# CLIFFS MINERALS, INC.
# EASTERN GAS SHALES PROJECT
# PENNSYLVANIA #2 WELL, ALLEGHENY COUNTY
# PHASE III REPORT
# SUMMARY OF LABORATORY ANALYSES AND MECHANICAL CHARACTERIZATION RESULTS

FEBRUARY 1981

EGSP-Pennsylvania #2 Well, Allegheny County

## Executive Summary

### General

This report summarizes the results of characterization work performed on approximately 545 feet of 3-1/2-inch diameter core retrieved from the EGSP-Pennsylvania #2 well in Allegheny County. Information provided in previous reports 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 are also summarized.

Core retrieval by Cliffs Minerals, Inc. began on March 1, 1979 and was completed March 9, 1979. Three stratigraphic units were identified and described; these include: Harrel Formation (Harrel undifferentiated and the Burkett Shale Member), Hamilton Group (Tully Limestone, Mahantanto Shale, Marcellus Shale), and Onondaga Limestone. Natural fractures in the core consist primarily of subhorizontal bedding plane faults with well-developed slickenlines. The faults strike between N30$^{o}$E and N60$^{o}$W; most have dips of less than 15$^{o}$. Orientation of the slickenlines generally range from N51$^{o}$W to N71$^{o}$W. Three minor near-vertical fracture sets are also present in the core; these sets strike from N10$^{o}$W to N10$^{o}$E, N40$^{o}$W to N50$^{o}$W, and at or near N90$^{o}$E. Physical properties tests indicate the preferred direction of fracturing as listed: 1) N30$^{o}$E $\pm 15^{o}$ for the Harrel Formation as indicated by point load induced fractures, 2) N30$^{o}$E $\pm 15^{o}$ for the Mahantango Shale as indicated by pretest fractures, directional ultrasonic velocity measurements, and point load induced fractures. A sufficient number of samples could not be obtained from the Tully Limestone and Marcellus Shale to acquire statistically significant results.

## EGSP-Pennsylvania #2 Well, Allegheny County

## Technical Summary

### General

This summary presents a detailed characterization of the Devonian Shale occurrence in the EGSP-Pennsylvania #2 well. 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 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 545 feet of core retrieved from a well drilled in Allegheny County of southeastern Pennsylvania.

### Location

The well, designated EGSP-Pennsylvania #2, is located 0.5 miles north of the town of Monongahela, Pennsylvania on the east side of the Monongahela River. Monongahela, Pennsylvania is located approximately 17 miles south of Pittsburgh, Pennsylvania.

## Stratigraphy

A total of 545 feet of core was retrieved from the Allegheny County well designated EGSP-Pennsylvania #2. Coring began at 6,951 feet in the upper part of the Harrel Formation and was terminated at 7,496 feet in the upper part of the Onondaga Limestone. The entire interval was cored. Core retrieval was successful throughout the length of the cored interval, except for numerous zones of rubble which most probably originated during coring. Formation thicknesses are summarized below. A brief summary description for each formation or member follows.

### FORMATION THICKNESSES

| Formation | Depths | Formation Thickness | Depths Cored |
|---|---|---|---|
| Harrel Formation: | | | |
| Undifferentiated | C.P.-7,061' | --- | 6,951'-7,061' |
| Burkett Shale | 7,061'-7,084' | 23' | 7,061'-7,084' |
| Hamilton Group: | | | |
| Tully Limestone | 7,084'-7,144' | 60' | 7,084'-7,144' |
| Mahantango Shale | 7,144'-7,332' | 188' | 7,144'-7,332' |
| Marcellus Shale | 7,332'-7,496' (?) | 164' | 7,332'-7,496' |
| Onondaga Limestone | 7,496'(?)-T.D. | --- | 7,496'-7,496.2' |

## Harrel Formation

The Harrel Formation is present in the EGSP-Pennsylvania #2 well between 6,928(?) feet and 7,084 feet. The cored portion (6,951 ft. to 6,084 ft.) includes the lower 80% of the formation and one identifiable member, the Burkett Shale, which occurs between 7,061 and 7,084 feet.

The Harrel Formation consists mainly of grayish black to medium dark gray, thinly to thickly laminated silty mudstones and mudstones. Occasional, slightly calcareous siltstone laminae are present in the upper 1/2. The interval contains numerous calcareous and shaly zones. Fossils consist of inarticulate and articulate brachiopods, cephalopods, and plant fragments. Pyrite and mud-filled burrow structures are common in the upper 1/3, but are rare in the lower portion of the interval. Pyrite occurs as lenses, nodules, and disseminated grains throughout, but is most common in the lower 1/2.

The contact between the Harrel Formation and the underlying Tully Limestone (Hamilton Group) is marked on the geophysical well logs by a decrease in gamma radiation from ∿300 API units (Burkett Shale Member) to ∿100 API units (Tully Limestone). This contact is gradational in the core, but can be distinguished by a change to lighter colors and by an increase in carbonate content.

Hamilton Group

The Hamilton Group is composed of three formations: the Tully Limestone, Mahantango Shale, and Marcellus Shale. It is present in the core between 7,084 and 7,496 (?) feet, which comprises the entire group.

Tully Limestone

The Tully Limestone is present in the core from 7,084 to 7,144 feet. It consists of thin to thick bedded, dark gray to medium gray, lime mudstone and calcareous mudstone. The lime mudstones are present throughout, but are most common between 7,095 and 7,127 feet. Zones of mottling, pyritized burrow structures, and pyrite nodules and lenses occur throughout. Fossils contained in the interval include a few pyritized shell fragments in the upper 1/4 and a single articulate brachiopod at the base of the interval. Disc fracture frequency is much lower in this formation than in the adjacent formations.

The Tully Limestone is easily recognized by its relatively low gamma count (∿75 - 100 API units) on the geophysical logs, and by its lighter rock color and high carbonate content in the core.

Mahantango Shale

The Mahantango Shale is present in the core between 7,144 and 7,332 feet. It can be divided into two parts on the basis of rock color and fossil content. The upper part (7,144 ft. to 7,235 ft.) is composed of thinly laminated, grayish black mudstone. Fossils contained in this interval include abundant, finely divided carbonaceous fragments, occasional large plant fragments, and mud lumps (fecal pellets ?). Pyrite is infrequently present and occurs as lenses, nodules, and disseminated grains. The interval contains zones which are fissile and weakly calcareous.

The lower part (7,235 ft. to 7,332 ft.) also is composed of thinly laminated mudstone, but is slightly lighter in color (dark gray) than the overlying interval. This interval contains a varying assortment of fossils and biogenic structures which include articulate and inarticulate (Orbiculoidea sp.) brachiopods; cephalopods, pelecypods, unidentified fossil fragments, finely divided carbonaceous fragments, zones of bioturbation, and mud- and pyrite-filled burrow structures. Numerous calcareous concretions are also present.

The contact between the Mahantango Shale and the underlying Marcellus Shale is gradational in the core. This contact can be distinguished by a gradual color change from dark gray to grayish black. On the geophysical logs the contact is marked by a slight increase in gamma radiation from ∿150 to ∿200 API units.

Marcellus Shale

The Marcellus Shale, the lowest formation of the Hamilton Group, is present in the core from 7,332 to 7,496 (?) feet. The Marcellus Shale generally is composed of thinly laminated, black to grayish black mudstone and shaly mudstone. Thinly laminted to thin bedded olive gray lime mudstones also are present at 7,381 feet, 7,416 feet, 7,442 feet, and between 7,483 feet and the base of the core. Fossils contained within the formation include articulate and inarticulate (Orbiculoidea sp.) brachiopods, pelecypods, and fecal pellets in addition to coral and shell fragments. These fossils are most commly present between 7,371 and 7,417 feet, and below 7,460 feet. Zones containing fossils and biogenic structures are commonly less shaly, more calcareous, and occasionally contain calcareous concretions. Pyrite occurs as lenses, nodules, and disseminated grains, as coatings on shell fragments and fecal pellets, and as mineralized burrow structures.

The contact between the Marcellus Shale and the underlying Onondaga Limestone is difficult to determine. In the core, no distinct contact is present. Near the base of the Marcellus, numerous thin interbedded limestones, mudstones, and calcareous mudstones are present.

On the geophysical logs there is a decrease in gamma count below 7,496 feet. This is the sole reason for placing the contact at 7,496 feet. However, the gamma ray log only extends down to 7,500 feet, so there remains the possibility of additional mudstones interbedded with limestones below 7,500 feet.

## Onondaga Limestone

The Onondaga Limestone is composed of thin bedded, medium dark gray wackestone and packstone. Sand size skeletal fragments, mud-filled burrow structures, and a few pyrite nodules and lenses occur throughout. As noted above, there is some doubt as to whether the cored interval extends into the main body of the Onondaga or only into a transitional zone between the Onondaga and the overlying Marcellus.

## Fracture Analysis

Approximately 226 natural fractures (165 faults, 19 microfaults, 35 simple joints, and 7 compound joints) are present in the core. The distribution of natural fractures throughout the cored interval is shown below.

The greatest concentration of natural fractures occurs within the Marcellus Shale where natural fracture frequency exceeds 1.0 fractures per foot.

DISTRIBUTION OF NATURAL FRACTURES

| Formation | Depths Cored | Core Length | Number of Fractures | Frequency Per Foot |
|---|---|---|---|---|
| Harrel Formation: | | | | |
| Undifferentiated | 6,951'-7,061' | 110' | 41 | 0.37 |
| Burkett Shale | 7,061'-7,084' | 23' | 1 | 0.04 |
| Hamilton Group: | | | | |
| Tully Limestone | 7,084'-7,144' | 60' | 2 | 0.03 |
| Mahantango Shale | 7,144'-7,332' | 188' | 8 | 0.04 |
| Marcellus Shale | 7,332'-7,496' | 164' | 174 | 1.06 |
| Onondaga Limestone | 7,496'-7,496.2' | 0.2' | 0 | 0.00 |

Fractures contained in the Marcellus Shale are generally low angle near-horizontal faults. Slickensides are common on the fault plane surfaces.

Natural fracture frequency also is relatively high in the Harrel Formation. Fractures contained in this formation are usually faults or microfaults. Frequency within the interval is 0.32 fractures per foot. Slickensides are common and well developed.

All planar fractures were analyzed to identify common structural trends in the core. One major fault trend and three minor joint trends are evident.

TREND 1: Faults striking between N30°E and N60°W, dipping ~15°NE.

TREND 2: Joints striking between N10°W and N10°E, near-vertical.

TREND 3: Joints striking ~N90°E, near-vertical.

TREND 4: Joints striking N40°W and N50°W, near-vertical.

Trend 1 represents the greatest number of individual fractures. The majority of fractures in this set are near-horizontal bedding plane faults with well-developed slickensides present on most of the fault surfaces. The direction of movement, as indicated by slickenlines, ranges between N15°W and N71°W with a concentration within this trend plunging 8° in the direction S26°E. These slickenlines are approximately perpendicular to the fold axes of the local anticlines (Bennison, 1976; Gray, et al, 1960). Also, a minor concentration of near-horizontal slickenlines trend between N46°E and N51°E and both dip-slip and oblique-slip movement is evident in both slickenline trends.

Trends 2 and 3, which are poorly defined, appear to be near-vertical conjugate joint sets. The fractures in these sets vary in length from 0.1 to 2.4 feet and are mineralized with either calcite or pyrite.

Trend 4, which is also poorly defined, is composed of near-vertical joints, some of which are calcite mineralized.

It should be noted that numerous (~20%) fractures present in the core do not fit into the defined trends. This is probably due to a relative lack of structural control resulting from very low dips associated with the regional structures. Due to the excessive "poker chipping," rubble zones, and low angle dips involved, the interpretations given above should be considered somewhat speculative.

Physical Properties Testing

The results of pretest fracture studies, point load induced fracture studies, and directional ultrasonic velocity measurements performed on the EGSP-Pennsylvania #2 samples indicate a preferred direction of fracturing of N30°E $\pm 15^{\circ}$ in the Harrel Formation (6,928 to 7,084 ft. tested) and in the Mahantango Member (7,215 to 7,320 ft. tested) of the Hamilton Group.

Available Reports

For a more detailed account of field operations and lithology and fracture analyses, the following report is available:

1) EGSP-Pennsylvania #2 Well - Allegheny County, Phase II Report, Preliminary Laboratory Results, June 1980; Cliffs Minerals, Inc.: Prepared under Contract No. DE-AC21-78MC 08100, U.S. Department of Energy, Morgantown Energy Technology Center, Morgantown, West Virginia 26505.

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

Well Report for

EGSP-Pennsylvania #2 - Allegheny County

Department of Mining Engineering
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## Summary of Mechanical Characterization Results

The purpose of mechanical characterization of samples from the EGSP-Pennsylvania #2 core is to determine the orientation of preferred planes of weakness in the Devonian gas shales at the Allegheny County well site.

Prior to testing, the length and orientation of pretest fractures identified in each sample were recorded. Numerous bedding fractures occur on the surface of these samples, but very few additional pretest fractures are present.

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 interval of N30°E ±15° in five out of twelve total 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 occur most frequently in the N30°E ±15° orientation (47 percent of 36 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. Samples from a given interval are tested with the loading axis in six different orientations by this method. The preferred direction of fracture will be parallel to the loading axis in the specimen for which the lowest tensile strength value was obtained. An insufficient number of samples were received from this well to perform more than one set of directional tensile strength measurements.

# INTRODUCTION

The purpose of mechanical characterization of samples from the EGSP-Pennsylvania #2 well is to determine the orientation of preferred planes of weakness in the Devonian gas shales at the Allegheny County well site.

A series of samples, representing 545 feet of core taken from the Pennsylvania #2 well, were tested. The tested core intervals extend from 6,965 feet to 7,320 feet below surface and are summarized in Table 1.

Table 1: Formations Tested

| Formation | Depth Cored | Depth Tested |
|---|---|---|
| Harrel Formation | 6,951'-7,084' | 6,965'-7,016' |
| Hamilton Group | | |
| Tully Limestone Member | 7,084'-7,144' | 7,136' |
| Mahantango Shale Member | 7,144'-7,332' | 7,215'-7,320' |
| Marcellus Shale Member | 7,332'-7,496' | None |
| Onondaga Limestone | 7,496'-7,496.2' | None |

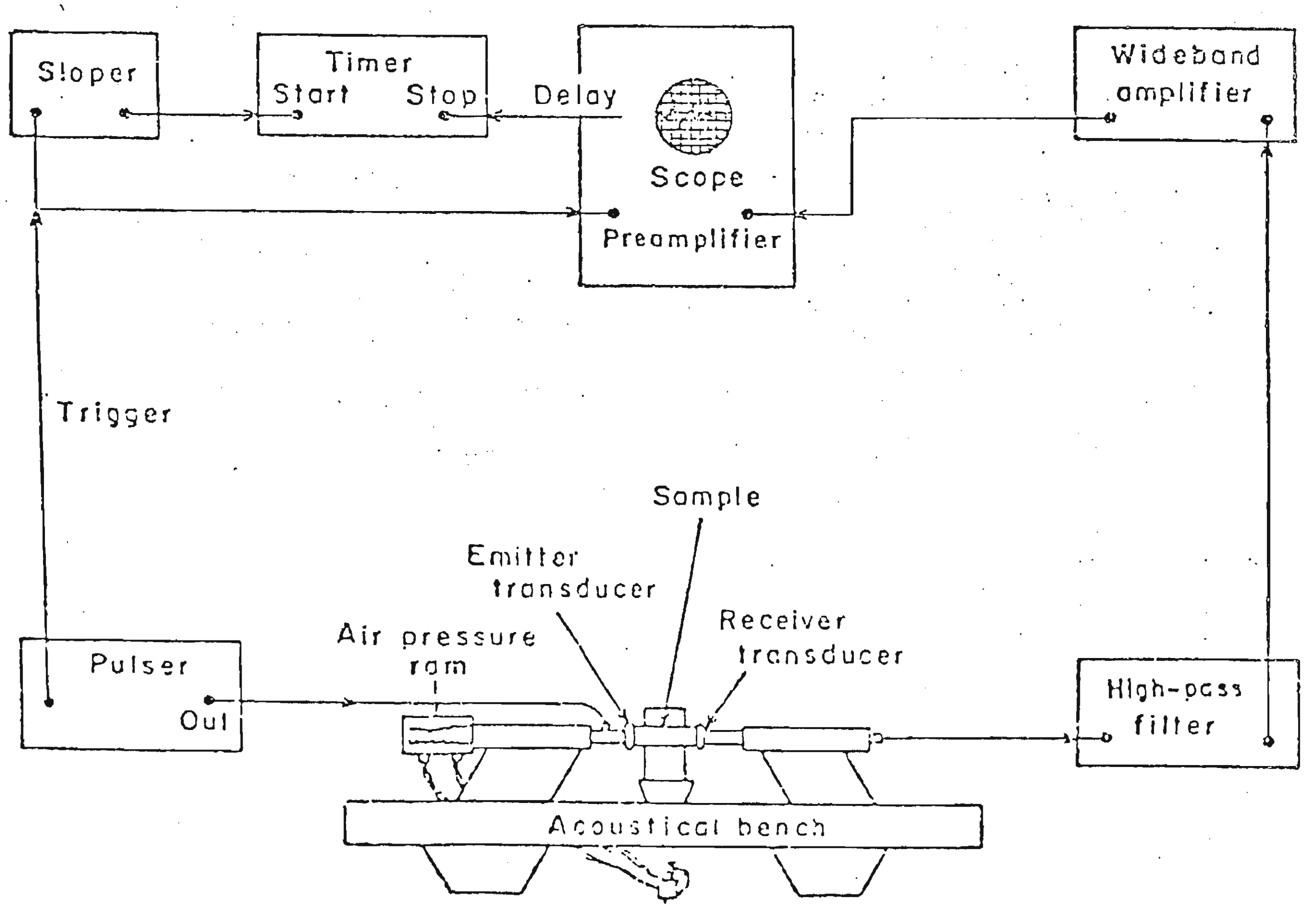
The physical property tests employed are: 1) directional ultrasonic velocity mesurements; 2) point load induced fracture; and 3) directional tensile strength tests. In addition, all fractures (hereafter referred to as "pretest fractures") are systematically recorded before the physical property tests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

The theories on which these tests are based are summarized as follows:

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 (Birth, 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).

Figure 1: Schematic Diagram of Ultrasonic Pulse Apparatus (Thill, Peng, 1974)



An ultrasonic pulse measurement system operates as shown in Figure 1. 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 (Anderson, Liebermann, 1966):

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

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 will 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

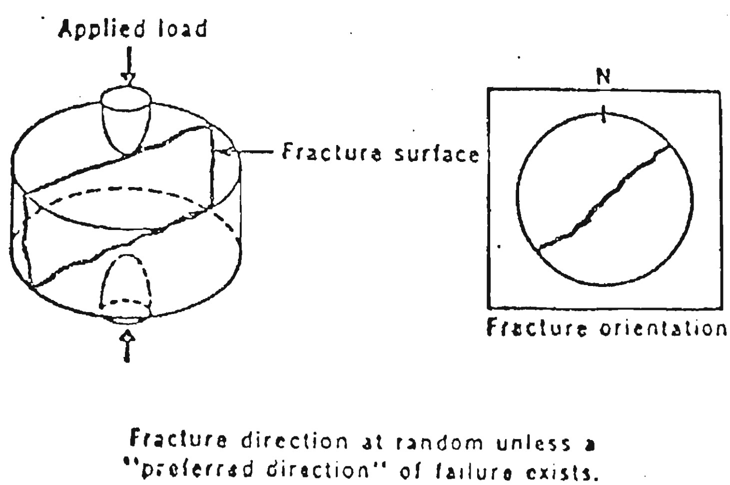
s = standard deviation

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 (Anderson, Liebermann, 1966; McWilliams, 1966) (Figure 2).

Figure 2. Schematic Diagram of Point Load Test (Anderson, Liebermann, 1966)



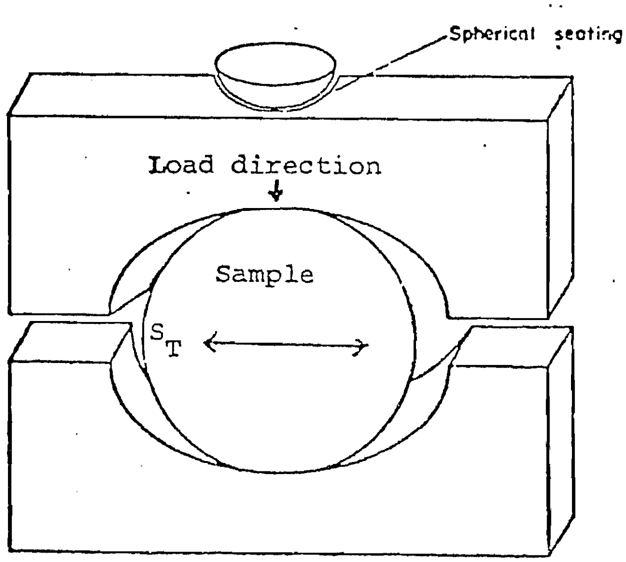
The point load testing apparatus consists of a load frame with two identical platens. These loading contact points are spherically truncated cones between which the specimen is axially centered.

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




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 incorporates 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 speciments 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 ($0^\circ$, $30^\circ$, $60^\circ$, $90^\circ$, $120^\circ$, $150^\circ$), and its edges corresponding to this mark are sanded if necessary to insure even loading.

4. The dimensions of the samples are recorded; diameter and thickness in inches; if necessary, the samples are taped with masking tape.

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. Tensile strength normal to the axis of loading is determined using the formula: $S_T = 2P(\pi dt)^{-1}$ 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 fractures, 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 formation.

Table 2

EGSP-Pennsylvania #2 Core, Allegheny County
Frequency Distribution of Preferred
Direction of Fracturing
Orientation in Degrees from North

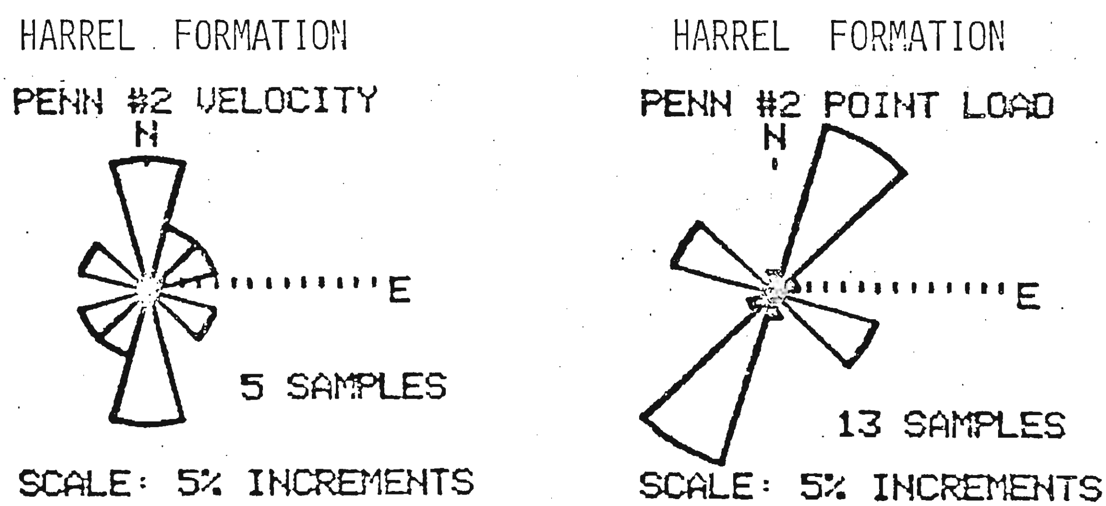
| Formation | Test | $0^{\circ}$ | $30^{\circ}$ | $60^{\circ}$ | $90^{\circ}$ | $120^{\circ}$ | $150^{\circ}$ | Total Samples* |
|---|---|---|---|---|---|---|---|---|
| Harrel Formation 6,965'-7,016' | Velocity | 2 | 1 | 1 | 0 | 1 | 0 | 5 |
| | Point Load | 1 | 7 | 1 | 0 | 4 | 0 | 13 |
| | DTS | 0 | 0 | 0 | 0 | 1 | 0 | 6 |
| Hamilton Group Tully Limestone Member 7,136' | Pretest Fractures | 1 | 0 | 0 | 1 | 0 | 0 | 2 |
| | Velocity | 0 | 0 | 1 | 0 | 0 | 0 | 1 |
| Mahantango Shale Member 7,215'-7,320' | Pretest Fractures | 0 | 2 | 0 | 0 | 0 | 1 | 3 |
| | Velocity | 2 | 4 | 0 | 0 | 0 | 0 | 6 |
| | Point Load | 7 | 10 | 4 | 0 | 1 | 1 | 23 |
| Well Composite | Pretest Fractures | 1 | 2 | 0 | 1 | 0 | 1 | 5 |
| | Velocity | 4 | 5 | 2 | 0 | 1 | 0 | 12 |
| | Point Load | 8 | 17 | 5 | 0 | 5 | 1 | 36 |
| | DTS | 0 | 0 | 0 | 0 | 1 | 0 | 6 |

* Total samples tested or total number of pretest fractures identified.

Harrel Formation - 6,965 to 7,016 feet:

No pretest fractures other than bedding fractures at a 150° ±10° strike are present. Point load induced fractures occur most frequently in the N30°E ±15° orientation (7 out of 13 induced fractures). Of the five ultrasonic velocity samples received, no preferred orientation is statistically significant. An insufficient number of samples were received from this interval to determine a statistically significant preferred direction of fracturing from the set of directional tensile strength samples. Figure 4 is the frequency distribution of preferred direction of fracturing in the Harrel Formation. Tabulated results are presented in Appendices B, C, and D.

Figure 4



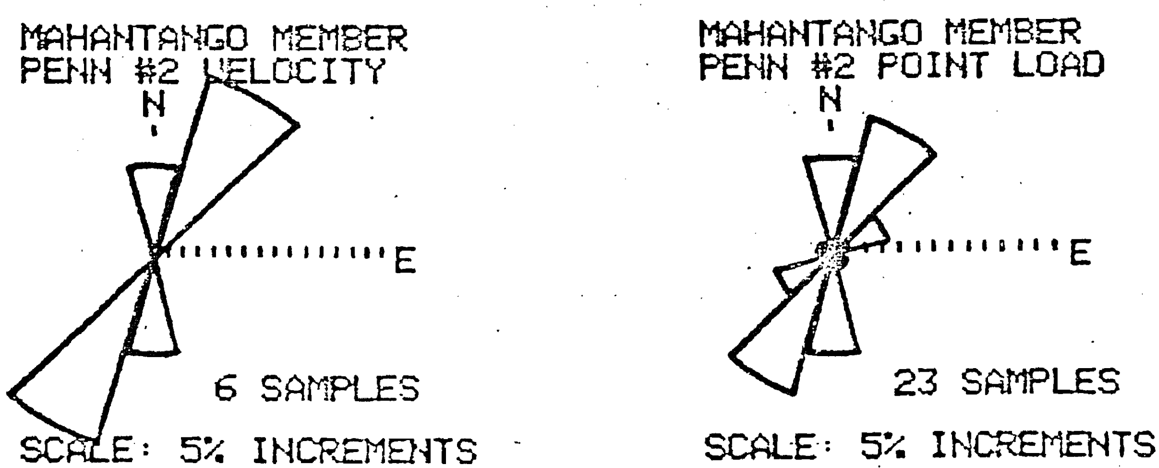
Hamilton Group: Tully Limestone Member - 7,084 to 7,144 feet:

Two pretest fractures were present on the one sample received from this interval. The pretest fractures originated directly from orientation grooves at N10°E and N90°E. The velocity sample indicates N60°E as the preferred direction of fracturing. Tabulated results are presented in Appendices A and B.

Hamilton Group: Mahantango Shale Member - 7,215 to 7,320 feet:

Pretest fractures occur most frequently in the N30°E orientation (2 out of 3 pretest fractures). Velocity measurements indicate N30°E as the preferred direction of fractures (4 out of 6 velocity samples). Point load induced fractures occur most frequently in the N30°E orientation (10 out of 23 induced fractures). Figure 5 is the frequency distribution of preferred direction of fracturing in the Mahantango Shale. Tabulated results are presented in Appendices A, B, and C.

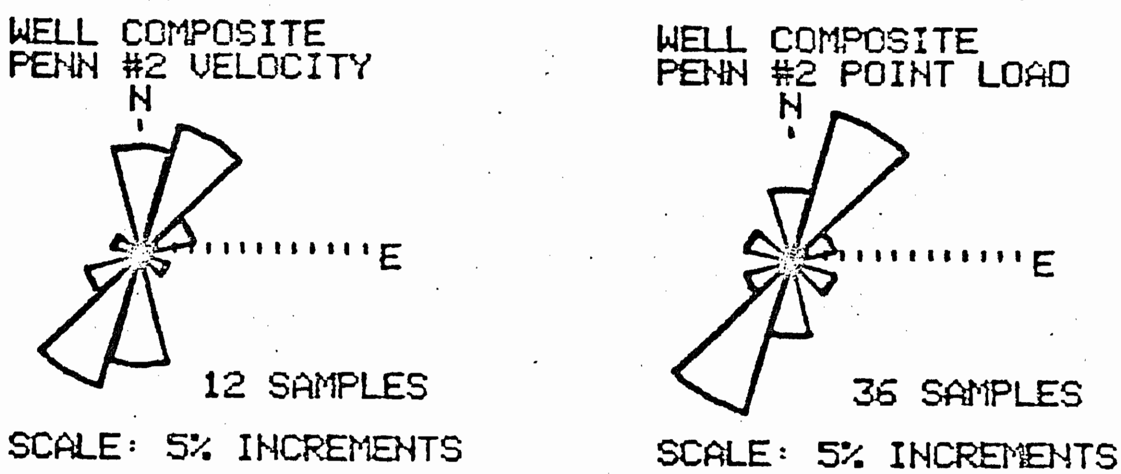
Figure 5



Well Composite:

The frequency distributions of preferred direction of fracturing for the entire cored well are displayed in Figure 6. Pretest fractures occur most frequently in the N30°E orientation (40 percent of the pretest fractures). Ultrasonic velocity measurements indicate a preferred direction of fracturing of N30°E (42 percent of the velocity samples). Point load induced fractures occur most frequently in the N30°E orientation (47 percent of the induced fractures). Tabulated results are presented in Appendices A, B, C, and D.

Figure 6



## CONCLUSIONS

The data presented in this report indicate that core samples from EGSP-Pennsylvania #2 well exhibit a directional variation in physical properties. Prediction of the preferred direction of induced fracturing at the Allegheny County well site was 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 overall agreement between these tests in each stratigraphic interval suggests that these physical property measurements do indicate a preferred direction of fracturing in core samples.

The following conclusions may be drawn from this investigation:

1) The preferred direction of fracturing for the Harrel Formation (6,965 to 7,016 feet tested) is N30°E $\pm 15^\circ$ as indicated by point load induced fractures.

2) The preferred direction of fracturing for the Tully Limestone Member of the Hamilton Group (7,084 to 7,144 feet cored) cannot be interpreted because of the statistically small number of samples received. The one velocity sample indicated N60°E $\pm 15^\circ$ as the direction of fracturing.

3) The preferred direction of fracturing for the Mahantango Shale Member of the Hamilton Group (7,215 to 7,320 feet tested) is N30°E $\pm 15^\circ$ as indicated by pretest fractures, directional ultrasonic velocity measurements, and point load induced fractures.

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# APPENDICES

# APPENDIX A

Results of Pretest Fracture Measurements

## TABLE A-1

Pretest Fractures in Specimens*

| | Depth | 0° | 30° | 60° | 90° | 120° | 150° | Total Fractures |
|---|---|---|---|---|---|---|---|---|
| Hamilton Group | | | | | | | | |
| Tully Limestone Shale Member | 7,136.6 | .6 | | | .5 | | | 2 |
| Mahantango Shale Member | 7,315.5 | | .6,.7 | | | | 2.0 | 3 |

* All pretest fractures identified were found on velocity samples only.

# APPENDIX B

Results of Directional Ultrasonic Velocity Measurements

TABLE B-1

## WELL # 2 IN PENN

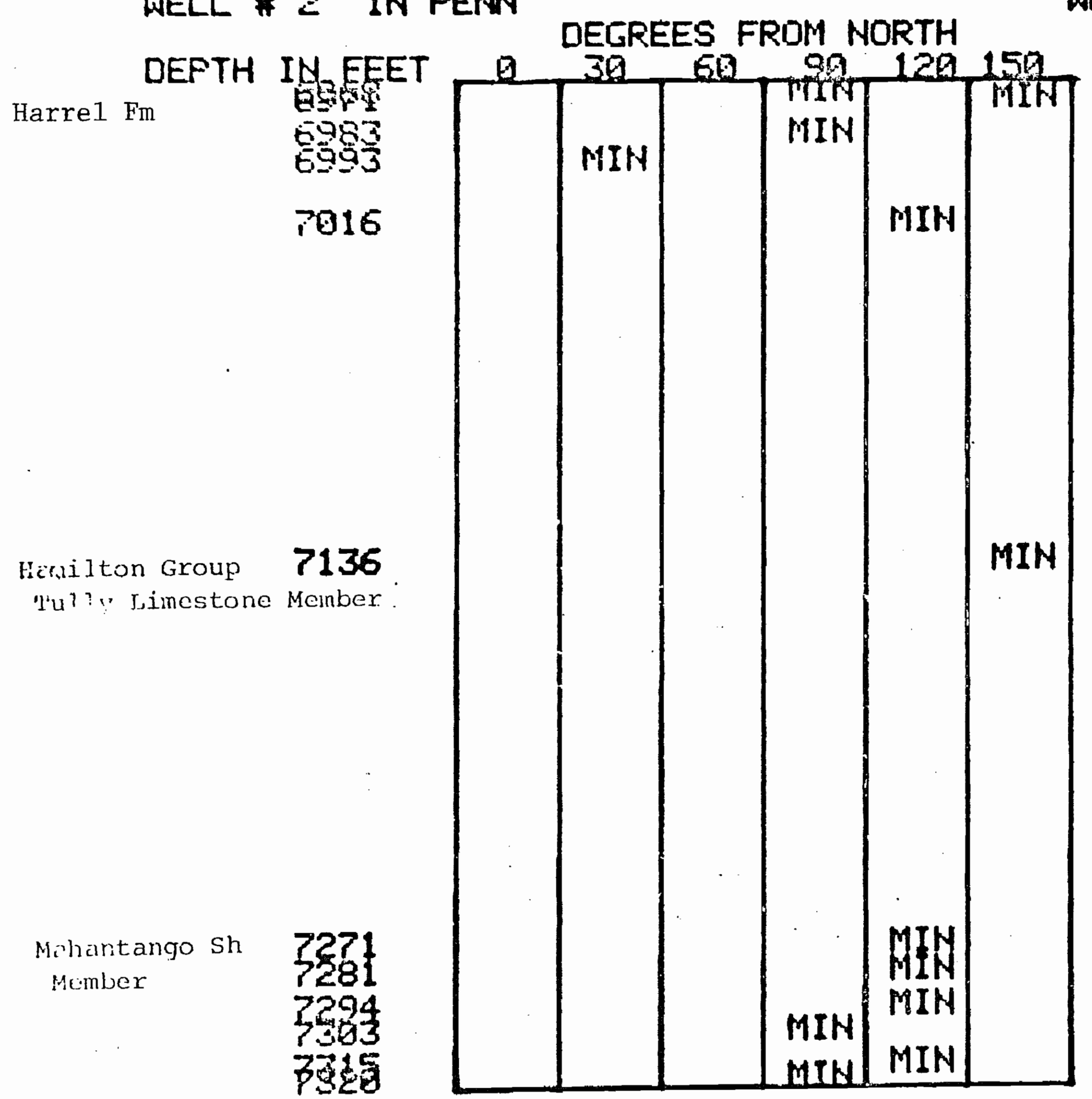
### DIRECTIONAL P WAVE VELOCITIES

AVERAGE VELOCITIES IN KM/SEC & ORIENTATION IN DEGREES FROM NORTH

| | DEPTH IN FEET | 0 DEG | 30 DEG | 60 DEG | 90 DEG | 120 DEG | 150 DEG |
|---|---|---|---|---|---|---|---|
| Harrel Fm | 6968 | 5.116 | 5.101 | 5.069 | 5.031 | 5.032 | 5.076 |
| | 6971 | 5.08 | 5.045 | 5.065 | 5.037 | 5.044 | 5.025 |
| | 6983 | 5.091 | 5.094 | 4.993 | 4.992 | 5.018 | 5.063 |
| | 6993 | 5.623 | 5.532 | 5.567 | 5.567 | 5.576 | 5.632 |
| | 7016 | 4.515 | 4.693 | 4.615 | 4.419 | 4.284 | 4.344 |
| Tully Limestone | 7136 | 4.678 | 4.799 | 4.918 | 4.918 | 4.846 | 4.613 |
| Mahantango Sh | 7271 | 5.175 | 5.194 | 5.152 | 5.08 | 5.063 | 5.093 |
| Member of | 7281 | 5.052 | 5.073 | 5.061 | 5.025 | 5.007 | 5.018 |
| Hamilton Group | 7294 | 5.056 | 5.107 | 5.074 | 5.005 | 4.99 | 5.006 |
| | 7303 | 5.069 | 5.134 | 5.126 | 4.98 | 5.02 | 5.039 |
| | 7315 | 5.07 | 5.116 | 5.058 | 5.022 | 5 | 5.02 |
| | 7320 | 4.969 | 5.004 | 5.005 | 4.962 | 4.971 | 5.026 |
| | AVERAGE VELOCITY | 5.041 | 5.074 | 5.059 | 5.003 | 4.988 | 4.996 |

TABLE B-2

ORIENTATION OF ULTRASONIC VELOCITY MINIMUM
WELL # 2 IN PENN




WELL COMPOSITE

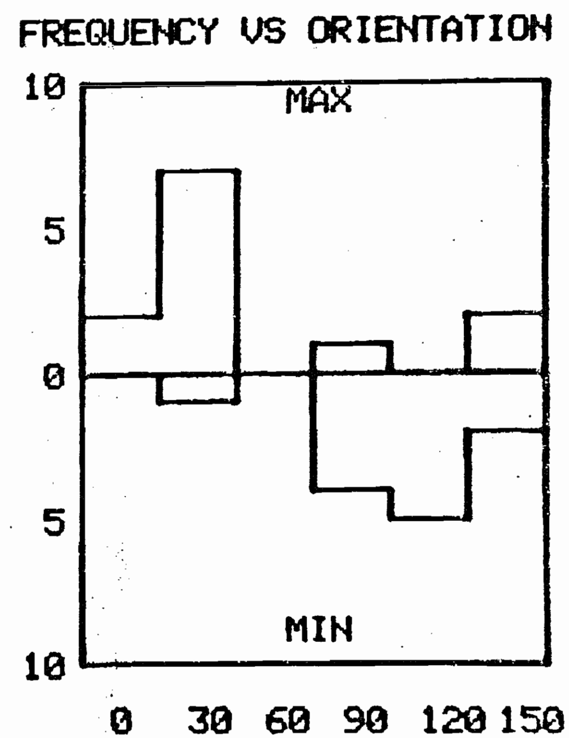


FIGURE B-1

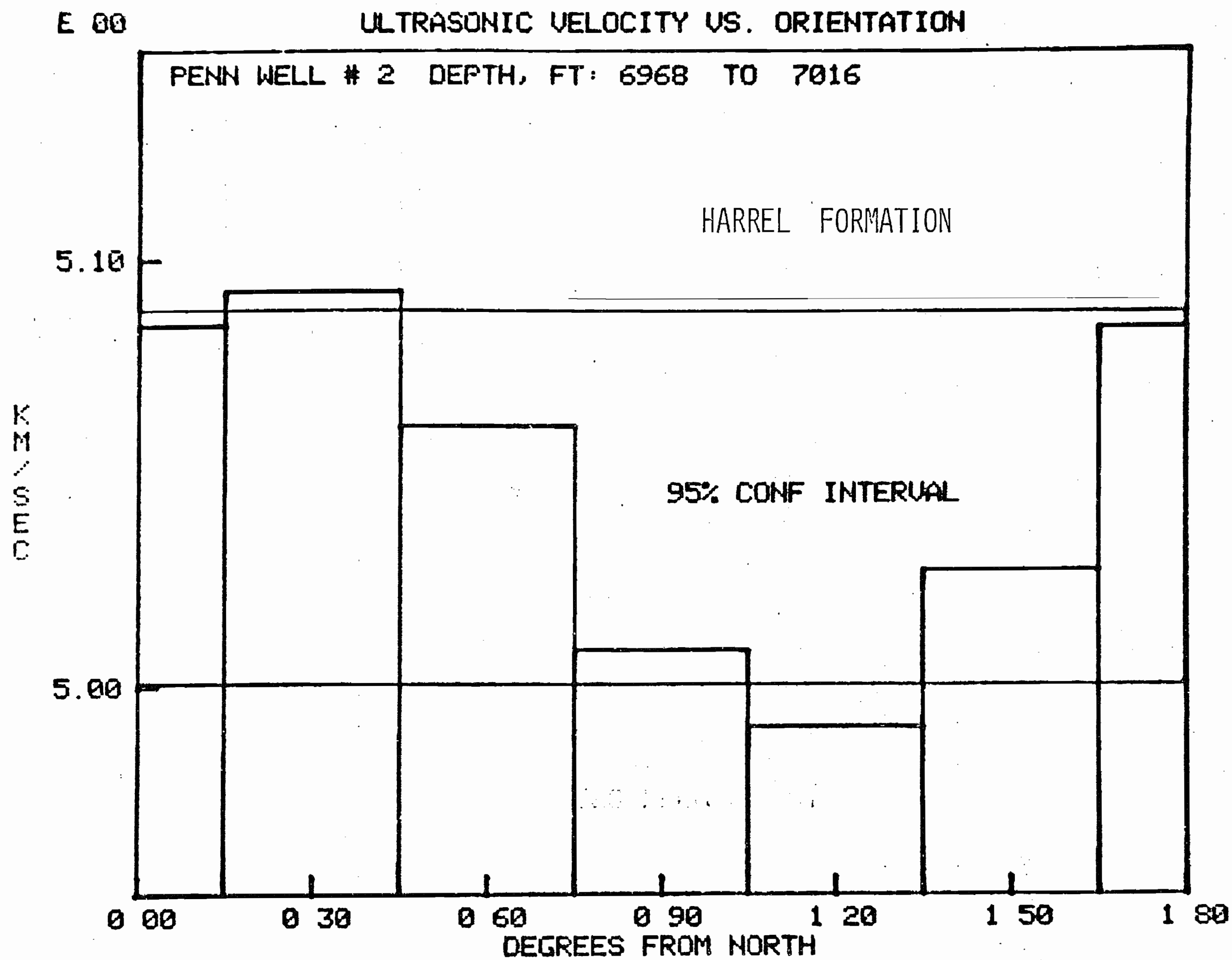

E 00
ULTRASONIC VELOCITY VS. ORIENTATION
PENN WELL # 2 DEPTH, FT: 6968 TO 7016
HARREL FORMATION
5.10
95% CONF INTERVAL
KM/SEC
5.00
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES FROM NORTH

FIGURE B-2

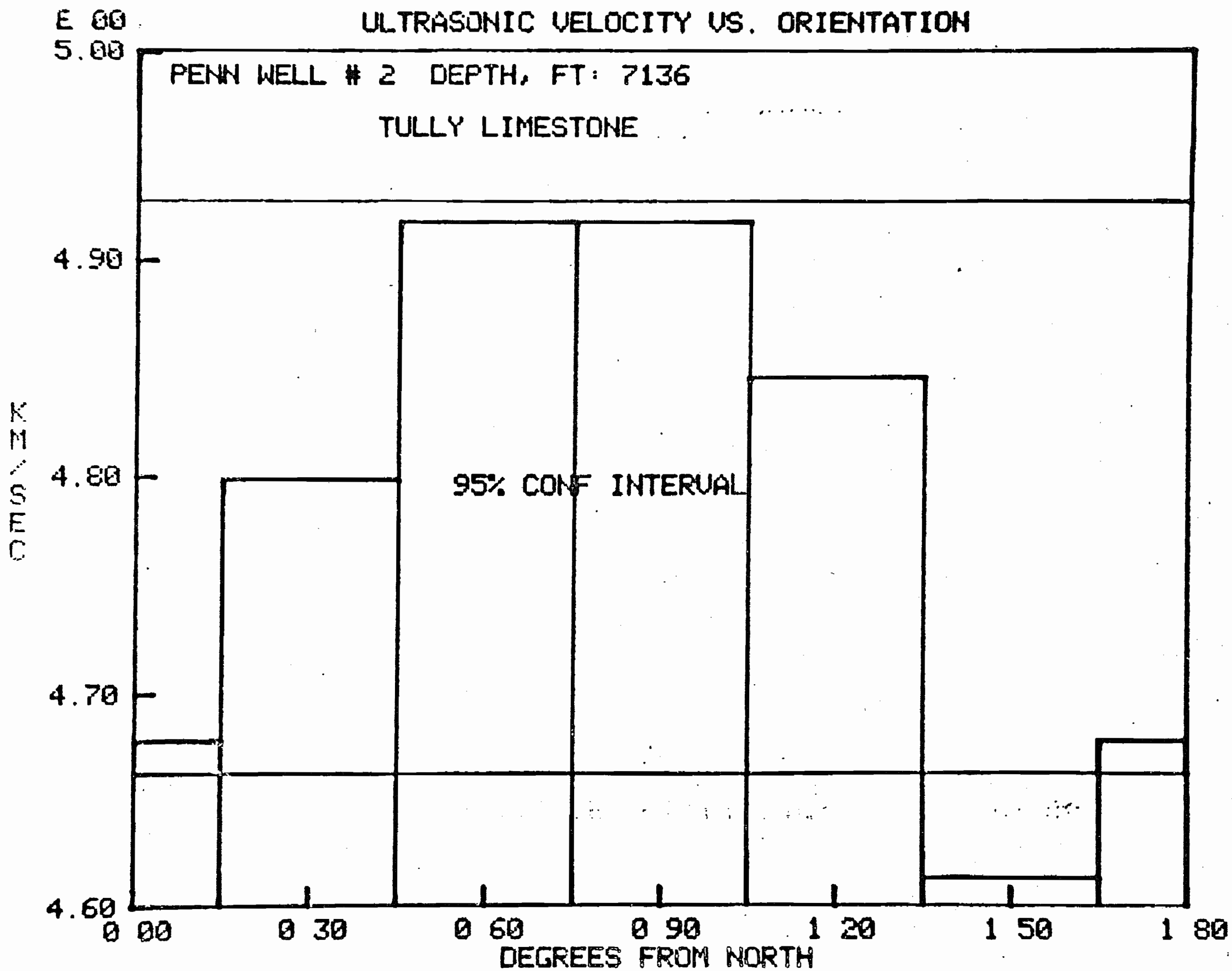

ULTRASONIC VELOCITY VS. ORIENTATION
PENN WELL # 2 DEPTH, FT: 7136
TULLY LIMESTONE
95% CONF INTERVAL
E 00
5.00
4.90
4.80
4.70
4.60
KM/SEC
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES FROM NORTH

FIGURE B-3

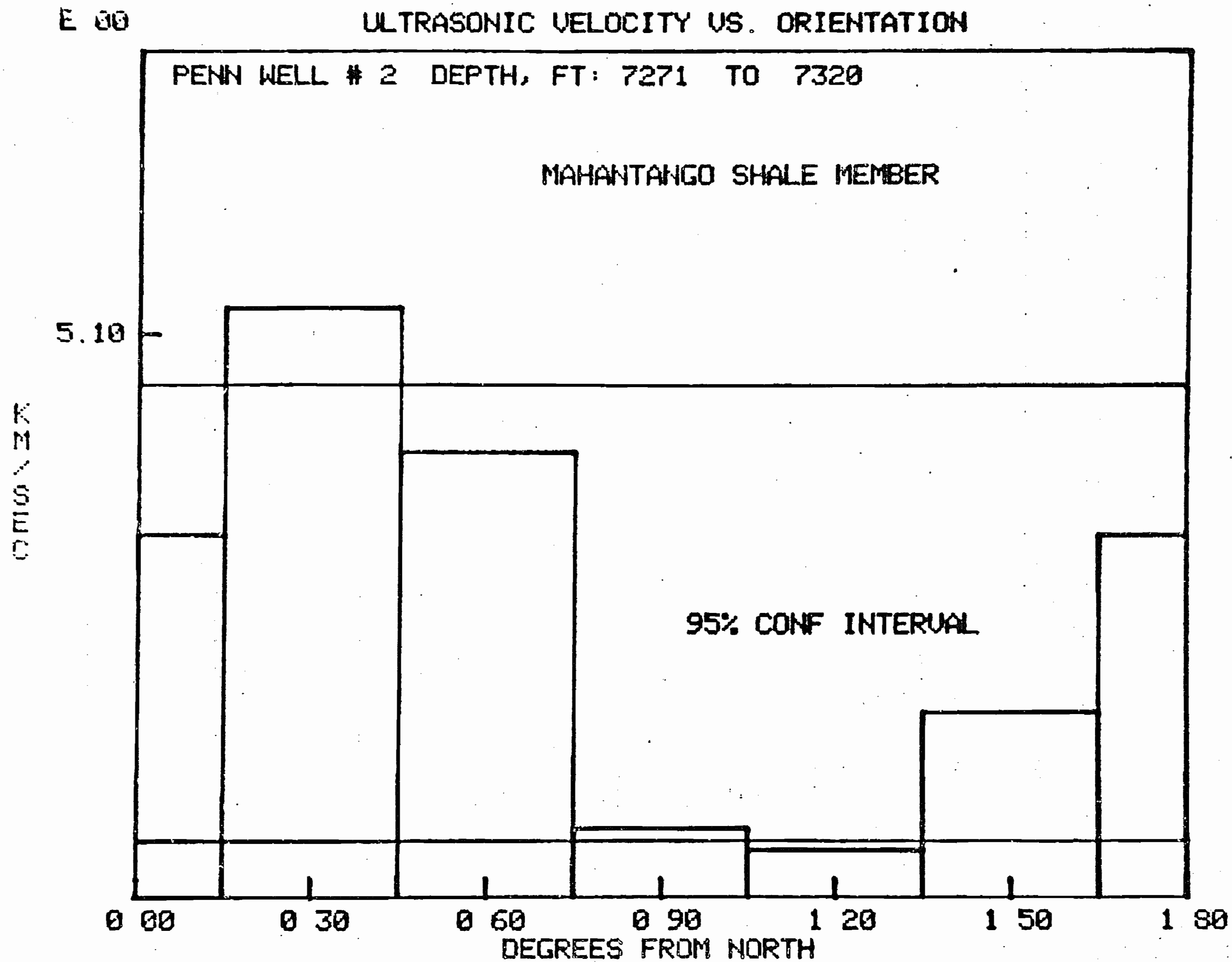
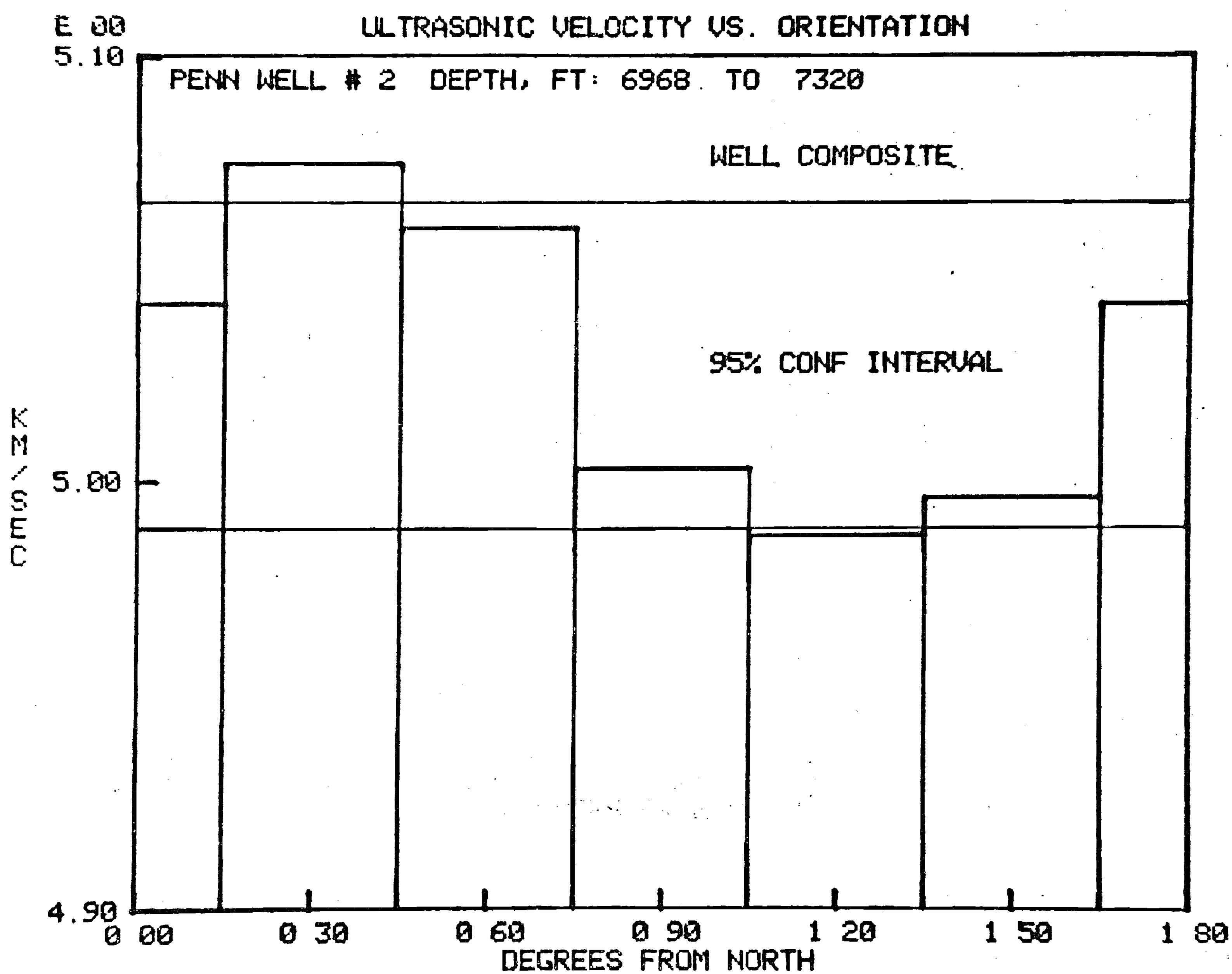

ULTRASONIC VELOCITY VS. ORIENTATION
PENN WELL # 2 DEPTH, FT: 7271 TO 7320
MAHANTANGO SHALE MEMBER
95% CONF INTERVAL
E 00
5.10
KM/SEC
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES FROM NORTH

FIGURE B-4


ULTRASONIC VELOCITY VS. ORIENTATION
PENN WELL # 2 DEPTH, FT: 6968 TO 7320
WELL COMPOSITE
95% CONF INTERVAL
E 00
5.10
5.00
4.90
KM/SEC
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES FROM NORTH

# APPENDIX C

Results of Point Load Tests

TABLE C-1

## WELL # 2 IN PA

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

| | DEPTH FEET | FREQUENCY 0 DEG | 30 DEG | 60 DEG | 90 DEG | 120 DEG | 150 DEG | # OF SAMPLES |
|---|---|---|---|---|---|---|---|---|
| Harrel Fm | 6965 | 1 | 1 | 0 | 0 | 0 | 0 | 2 |
| | 6975 | 0 | 4 | 1 | 0 | 0 | 0 | 5 |
| | 6985 | 0 | 2 | 0 | 0 | 4 | 0 | 6 |
| Hamilton Group | 7215 | 0 | 1 | 0 | 0 | 0 | 0 | 1 |
| Mahantango Sh | 7275 | 2 | 1 | 3 | 0 | 1 | 0 | 7 |
| Member | 7285 | 2 | 2 | 1 | 0 | 0 | 1 | 6 |
| | 7295 | 1 | 2 | 0 | 0 | 0 | 0 | 3 |
| | 7305 | 1 | 1 | 0 | 0 | 0 | 0 | 2 |
| | 7315 | 1 | 3 | 0 | 0 | 0 | 0 | 4 |
| | TOTAL FREQ | 8 | 17 | 5 | 0 | 5 | 1 | 36 |

TABLE C-2

# WELL # 2 IN PA

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

| | DEPTH | POINT LOAD INDEX | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | FEET | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Harrel Fm | 6965 | 8886 | 5571 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 6975 | 3780 | 5099 | 3549 | 4091 | 4817 | 0 | 0 | 0 | 0 | 0 |
| | 6985 | 3280 | 3855 | 6180 | 4533 | 7471 | 4150 | 0 | 0 | 0 | 0 |
| Hamilton Group | 7215 | 6420 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mahantango Sh | 7275 | 5544 | 6128 | 3211 | 5136 | 6789 | 7656 | 4466 | 0 | 0 | 0 |
| Member | 7285 | 3815 | 4503 | 4935 | 4418 | 7725 | 4335 | 0 | 0 | 0 | 0 |
| | 7295 | 4817 | 4139 | 6125 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7305 | 7389 | 5813 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | 7315 | 6929 | 4687 | 7022 | 4402 | 0 | 0 | 0 | 0 | 0 | 0 |

# APPENDIX D

Results of Directional Tensile Strength Tests

TABLE D-1

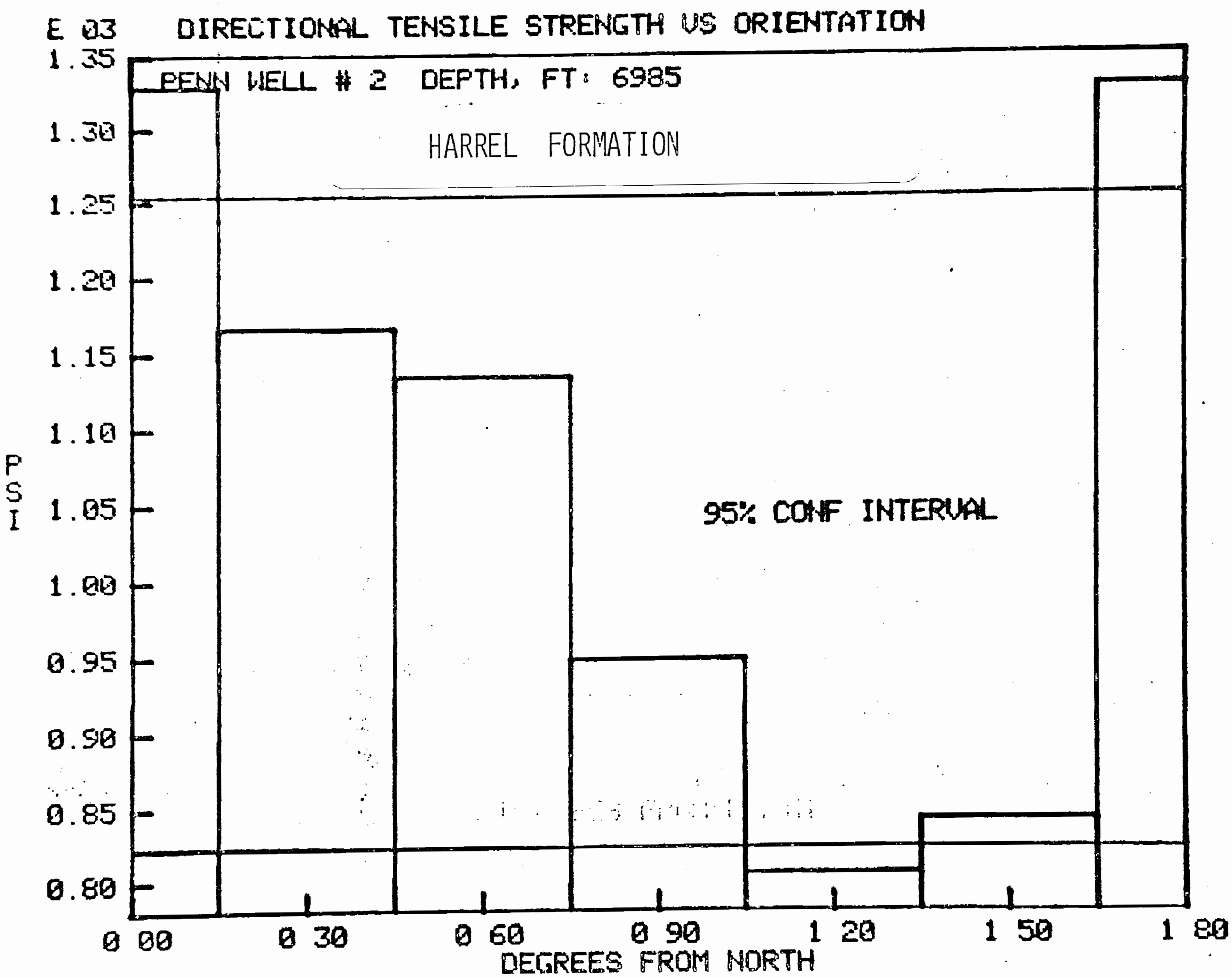
WELL NUMBER 2 IN PENNSLYVANIA

DIRECTIONAL TENSILE STRENGTHS

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

| | DEPTH IN FEET | 0 DEG | 30 DEG | 60 DEG | 90 DEG | 120 DEG | 150 DEG |
|---|---|---|---|---|---|---|---|
| Harrel Fm | 6985 | 1329 | 1167 | 1135 | 949 | 806 | 843 |
| | AVERAGE STRENGTH | 1329 | 1167 | 1135 | 949 | 806 | 843 |

FIGURE D-1


E 03
DIRECTIONAL TENSILE STRENGTH VS ORIENTATION
PENN WELL # 2 DEPTH, FT: 6985
HARREL FORMATION
95% CONF INTERVAL
PSI
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES FROM NORTH