicts the upper termination, the lower entry depicts the lower.

M: The fracture exits the margin of the core.

(M): A subhorizontal fracture that exits the margin of the core. This symbol is entered only once straddling the dividing line.

→: A fracture that terminates within the core as a dying hairline fracture.

↗↙: The upper and lower extents of the fracture die out within the core. This symbol is drawn straddling the dividing line.

?: Missing or disrupted core prohibits observation of the mode of termination.

?/M: Same as above, but the fracture probably exits the core margin.

?/(C): Same as above, but the fracture probably terminates within the core margin.

BDG: The fracture terminates along a conspicuous bedding plane indicating an abrupt change in lithology.

TAL: The fracture terminates as a terminal arrest line which is visible only on the fracture face.

(TAL): The fracture terminates in a terminal arrest line so that the fracture enters one side of the core but does not exit the other. This symbol is entered only once straddling the dividing line.

F22: This symbol is used when one fracture terminates against another (i.e., fracture 23 terminates against fracture 22).

A P P E N D I X E

FRACTURE LOGS
DOW CHEMICAL #100 CORE, SANILAC COUNTY, MICHIGAN

CORING DATE: JUNE 1977

LOG DATE: APRIL 1981

E.G.S.P. REVISED FRACTURE LOGGING FORMAT

WELL: Dow Chemical #100 Core, Sanilac County, Michigan

NATURAL FRACTURES

NUMBER	DEPTH EXTENT	LENGTH	LITHOLOGY	TERMINATIONS	CHARACTER	STRIKE / DIP	FRACTURE TYPE	MINERALIZATION	SLICKENSIDES	FRACTOGRAPHIC FEATURES	COMMENTS
1	823.6 / 824.4	0.8	Shaly Mudstone 5Y 2/1		P	No orient / 90°	Spl. Jt.			Fn. Hkl. Plm.	
2	838.0 / ---	<0.1	A/A		P		Flt.		Present		Slickenlines very faint.
3	853.8 / 853.9	0.1	A/A		CP	No orient / ~20°	Mcr. Flt	Present	Present		Soft sediment compaction - associated with a vitrinite frag.
4	860.1 / ---	<0.1	A/A		P	No orient / ~ 6°	Flt.	Present	Present		
5	886.4 / ---	<0.1	A/A		P	No orient / ~ 6°	Flt.	Present	Present		
6	923.1 / ---	<0.1	Shaly Mudstone 5Y 4/1		P		Mcr. Flt	Present	Present		
7	953.7 / 954.2	0.5	Silty Shale N4		P	No orient / 90°	Spl. Jt.				
8	1004.7 / 1005.0	0.3	Shaly Mdst Sltst 5Y 2/1, N6		CP	No orient	Flt.		Present		Possible slump feature.
9	1019.7 / 1020.2	0.5	Shaly Mudstone N4		CP	No orient	Mcr. Flt		Present		Curves around a siltstone lens; slump feature.
10	1071.6 / 1071.7	0.1	Shaly Mudstone 5G 2/1		CP	No orient	Mcr. Flt		Present		Soft sediment compaction.
11	1081.4 / 1081.6	0.2	A/A		P	No orient	Flt.		Present		
12	1084.0 / 1085.0	1.0	A/A		CP	No orient	Mcr. Flt		Present		Series of microfaults. Soft sediment compaction.
13	1093.7 / 1093.8	0.1	A/A		CP	No orient	Mcr. Flt		Present		Soft sediment compaction.
14	1119.8 / 1119.9	0.1	Silty Mudstone 5Y 4/1		P	No orient / 90°	Spl. Jt.				
15	2007.0 / 2007.8	0.8	Limestone 5Y 6/1		P	No orient / 75°	Spl. Jt.			Hkl.	
16	2007.6 / 2008.3	0.7	A/A		P	No orient / 75°	Spl. Jt.				Closed fracture.
17	2008.9 / 2009.7	0.8	A/A		P	No orient / 90°	Spl. Jt.				Closed fracture.

CORING DATE: JUNE 1977

LOG DATE: APRIL 1981

E.G.S.P. REVISED FRACTURE LOGGING FORMAT

WELL: Dow Chemical #100 Core, Sanilac County, Michigan

NATURAL FRACTURES

NUMBER	DEPTH EXTENT	LENGTH	LITHOLOGY	TERMINATIONS	CHARACTER	STRIKE / DIP	FRACTURE TYPE	MINERALIZATION	SLICKENSIDES	FRACTOGRAPHIC FEATURES	COMMENTS
18	2010.7 2011.3	0.6	A/A	↗↙	P	No orient 90°	Spl. Jt.				Closed fracture.
19	2028.1 2028.7	0.6	A/A	→ M	P	No orient 80°	Spl. Jt.			Cs. Tw. Hkl.	
20	2030.4 2030.8	0.4	A/A	↗↙	P	No orient 90°	Cpd. Jt.				Closed fracture.
21	2041.9 2042.1	0.2	Limestone 10YR 6/2	↗↙	P	No orient 65°	Spl. Jt.				Closed fracture.
22	2046.3 2046.7	0.4	A/A	↗↙	P	No orient 90°	Spl. Jt.				Closed fracture.
23	2050.0 2050.6	0.6	A/A	↗↙	P	No orient 90°	Spl. Jt.				Closed fracture.

CORING DATE: JUNE 1977

EG&G REVISED FRACTURE LOGGING FORMAT

LOG DATE: APRIL 1981

WELL: Dow Chemical #100 Core, Sanilac County, Michigan

CORING INDUCED FRACTURES

NUMBER	DEPTH (FEET)	LENGTH	LITHOLOGY	TERMINATIONS	CHARACTER	STRIKE / DIP	FRACTURE TYPE	MINERALIZATION	SLICKENSIDES	FRACTOGRAPHIC FEATURES	COMMENTS
1	851.9 / ---	<0.1	Shaly Mudstone / 5Y 2/1	M	CP		DCS				
2	942.9 / 943.3	0.4	Shaly Mudstone / 5Y 4/1	↗ ↙	CP		TF			s. Tw. Hkl.	
3	969.1 / ---	<0.1	Sandstone / N5	M	CP		DCS				
4	1043.1 / ---	<0.1	Shaly Mudstone / 5Y 4/1	M	CP		DCS				
5	1078.9 / ---	<0.1	Shaly Mudstone / 5G 2/1	M	CP		DCS				
6	1140.1 / ---	<0.1	Mudstone / 5Y 4/1	M	CP		DCS				
7	2001.8 / 2002.8	1.0	Limestone / N7	M / →	CP		TF				
8	2005.4 / ---	<0.1	Limestone / 5Y 5/2	M	CP		DCS				
9	2007.2 / 2007.6	0.4	A/A	M / M	CP		See Comment				Offset fracture.
10	2032.0 / 2034.0	2.0	A/A	M / →	CP		TF			Cs. Tw. Hkl.	
11	2051.4 / ---	<0.1	Limestone / 10YR 6/2	M	CP		DCS				

EASTERN GAS SHALES PROJECT
DISC FRACTURE FREQUENCY LOG

DOW CHEMICAL #100 CORE, SANILAC COUNTY, MICHIGAN

Feet (Top of Interval)	Frequency/ Foot
820	9.0
825	6.4
830	8.0
835	7.2
840	6.2
845	6.0
850	6.4
855	8.6
860 - 862	15.5
862 - 880	No Core Received
880	5.2
885	6.2
890 - 894	8.0
894 - 915	No Core Received
915	5.8
920	3.6
925	4.4
930	6.2
935	7.6
940	5.2
945	1.0
950	2.6
955	4.2
960	4.6
965	5.6
970	2.0
975	1.6
980	1.6
985	2.4
990	1.6
995	1.8
1000	2.4
1005	3.6
1010	5.4
1015	3.6
1020	5.0
1025	4.4
1030 - 1032	8.6
1032 - 1035	No Core Received
1035	4.2
1040	3.0
1045	3.2

EASTERN GAS SHALES PROJECT
DISC FRACTURE FREQUENCY LOG

DOW CHEMICAL #100 CORE, SANILAC COUNTY, MICHIGAN
PAGE 2

Feet (Top of Interval)	Frequency/ Foot
1050	3.8
1055	6.2
1060	7.2
1065	6.2
1070	5.2
1075	3.6
1080	5.2
1085	3.5
1090 - 1091	Rubble Induced by Coring
1091	5.2
1095	3.8
1100	5.8
1105	4.0
1110	3.4
1115	3.6
1120	4.6
1125	4.4
1130	3.8
1135	5.2
1140	7.2
1145 - 1146	1.2
1146 - 2000	No Core Received
2000	1.8
2005	2.0
2010	1.8
2015	2.0
2020	2.3
2025	2.0
2030	1.8
2035	1.6
2040	1.4
2045	1.4
2050	1.4
2055 - 2057	1.0

A P P E N D I X F

FRACTURE LOGS
DOW CHEMICAL #103 CORE, SANILAC COUNTY, MICHIGAN

CORING DATE: JANUARY 1978

LOG DATE: DECEMBER 1980

E.G.S.P. REVISED FRACTURE LOGGING FORMAT

WELL: DOW CHEMICAL #103, SANILAC COUNTY, MICHIGAN

NATURAL FRACTURES

NUMBER	DEPTH / EXTENT	LENGTH	LITHOLOGY	TERMINATIONS	CHARACTER	STRIKE / DIP	FRACTURE TYPE	MINERALIZATION	SLICKENSIDES	FRACTOGRAPHIC FEATURES	COMMENTS
1	1177.5	<0.1	5Y 3/2 Silty Shale	M	CP		MF	None	Present		No orientation.
2	1177.8	<0.1	A/A	M →	CP		MF	None			
3	1178.0	<0.1	A/A	M	CP		MF	None			
4	1178.4	<0.1	A/A	→ →	CP		MF	None			
5	1178.6	<0.1	A/A	M →	CP		MF	None			
6	1179.2	<0.1	A/A	M →	CP		MF	None			
7	1179.4	<0.1	A/A	→ M	CP		MF	None			
8	1179.6	<0.1	A/A	M →	CP		MF	None			
9	1179.8	<0.1	A/A	↗	CP		MF	None			
10	1180.1	<0.1	A/A	↗	CP		MF	None			
11	1180.3	<0.1	A/A	→ M	CP		MF	None			
12	1180.4	<0.1	A/A	M →	CP		MF	None			
13	1181.0	<0.1	A/A	↗	CP		MF	None			
14	1185.3	<0.1	A/A	↗	CP		MF	None			
15	1193.1	<0.1	A/A	M →	CP		MF	None			
16	1194.4 1196.7	2.3	N1 Shale	→ TAL	P	N40°W 87°NE	Spl. Jt.	Unknown	No	Fn. Hkl. Plm.	Yellow-brown stain on surface possibly not original.
17	1205.75	<0.1	N1 Shale	M	P		Flt.	None	0° N70°E		

CORING DATE: JANUARY 1978

LOG DATE: DECEMBER 1980

E.G.S.P. REVISED FRACTURE LOGGING FORMAT

WELL: DOWN CHEMICAL #103, SANILAC COUNTY, MICHIGAN

NATURAL FRACTURES

NUMBER	DEPTH EXTENT	LENGTH	LITHOLOGY	TERMINATIONS	CHARACTER	STRIKE DIP	FRACTURE TYPE	MINERALIZATION	SLICKENSIDES	FRACTOGRAPHIC FEATURES	COMMENTS
18	1254.1 1255.5	1.4	5Y 2/1 Shale	→ →	P	N70°E 85°SE	Cpd. Jt.	None	No	Fn. Hkl. Plm.	Lower end becomes induced fracture F-8; dip changes to 90°.
19	1254.4 1256.3	1.9	5Y 2/1 Shale	→ M	P	N70°E 90°	Spl. Jt.	None	No	Fn. Hkl. Plm. Cs. Tw. Hkl.	Changing Dip - core very broken. strike & dip change to N60°E,83°SE.
20	1270.0 1273.8	3.8	5Y 2/1 Shale	↗	P	No orient.	Spl. Jt.	None	No	Fn. Hkl. Plm.	Missing core 1271.9 - 1273.0.
21	1321.05	<0.1	N1 Shale	↗	P	N64°E 90°	Spl. Jt.	Pyrite	No		Closed fracture extends from a pyrite lamina.
22	1322.5	<0.1	N1 Shale	↗	P	N64°E 90°	Spl. Jt.	Pyrite	No		Closed fracture extends from a pyrite lamina.
23	1327.0 1328.7	1.7	N1 Shale	↗	P	N74°E 90°	Cpd. Jt.	Calcite	No	Fn. Hkl. Plm.	2 planes, propagation E to W ends on induced fracture F-21.
24	1333.0 1334.9	1.9	N1 Shale	M →	P	N24°E 90°	Spl. Jt.	Calcite	No	Fn. Hkl. Plm.	Starts at the top of core #4.
25	1334.1 1337.7	3.6	N1 Shale	↗	P	N32°E 90°	Cpd. Jt.	None	No	Fn. Hkl. Plm. Cs. Tw. Hkl..	End on induced fracture F-23. Propagation NE-SW.
26	1334.9 1335.1	0.2	N1 Shale	↗	P	N56°E 90°	Spl. Jt.	None	No	Fn. Hkl. Plm.	Intersection of fractures F-24 and F-27.
27	1335.2 1336.2	1.0	N1 Shale	M →	P	N48°E 84°NW	Spl. Jt.	None	No	Fn. Hkl. Plm.	
28	1338.8 1350.6	11.8	N1 & 5GY 5/2 Shale	M →	P	N60°E 38°NW	Spl. Jt.	Min. Calcite	No	Fn. Hkl. Plm. Cs. Tw. Hkl.	Dip angle changes several times. Propagation W - E.
29	1345.5 1346.2	0.7	N1 Shale	M F-28	P	N58°E 85°NW	Spl. Jt.	None	No	Fn. Hkl. Plm.	Some missing core. Termination questionable.
30	1349.6 1353.2	3.6	N1 & 5GY 5/2 Shale	Bdg M	P	N66°E 86°SE	Spl. Jt.	Calcite	No	Fn. Hkl. Plm. Cs. Tw. Hkl.	Dip changes to 82°NW @1352.4.
31	1364.1 ?	?	N1 & 5GY 5/2 Shale	→ ?/(c)	P	N64°E 90°	Spl. Jt.	Calcite	No	Fn. Hkl. Plm.	Missing core - no length determination.

CORING DATE: JANUARY 1978

LOG DATE: DECEMBER 1980

EGGR REVISED FRACTURE LOGGING FORMAT

WELL: DOW CHEMICAL #103, SANILAC COUNTY, MICHIGAN

CORING INDUCED FRACTURES

NUMBER	DEPTH (ATEN)	LENGTH	LITHOLOGY	TERMINATIONS	CHARACTER	STRIKE / DIP	FRACTURE TYPE	MINERALIZATION	SLICKENSIDES	FRACTOGRAPHIC FEATURES	COMMENTS
1	1206.1	0	N1 Shale	M	CP		DCS	None			
2	1208.0	0	N1 Shale	M	CP		TF	None			
3	1218.3	0	N1 Shale	M	CP		TF	None			Connection
4	1219.0	0	N1 Shale	? / M	CP		TF	None			Connection
5	1236.0 / 1236.2	0.2	N1 Shale	M / M	CP		TF	None			No orientation.
6	1238.4	0	N1 Shale	M	CP		TF	None			Connection
7	1253.7 / 1254.1	0.4	N1 Shale	M / ?	CP		TF	None			
8	1255.5 / 1259.6	4.1	N1 Shale	F-18 / M	CP	N50°E / 90° var	PCF	None			Starts on natural fracture F-18.
9	1255.9	0.05	N1 Shale	→ / F-8	CP	~N50°E / Var.	HK	None			
10	1256.2 / 1256.4	0.2	N1 Shale	F-19 / F-8	CP	N52°E / Var.	PF	None			
11	1257.5 / 1257.7	0.2	N1 Shale	M / F-8	CP	N50°E / 25°NW var	PF	None			
12	1273.0 / 1273.3	0.3	5Y 2/1 Shale	?/M / M	CP		TF	None			6 fracture plane connection top of core run.
13	1298.0 / 1298.1	0.1	5Y 2/1 Shale	M	CP		TF	None			Hammer blow.
14	1302.2 / 1302.3	0.1	5Y 2/1 Shale	M / M	CP		KES	None			
15	1302.5 / 1302.6	0.1	5Y 2/1 Shale	M / M	CP		KES	None			
16	1302.8 / 1302.9	0.1	5Y 2/1 Shale	M / M	CP		KES	None			
17	1305.7 / 1305.8	0.1	5YR 2/1 Shale	M / M	CP		KES	None			

CORING DATE: JANUARY 1978 — ERSP REVISED FRACTURE LOGGING FORMAT —

LOG DATE: DECEMBER 1980 — WELL: DOW CHEMICAL #103, SANILAC COUNTY, MICHIGAN — CORING INDUCED FRACTURES

FRACTURE	DEPTH (FEET)	LENGTH	LITHOLOGY	TERMINATIONS	CHARACTER	STRIKE / DIP	FRACTURE TYPE	MINERALIZATION	SLICKENSIDES	FRACTOGRAPHIC FEATURES	COMMENTS
18	1305.9 1306.0	0.1	5YR 2/1 Shale	M M	CP		KES	None			
19	1313.5 1313.7	0.2	N1 Shale	M M	CP		KES	None			
20	1321.3 1329.0	0.4	5Y 2/1 Shale	M M	CP		KES	None			
21	1328.7 1329.0	0.3	N1 Shale	F-23 M	CP	~N70°E Var. NW		None		Cs. Tw. Hkl.	Induced from a natural fracture F-23.
22	1337.8		5Y 2/1 Shale	M	CP		TF	None			
23	1337.7 1338.4	0.7	5Y 2/1 Shale	F-25 M	CP	N74°E Var. SE		None			Induced from a natural fracture F-25.
24	1338.2 1338.6	0.4	5Y 2/1 Shale	M M	CP		TF	None			
25	1344.4 1344.6	0.2	N1 Shale	M F-28	CP		TF	None			Cuts across a natural fracture F-28.
26	1346.3 1346.4	0.2	N1 Shale	F-28 M	CP		TF	None			Starts on natural fracture F-28.
27	1347.1 1347.4	0.3	N1 Shale	M F-28	CP		TF	None			Ends on natural fracture F-28.
28	1347.5 1347.7	0.2	N1 Shale	M F-28	CP		TF	None			Ends on natural fracture F-28.
29	1348.0 ?		N1 Shale	M F-28	CP	N50°E Var25°NW	PF	None			Core missing.
30	1350.2 1352.7	2.5	5Y 2/1 & 5GY 5/2 Shale	M →	CP	N66°E 90° Var	PCF	None			
31	1361.1 1361.2	0.1	N1 Shale N1 & 5Y 2/1	M M	CP		TF	None			
32	1362.4 1362.5	0.1	Shale	M M	CP	N34°E Var 30°SE	HK	None			

EASTERN GAS SHALES PROJECT
DISC FRACTURE FREQUENCY LOG

DOW CHEMICAL #103 CORE, SANILAC COUNTY, MICHIGAN

Feet (Top of Interval)	Frequency/ Foot
1177	9.7
1180	9.2
1185	12.8
1185.7 - 1191.3	No Core Received
1191.3	10.9
1195	12.2
1199.6 - 1202.4	No Core Received
1202.4	11.0
1203.4 - 1203.8	No Core Received
1203.8	12.5
1205	9.4
1210	12.5
1210.8 - 1216.4	No Core Received
1216.4	9.5
1218.3 - 1219.0	No Core Received
1219	8.0
1220	6.0
1225	6.2
1230	5.4
1235	5.0
1238.4 - 1247.5	No Core Received
1247.5	9.6
1250	7.4
1255	7.6
1260	9.0
1265	7.8
1270	8.3
1271.9 - 1273.0	No Core Received
1273	7.5
1275	4.4
1280	4.6
1285	6.0
1290	5.4
1295	3.8
1300	4.4
1305	4.0
1310	2.4
1315	4.0
1315.5 - 1318.2	No Core Received
1318.2	2.2
1320	2.8
1325	3.8
1330	4.4

EASTERN GAS SHALES PROJECT
DISC FRACTURE FREQUENCY LOG

DOW CHEMICAL #103 CORE, SANILAC COUNTY, MICHIGAN
PAGE 2

Feet (Top of Interval)	Frequency/ Foot
1332.7 - 1333.0	No Core Received
1333	2.0
1335	1.8
1340	2.0
1345	2.0
1350	1.8
1355	1.8
1360	3.5
1364.6 - 1365.9	No Core Received
1365.9 - 1368.0	2.8

A P P E N D I X G

FRACTURE LOGS
DOW CHEMICAL #205 CORE, SANILAC COUNTY, MICHIGAN

CORING DATE: JUNE 1978

LOG DATE: APRIL 1981

E.G.S.P. REVISED FRACTURE LOGGING FORMAT

WELL: DOW CHEMICAL # 205, SANILAC COUNTY, MICHIGAN

NATURAL FRACTURES

NUMBER	DEPTH EXTENT	LENGTH	LITHOLOGY	TERMINATIONS	CHARACTER	STRIKE DIP	FRACTURE TYPE	MINERALIZATION	SLICKENSIDES	FRACTOGRAPHIC FEATURES	COMMENTS
1	1386.2 1386.9	0.7	Mudstone 5YR 2/1	↗ ↙	P	No orient 90°	Spl. Jt.			Fn. Hkl. Plm. Int. Ar. Ln.	
2	1405.4 	<0.1	Mudstone N2	(M)	P		Flt.		Present		
3	1471.3 1471.5	0.2	Limestone 5Y 6/1	↗ ↙	P	No orient 90°	Spl. Jt.	Calcite			Closed fracture.

CORING DATE: JUNE 1978

LOG DATE: APRIL 1981

E.G.S.P. REVISED FRACTURE LOGGING FORMAT

WELL: DOW CHEMICAL #205, SANILAC COUNTY, MICHIGAN

CORING INDUCED FRACTURES

NUMBER	DEPTH EXTENT	LENGTH	LITHOLOGY	TERMINATIONS	CHARACTER	STRIKE / DIP	FRACTURE TYPE	MINERALIZATION	SLICKENSIDES	FRACTOGRAPHIC FEATURES	COMMENTS
1	1387.1	<0.1	Mudstone 5Y 4/1	M	CP		DCS				
2	1388.0	<0.1	A/A	M	CP		DCS				
3	1388.6	<0.1	A/A	M	CP		See Comment				Offset Fracture. 1/8" displacement.
4	1409.1 1409.5	0.4	Mudstone N2	M Disk	CP		TF				
5	1419.1	< 0.1	Mudstone 5Y 2/1	M	CP		DCS				
6	1421.0	< 0.1	Mudstone 5Y 4/1	M	CP		See Comment				Offset Fracture. 5/16" displacement.
7	1422.5	< 0.1	A/A	M	CP		DCS				
8	1449.5	< 0.1	Mudstone 5GY 6/1	M	CP		DCS				
9	1472.2	< 0.1	Limestone N6	M	CP		DCS				
10	1490.7	< 0.1	Limestone N5	M	CP		See Comment				Offset Fracture. 1/8" displacement.

EASTERN GAS SHALES PROJECT
DISC FRACTURE FREQUENCY LOG

DOW CHEMICAL #205 CORE, SANILAC COUNTY, MICHIGAN

Feet (Top of Interval)	Frequency/ Foot
1383	1.2
1385	1.6
1390	2.6
1395 - 1396	2.0
1396 - 1401	No Core Received
1401	2.0
1405	4.2
1410	3.6
1415	2.6
1420	5.4
1425	9.0
1430	5.8
1435	2.2
1440	3.0
1445	3.4
1450	3.2
1455	2.4
1460	2.0
1465	2.2
1470	1.8
1475	3.0
1480	5.0
1485	0.8
1490	3.2
1495 - 1497	2.0

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U. S. DEPARTMENT OF ENERGY

MORGANTOWN ENERGY TECHNOLOGY CENTER

EASTERN GAS SHALES PROJECT

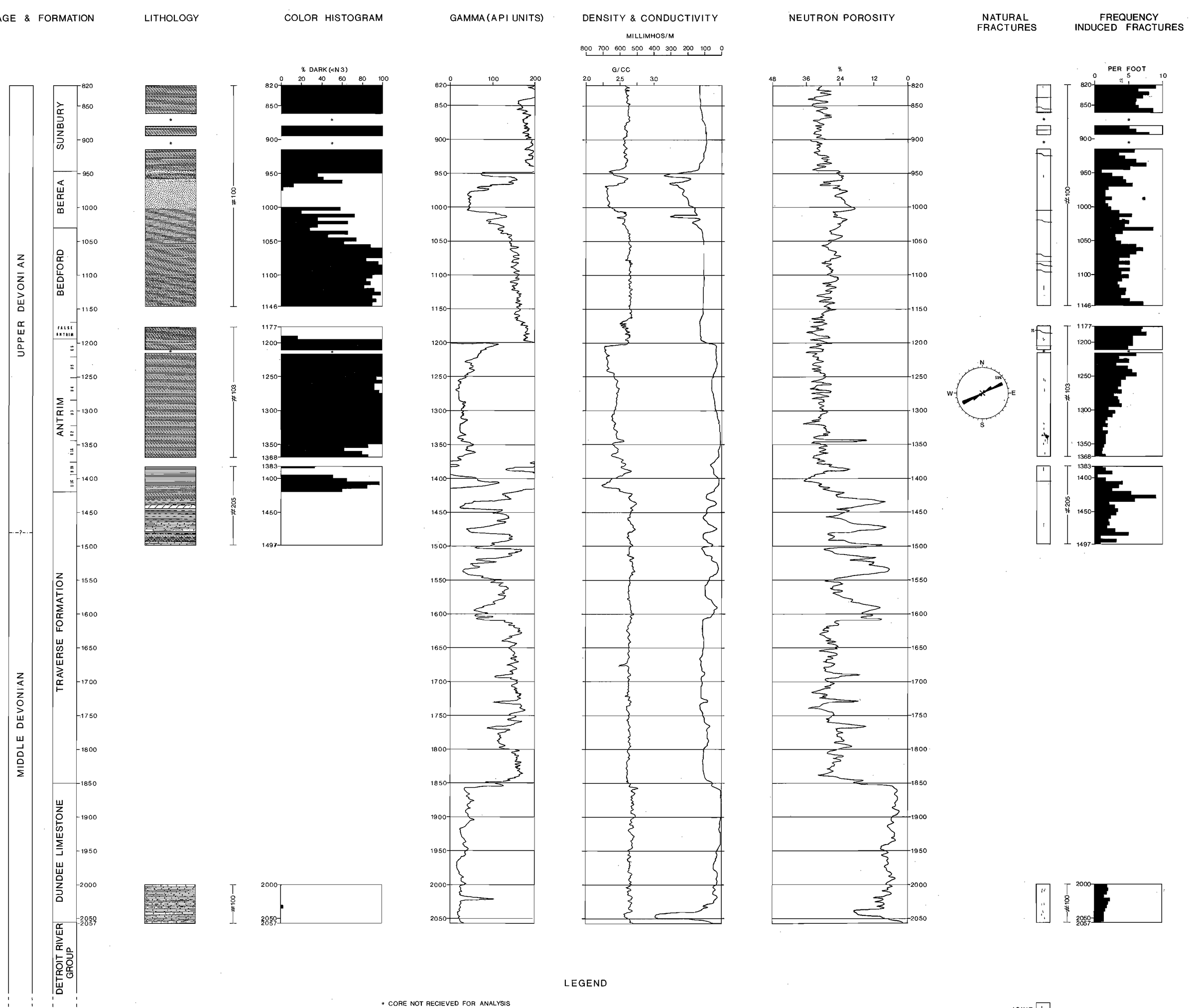
DOE/DOW CHEMICAL #100, #103, & #205 CORES

SANILAC COUNTY, MICHIGAN

CLIFFS MINERALS INC.

PREPARED UNDER
CONTRACT NO. DE-AC21-78MC08199

DRAWN MAY, 1981



LEGEND

* CORE NOT RECIEVED FOR ANALYSIS

JOINT
FAULT
MICROFAULT

MUDSTONE/SHALY MUDSTONE
SILTY MUDSTONE/SILTY SHALE
CALCAREOUS MUDSTONE/CALCAREOUS SHALY MUDSTONE
SANDSTONE
SILTSTONE
ARGILLACEOUS LIMESTONE
LIMESTONE
DOLOSTONE