CLIFFS MINERALS, INC.
EASTERN GAS SHALES PROJECT
DOW CHEMICAL WELLS #100, #103 AND #205

PHASE III REPORT
SUMMARY OF LABORATORY ANALYSES AND
MECHANICAL CHARACTERIZATION RESULTS
DECEMBER 1981

Dow Chemical #100, #103 and #205 Cores
Sanilac County, Michigan

Executive Summary

This report summarizes the characterization work performed on approximately 617 feet of 3-1/2 inch diameter core retrieved from three ERDA/Dow Chemical wells in Sanilac County, Michigan. Information provided in a previous report by Cliffs Minerals, Inc. includes a definitive lithologic description and tabulated fracture data resulting from detailed core examinations, and stratigraphic interpretations as indicated in the core and on geophysical logs. Plane of weakness orientations stemming from a program of physical properties testing on samples from the Dow Chemical #103 core (the only oriented core) are also summarized.

Eight stratigraphic units were identified and described; these include Sunbury Shale, Berea Sandstone, Bedford Shale, "False Antrim" Shale, Antrim Shale, Traverse Formation, Dundee Limestone, and Detroit River Group.

Physical properties tests (point load, directional tensile strength and directional ultrasonic velocity) and pretest fracture orientations suggest preferred orientations of fracturing for the Antrim Shale in the Dow Chemical #103 core, as follows:

The preferred direction of fracturing for Unit 3 of the Antrim Shale is N30°E ± 15° from one ultrasonic velocity sample; N90°E ± 15° and N30°W ± 15° from point load tests; and N30°W ± 15° from one set of directional tensile strength samples and the trend of the pretest fractures.

The preferred direction of fracturing for Unit 2 of the Antrim Shale is N0°E ± 15° and N60°E ± 15° from two ultrasonic velocity samples.

The preferred direction of fracturing for Unit 1A of the Antrim Shale is N30°E ± 15° and N60°E ± 15° from two ultrasonic velocity samples and two sets of directional tensile strength samples.

Dow Chemical #100, #103 and #205 Cores
Sanilac County, Michigan

Technical Summary

General

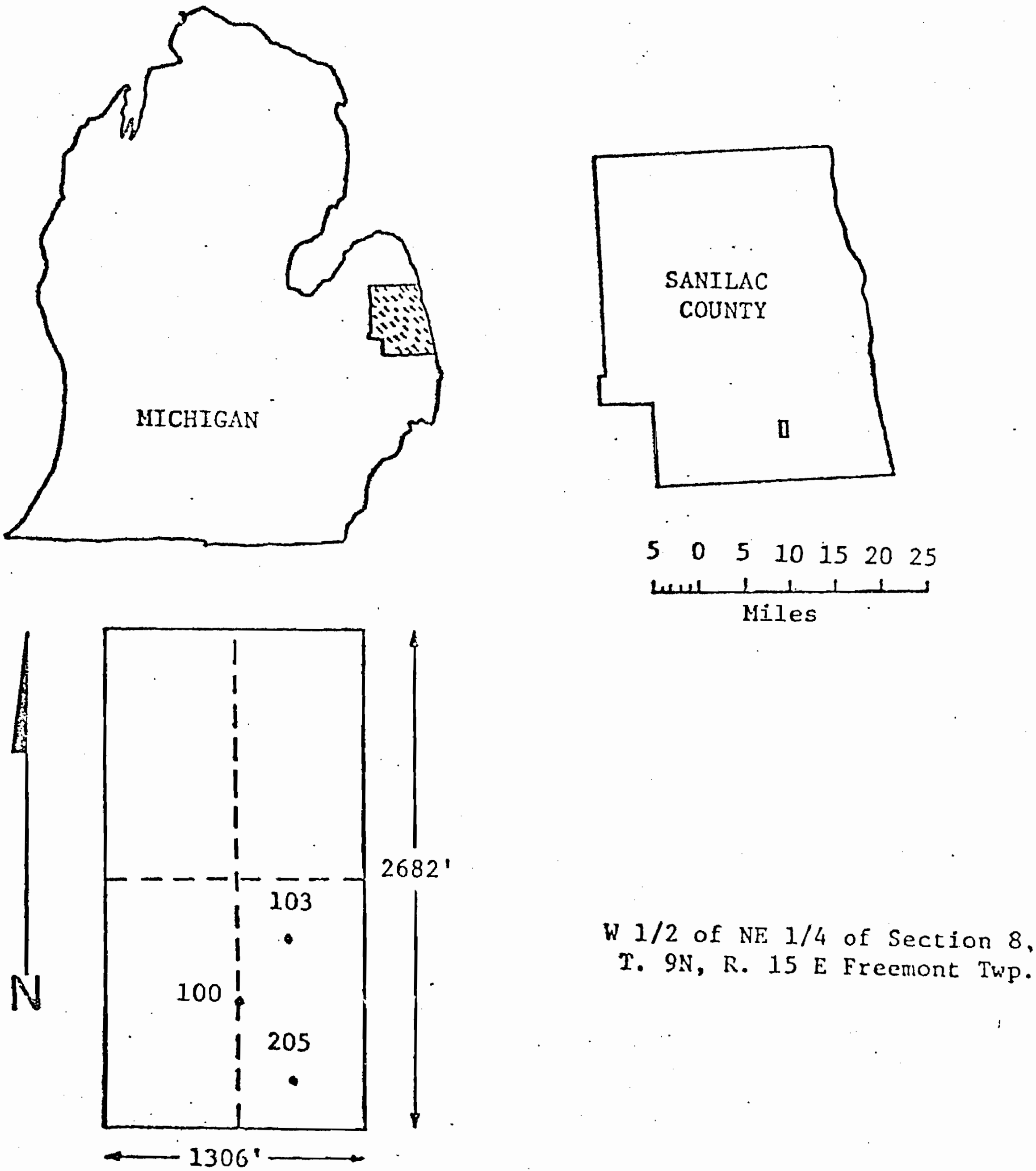
This summary presents a detailed characterization of the Devonian Shale occurrence in the Dow Chemical #100, #103 and #205 wells. Information provided includes a stratigraphic summary and lithology and fracture analyses resulting from detailed core examinations and geophysical log interpretations at the EGSP Core Laboratory. Plane of weakness orientations stemming from a program of physical properties testing on samples from the Dow Chemical #103 core at Michigan Technological University are also summarized; the results of physical properties testing are dealt with in detail in the accompanying report. The data presented was obtained from the study of approximately 617 feet of core retrieved from several wells drilled in Sanilac County of east-central 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 of three cores, #100, #103 and #205, to characterize the Antrim Shale for the Eastern Gas Shales Project.

Location

Specific site locations of the Dow Chemical #100, #103 and #205 wells are illustrated in the following diagram:



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

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 the following tables.

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'-1,030'	946'-1,030'	946'-1,030'
Bedford Shale	1,030'-1,170'	1,030'-1,150' 1,160'-1,170'	1,030'-1,146' -----
False Antrim Shale	1,170'-1,209'	1,170'-1,209'	-----
Antrim Shale:			
Unit 6	1,209'-1,240'	1,209'-1,240'	-----
Unit 5	1,240'-1,268'	1,240'-1,268'	-----
Unit 4	1,268'-1,303'	1,268'-1,303'	-----
Unit 3	1,303'-1,340'	1,303'-1,340'	-----
Unit 2	1,340'-1,358'	1,340'-1,358'	-----
Unit 1A	1,358'-1,394'	1,358'-1,394'	-----
Unit 1B	1,394'-1,410'	1,394'-1,410'	-----
Unit 1C	1,410'-1,429'	1,410'-1,429'	-----
Traverse Formation	1,429'-1,850'	1,429'-1,476'	-----
Dundee Limestone	1,850'-2,055'	2,000'-2,055'	2,000'-2,015' 2,022'-2,055'
Detroit River Group	2,055'-T.D.	2,055'-2,059'	2,055'-2,057'

FORMATION THICKNESSES, DOW CHEMICAL WELL #103

Formation	Depths	Depths Cored	Cored Intervals Received
False Antrim Shale	1,155'-1,194'	1,177'-1,194'	1,177'-1,186' 1,191'-1,194'
Antrim Shale:			
Unit 6	1,194'-1,220'	1,194'-1,220'	1,194'-1,200' 1,202'-1,203' 1,204'-1,211' 1,216'-1,218' 1,219'-1,220'
Unit 5	1,220'-1,251'	1,220'-1,251'	1,220'-1,238' 1,241'-1,251'
Unit 4	1,251'-1,284'	1,251'-1,284'	1,251'-1,284'
Unit 3	1,284'-1,322'	1,284'-1,322'	1,284'-1,316' 1,318'-1,322'
Unit 2	1,322'-1,344'	1,322'-1,344'	1,322'-1,344'
Unit 1A	1,344'-T.D.	1,344'-1,368'	1,344'-1,364' 1,365'-1,368'

FORMATION THICKNESSES, DOW CHEMICAL WELL #205

Formation	Depths	Depths Cored	Cored Intervals Received
Antrim Shale:			
Unit 1B	1,376'-1,394'	1,383'-1,394'	1,383'-1,394'
Unit 1C	1,394'-1,420'	1,394'-1,420'	1,394'-1,396' 1,401'-1,420'
Traverse Formation	1,420'-T.D.	1,420'-1,497'	1,420'-1,497'

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 series core. The Dow Chemical #103 core contains part 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. 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).

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.

The Sunbury Shale is composed of olive black, 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 shaly mudstone to pale yellowish brown 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 1,030 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 (0.2 to 0.3 mmϕ), 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 limonite staining. The unstained sandstone is a uniform, medium light gray color. The basal portion of the Berea Sandstone (1,003.7 to 1,030.0 ft.) is a transition zone adjacent to the underlying Bedford Shale. This zone consists of interbedded sandstone, siltstone and silty shale with cross lamination, ripple lamination, distorted bedded planes, and small-scale ball and pillow structures.

The contact (1,030.0 ft.) in the Dow #100 core between the Berea Sandstone and the underlying Bedford Shale is gradational over a distance of 50.3 feet (1,003.7 to 1,054.0 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 change occurs in the Dow #100 well at 1,030 feet, although no marked lithological boundary is visible at this depth in the Dow #100 core.

Bedford Shale

The Bedford Shale appears in the Dow Chemical #100 core from 1,030 to 1,170 feet. The intervals from 1,030 to 1,150 and from 1,160 to

1,170 feet were cored, but only the interval from 1,030 to 1,146 feet was available for analysis by Cliffs Minerals, Inc.

The Bedford Shale is mainly composed of greenish black, 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 1,084 and 1,094 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 between the Bedford Shale and the underlying False Antrim Shale (at 1,170 ft.) was not cored in 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.

<u>False Antrim Shale</u>

The False Antrim Shale occurs from 1,170 to 1,209 feet in Dow Chemical well #100 and from 1,155 to 1,194 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 1,177 to 1,194 feet was cored. Except for the interval from 1,186 to 1,191 feet, the core was received for analysis.

In the Dow Chemical #103 core, the False Antrim Shale is composed of olive gray and grayish olive, 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 lower most 2 cm of the False Antrim is mottled due to bioturbation. Resinous spore bodies are sparse. The lower two feet contains several poorly preserved, partially pyritized brachiopod casts.

In the core, the contact (1,194 ft.) between the False Antrim Shale and the underlying Antrim Shale can be identified by a distinct change from olive gray and olive brown shaly mudstones to black 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. Units 1B and 1C are represented fairly well in the Dow Chemical #205 core.

Unit 6:

Unit 6, the uppermost member of the Antrim Shale, occurs in the Dow Chemical #103 core between 1,194 and 1,220 feet and is composed of black, 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, 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 1,220 to 1,251 feet. This unit is made up of black, brownish black, and olive black, thick bedded, shaly mudstones. Fish scales, fish teeth, and fossil 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 1,251 feet and can be distinguished by a gradational change over several feet in the core from brownish black, thick bedded, shaly mudstones to olive black and olive gray laminated shaly mudstones and mudstones.

On the geophysical logs the basal contact of Unit 5 is displayed as a change from 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 1,251 and 1,284 feet and contains olive black and grayish olive, thinly laminated to thick bedded shaly mudstone 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 1,284 feet and can be distinguished in the core by a gradual darkening of the core from laminated olive black and grayish olive 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 1,284 and 1,322 feet. It is made up of olive black and brownish black, thinly laminated to thin bedded, shaly mudstones. The upper 1/2 of the unit is predominatly 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 between Units 3 and 2 (at 1,322 ft.) can be identified in the core as a gradational change from brownish black to olive black 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 1,322 and 1,344 feet in the Dow Chemical #103 core. It is composed of olive black and dusky yellow green, thinly laminated to thick bedded shaly mudstones and mudstones. A zone of Foerstia sp. extends from 1,326.4 to 1,336.3 feet. Resinous spore bodies are common throughout and occasional fish scales occur in the lower 5 feet. A bioturbated zone is present at 1,335.3 feet. Pyrite exists in thin laminae and small nodules which are weakly calcareous.

The contact between Unit 2 and Unit 1 (at 1,344 ft.) is present in the core as a change from olive black, thick bedded, shaly mudstone to sequences of dusky yellow green and light olive gray bioturbated mudstones which eventually grade downcore into olive black shaly mudstones. On the gamma ray log, the contact between Units 2 and 1A is expressed as an abrupt decrease 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 1,344 feet and the base of the well. The interval from 1,344 to 1,368 feet was cored. The interval consists of olive black, dusky yellow green, and light olive gray, 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 decrease 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 1,376 and 1,394 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 in the upper 1/2 and olive black in the lower 1/2; olive gray is 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 between Unit 1B and Unit 1C (at 1,394 ft.) 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 1,394 and 1,420 feet. The intervals from 1,394 to 1,396 and from 1,401 to 1,420 feet were available for analysis. These intervals are composed predominantly of olive black mudstone in the upper 2/3 and dusky yellowish brown 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 and dusky yellow green. 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 between Unit 1C and the underlying Traverse Formation (at 1,420 ft.) is evident as an abrupt change from olive gray pyritic mudstone to a light olive gray 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 (1,420 - 1,497 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 1,438 and 1,444 feet. Rock colors that typify the Traverse Formation include olive gray, light olive gray, yellowish gray, pinkish gray, greenish gray, dark greenish gray, dark gray, very light gray, and pale yellowish brown. 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 inarticulate 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 1,438 and 1,444 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 is present in the Dow Chemical #100 core from 2,000 to 2,055 feet. This interval is composed of interbedded lime mudstones, wackestones, and argillaceous limestone in the upper part (2,000 to 2,037 ft.), and crystalline (lithographic) limestones in the remainder. Core colors range from pinkish gray and yellowish gray to olive gray and dark greenish gray; 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 2,009 to 2,010 feet; a dolostone bed is present between 2,025.7 and 2,026.8 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 (2,037 to 2,048 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 (2,055 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.

<u>Detroit River Group</u>

The Dow Chemical #100 well was terminated four feet into the Detroit River Group (2,055 to 2,059 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 and dusky yellowish brown thinly to thickly laminated. Intense bioturbation occurs at 2,056.1 feet. Occasional stylolites are present; fossils are absent.

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.

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 below.

DISTRIBUTION OF NATURAL FRACTURES, DOW CHEMICAL #103 CORE

Formation	Cored Intervals Received	Core Length	Number of Fractures	Frequency/ Foot
False Antrim	1,177'-1,186'	9'	14	1.56
	1,191'-1,194'	3'	1	0.33
Antrim Shale:				
Unit 6	1,194'-1,200'	6'	1	0.17
	1,202'-1,203'	1'	0	0.00
	1,204'-1,211'	7'	1	0.14
	1,216'-1,218'	2'	0	0.00
	1,219'-1,220'	1'	0	0.00
Unit 5	1,220'-1,238'	18'	0	0.00
	1,241'-1,251'	10'	0	0.00
Unit 4	1,251'-1,284'	33'	3	0.09
Unit 3	1,284'-1,316'	32'	0	0.00
	1,318'-1,322'	4'	1	0.25
Unit 2	1,322'-1,344'	22'	7	0.32
Unit 1A	1,344'-1,364'	20'	3	0.15
	1,365'-1,368'	3'	0	0.00

All planar natural fractures in the Dow Chemical #103 core were analyzed to identify common structural trends. The strike of the fractures ranges from N24°E to N76°E with a concentration at N65°E. Dips are generally vertical to near vertical. All curviplanar natural fractures (microfaults) in the Dow Chemical #103 core occur in a section that could not be oriented.

The core was analyzed for occurrence and type of natural fractures within each formation. Criteria examined include location of fracture concentrations, and any predominance of fracture strike trends, or conversely, the lack of fractures within the stratigraphic unit.

False Antrim:

The False Antrim (Core #103) 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.

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 that occurs in Unit 1B of the Antrim Shale at a depth of 1,386 feet. A horizontal fault occurs at 1,405 feet in Unit 1C of the Antrim Shale. The Traverse Formation contains a calcite mineralized simple joint at 1,471 feet. Distribution of natural fractures throughout the #205 core is summarized in the table below.

DISTRIBUTION OF NATURAL FRACTURES, DOW CHEMICAL #205 CORE

Formation	Cored Intervals Received	Number of Fractures	Frequency/ Foot
Antrim Shale:			
Unit 1B	1,383'-1,394'	1	0.09
Unit 1C	1,394'-1,396'	0	0.00
	1,401'-1,420'	1	0.05
Traverse Formation	1,420'-1,497'	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 the table on the following page. This core was not oriented; hence, strike and dip direction of fractures could not be measured.

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 Chemical #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.

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'-1,030'	3	0.04
Bedford Shale	1,030'-1,146'	5	0.04
False Antrim Shale	----	-	----
Antrim Shale	----	-	----
Traverse Formation	----	-	----
Dundee Limestone	2,000'-2,015'	4	0.27
	2,022'-2,055'	5	0.15
Detroit River Group	2,055'-2,057'	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.

Physical Properties Testing

The physical property tests employed in the testing of the EGSP-Dow Chemical Well #103, Sanilac County, Michigan core samples are directional ultrasonic velocity measurements; point load induced fractures; and directional tensile strength tests. All fractures are systematically recorded before the physical property tests are performed. The data presented in this report do not indicate that the core samples from Dow #103 well exhibit a statistically significant preferred direction of fracturing.

Following are conclusions developed from the results of the physical property tests. It should be pointed out that they are based on the statistically small number of samples received from this well. The preferred direction of fracturing for Unit 3 in the Antrim Shale (1,311'-1,320' tested) is N30°E ± 15° as indicated by the one ultrasonic velocity sample received; N90°E ± 15° and N30°W ± 15° as indicated by point load induced fractures; and N30°W ± 15° as indicated by the one set of directional tensile strength measurements and the directional trend of pretest fractures.

The preferred direction of fracturing for Unit 2 in the Antrim Shale (two samples: 1,323', 1,339' tested) is N0°E ± 15° and N60°E ± 15° as indicated by the two ultrasonic velocity samples tested. No pretest fractures were identified in the Unit 2 samples.

The preferred direction of fracturing for Unit 1A in the Antrim Shale (1,353'-1,363' tested) is N30°E ± 15° and N60°E ± 15° as indicated by the two ultrasonic velocity samples and the two sets of directional tensile strength measurements. Point load induced fractures do not indicate a statistically significant preferred direction of fracturing. No pretest fractures were identified in the Unit 1A samples.

Available Reports

For a more detailed account of lithology and fracture analyses the reader is referred to the following Cliffs Minerals, Inc. report:

(1) EGSP-Dow Chemical Cores #100, #103, and #205, Sanilac County, Michigan, Phase II Report, Preliminary Laboratory Results, May 1981.

PREFERRED PLANES OF WEAKNESS IN DEVONIAN GAS SHALES DETERMINED BY MECHANICAL CHARACTERIZATION

Report for

EGSP-Dow Chemical Well #103

Sanilac County, Michigan

Department of Mining Engineering

Michigan Technological University

Houghton, Michigan 49931

December 1981

Prepared For

Cliffs Minerals, Inc.

Under Contract No. EW-78-C-21-8199

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Summary of Mechanical Characterization Results

The purpose of mechanical characterization of samples from the EGSP-Dow Chemical Well #103 core is to determine the orientation of preferred planes of weakness in the Devonian gas shales at the Sanilac County, Michigan well site. Mechanical characterization test results on the Dow #103 core samples do not clearly indicate statistically significant preferred directions of fracturing in the individual depth intervals defined or the well composite from the few samples received for testing.

Prior to testing, the length and orientation of pretest fractures identified in each sample were recorded. Pretest fractures occur most frequently in the N30°W ± 15° direction (6 out of 8 total pretest fractures).

In ultrasonic velocity testing, minimum velocity values are assumed to be perpendicular to the preferred direction of fracturing because large numbers of microcracks encountered along this direction will impede propagation of the sonic wave. Ultrasonic velocity measurements indicate a preferred direction of fracturing in the N30°E ± 15° and N60°E ± 15° directions (a sum of 4 out of 5 total velocity samples).

In point load testing, fractures induced by applying a point load to the central axis of a disc are assumed to propagate parallel to the preferred direction of fracturing. Point load induced fractures do not indicate a statistically significant preferred direction of fracturing in the Dow #103 core samples.

In directional tensile strength testing, compressive loads are applied across the diameter of the specimen in order to induce diametrical fractures and thus determine tensile strength normal to the loading axis. By this method, six samples from a given interval are tested with the loading axis in six different orientations. The preferred direction of fracture will be parallel to the loading axis in the specimen for which the lowest tensile strength value was obtained. The three sample sets of directional tensile strength measurements do not indicate a statistically significant preferred plane of weakness.

INTRODUCTION

The purpose of mechanical characterization of samples from the EGSP-Dow Chemical #103 well is to determine the orientation of preferred planes of weakness in the Devonian gas shales at the Sanilac County, Michigan well site.

A series of samples, representing 50 feet of core taken from the Dow Chemical #103 well, were tested. The tested core intervals extend from 1,311 feet to 1,363 feet below surface and are summarized in Table 1.

TABLE 1

EGSP-Dow Chemical #103 Well
Sanilac County, Michigan
Formations Tested

Formation	Depth Cored	Depth Tested
ANTRIM SHALE		
Unit 3	1,284'-1,322'	1,311'-1,320'
Unit 2	1,322'-1,344'	1,323',1,339' (2 samples)
Unit 1A	1,344'-1,368'	1,353'-1,363'

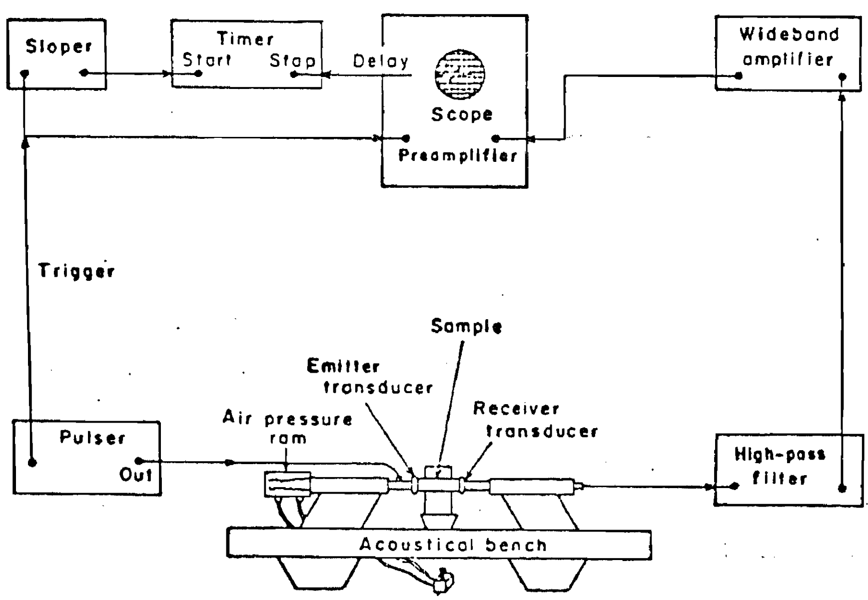
The physical property tests employed are: 1) directional ultrasonic velocity measurements; 2) point load induced fracturing; and 3) directional tensile strength tests. In addition, all fractures (hereafter referred to as 'pretest fractures') are systematically recorded before the physical property tests are performed.

A. Directional Ultrasonic Velocity Measurements

The orientation of linear features such as microfractures in a rock specimen may be found by measuring the longitudinal wave velocity through the specimen. Fractures which are oriented perpendicular to the direction of wave propagation impede the wave; fractures which are oriented parallel to the direction of wave propagation do not (Birch, 1960). Measurements are performed diametrically at 30 degree intervals from true north. Minimum values of sonic velocity are expected to occur in azimuths normal to the preferred direction of microfractures (Komar, Kovach, 1969). An ultrasonic pulse measurement system operates as shown in Figure 1.

FIGURE 1

Schematic Diagram of Ultrasonic Pulse Apparatus
(Thill, Peng, 1974)



A pulse generator supplies a rectangular electrical pulse which is converted to a mechanical pulse by a piezoelectric transducer and transmitted into one end of the specimen. The mechanical pulse is received at the other end of the specimen by another piezoelectric transducer and is converted back to an electrical signal. An oscilloscope and timer are synchronized with the output of each pulse to the specimen by the trigger pulse from the pulse generator. Low frequency noise is filtered from the arrival signal and the signal is tapped to the vertical amplifier of the oscilloscope. The first arrival is highly amplified and the sensitivity of the stop trigger of the timer is adjusted to a level just exceeding the noise level of the received signal. Therefore, the time elapsed between initiation of the pulse at the pulse generator and the first arrival of the elastic wave at the receiver is recorded automatically (Thill, Bur, 1969; Thill, Peng, 1974). The counter averages 100 pulses before displaying the digitized result to 0.001 microseconds (Komar, et al, 1976).

Travel times are corrected for instrumentation and system delays using various lengths of aluminum standards. A plot of length versus transit time is made; the intersection of the least squares line indicates the instrument delay time (Thill, Bur, 1969).

The velocity, V, of the longitudinal wave is calculated using the distance, D, traversed by the wave (the diameter of the specimen) and the travel time, t, by the formula (Thill, McWilliams, Bur, 1968):

$$V = Dt^{-1}$$

The ultrasonic pulse method is the laboratory counterpart of field seismic methods that operate at much lower frequencies.

The statistical analysis of these measurements identifies the 95% confidence interval. This is a statistical parameter which indicates the interval in which the measurement may occur 95% of the time, and is calculated by the formula:

$$\overline{X} \pm tsN^{-1/2}$$

where: $\overline{X}$ = mean

t = t factor for 5 degrees of freedom and 95% confidence

s = standard deviation

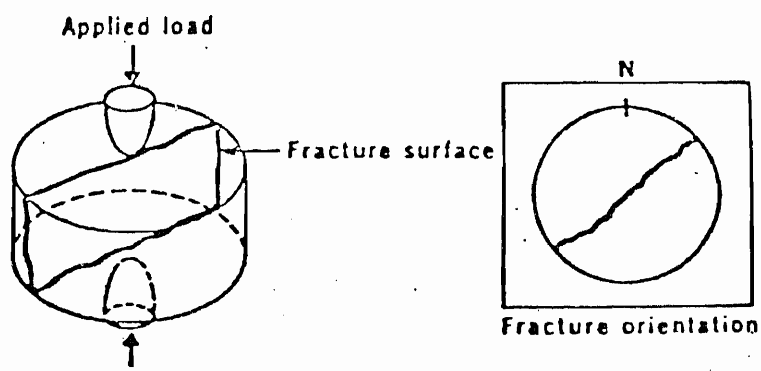
N = number of measurements

B. Point Load Testing

The orientation of a weakness plane in rock specimens may be found by inducing tensile fractures in discs when a load is applied through the disc's central axis (Komar, Overbey and Watts, 1976; McWilliams, 1966) (Figure 2).

FIGURE 2

Schematic Diagram of Point Load Test
(Komar, Overbey and Watts, 1976)



Fracture direction at random unless a "preferred direction" of failure exists.

The point load testing apparatus consists of a load frame with two identical platens. These loading contact points are spherically truncated cones between which the specimen is axially centered.

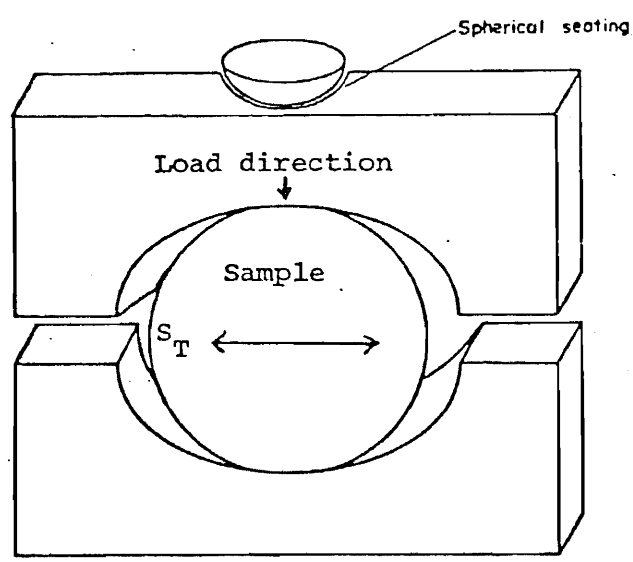
Fractures induced by point load will indicate a random orientation only if the rock specimens are of homogeneous isotropic material; if the specimen is anisotropic, the induced fracture would be expected to occur in directions parallel to the preferred directions of microfracture (Peng, Ortiz, 1972).

C. Directional Tensile Strength Testing

The orientation of minimum tensile strength may be found by applying a compressive load across the diameter of a cylindrical specimen (Mellor, Hawkes, 1971) (Figure 3).

FIGURE 3

Directional Tensile Strength Test Apparatus
(Mellor, Hawkes, 1971)



Curved-jaw loading rig for the "Brazilian" indirect tensile test on rock discs (Hawkes and Mellor).

In this diametric or line load test, tensile strength normal to the axes of loading is determined from the magnitude of the applied load at failure by the formula (Peng, Ortiz, 1972):

$$S_T = 2P(\pi dt)^{-1}$$

where: S_T = tensile strength, psi

P = applied load at failure, lb.

d = diameter of disc, in.

t = thickness of disc, in.

Line load specimens are tested diametrically at 30 degree intervals from true north. Tensile strength minimums are expected to occur in azimuths normal to the preferred direction of fracture (Anderson, Liebermann, 1966).

EXPERIMENTAL PROCEDURES

Tests follow the "Field and Laboratory Procedures for Oriented Core Analysis of Devonian Shales" published by Morgantown Energy Technology Center, U.S. Department of Energy, and incorporate American Society of Testing Methods and International Society of Rock Mechanics suggested methods as guidelines.

A. Pretest Fracture Measurements

Pretest fractures are recorded on all specimens prior to testing as summarized:

1. The surface of the specimen is dampened with a moist sponge.
2. When water evaporates from the surface, the cracks are accentuated because the water is momentarily retained by the fractures; the cracks are traced by pencil while they are still visible.

3. The orientation of the crack is determined by running a line parallel to the crack through the center of the oriented specimen. The orientation of the crack is recorded in degrees from true north.

4. The length of the crack is recorded in inches.

5. A sketch is made of each specimen illustrating the pretest fractures.

6. A composite sheet is kept with the orientation and length of each identified fracture for all tested specimens.

B. Directional Ultrasonic Velocity Measurements

Directional ultrasonic velocity measurements are performed as summarized:

1. Pretest fractures are recorded as outlined above including a description of bedding or other significant features.

2. The mid-portion of the sample is taped with black vinyl tape. Three strips of tape are used which touch but do not overlap each other. The ends of the tape are positioned at an orientation groove so the transducer heads are not positioned over the splice.

3. The sample is placed on the (foam rubber) cushioned, indexed, rotating stage with the north orientation mark against the transmitting head.

4. A generous amount of high vacuum silicone grease is applied to each of the 12 contact positions at 30 degree intervals from true north.

5. The opposite traveling head is moved to nearly touch the core surface to avoid jarring the specimen.

6. The solenoid switch is actuated, gripping the specimen with an indicated air hydraulic pressure of 35 psi.

7. With the pulse rate set at 30 sec^{-1}, the powerstat is turned on and increased to an indicated 62%.

8. A wait of three minutes is necessary for the decay and stabilization of indicated travel time.

9. While waiting, the diameter of the core at this position is recorded (to .001 inch) using the on line dial indicator.

10. After three minutes, ten consecutive travel time values registered on the digital counter are recorded (to .001 microseconds). Each travel time recorded is the average of 100 pulses.

11. The pressure is released on the sample.

12. The specimen is rotated on the stage to the next marked 30 degree interval and numbers 5 through 12 are repeated until the travel times in each of the six orientations, 0, 30, 60, 90, 120, 150 degrees, have been recorded.

C. Point Load Testing

The point load test is performed as summarized:

1. At intervals of 10 feet, 2-inch diameter by approximately 5/8-inch thick samples are selected.

2. Pretest fractures are recorded as outlined above.

3. The dimensions of the samples are recorded; diameter and thickness in inches.

4. The circumference of the samples are taped with masking tape to preserve the fractures after the point load test is performed.

5. The sample is centered and placed vertically between two conical platens in the load frame (see Figure 2).

6. A compressive load is applied directly in the center on both the top and bottom sides of the sample.

7. The magnitude of the applied load at failure is recorded and the point load strength index can be obtained by the formula (Roberts, 1977):

$$I_S = P \times a(D^2)^{-1}$$

where: I_S = point load strength index
P = applied load at failure, lbs.
D = distance between load applicators at failure, in.
a = piston area (5)

8. The induced fractures are sketched and their orientation recorded on a composite sheet.

D. Directional Tensile Strength Testing

Directional tensile strength measurements are determined as summarized:

1. At intervals of 10 feet, six to ten closely grouped samples (2-inch diameter by approximately 5/8-inch thick) are selected.
2. Pretest fractures are recorded as outlined above.
3. Each sample is oriented and marked in one of six directions (0°, 30°, 60°, 90°, 120°, 150°).
4. The dimensions of the samples are recorded; diameter and thickness in inches.
5. The sample is placed diametrically between two platens in the load frame (see Figure 3).
6. A compressive load is applied across the previously oriented diameter of the sample.
7. The magnitude of the applied load at failure is recorded.
8. The tensile strength normal to the axis of loading is determined using the formula: $S_T = (\pi dt)^{-1}$ as defined in the Introduction.
9. The induced fractures are sketched.

RESULTS

The results of the physical property measurements of pretest fractures, directional ultrasonic velocity, point load induced fracturing, and directional tensile strength tests, are compiled in Appendices A, B, C, and D respectively. Table 2 is a summary of the mechanical property testing results for each stratigraphic formation.

TABLE 2

EGSP-Dow Chemical Well #103 Core
Sanilac County, Michigan
Frequency Distribution of Preferred Direction of Fracturing

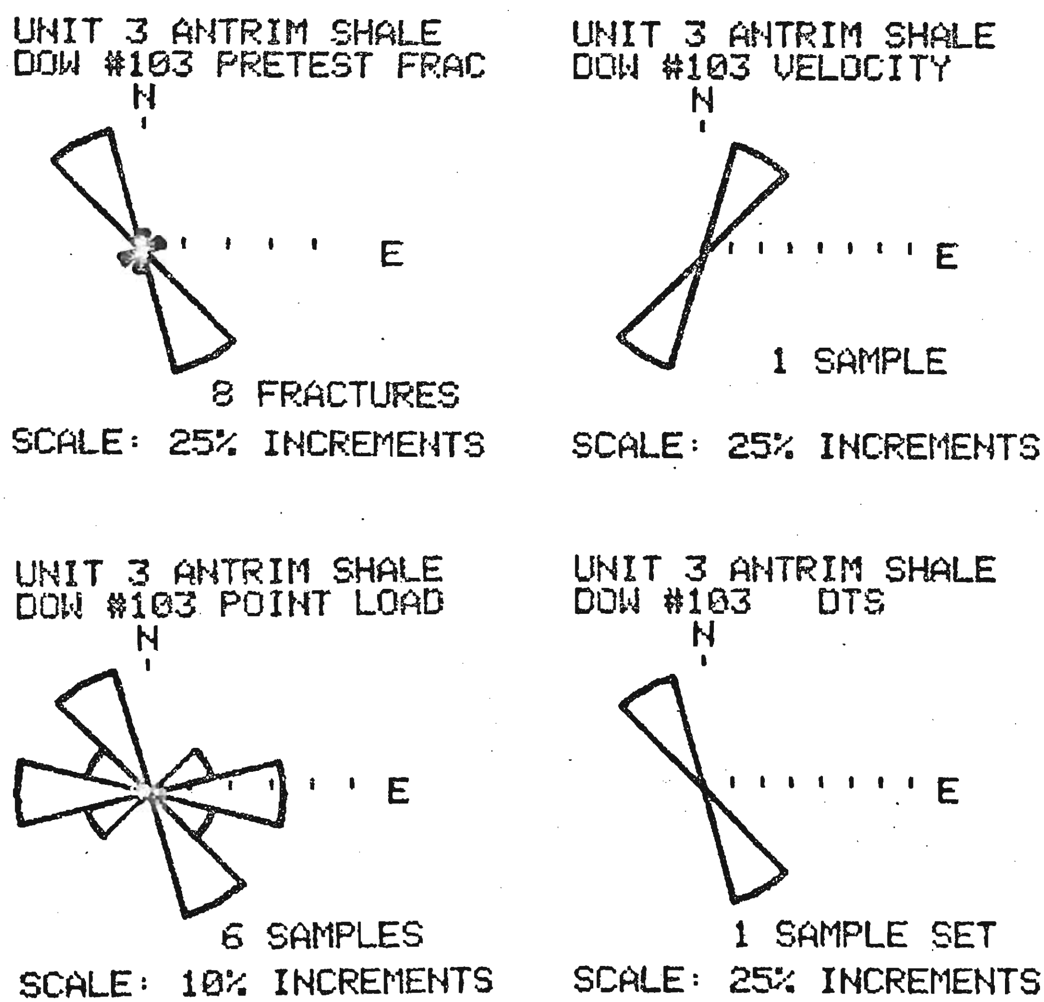
		Degrees East of North						
Formation	Test	0°	30°	60°	90°	120°	150°	Total
ANTRIM SHALE								
Unit 3	Pretest Frac	1	0	1	0	0	6	8
1,311'-1,320' tested	Velocity	0	1	0	0	0	0	1
	Point Load	0	0	1	2	1	2	6
	DTS	0	0	0	0	0	1	1 set
Unit 2	Pretest Frac	0	0	0	0	0	0	0
1,323', 1,339' tested	Velocity	1	0	1	0	0	0	2
Unit 1A	Pretest Frac	0	0	0	0	0	0	0
1,353'-1,363' tested	Velocity	0	1	1	0	0	0	2
	Point Load	3	1	3	2	2	2	13
	DTS	0	1	1	0	0	0	2 sets
WELL COMPOSITE	Pretest Frac	1	0	1	0	0	6	8
1,311'-1,363' tested	Velocity	1	2	2	0	0	0	5
	Point Load	3	1	4	4	3	4	19
	DTS	0	1	1	0	0	1	3 sets

Unit 3 in the Antrim Shale; 1,311'-1,320' tested:

Pretest fractures occur most frequently in the N30°W ± 15° direction (6 out of 8 pretest fractures). The one ultrasonic velocity sample indicates N30°E ± 15° as the preferred direction of fracturing. The six point load induced fractures do not indicate a statistically significant preferred direction of fracture. The one directional tensile strength sample set indicates N30°W ± 15° as the preferred plane of weakness. Figure 4 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in Unit 3 of the Antrim Shale. Tabulated results are presented in Appendices A, B, C and D.

FIGURE 4

Unit 3 in the Antrim Shale
Frequency Distribution Rose Diagrams of Results

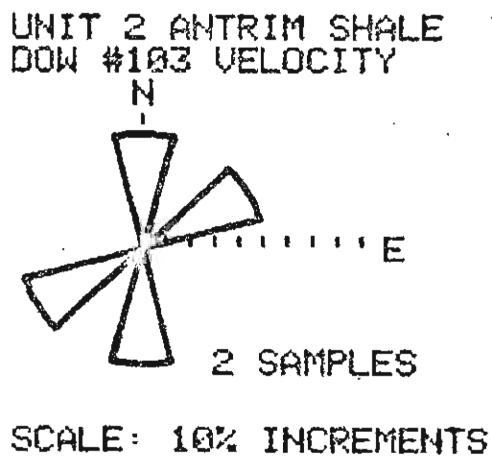


Unit 2 in the Antrim Shale; (two samples) 1,323', 1,339' tested:

No pretest fractures occur in the two samples received from Unit 2. The two ultrasonic velocity measurements indicate N0°E ± 15° and N60°E ± 15° as the preferred directions of fracturing. Figure 5 illustrates the frequency distribution rose diagram of preferred direction of fracturing in Unit 2 of the Antrim Shale. Tabulated results are presented in Appendix B.

FIGURE 5

Unit 2 in the Antrim Shale
Frequency Distribution Rose Diagrams of Results

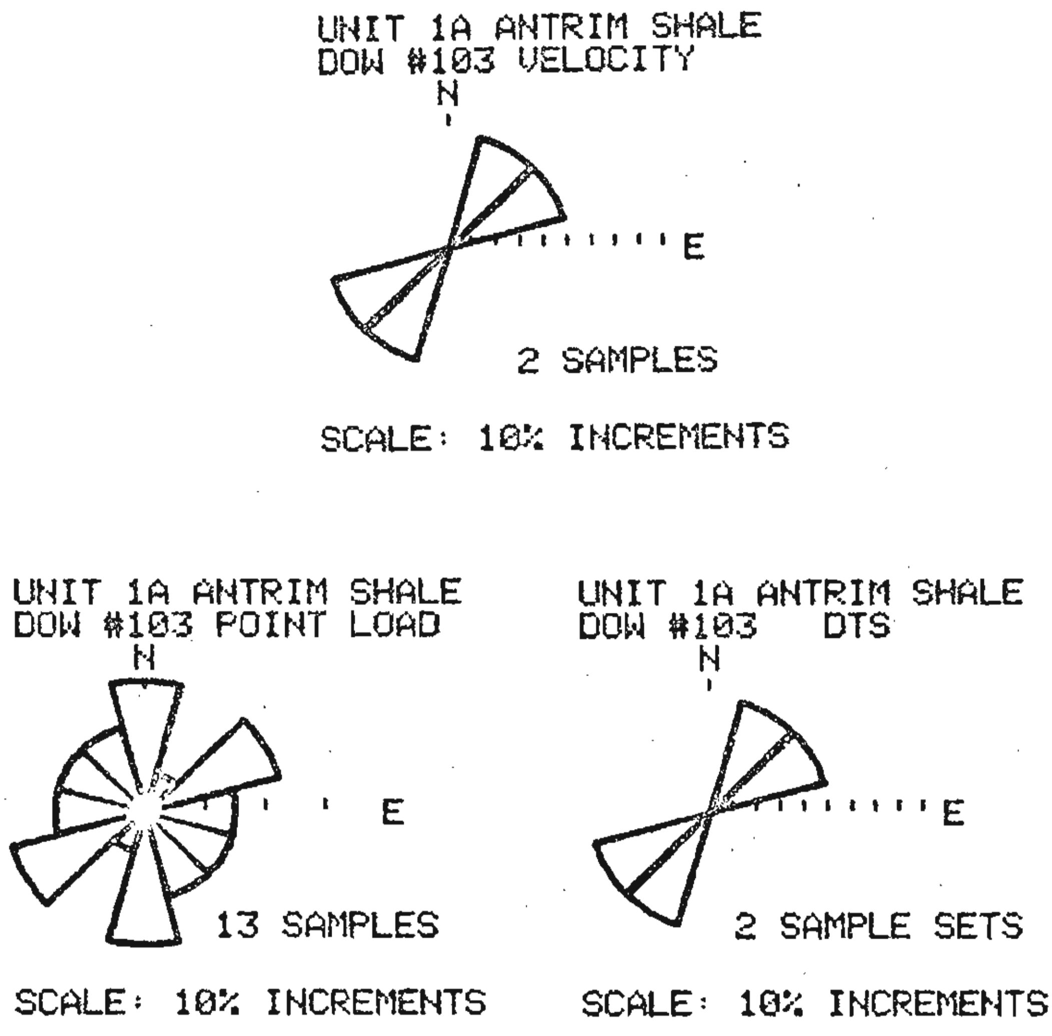


Unit 1A in the Antrim Shale; 1,353'-1,363' tested:

No pretest fractures occur in the samples received from Unit 1A. The two ultrasonic velocity samples indicate N30°E ± 15° and N60°E ± 15° as the preferred directions of fracturing. The thirteen point load induced fractures do not indicate a statistically significant preferred direction of fracturing. The two directional tensile strength sample sets indicate N30°E ± 15° and N60°E ± 15° as the preferred planes of weakness. Figure 6 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in Unit 1A of the Antrim Shale. Tabulated results are prestented in Appendices B, C and D.

FIGURE 6

Unit 1A in the Antrim Shale
Frequency Distribution Rose Diagrams of Results

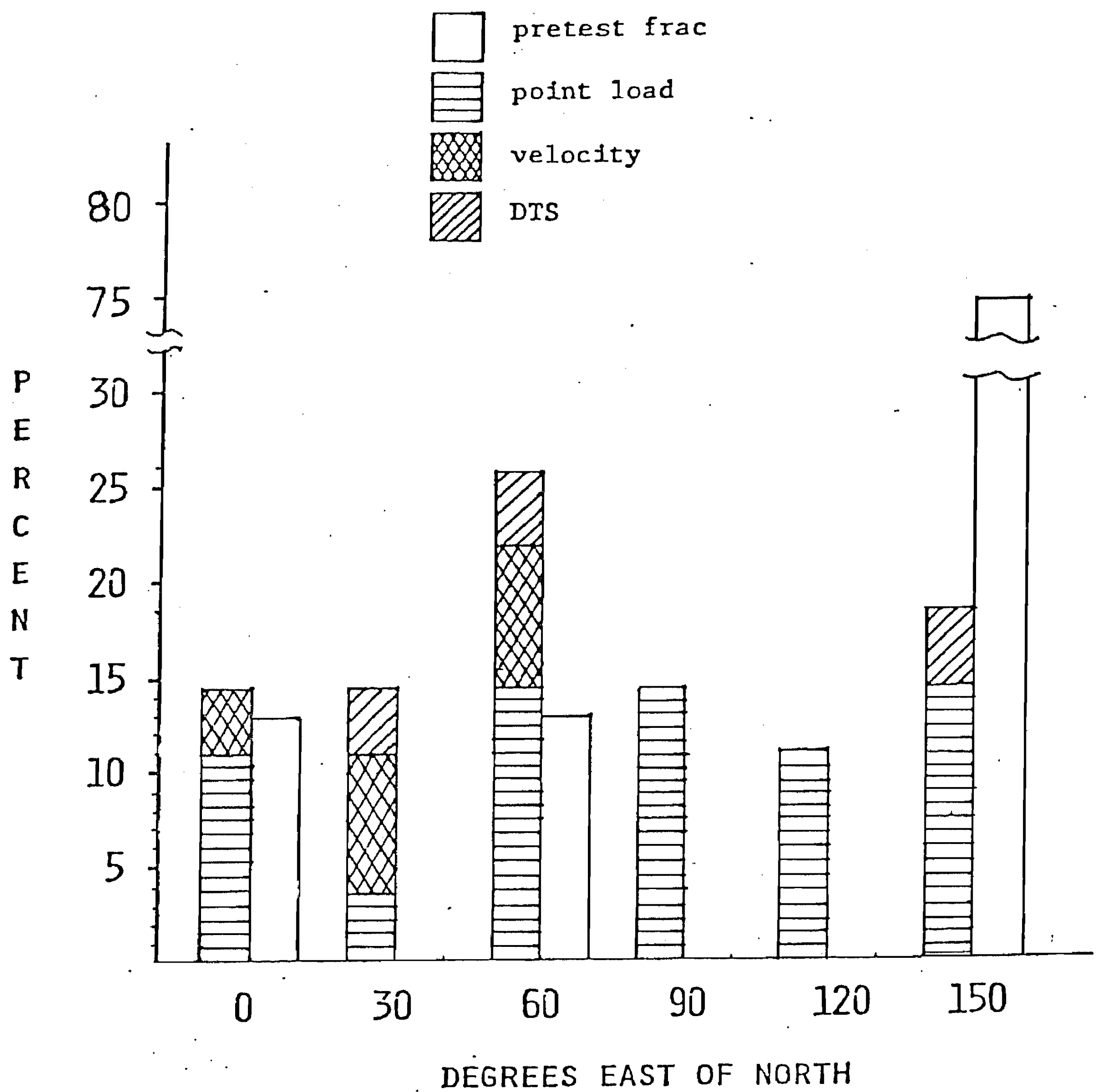


Well Composite; 1,311'-1,363' tested:

Figure 7 is a grouped histogram comparing the frequency distribution of all mechanical test results with the frequency distribution of pretest fractures.

FIGURE 7

Dow #103 Well Composite
Grouped Histogram Comparing Frequency Distribution of Mechanical Test Results (n = 27) with Pretest Fractures (n = 8)

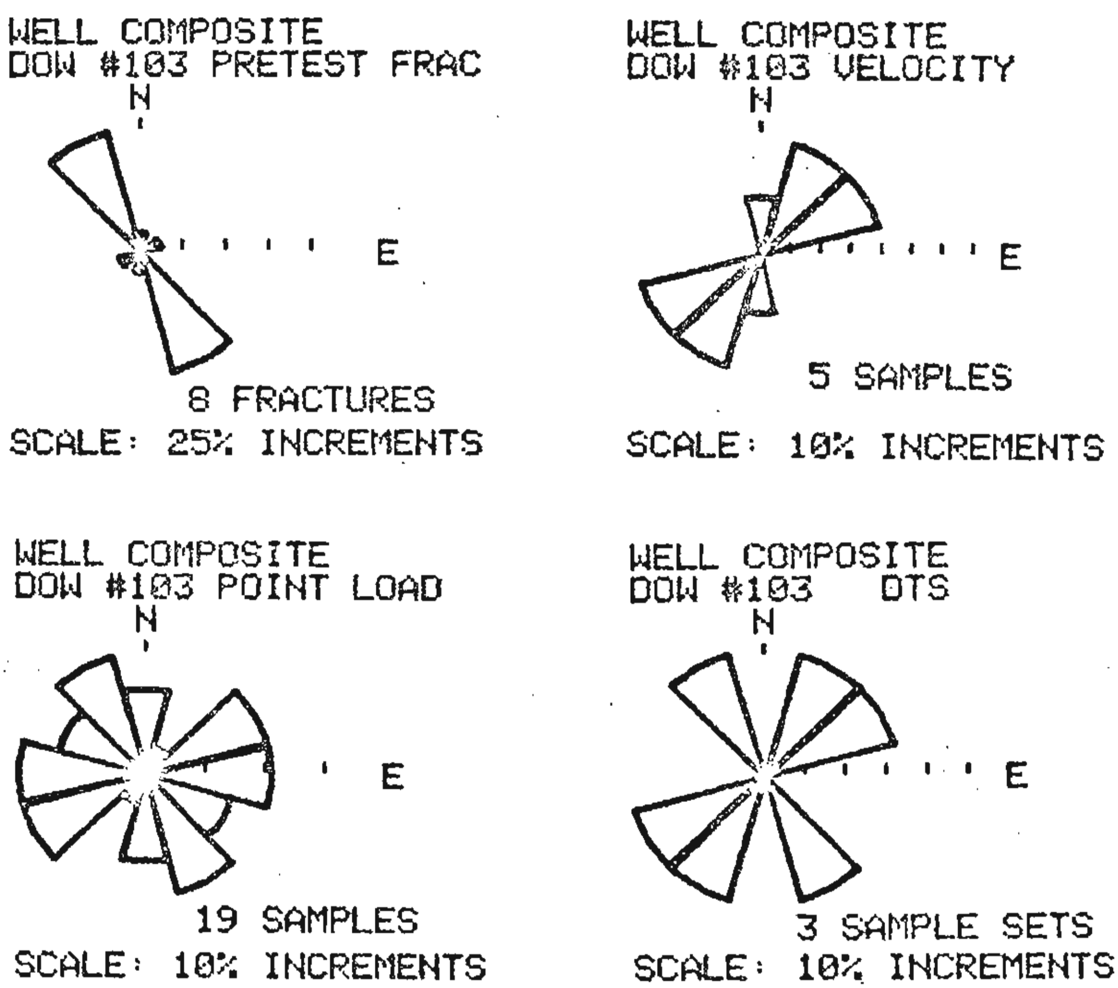


Pretest fractures (identified only in Unit 3) occur most frequently in the N30°W ± 15° direction (6 out of 8 total pretest fractures). A sum of four out of the five ultrasonic velocity samples indicate N30°E ± 15° and

N60°E ± 15° as the preferred direction of fracturing. The nineteen point load induced fractures do not indicate a statistically significant preferred direction of fracturing. The three sets of directional tensile strength measurements do not indicate a statistically significant preferred plane of weakness. Figure 8 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Dow #103 Well Composite. Tabulated results are presented in Appendices A, B, C and D.

FIGURE 8

Dow #103 Well Composite
Frequency Distribution Rose Diagrams of Results



CONCLUSIONS

The data presented in this report do not indicate that the small number of core samples from EGSP-Dow Chemical #103 well exhibit a statistically significant directional variation in physical properties. Prediction of the preferred direction of induced fracturing at the Sanilac County, Michigan well site is based on inherent weaknesses in the core samples found by: 1) point load induced fractures; 2) directional tensile strength measurements; 3) normality to measured ultrasonic velocity minimum; and 4) the directional trend of pretest fractures.

The following conclusions may be drawn from this investigation:

1) The preferred direction of fracturing for Unit 3 in the Antrim Shale (1,311'-1,320' tested) is N30°E ± 15° as indicated by the one ultrasonic velocity sample received; N90°E ± 15° and N30°W ± 15° as indicated by point load induced fractures; and N30°W ± 15° as indicated by the one set of directional tensile strength measurements and the directional trend of pretest fractures.

2) The preferred direction of fracturing for Unit 2 in the Antrim Shale (two samples: 1,323', 1,339' tested) is N0°E ± 15° and N60°E ± 15° as indicated by the two ultrasonic velocity samples tested. No pretest fractures were identified in the Unit 2 samples.

3) The preferred direction of fracturing for Unit 1A in the Antrim Shale (1,353'-1,363' tested) is N30°E ± 15° and N60°E ± 15° as indicated by the two ultrasonic velocity samples and the two sets of directional tensile

strength measurements. Point load induced fractures do not indicate a statistically significant preferred direction of fracturing. No pretest fractures were identified in the Unit 1A samples.

BIBLIOGRAPHY

Anderson, O. L. and Liebermann, R. C. Sound Velocities in Rocks and Minerals. VESIAC State-of-the-Art Report 7885-4-X. Willow Run Laboratories, Univ. of Michigan, 1966, 182 pp.

Birch, F. The Velocity of Compressional Waves in Rocks to 10 Kilobars. Part I. J. Geophys. Res., v. 65, 1960, pp. 1083-1102.

Blaisdell, G. L.; (Kim, K.). Influence of the Weak Bedding Plane in Michigan Antrim Shale on Laboratory Hydraulic Fracture Orientation. Master's Thesis, Michigan Technological University, 1979.

GangaRao, H. V. S.; Advani, S. H.; Chang, P.; Lee, S. C.; Dean, C. S. Insitu Stress Determination Based on Fracture Responses Associated with Coring Operations. 20th U.S. Symposium on Rock Mechanics, Austin, TX, 1979.

Komar, C. A. and Kovach, S. J. Directional Ultrasonic Pulses Orient Failure Planes in Sedimentary Rocks, W. Va. Acad. Sci., West Liberty, W. Va., 1969.

Komar, C. A.; Overbey, Jr., W. K.; Watts, R. J. Prediction of Fracture Orientation from Oriented Cores and Aerial Photos. West Poison Spider Field, Casper, Wyoming, U.S. Energy Res. & Dev. Admin., March 1976.

McWilliams, J. R. The Role of Microstructure in the Physical Properties of Rock. ASTM STP 402, 1966, pp. 175-189.

Mellor, M. and Hawkes, I. Measurement of Tensile Strength by Diametral Compression of Discs and Annuli. Engng Geol., v. 5, 1971, pp. 173-225.

Peng, S. S. and Ortiz, C. Crack Propagation and Fracture of Rocks Loaded in Compression. Proc. Int'l. Conf. Dynamic Crack Propagation, Lehigh Univ., July 1972, pp. 113-129.

Roberts, A. F. "Geotechnology". 1st ed., Oxford, NY, Pergamon Press, 1977.

Smith, M. B.; Holman, G. B.; Fast, C. R.; and Covlin, R. J. The Azimuth of Deep, Penetrating Fractures in the Wattenberg Field. Jour. Pet. Tech., Feb. 1978, pp. 185-193.

Thill, R. E. and Bur, T. R. An Automated Ultrasonic Pulse Measurement System. Geophysics, v. 34, no. 1, 1969, pp. 101-105.

Thill, R. E. and Peng, S. S. Statistical Comparison of the Pulse and Resonance Methods for Determining Elastic Moduli. U.S. Bureau of Mines RI 7831, 1974, p. 9.

Thill, R. E.; McWilliams, J. R. and Bur, T. R. An Acoustical Bench for an Ultrasonic Pulse System. U.S. Bureau of Mines RI 7164, July 1968, p. 22.

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APPENDIX A

RESULTS OF PRETEST FRACTURE MEASUREMENTS

TABLE A-1

EGSP-Dow Chemical #103

Orientation of Scribe Cuts in Velocity Samples*

Depth	Groove Orientation Degrees East of North					
1,311	55	140	270	minor 15	minor 150	minor 295
1,323	30	160	310			
1,339	45	175	325			
1,354	90	235	300			
1,361	115	200	325			

*Scribe cuts are made at the well site during drilling to orient the cores.

TABLE A-2

EGSP-Dow Chemical #103 Well

Orientation and Length of Pretest Fractures in Velocity Samples measured in inches

Depth ft.	0°	30°	60°	90°	120°	150°	Total
ANTRIM SHALE Unit 3							
1,311			1.8*			1.6*,2*	3

*Fracture originated at orientation groove. Note: all pretest fractures in velocity samples originate at orientation grooves.

TABLE A-3

Orientation and Length of Pretest Fractures in Point Load Samples

1,315	1					1.4,.6, .6,1	5

Note: There were no pretest fractures in DTS samples.

APPENDIX B

RESULTS OF DIRECTIONAL ULTRASONIC VELOCITY MEASUREMENTS

TABLE B-1

WELL # 103 IN SANILAC CO. MICHIGAN

DIRECTIONAL P WAVE VELOCITIES

AVERAGE VELOCITIES IN KM/SEC & ORIENTATION IN DEGREES EAST OF NORTH

	DEPTH IN FEET	0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG
ANTRIM SHALE							
Unit 3	1311	4.315	4.268	4.235	4.215	4.214	4.348
Unit 2	1323	4.315	4.306	4.301	4.307	4.302	4.29
	1339	4.622	4.625	4.606	4.57	4.622	4.635
Unit 1A	1354	4.445	4.425	4.429	4.422	4.399	4.427
	1361	4.337	4.339	4.335	4.331	4.32	4.316
	AVERAGE VELOCITY	4.407	4.393	4.381	4.369	4.371	4.403

TABLE B-2

ORIENTATION OF ULTRASONIC VELOCITY MINIMUM
WELL # 103 IN DOW WELL

DEGREES EAST OF NORTH

	DEPTH IN FEET	0	30	60	90	120	150
ANTRIM SHALE Unit 3	1311					MIN	
Unit 2	1323						MIN
	1339				MIN		
Unit 1A	1354					MIN	
	1361						MIN

WELL COMPOSITE

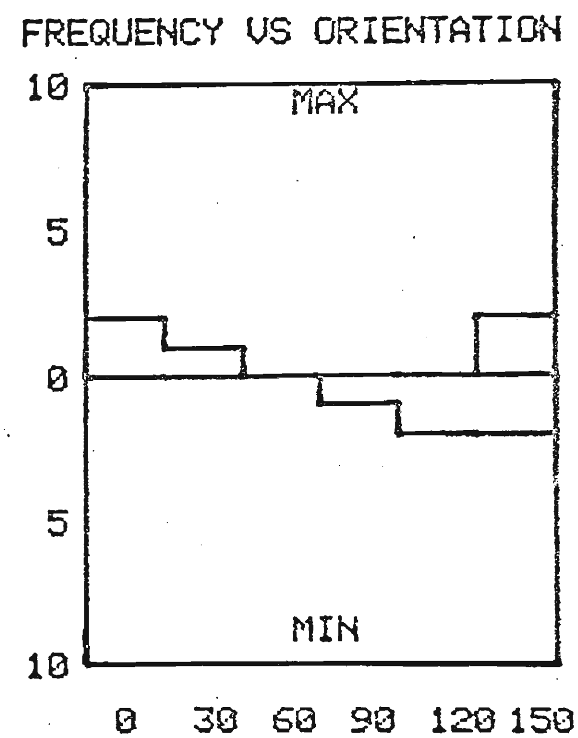


FIGURE B-1

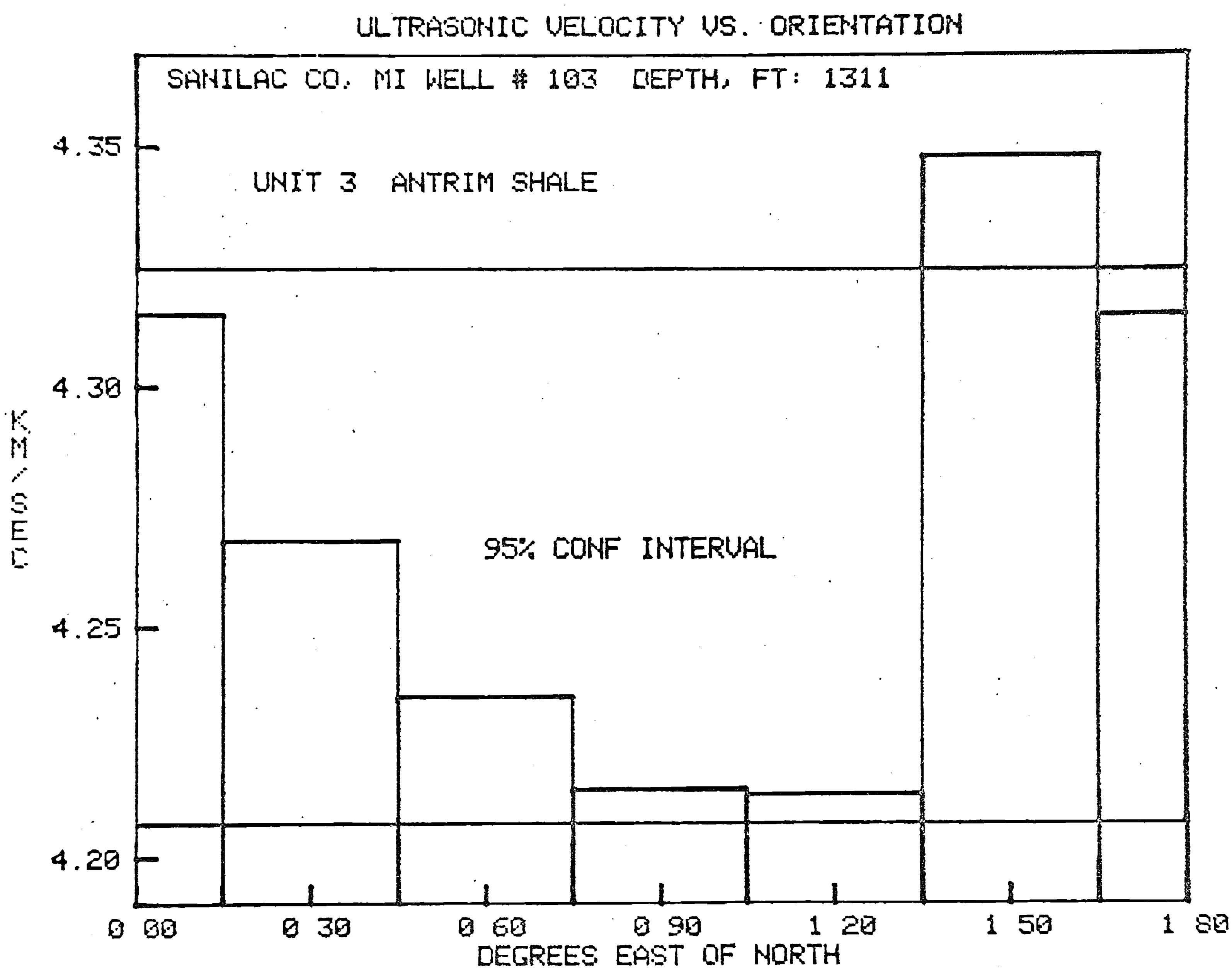

ULTRASONIC VELOCITY VS. ORIENTATION
SANILAC CO. MI WELL # 103 DEPTH, FT: 1311
UNIT 3 ANTRIM SHALE
95% CONF INTERVAL
4.35
4.30
4.25
4.20
KM/SEC
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE B-2

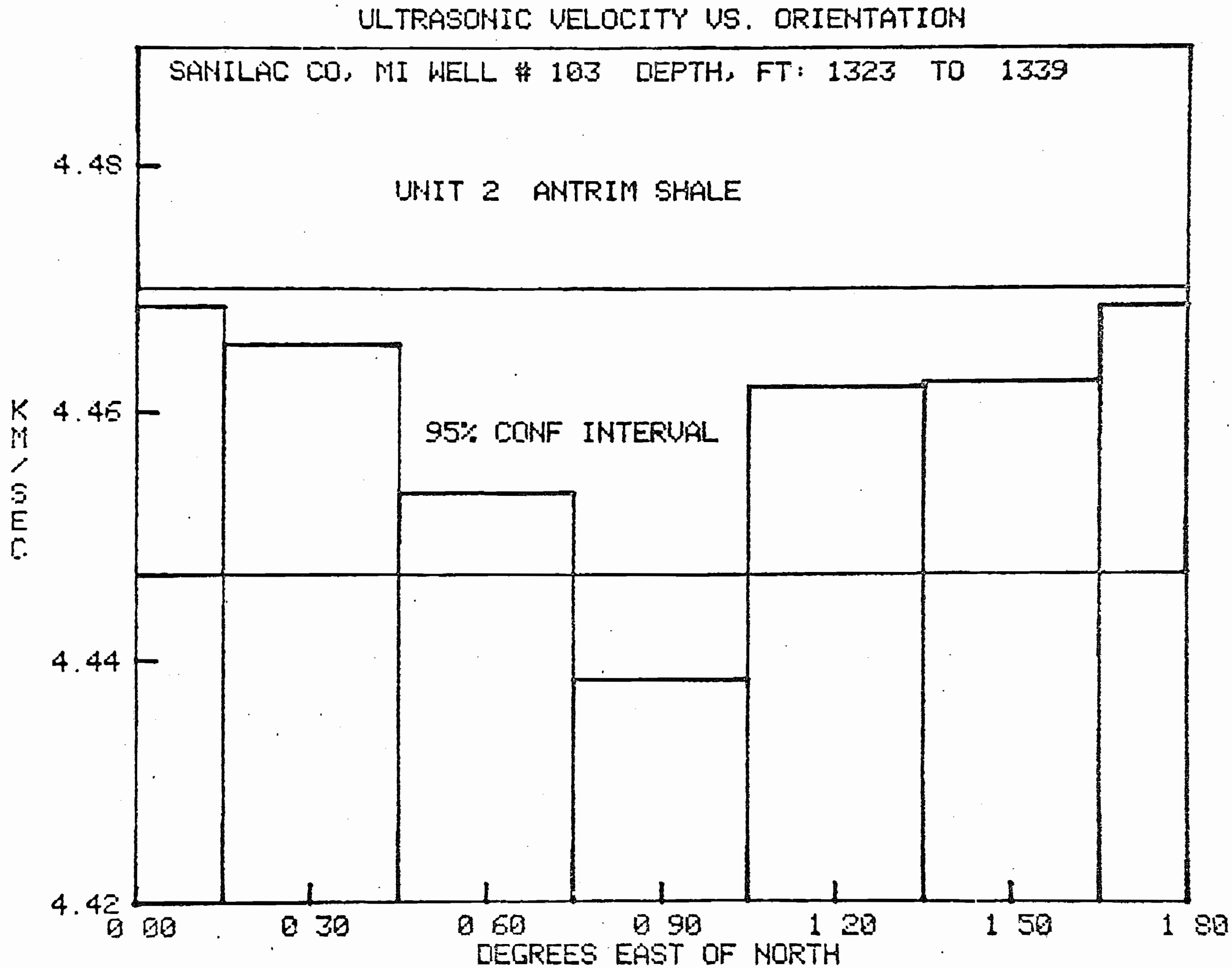

ULTRASONIC VELOCITY VS. ORIENTATION
SANILAC CO, MI WELL # 103 DEPTH, FT: 1323 TO 1339
UNIT 2 ANTRIM SHALE
95% CONF INTERVAL
KM/SEC
4.48
4.46
4.44
4.42
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE B-3

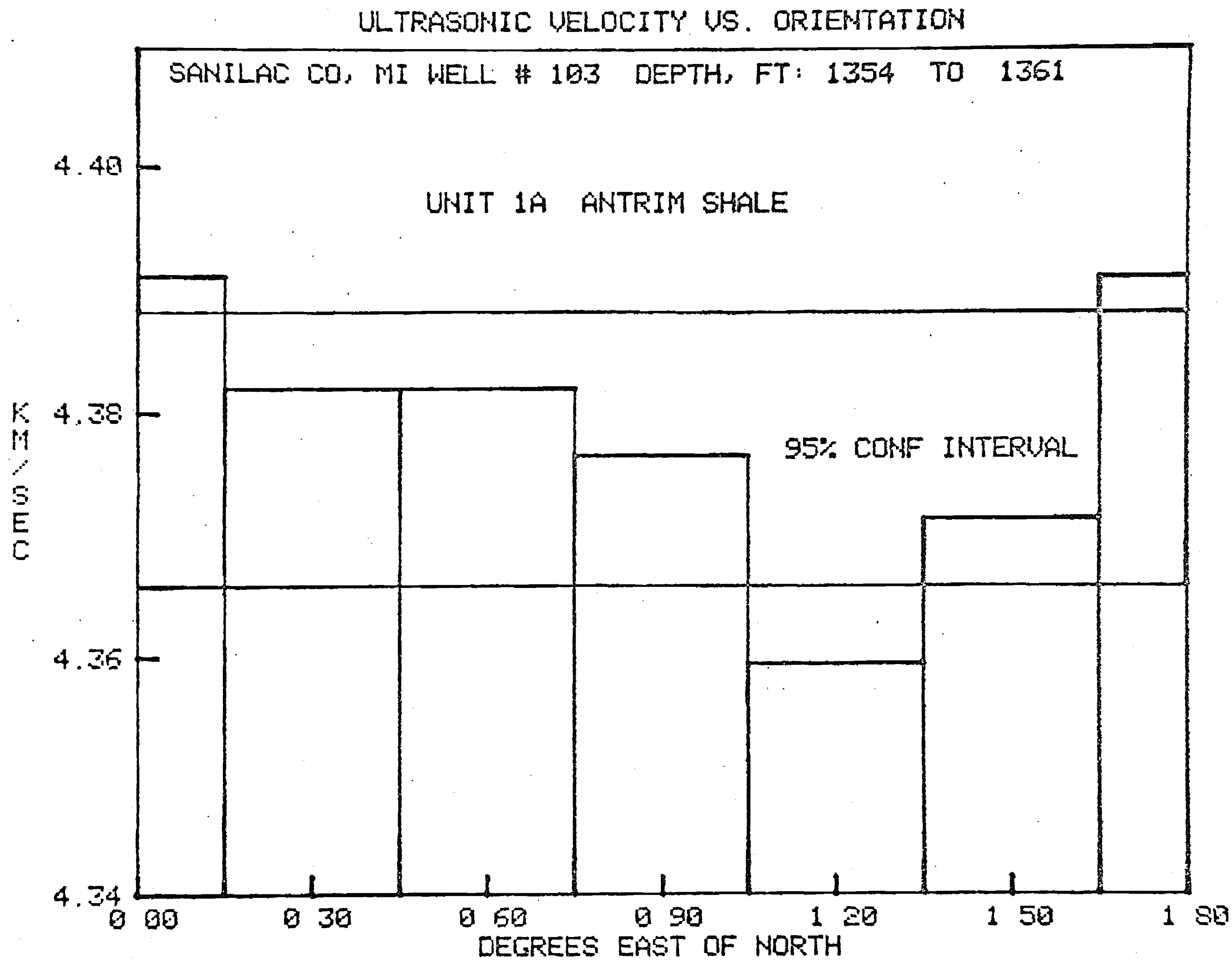
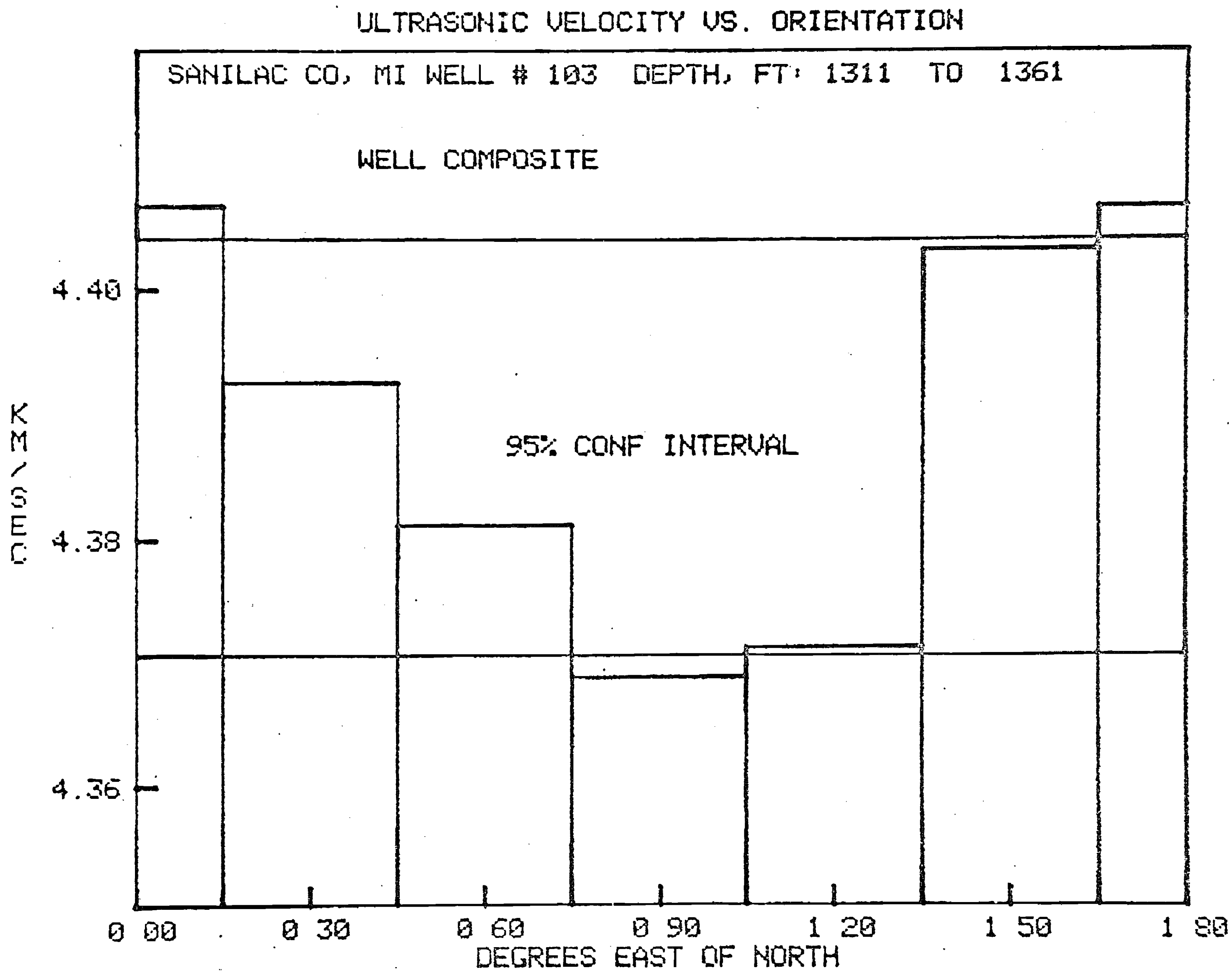

ULTRASONIC VELOCITY VS. ORIENTATION
SANILAC CO, MI WELL # 103 DEPTH, FT: 1354 TO 1361
UNIT 1A ANTRIM SHALE
95% CONF INTERVAL
KM/SEC
4.40
4.38
4.36
4.34
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE B-4


ULTRASONIC VELOCITY VS. ORIENTATION
SANILAC CO, MI WELL # 103 DEPTH, FT: 1311 TO 1361
WELL COMPOSITE
95% CONF INTERVAL
KM/SEC
4.40
4.38
4.36
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

APPENDIX C

RESULTS OF POINT LOAD TESTS

TABLE C-1

WELL # 103 IN SANILAC COUNTY, MICHIGAN

FREQUENCY OF FRACTURES INDUCED BY POINT LOAD
ORIENTATION IN DEGREES EAST OF NORTH; DEPTH IS MIDPT OF 10 FT INTERVAL

	DEPTH FEET	FREQUENCY 0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG	# OF SAMPLES
ANTRIM SHALE								
Unit 3	1315	0	0	1	2	1	2	6
Unit 1A	1355	2	0	2	1	1	1	7
	1363	1	1	1	1	1	1	6
	TOTAL FREQ	3	1	4	4	3	4	19

TABLE C-2

WELL # 103 IN SANILAC COUNTY, MICHIGAN

POINT LOAD INDEX FOR RESPECTIVE TESTS VS DEPTH
(DEPTH IS MIDPT OF 10 FOOT INTERVAL)

ANTRIM	DEPTH	POINT LOAD INDEX									
SHALE	FEET	1	2	3	4	5	6	7	8	9	10
Unit 3	1315	4208	3152	4868	856	1356	4298	0	0	0	0
Unit 1A	1355	3882	3022	2536	5871	2290	2438	2327	0	0	0
	1363	2739	2785	2176	2161	3216	4035	0	0	0	0

APPENDIX D

RESULTS OF DIRECTIONAL TENSILE STRENGTH TESTS

TABLE D-1

WELL NUMBER 103 IN SANILAC CO. MI

DIRECTIONAL TENSILE STRENGTHS

TENSILE STRENGTH IN PSI & ORIENT OF LOAD AXIS IN DEGREES EAST OF NORTH

	DEPTH IN FEET	0 DEG	30 DEG	60 DEG	90 DEG	120 DEG	150 DEG
ANTRIM SHALE							
Unit 3	1315	1555	1434	1635	1582	1486	1152
Unit 1A	1359	1515	1356	1351	1488	1573	1530
	1363	1479	1449	1449	1475	1468	1624
	AVERAGE STRENGTH	1516	1413	1478	1515	1509	1435

TABLE D-2

ORIENTATION OF DIRECTIONAL TENSILE STRENGTH MINIMUM
WELL # 103 IN SANILAC CO. MI

	DEPTH IN FEET	0	30	60	90	120	150
ANTRIM SHALE Unit 3	1315						MIN
Unit 1A	1359			MIN			
	1363		MIN				

DEGREES EAST OF NORTH

FREQUENCY VS ORIENTATION

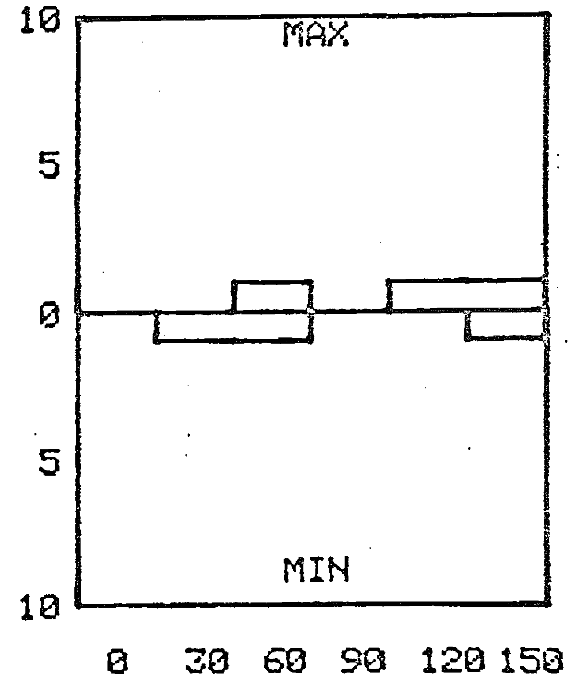


FIGURE D-1

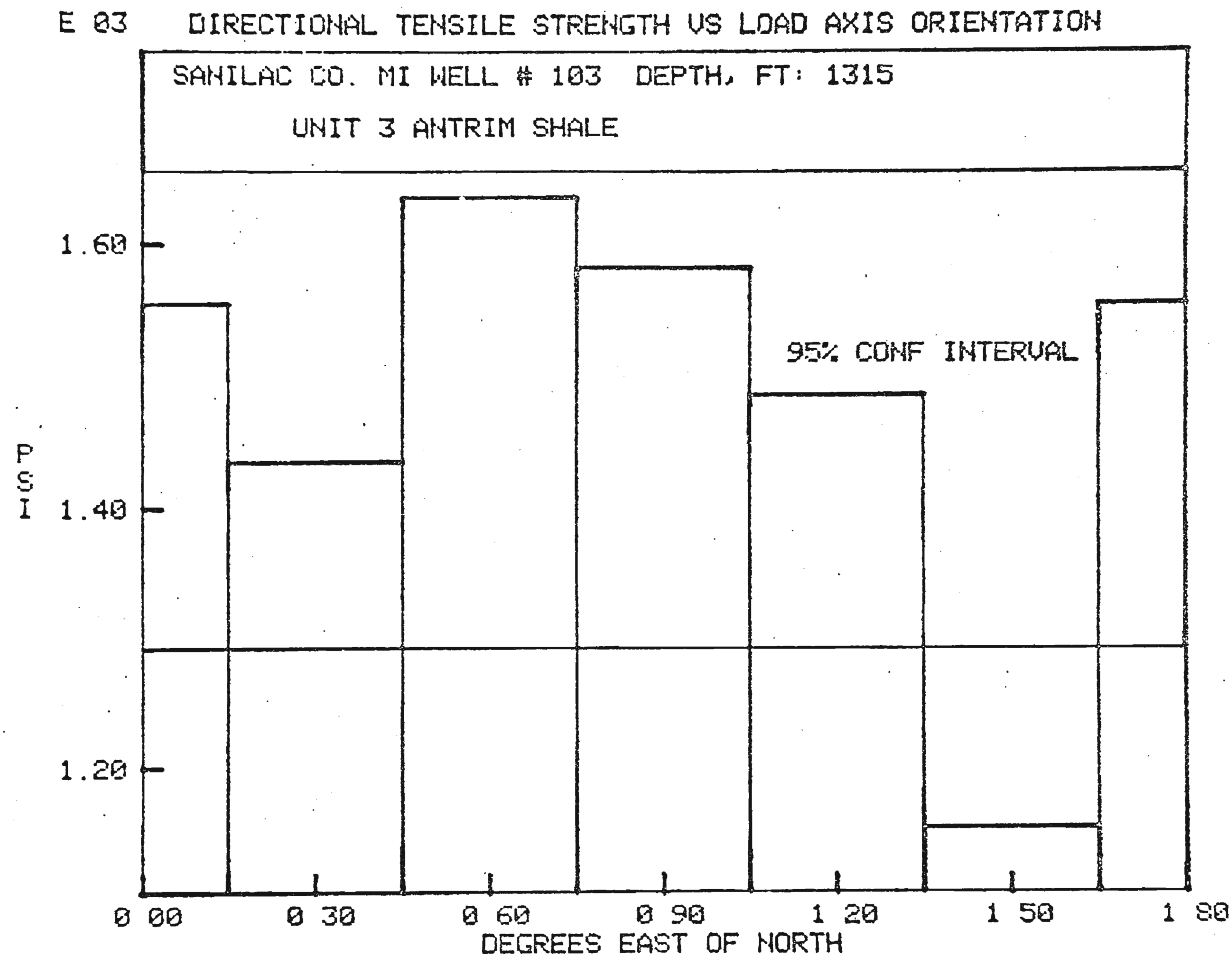
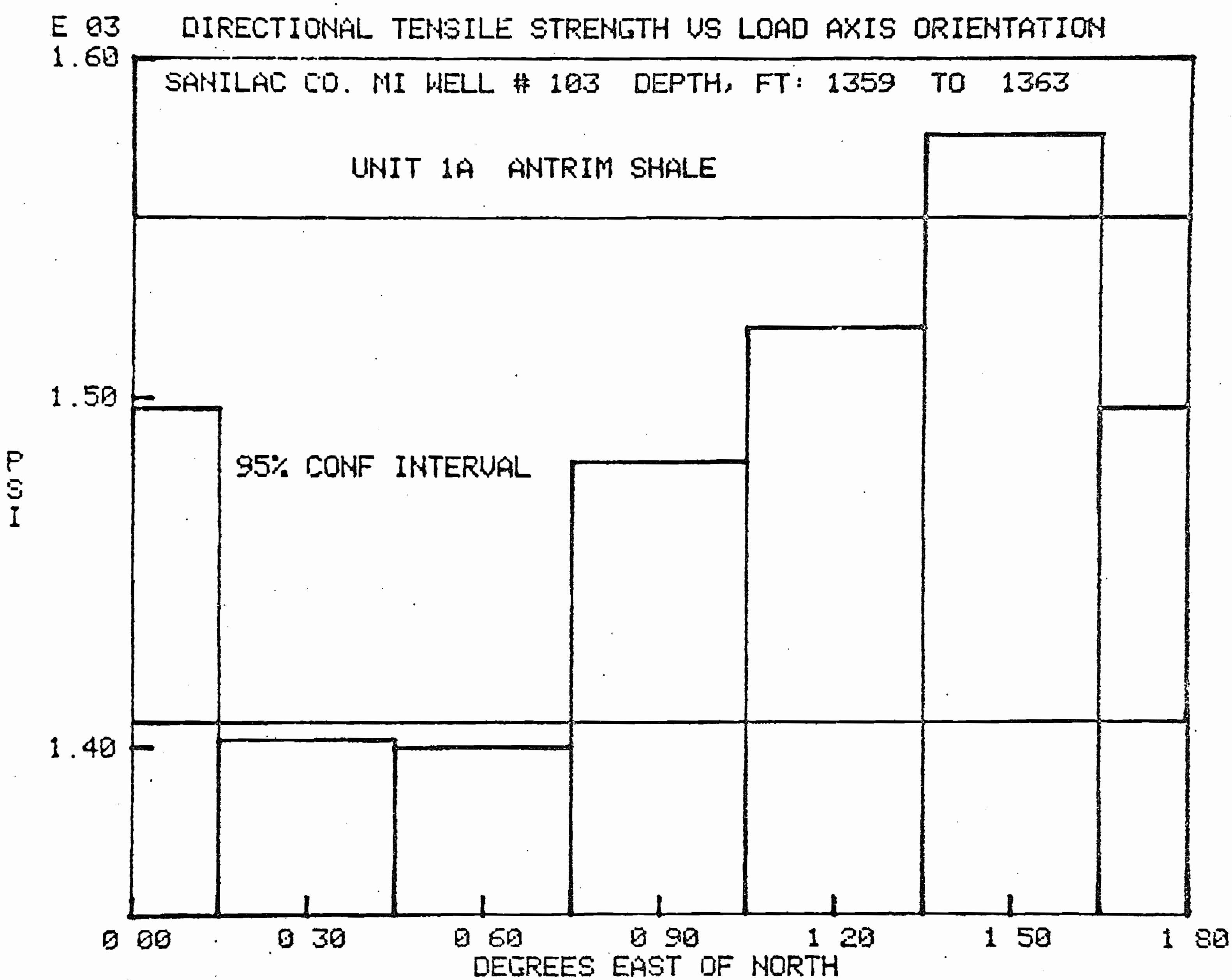
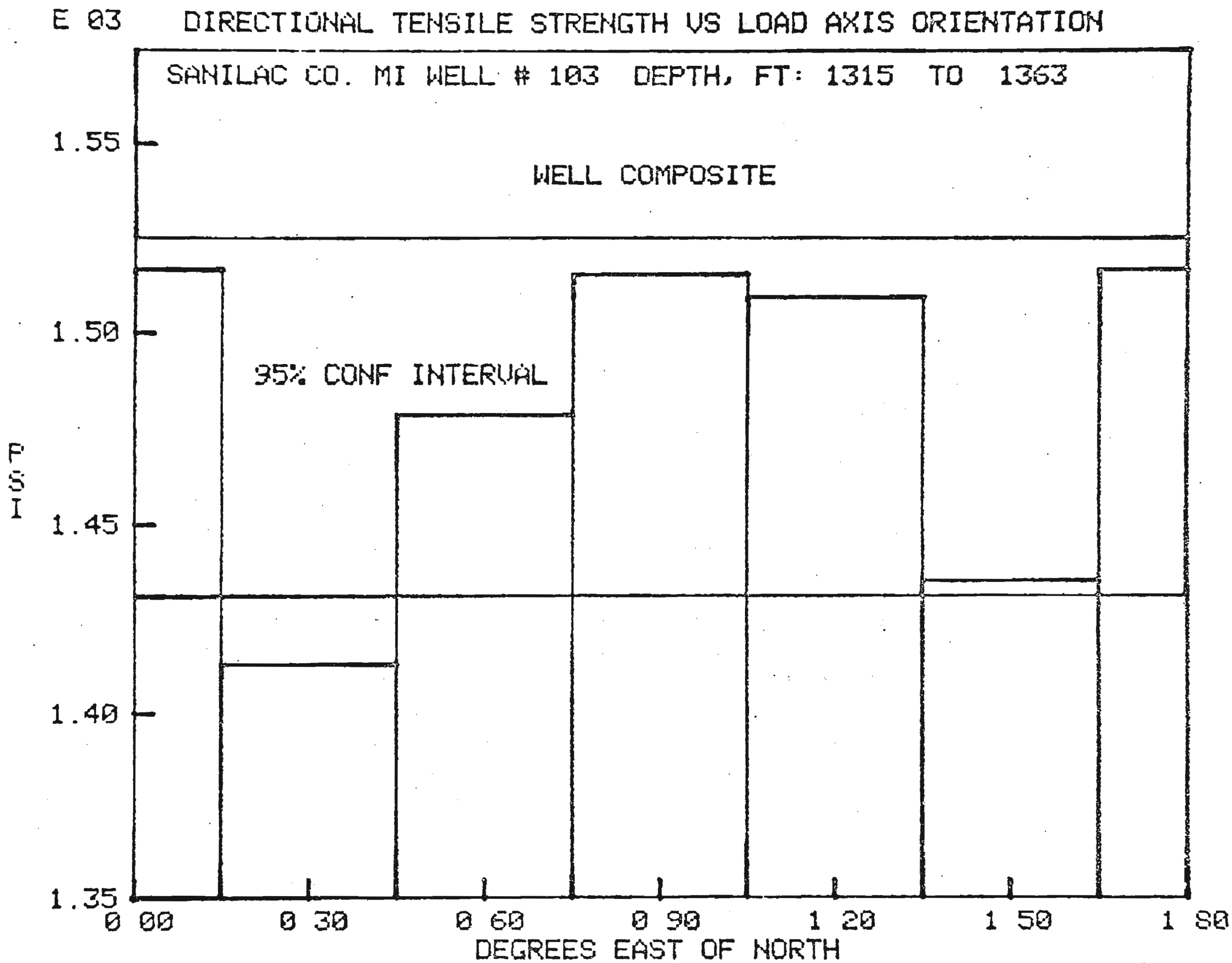

E 03
DIRECTIONAL TENSILE STRENGTH VS LOAD AXIS ORIENTATION
SANILAC CO. MI WELL # 103 DEPTH, FT: 1315
UNIT 3 ANTRIM SHALE
95% CONF INTERVAL
P S I
1.60
1.40
1.20
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE D-2



E 03
DIRECTIONAL TENSILE STRENGTH VS LOAD AXIS ORIENTATION
SANILAC CO. MI WELL # 103 DEPTH, FT: 1359 TO 1363
UNIT 1A ANTRIM SHALE
95% CONF INTERVAL
1.60
1.50
1.40
PSI
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE D-3


E 03
DIRECTIONAL TENSILE STRENGTH VS LOAD AXIS ORIENTATION
SANILAC CO. MI WELL # 103 DEPTH, FT: 1315 TO 1363
WELL COMPOSITE
95% CONF INTERVAL
1.55
1.50
1.45
1.40
1.35
PSI
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH