CLIFFS MINERALS, INC.

EASTERN GAS SHALES PROJECT

PENNSYLVANIA #5 WELL - LAWRENCE COUNTY

PHASE III REPORT

SUMMARY OF LABORATORY ANALYSES AND

MECHANICAL CHARACTERIZATION RESULTS

OCTOBER 1981

EGSP-Pennsylvania #5 Well - Lawrence County

Executive Summary

This report summarizes the characterization work performed on approximately 604 feet of 3-1/2 inch diameter core retrieved from the EGSP-Pennsylvania #5 well in Lawrence 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 began on December 7 and was completed December 15, 1979. Nine stratigraphic units were identified and described; these include: Rhinestreet Shale, Cashaqua Shale, Middlesex Shale, Undifferentiated portion of the Genesee Formation, Geneseo Shale, Tully Limestone, Mahantango Shale, Marcellus Shale, and Onondaga Limestone.

Physical properties tests (point load, directional tensile strength, and directional ultrasonic velocity) and pretest fracture orientations suggest preferred orientations of fracturing for the nine stratigraphic units. The preferred direction of fracturing for the Rhinestreet Shale is N30°E ±15° as indicated by the ultrasonic velocity, point load and pretest fractures. For the Cashaqua Shale it is N30°E ±15° from the ultrasonic velocity and point load measurements and due North ±15° from the pretest fractures. For the Middlesex Shale it is N30°E ±15° from the ultrasonic velocity and point load measurements and N60°W ±15° from the pretest fractures. For the undifferentiated members of the Genesee

it is N60°E ±15° from the ultrasonic velocity, point load and pretest fracture measurements. For the Marcellus Shale it is indeterminate because of limited sample quality material. For the well composite the preferred direction of fracturing is N30°E ±15° as indicated by the ultrasonic velocity and point load measurements.

EGSP-Pennsylvania #5 Well - Lawrence County

Technical Summary

General

This summary presents a detailed characterization of the Devonian Shale occurrence in the EGSP-Pennsylvania #5 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 604 feet of core retrieved from a well drilled in Lawrence County of west-central Pennsylvania.

Location

The EGSP-Pennsylvania #5 well is located in northeastern Lawrence County on the Sokevitz property in Wilmington Township, about 3-1/4 miles southeast of New Wilmington, Pennsylvania. Specific site location is as follows: 12,020 feet south of 41°7'30" north latitude, 8,800 feet west of 80°15'0" west longitude.

Stratigraphy

A total of 603.8 feet of continuous core was cut from the Pennsylvania #5 well. Coring began at 3,522.0 feet in the Rhinestreet Shale and was terminated at 4,125.8 feet, approximately 1.3 feet into the Onondaga Limestone. Additional geophysical log interpretation by

Cliffs Minerals, Inc. has determined that the Rhinestreet Shale occurs from 3,508 to 3,846 feet, rather than from 3,663 to 3,846 feet as previously stated. The following report stands corrected. Revised formation thicknesses as encountered within the well are summarized below, and are followed by a short description of each formation or member.

Formation Thicknesses

Formation	Depth	Thickness	Depths Cored
West Falls Formation:			
Rhinestreet Shale Mem.	3,508.0'- 3,846.0'	338.0'	3,522.0'-3,846.0'
Sonyea Formation:			
Cashaqua Shale Member	3,846.0'- 3,909.0'	63.0'	3,846.0'-3,909.0'
Middlesex Shale Member	3,909.0'- 3,925.0'	16.0'	3,909.0'-3,925.0'
Genesee Formation:			
Undifferentiated	3,925.0'- 3,967.7'	42.7'	3,925.0'-3,967.7'
Geneseo Shale Member	3,967.7'- 3,975.4'	7.7'	3,967.7'-3,975.4'
Hamilton Group:			
Tully Limestone	3,975.4'- 3,979.1'	3.7'	3,975.4'-3,979.1'
Mahantango Shale	3,979.1'-∿4,113.0'	133.9'	3,979.1'-4,113.0'
Marcellus Shale	∿4,113.0'- 4,124.5'	11.5'	4,113.0'-4,124.5'
Onondaga Limestone	4,124.5'-T.D.	1.3'	4,124.5'-4,125.8'

West Falls Formation

Rhinestreet Shale:

The Rhinestreet Shale was divided into four intervals for analysis. The uppermost portion of the retrieved core contains 41.7 feet of Rhinestreet Shale (3,522.0 to 3,563.7 ft.) and consists of an olive gray, thinly laminated to thin-bedded mudstones. Moderate yellowish brown concretionary bands, <2 cm thick, and calcareous siltstone laminae are contained throughout the interval. Fossils present include: articulate brachiopods, cephalopods, and vitrinized and carbonaceous fragments. Burrow structures occur throughout, and are mud filled and pyrite mineralized. Disseminated grains of pyrite are prevalent. Occasional cross-stratified laminae and scour features are present as siltstone basal features.

The contact (3,563.7 ft.) is sharp between this interval and the underlying interval and is marked by a change from an olive gray mudstone to a brownish black silty mudstone. The contact also is distinct on the geophysical logs. The gamma ray log increases from 160 API units in the upper interval to 240 API units in the lower interval; bulk density decreases from 2.70 g/cc to 2.60 g/cc across the contact.

The second interval is present within the core (3,563.7' to 3,565.3') as a thin bed of brownish black silty mudstone. It contains no pyrite, biogenic or sedimentary structures, or fossils, other than a large vitrinized fragment (4 mm diam. by 85 mm).

This interval's contact with the underlying interval is sharp and is marked by a change from brownish black silty mudstone to olive gray silty mudstone. Crossing this contact in a downcore direction, gamma ray count decreases from 240 to 170 API units; bulk density increases from 2.60 to 2.70 g/cc.

The third interval (3,565.3 to 3,663.4 ft.) predominantly consists of alternating laminae and bands (<1.0 ft. thick) of olive gray and brownish black mudstone and silty mudstone. These lithologies are thinly laminated to thin bedded. Moderate yellowish brown concretionary bands (siderite ?), 0.1 foot thick, occur throughout the interval. The interval is moderately fossiliferous. These fossils include: spore bodies (Tasmanites sp.), which are both resinous and pyrite mineralized;

many articulate brachiopods and carbonaceous fragments; and rarely, cephalopods and vitrinized fragments. Pyrite mineralized and mud filled horizontal burrow structures commonly occur within the interval; a 0.3-foot thick zone of concentrated horizontal and subhorizontal burrows (2 mm diam. by 10 mm) is located at 3,647.2 feet. Pyrite occurs occasionally as nodules and frequently as disseminated grains. Cross-stratification and scour features are present within and beneath the siltstone laminae and beds (<0.5 ft. thick). Occasional siltstone concretions are also present. Current lineation marks bearing N83°W and N86°W are present at 3,598.7 and 3,623.0 feet, respectively. A 0.3-foot thick zone of soft sediment deformation (?) occurs at 3,655.8 feet, seven feet above the base of this interval.

The contact (3,663.4 ft.) between the third interval and the underlying fourth interval is sharp, both in the core and on the geophysical logs. Preceding downcore across the contact, the core changes from an olive gray mudstone to a brownish black silty mudstone. The gamma ray log increases from 160 API units to 238 API units; the bulk density log shows a decrease across the contact from 2.70 to 2.55 g/cc.

The fourth interval of the Rhinestreet Shale (3,663.4 to 3,846.0 ft.) is composed of alternating laminae and bands (<1.0 ft. thick) of brownish black and olive gray silty mudstone and mudstone. Occasional thick beds (up to 5.0 ft.) of brownish black silty mudstone are present within this interval. Siltstone, much of which is calcareous, is present throughout, occasionally cross-stratified as laminae and thin beds and concretions. Moderate yellowish brown concretionary bands (siderite ?) <1.0 foot thick are found in an interval extending from 3,701.0 to 3,722.6 feet. Vitrinized and carbonaceous fragments commonly occur throughout, as do pyrite mineralized burrow structures. Other common forms of pyrite include disseminated grains and nodules. A few load casts are present as basal features on siltstone beds at 3,693.6 and 3,721.7 feet. Several zones of soft sediment deformation are contained between the intervals from 3,699.6 to 3,703.1 feet, and from 3,800.0 to 3,804.0 feet. This portion of the Rhinestreet also contains several calcite mineralized simple joints.

The contact zone between the Rhinestreet and the underlying Cashaqua Shale of the Sonyea Formation is gradational over several feet. This zone is represented by an intermixing of brownish black and olive gray silty mudstone and mudstone bands (<0.8 ft. thick). On the logs, there is a decrease in gamma ray count going downhole across the contact from 230 API units in the Rhinestreet to 175 API units in the Cashaqua; bulk density increases across the contact from 2.60 to 2.65 g/cc.

Sonyea Formation

Cashaqua Shale Member:

The Cashaqua (3,846.0 to 3,909.0 ft.) is composed of thinly laminated to thin bedded olive gray mudstone and silty mudstone, with alternating laminae and bands (<0.8 ft. thick) of brownish black silty mudstone scattered throughout. Occasional thin siltstone laminae are present and a 0.4-foot thick septarian concretion occurs at 3,849.8 feet. Pyrite is present in several forms: as the mineralization on numerous horizontal and subvertical burrow structures; commonly as nodules; and rarely, as disseminated grains. Occasional carbonaceous plant fragments are present in the upper and lower extents of the interval. Other fossils which are located at the base of the Cashaqua include: articulate brachiopods, pelecypods, cephalopods and vitrinized fragments.

The contact (3,909.0 ft.) between the Cashaqua and the underlying Middlesex Shale is gradational over several feet in the core. The core changes from an olive gray mudstone to a grayish black silty mudstone across the contact. This contact zone is more distinct on the geophysical logs than it is in the core itself. The gamma ray log registers a sharp increase of radiation, from 160 API units in the Cashaqua to 230 API units in the darker Middlesex; bulk density readings of 2.60 g/cc in the Cashaqua drop to 2.50 g/cc in the Middlesex.

Middlesex Shale Member:

The Middlesex Shale (3,909.0 to 3,925.0 ft.), also of the Sonyea Formation, is primarily composed of a brownish black silty mudstone containing olive gray and occasional grayish black laminae and bands (<1.0 ft. thick). Siltstone occurs throughout as occasional light olive gray thin laminae and lenses (4 mm diam. by 25 mm). Pyrite laminae are scarce. A few carbonaceous spore bodies (Tasmanites sp.) are present at 3,925.0 feet. Horizontal and subvertical pyrite mineralized burrow structures (up to 2 mm diam. by 17 mm) are common throughout the interval.

The contact (3,925.0 ft.) between the Middlesex Shale and the Genesee Formation is gradational over several feet in the core. The change downcore across the contact is from a brownish black silty mudstone to an olive gray mudstone. The contact between these formations is more distinct on the geophysical logs. Gamma radiation decreased from 200 API units in the Middlesex to 160 API units in the Genesee; bulk density increased from 2.50 to 2.60 g/cc.

Genesee Formation

An undifferentiated interval of the Genesee Formation extends from 3,925.0 to 3,967.7 feet. The upper 20 feet consists primarily of an olive gray silty mudstone and mudstone, containing alternate laminae and bands (<0.8 ft. thick) of light olive gray and brownish black silty mudstone and mudstone. The remainder of this interval (3,945.0 to 3,967.7 ft.) is composed mainly of olive black, brownish black and olive gray mudstone and silty mudstone. This portion of the formation is thinly laminated to thin bedded. Laminae of siltstone occur throughout. A variety of fossils is contained within the zone from 3,931.0 to 3,957.2 feet: inarticulate and articulate brachiopods, pelecypods, cephalopods, and a vitrinized plant fragment. Pyrite mineralized burrow structures are occasional; disseminated grains of pyrite, however, are rare.

The contact (3,967.7 ft.) between the undifferentiated portion of the formation and the dark, basal member of the Genesee, the Geneseo Shale, is sharp in the core. Olive black silty mudstone of the undifferentiated portion of the Genesee changes to grayish black silty mudstone of the Geneseo at this contact. On the geophysical logs, the gamma ray log reflected a sharp increase from 160 API units in the Genesee to 360 API units in the Geneseo; a similarly pronounced change occurs on the bulk density log, 2.60 g/cc in the upper part of the Genesee Formation decreases to 2.32 g/cc in the Geneseo Shale Member.

Geneseo Shale Member:

The Geneseo Shale (3,967.7 to 3,975.4 ft.), which correlates with the Burkett Shale Member of the Harrel Formation, consists of a uniformly colored grayish black (N2) silty to very silty mudstone. The thinly laminated to thin bedded interval contains no fossils or sedimentary structures. Pyrite occurs in several forms: as mineralization on burrow structures; as nodules; and as laminae of disseminated grains.

The Geneseo's contact (3,975.4 ft.) with the underlying Tully Limestone is very distinct in the core. The lithology changes abruptly from the grayish black silty mudstone of the Geneseo to the light olive gray lime mudstone of the Tully. The geophysical logs record an abrupt change downcore across the contact: gamma radiation decreases sharply from 360 API units to 60 API units; bulk density increases sharply from 2.45 to 2.70 g/cc.

Hamilton Group

Tully Limestone:

The Tully (3,975.4 to 3,979.1 ft.) is composed of thick bedded, light olive gray, lime mudstone and wackestone. Both calcite and pyrite occur as mineralization on the numerous burrow structures which are found throughout. Fossils and sedimentary structures are not present within the interval.

The contact (3,979.1 ft.) between the Tully Limestone and the underlying Mahantango Shale, also of the Hamilton Group, is gradational in the core over several inches. This contact is gradational due to moderate bioturbation; a zone of numerous light olive gray lime filled burrow structures is present in the brownish black mudstone at the top of the Mahantango. Geophysical logs reflect an increase in gamma radiation across the contact from 60 API units in the Tully to 120 API units in the Mahantango; bulk density decreases abruptly from 2.70 to 2.55 g/cc.

Mahantango Shale:

The Mahantango Shale extends from 3,979.1 feet to approximately 4,113.0 feet, and consists primarily of thinly laminated to thin bedded silty mudstone. The upper 35 feet of the interval is predominantly brownish black, while olive black predominates the remainder. Siltstone is present as two light olive gray concretions. The formation contains only occasional fossils, including: cephalopods, carbonaceous spore bodies (<u>Tasmanites</u> sp.) and a single vitrinized plant fragment. Pyrite is common throughout the interval; it occurs as the mineralization on numerous horizontal and vertical burrow structures, and frequently as nodules, lenses and disseminated grains. A 0.2-foot thick pyritic concretion containing calcite veins is present at 4,051.6 feet. The majority of the Mahantango is calcareous.

The contact (∿4,113.0 ft.) between the Mahantango and the basal member of the Hamilton Group, the Marcellus, was determined from geophysical logs because the section from 4,103.6 to 4,116.1 feet, which contains this contact, was rubblized during coring and could not be retrieved. Both gamma ray and bulk density logs indicate a sharp contact between the two shales. Gamma radiation increases from 160 API units in the Mahantango to 375 API units in the Marcellus; bulk density readings register a drop downcore from 2.55 to 2.32 g/cc.

Marcellus Shale:

The Marcellus Shale (∿4,113.0 to 4,124.5 ft.) is composed of a uniformly colored grayish black thinly laminated to thin bedded silty mudstone. Pyrite occurs in a variety of forms: as mineralization on horizontal and vertical burrow structures; as thick laminae of disseminated grains; as occasional pyrite nodules; and rarely, as lenses. The lower 3.0 feet of the formation and the zone from 4,118.0 to 4,119.0 feet are calcareous.

The contact (4,124.5 ft.) between the Marcellus and the underlying Onondaga Limestone is sharp in the core. Grayish black silty mudstone of the Marcellus rests on medium light gray wackestone of the Onondaga. The uppermost portion of the Onondaga contains a 1-cm thick concentrated layer of medium grained sand-sized particles. Gamma radiation in the Marcellus Shale, 375 API units, is much higher as compared to the Onondaga, 42 API units. The bulk density log registers an increase across this contact from 2.32 to 2.68 g/cc.

Onondaga Limestone

The cored portion of the Onondaga (4,124.5 to 4,125.8 ft.) in the Pennsylvania #5 well is composed primarily of a thin bedded medium dark gray lime mudstone; medium light gray and light olive gray wackestone comprise the upper 0.3 feet of the formation. Moderate bioturbation, stylolites, and disseminated pyrite grains are present throughout.

Fracture Analysis

Forty-five natural fractures were observed in the core. Of these, fifteen fractures are classified as joints, and the other thirty are either faults or microfaults. The distribution of natural fractures throughout the cored intervals is indicated on the following page.

Distribution of Natural Fractures

Formation	Depths Cored	Core Length	Number of Fractures	Frequency Per Foot
West Falls Formation:				
Rhinestreet Shale Member	3,522.0'- 3,846.0'	324.0'	26	0.08
Sonyea Formation:				
Cashaqua Shale Member	3,846.0'- 3,909.0'	63.0'	2	0.03
Middlesex Shale Mem.	3,909.0'- 3,925.0'	16.0'	0	0.00
Genesee Formation:				
Undifferentiated	3,925.0'- 3,967.7'	42.7'	0	0.00
Geneseo Shale Member	3,967.7'- 3,975.4'	7.7'	0	0.00
Hamilton Group:				
Tully Limestone	3,975.4'- 3,979.1'	3.7'	0	0.00
Mahantango Shale	3,979.1'-~4,113.0'	133.9'	17	0.13
Marcellus Shale	~4,113.0'- 4,124.5'	11.5'	0	0.00
Onondaga Limestone	4,124.5'- T.D.	1.3'	0	0.00

The faults and microfaults present in the core strike from approximately N14°W to N78°W, with a concentration at N42°W. Dips range from 0° to 70°NE, with a major concentration from 0° to 20°NE. Two of the natural microfaults have variable dips.

Slickenlines present in the Pennsylvania #5 core exhibits three directions of movement:

SLICKENLINE TREND 1: plunging 0° to 50°, and bearing between N8°W and N81°W, with a concentration plunging 0° to 20°, and bearing N50°W to N64°W.

SLICKENLINE TREND 2: plunging 0° to 60°, and bearing between N30°E and N48°E, with a concentration plunging 0° to 20°, and bearing N38°E to N44°E.

SLICKENLINE TREND 3: plunging 0° to 50°, and bearing between S30°W and S48°W, with a concentration plunging 0° to 30°, and bearing S38°W to S44°W.

Of the fourteen simple joints and one compound joint present in the core, seven occur in the Rhinestreet, one occurs in the Cashaqua, and the remaining six simple joints and one compound joint are found in the Mahantango. There are two joint trends in the Pennsylvania #5 core: strikes ranging from N4°W to N18°E, with a major concentration occurring from N4°E to N14°E; and strikes ranging from N30°E to N56°E, with a major concentration from N35°E to N41°E. Dips on all joints occur between 80° and 90°NE.

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

West Falls Formation

Rhinestreet Shale Member:

A portion of the Rhinestreet Shale contains a series of five microfaults adjacent to, or contained within, areas of soft-sediment deformation (concretions ?). The fractures terminate against each other, and occur between 3,655.9 and 3,656.1 feet; none are more than 0.1 foot in length. The major strike trend (N40°W to N50°W) of the natural fractures present within this portion of the Rhinestreet is roughly perpendicular to the major trend (N40°E) of the contained slickenlines.

The remainder of the Rhinestreet (3,663.4 - 3,846.0 ft.) contains twenty-one natural fractures. Of these fractures, thirteen are classified as microfaults, seven as simple joints, and one as a fault.

Three series of fractures, each containing three to four curviplanar microfaults, are found adjacent to concretions at 3,700.6, 3,776.0 and 3,807.0 feet. Many of these microfaults are mineralized with calcite, and are up to 0.3 feet in length. A 0.4-foot long calcite mineralized fault is present at 3,711.7 feet. All of the simple joints are also calcite mineralized, and display fracture propagation from west to east, where plumes are visible.

The most prominent natural fracture trend, N10°E, represents fractures adjacent to a concretion, and is contained within the lower part of the Rhinestreet (3,807.0 - 3,807.6 ft.). Minor fracture trends occur from N40°W to N50°W, and from N80°W to N90°W.

The major trend (bearing) of the associated slickenlines is N40°E. Minor slickenline trends in the Rhinestreet occur from N20°E to N30°E, and from N10°W to N20°W.

Sonyea Formation

Cashaqua Shale Member:

The Cashaqua (3,846.0 to 3,909.0 ft.) contains only two natural fractures: a 0.4-foot long simple joint located at 3,880.1 feet, and a 0.1-foot long microfault present at 3,889.4 feet. The strike of these natural fractures is between N40°W and N50°W. The bearing of slickenlines on the microfault is N50°E to N60°E.

Middlesex Shale Member:

No natural fractures are present in the 16.0 feet (3,909.0 to 3,925.0 ft.) of core cut from the Middlesex Shale.

Genesee Formation

No natural fractures are present in the 50.4 feet (3,925.0 to 3,975.4 ft.) of core cut from this formation.

Hamilton Group

Tully Limestone:

No natural fractures are present in the 3.7 feet (3,975.4 to 3,979.1 ft.) of core cut from the Tully.

Mahantango Shale:

The 133.9 feet of core cut from the Mahantango Shale (3,979.1 to 4,113.0 ft.) contains seventeen natural fractures: eight faults, two microfaults, six simple joints and one compound joint.

The simple joints present between 4,014.2 and 4,021.9 feet are pyrite mineralized, whereas, simple and compound joints occurring throughout the remainder of the interval are mineralized with calcite. Faults and microfaults are present throughout; those occurring between 4,024.0 and 4,046.5 feet are calcite mineralized.

The most prominent natural fracture trend, N80°W to N90°W, represents the joints contained within the lower part of the Mahantango (4,075.6 to 4,101.8 ft.). Minor strike trends occur at N50°W, and from 0° to N10°E.

The major trend (bearing) of the associated slickenlines occurs from N50°W to N70°W, somewhat parallel to a minor fracture strike trend (N50°W to N60°W). Minor slickenline trends are present from N10°E to N10°W and from N20°W to N40°W, the former being both parallel and perpendicular to the minor and major fracture strike trends.

Marcellus Shale:

No natural fractures are present in the 11.5 feet (∿4,113.0 to 4,124.5 ft.) of core cut from the Marcellus.

Onondaga Limestone

No natural fractures are present in the 1.3 feet (4,124.5 to 4,125.8 ft.) of core cut from the Onondaga.

Coring-Induced Fractures

Over ninety-five percent of the individually analyzed fractures in the EGSP-Pennsylvania #5 core were interpreted to be coring- or handling-induced. Disc fractures were the most common type observed. Because these fractures are less diagnostic than other types, they were not recorded individually or analyzed further.

Physical Properties Testing

The physical property tests employed in the testing of the EGSP-Pennsylvania #5, Lawrence County core samples are: directional ultrasonic velocity measurements; point load induced fractures; and directional tensile strength tests. In addition, all fractures are systematically recorded before the physical property tests are performed.

The preferred direction of fracturing for the Rhinestreet Shale Member of the West Falls Formation (3,552.0 to 3,846.0 ft. tested) is N30°E ±15° as indicated by ultrasonic velocity measurements, point load induced fractures and the directional trend of pretest fractures. A secondary preferred direction of fracturing of N60°E ±15° is also indicated.

The preferred direction of fracturing for the Cashaqua Shale Member of the Sonyea Formation (3,853.0 to 3,909.0 ft. tested) is N30°E ±15° as indicated by ultrasonic velocity measurements and point load induced fractures. Three of the four pretest fractures in the Cashaqua Shale occur in the due North ±15° direction. A secondary preferred direction of fracturing of N60°E ±15° is also indicated.

The preferred direction of fracturing in the Middlesex Shale Member of the Sonyea Formation (3,910.0 to 3,925.0 ft. tested) is N30°E ±15° as indicated by ultrasonic velocity measurements and point load induced fractures. Pretest fractures in the Middlesex Shale occur most frequently in the N60°W ±15° direction. A possible secondary preferred direction of fracturing of N60°E ±15° is indicated by point load induced fractures.

The preferred direction of fracturing in the Undifferentiated Members of the Genesee Formation (3,937.0 to 3,967.0 ft. tested) is N60°E ±15° as indicated by ultrasonic velocity measurements, point load induced fractures and the directional trend of pretest fractures. A possible secondary preferred direction of fracturing of N30°E ±15° is also indicated.

The preferred direction of fracturing for the Mahantango Shale in the Hamilton Group (3,988.0 to 4,103.0 ft. tested) is N30°E ±15° as indicated by ultrasonic velocity measurements, point load induced fractures and the directional trend of pretest fractures. A secondary preferred direction of fracturing of N60°E ±15° is also indicated.

The preferred direction of fracturing for the Marcellus Shale in the Hamilton (4,113.0 to 4,124.0 ft. tested) cannot be determined because of the statistically small number of samples received from this interval. The one velocity sample indicates that N90°E ±15° is the preferred direction of fracturing while four of the five point load induced fractures indicate that due North ±15° and N30°E ±15° are the preferred directions of fracturing. The one pretest fracture identified in the Marcellus Shale core occurs in the N30°E ±15° direction.

The overall preferred direction of fracturing for the Pennsylvania #5 well core (3,522.0 to 4,124.0 ft. tested) is N30°E ±15° as indicated by ultrasonic velocity measurements and point load induced fractures. A secondary preferred direction of fracturing of N60°E ±15° is also indicated. Pretest fractures in the well core occur most frequently in the N60°E ±15° and N30°E ±15° directions.

Available Reports

For a more detailed account of field operations, lithology, and fracture analyses and physical property test results, the reader is referred to the following Cliffs Minerals, Inc. reports:

(1) EGSP-Pennsylvania #5, Lawrence County, Phase I Report, Field Operations, December 1979.

(2) EGSP-Pennsylvania #5, Lawrence County, Phase II Report, Preliminary Laboratory Results, January 1981.

PREFERRED PLANES OF WEAKNESS IN DEVONIAN GAS SHALES

DETERMINED BY MECHANICAL CHARACTERIZATION

Report for

EGSP-Pennsylvania #5

Lawrence County

Report by Connie Thompson

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Summary of Mechanical Characterization Results

The purpose of mechanical characterization of samples from the EGSP-Pennsylvania #5 core is to determine the orientation of preferred planes of weakness in the Devonian gas shales at the Lawrence County well site.

Prior to testing, the length and orientation of pretest fractures identified in each sample were recorded. Pretest fractures occur most frequently in the N30°E ± 15° and N60°E ± 15° directions (a sum of 40 out of 60 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 that the preferred direction of fracturing is the N30°E ± 15° direction (42 out of 58 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 occur most frequently in the N30°E ± 15° direction in 105 of the 265 total induced fractures.

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.

Six 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. Directional tensile strength measurements do not indicate a statistically significant preferred plane of weakness in the Pennsylvania #5 core samples.

INTRODUCTION

The purpose of mechanical characterization of samples from the EGSP-Pennsylvania #5 well is to determine the direction of preferred planes of weakness in the Devonian gas shales at the Lawrence County well site.

A series of samples, representing 600 feet of core taken from the Pennsylvania #5 well, were tested. The tested core intervals extend from 3,522 feet to 4,125 feet below surface and are summarized in Table 1.

TABLE 1

EGSP-Pennsylvania #5
Lawrence County
Formations Tested

Formation	Depth Cored	Depth Tested
WEST FALLS FORMATION		
Rhinestreet Shale Member	3,522'-3,846'	3,522'-3,846'
SONYEA FORMATION		
Cashaqua Shale Member	3,846'-3,909'	3,853'-3,909'
Middlesex Shale Member	3,909'-3,925'	3,910'-3,925'
GENESEE FORMATION		
Undifferentiated	3,926'-3,967'	3,937'-3,967'
Geneseo Shale Member	3,967'-3,975'	---
HAMILTON GROUP		
Tully Limestone	3,975'-3,979'	---
Mahantango Shale	3,979'-4,113'	3,988'-4,103'
Marcellus Shale	4,113'-4,124'	4,113'-4,121'
ONONDAGA LIMESTONE	4,124'-4,125'	---

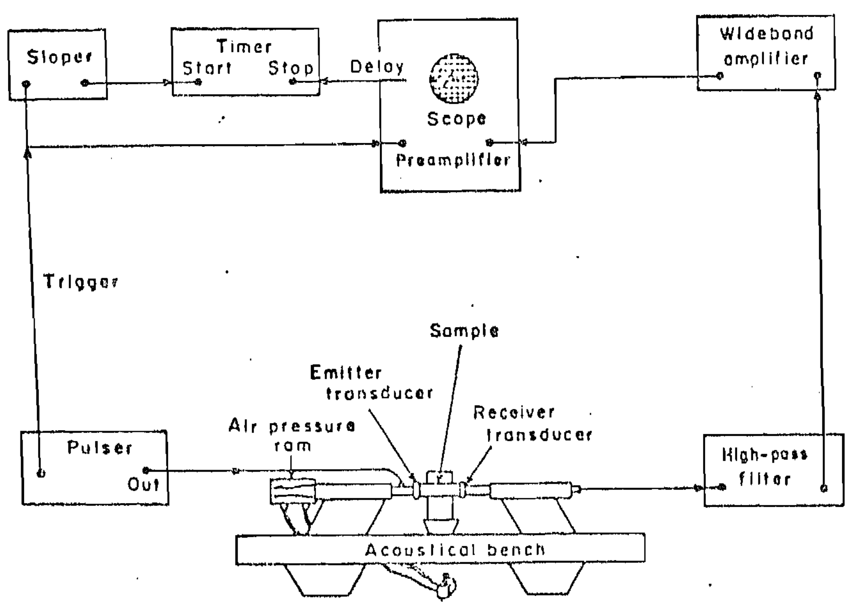
The physical property tests employed are: 1) directional ultrasonic velocity measurements; 2) point load induced fracturing; and 3) directional tensile strength tests. In addition, all fractures (hereafter referred to as 'pretest fractures') are systematically recorded before the physical property tests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

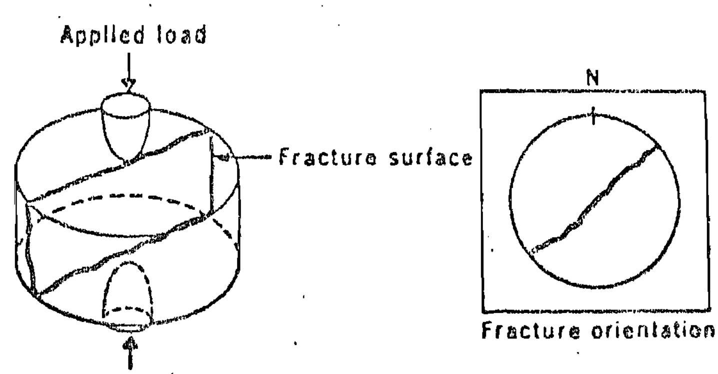
N = number of measurements

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 (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.

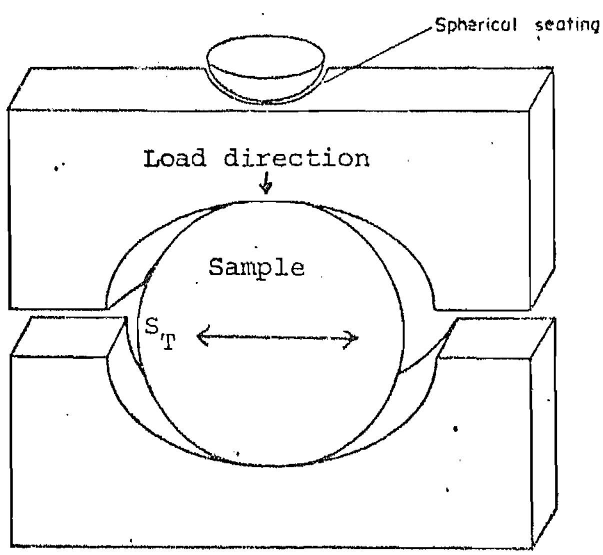
Fractures induced by point load will indicate a random orientation only if the rock specimens are of homogeneous isotropic material; if the specimen is anisotropic, the induced fracture would be expected to occur in directions parallel to the preferred directions of microfracture (Peng, Ortiz, 1972).

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 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 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 cushioned (by foam rubber), 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 - Pennsylvania #5
Lawrence County
Frequency Distribution of Preferred Direction of Fracturing

Formation	Test	Degrees East of North 0°	30°	60°	90°	120°	150°	Total
WEST FALLS FORMATION								
Rhinestreet Shale Member	Pretest Frac	4	10	7	5	1	2	29
3,522'-3,846' tested	Velocity	1	24	7	0	0	0	32
	Point Load	9	58	36	7	8	5	123
	DTS	4	0	0	5	3	2	14 sets
SONYEA FORMATION								
Cashaqua Shale Member	Pretest Frac	3	1	0	0	0	0	4
3,853'-3,909' tested	Velocity	0	4	2	0	0	0	6
	Point Load	3	16	14	3	0	2	38
	DTS	2	0	0	1	0	3	6 sets
Middlesex Shale Member	Pretest Frac	0	0	3	0	5	0	8
3,910'-3,925' tested	Velocity	0	2	0	0	0	0	2
	Point Load	1	6	4	1	1	0	13
	DTS	0	1	0	1	0	0	2 sets
GENESEE FORMATION								
Undifferentiated	Pretest Frac	0	3	11	0	0	0	14
3,937'-3,967' tested	Velocity	1	1	2	0	0	0	4
	Point Load	3	8	10	6	2	3	32
	DTS	1	0	0	2	0	1	4 sets
HAMILTON GROUP								
Mahantango Shale	Pretest Frac	0	4	0	0	0	0	4
3,988'-4,103' tested	Velocity	0	11	2	0	0	0	13
	Point Load	9	15	11	10	3	6	54
	DTS	1	0	1	0	0	2	4 sets
Marcellus Shale	Pretest Frac	0	1	0	0	0	0	1
4,113'-4,124' tested	Velocity	0	0	0	1	0	0	1
	Point Load	2	2	0	0	1	0	5
WELL COMPOSITE	Pretest Frac	7	19	21	5	6	2	60
3,522'-4,124' tested	Velocity	2	42	13	1	0	0	58
	Point Load	27	105	75	27	15	16	265
	DTS	8	1	1	9	3	8	30 sets

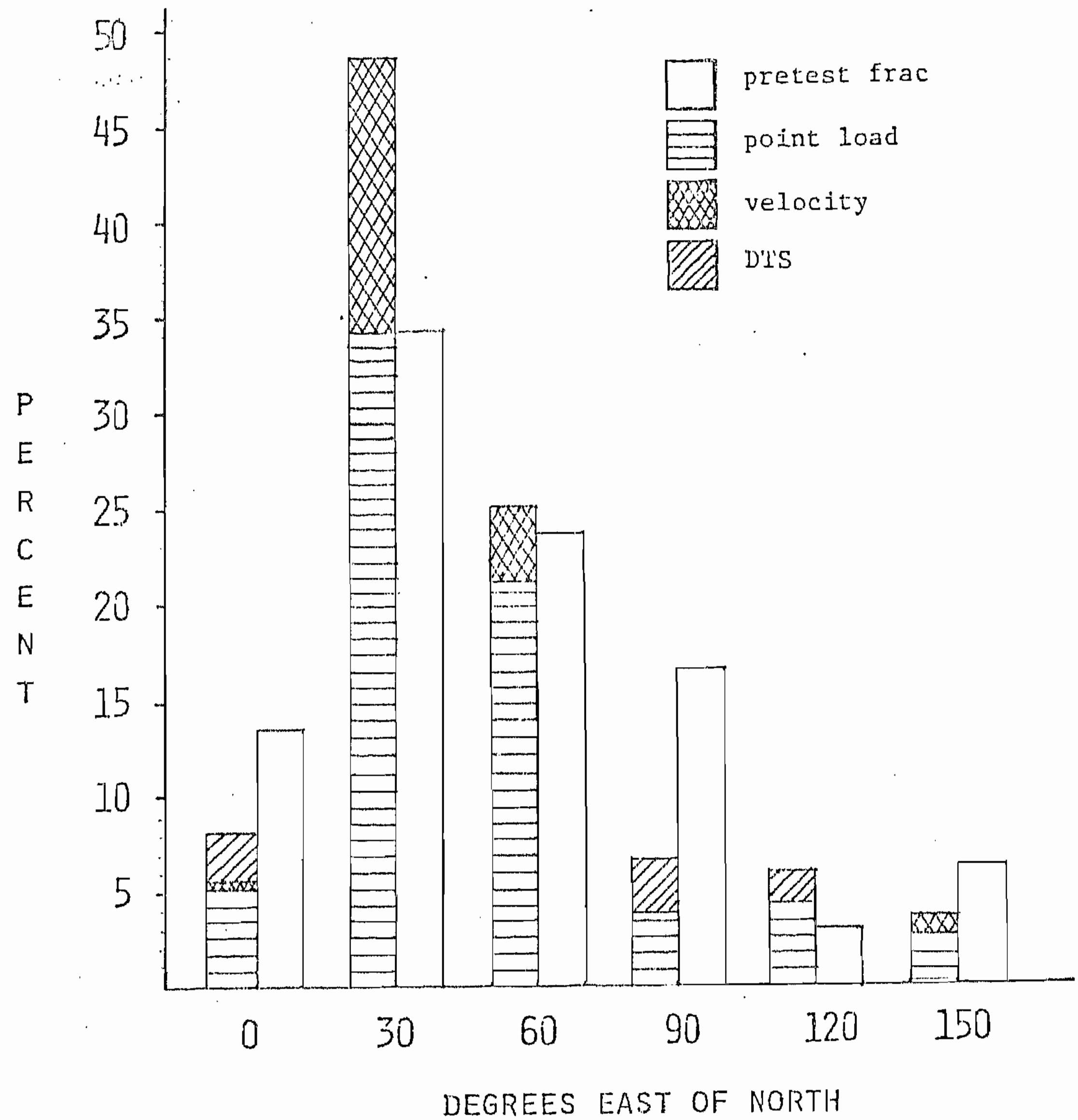
WEST FALLS FORMATION

Rhinestreet Shale Member of the West Falls Formation; 3,522'-3,846' tested:

Figure 4 is a grouped histogram comparing the frequency distribution of all mechanical test results with the frequency distribution of pretest fractures.

FIGURE 4

Rhinestreet Shale Member of the West Falls Formation
Grouped Histogram Comparing Frequency Distributions of
Mechanical Test Results (n = 169) with
Pretest Fractures (n = 29)



Pretest fractures occur most frequently in the N30°E ± 15° direction (10 out of 29 pretest fractures). Ultrasonic velocity measurements and point load induced fractures indicate that N30°E ± 15° is the preferred direction of fracturing (24 out of 32 velocity samples and 58 out of 123 induced fractures). Five sets of directional tensile strength measurements indicate N90°E ± 15° and four sets indicate due North ± 15° as the direction of the preferred plane of weakness (out of 14 DTS sets tested). Figure 5 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Rhinestreet Shale Member of the West Falls Formation. Tabulated results are presented in Appendices A, B, C, and D.

FIGURE 5

Rhinestreet Shale Member of the West Falls Formation
Frequency Distribution Rose Diagrams of Results

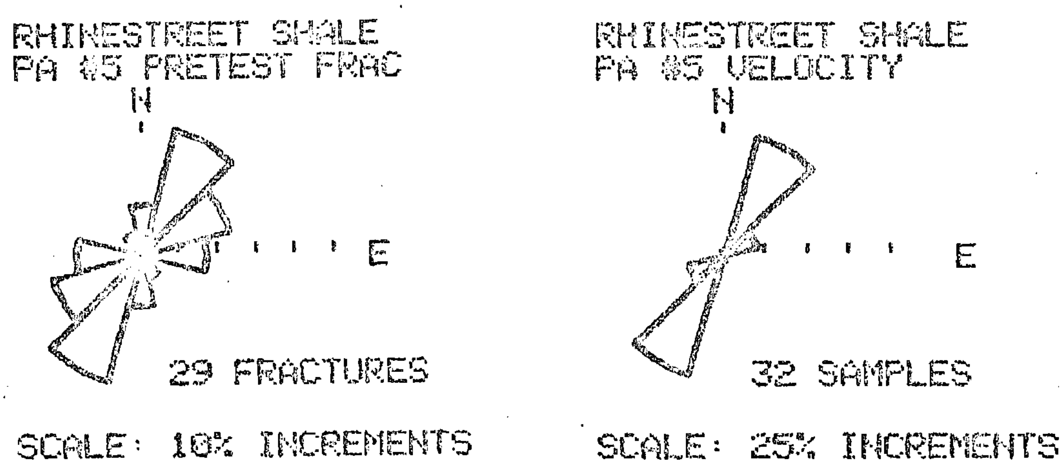
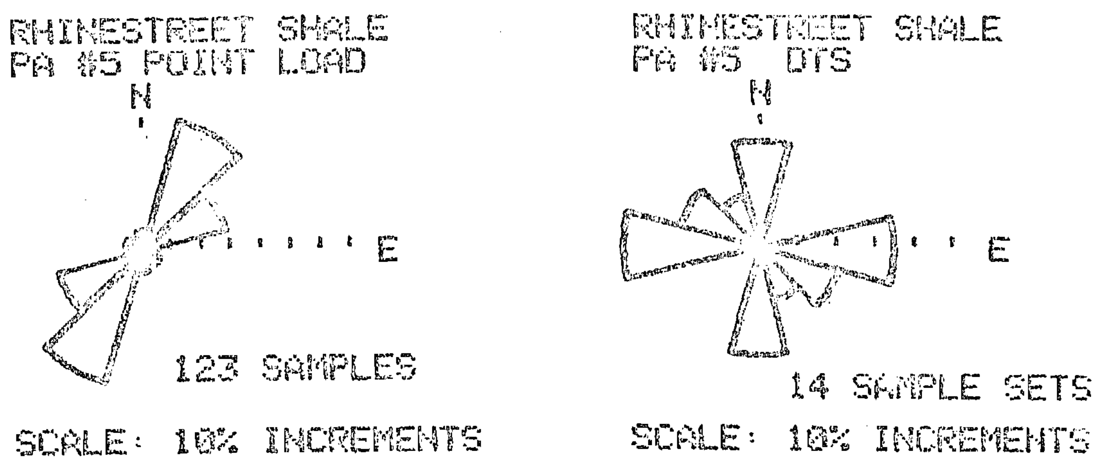


FIGURE 5
(continued)



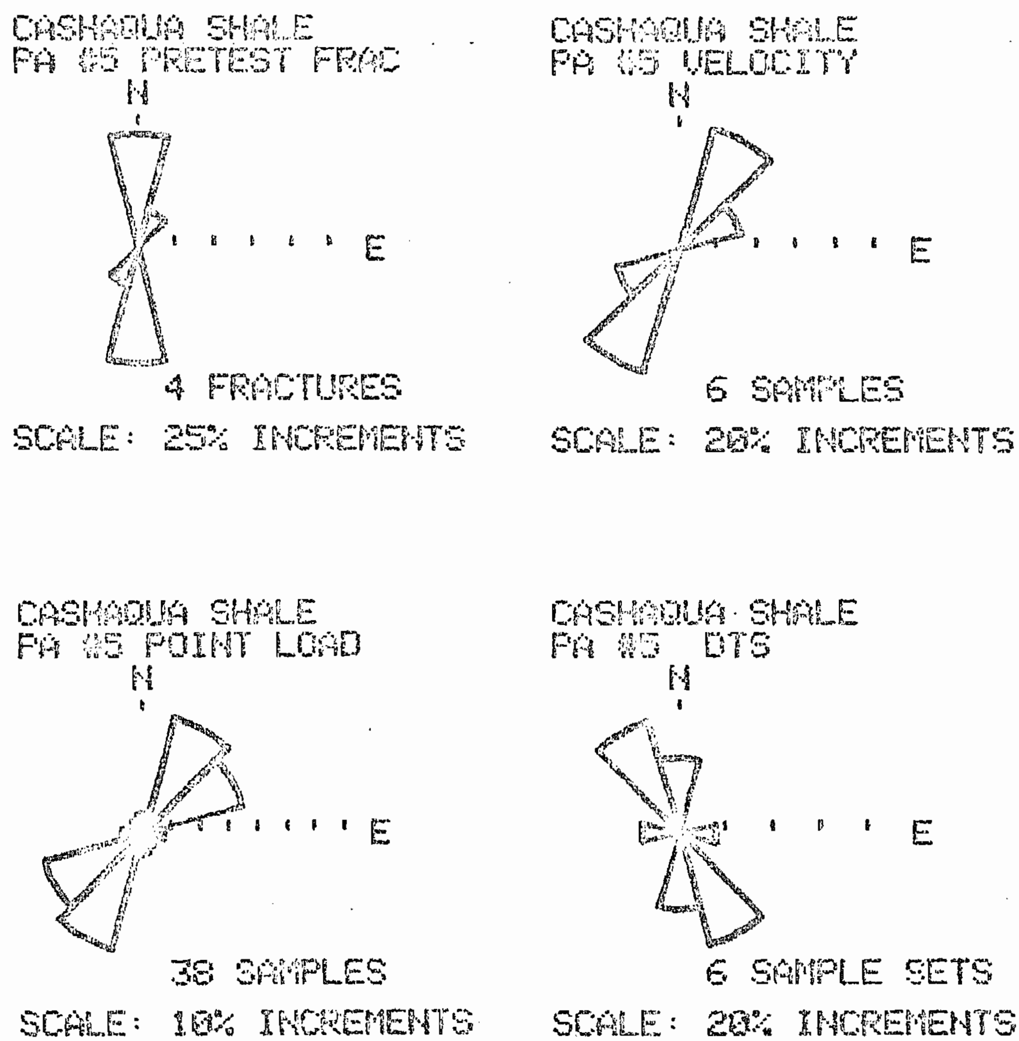
SONYEA FORMATION

Cashaqua Shale Member of the Sonyea Formation; 3,853'-3,909' tested:

Three out of the four pretest fractures identified in this depth interval occur in the due North ± 15° direction. Ultrasonic velocity measurements and point load induced fractures indicate the N30°E ± 15° direction as the preferred direction of fracturing (4 out of 6 velocity samples and 16 out of 38 induced fractures). Directional tensile strength measurements indicate N30°W ± 15° and due North ± 15° as the direction of the preferred planes of weakness (a sum of 5 out of 6 DTS sample sets). Figure 6 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Cashaqua Shale Member of the Sonyea Formation. Tabulated results are presented in Appendices A, B, C and D.

FIGURE 6

Cashaqua Shale Member of the Formation
Frequency Distribution Rose Diagrams of Results



Middlesex Shale Member of the Sonyea Formation; 3,910'-3,925' tested:

The eight pretest fractures identified in this depth interval occur in the N60°W ± 15° direction (5 out of 8 pretest fractures) and in the N60°E ± 15° direction (3 out of 8 pretest fractures). The two ultrasonic velocity samples indicate N30°E ± 15° as the preferred direction of fracturing. Point load induced fractures occur most frequently in the N30°E ± 15° direction (6 out of 13 induced fractures) and in the N60°E ± 15° direction (4 out of 13 induced fractures). The two sets of directional tensile strength measurements indicate N30°E ± 15° and N90°E ± 15° as the preferred planes of weakness. Figure 7 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Middlesex Shale Member of the Sonyea Formation. Tabulated results are presented in Appendices A, B, C and D.

FIGURE 7

Middlesex Shale Member of the Sonyea Formation
Frequency Distribution Rose Diagrams of Results

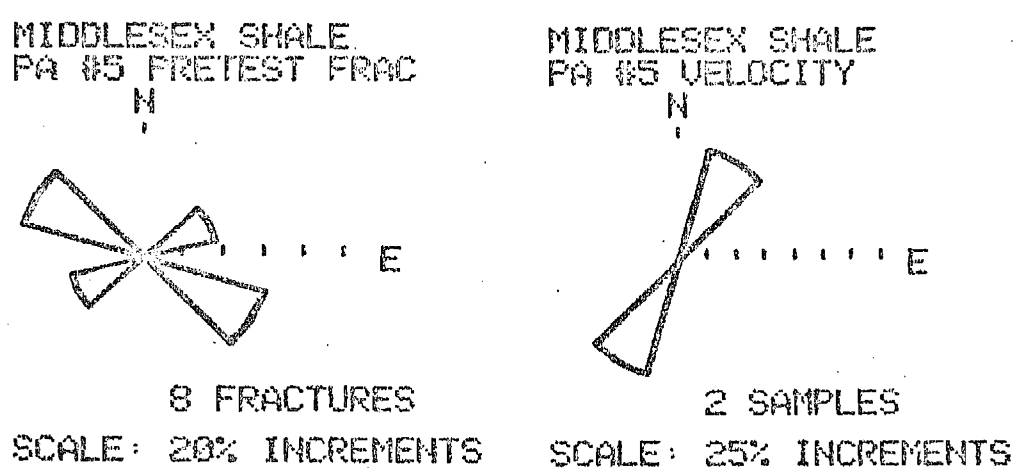
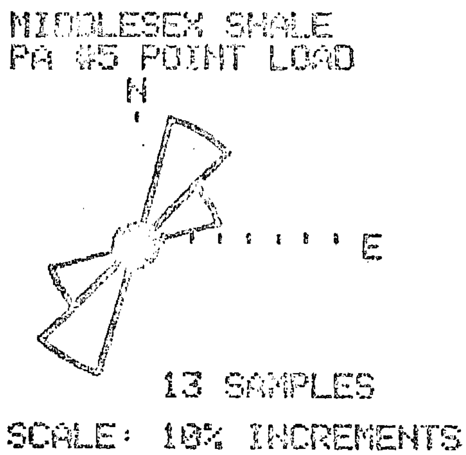
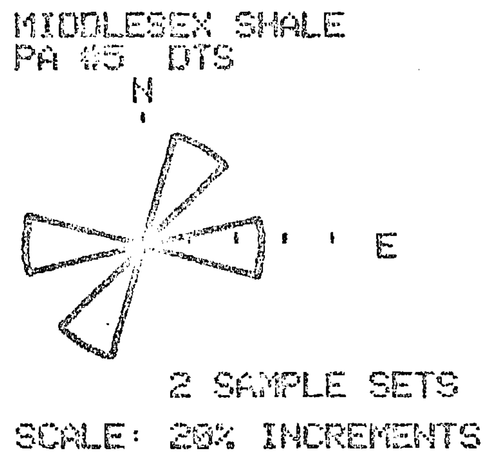


FIGURE 7
(continued)



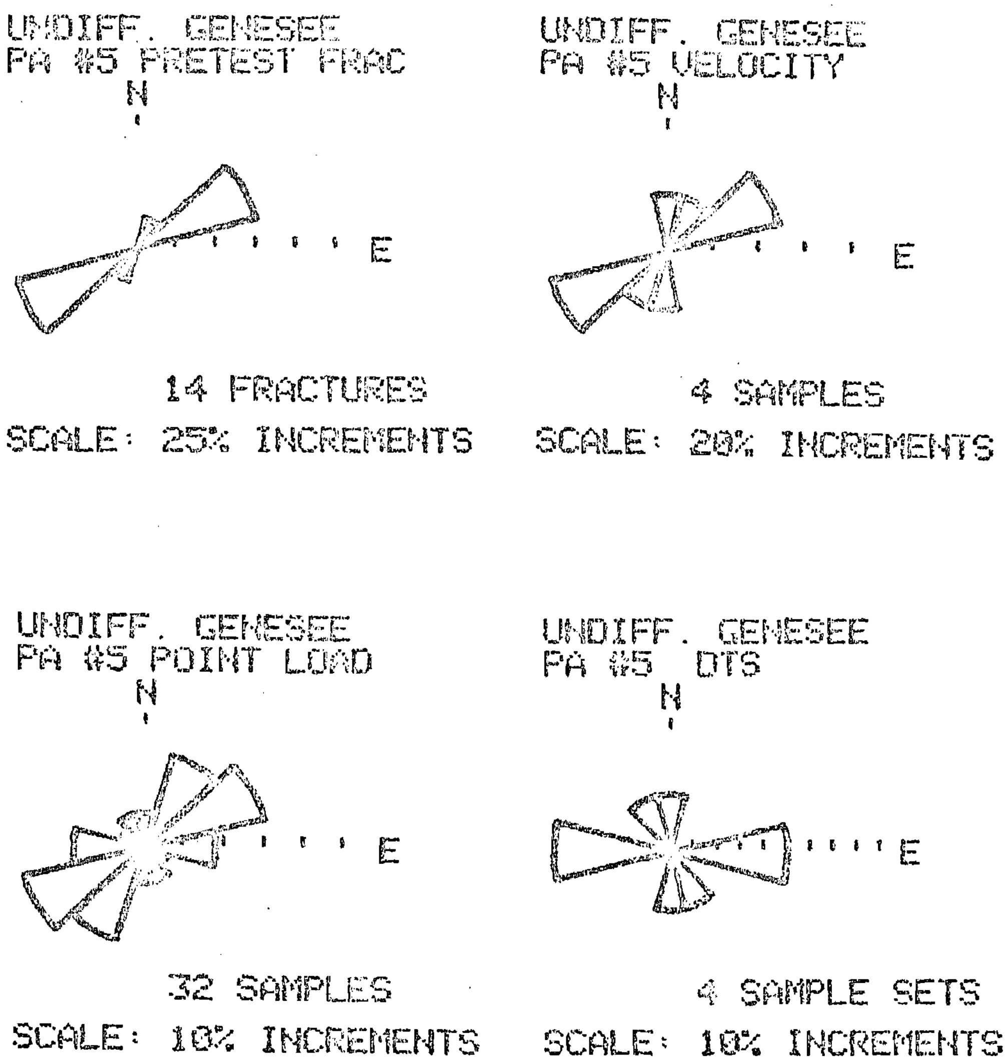


GENESEE FORMATION
Undifferentiated Members in the Genesee Formation; 3,937'-3,967' tested:

Pretest fractures occur most frequently in the N60°E ± 15° direction (11 out of 14 pretest fractures). Two of the four ultrasonic velocity measurements indicate the N60°E ± 15° direction as the preferred direction of fracturing. Point load induced fractures occur most frequently in the N60°E ± 15° direction (10 out of 32 induced fractures) and in the N30°E ± 15° direction (8 out of 32 induced fractures). Two of the four sets of directional tensile strength measurements indicate N90°E ± 15° as the direction of the preferred plane of weakness. Figure 8 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Undifferentiated Members of the Genesee Formation. Tabulated results are presented in Appendices A, B, C and D.

FIGURE 8

Undifferentiated Members of the Genesee Formation
Frequency Distribution Rose Diagrams of Results



HAMILTON GROUP

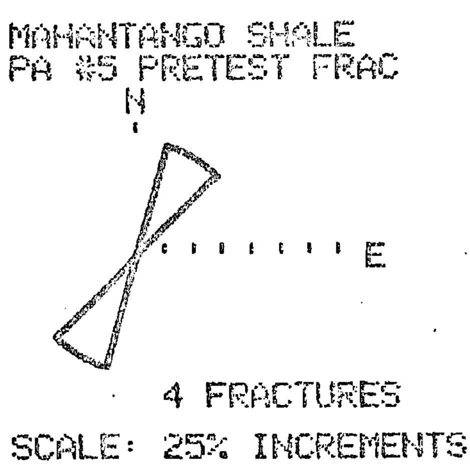
Mahantango Shale in the Hamilton Group; 3,988'-4,103' tested:

The four pretest fractures identified in this depth interval occur in the N30°E ± 15° direction. Ultrasonic velocity measurements indicate the

N30°E ± 15° direction as the preferred direction of fracturing (11 out of 13 velocity samples). Point load induced fractures occur most frequently in the N30°E ± 15° direction (15 out of 54 induced fractures). The four sets of directional tensile strength measurements do not indicate a statistically significant preferred plane of weakness. Figure 9 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Mahantango Shale in the Hamilton Group. Tabulated results are presented in Appendices A, B, C and D.

FIGURE 9

Mahantango Shale in the Hamilton Group
Frequency Distribution Rose Diagrams of Results



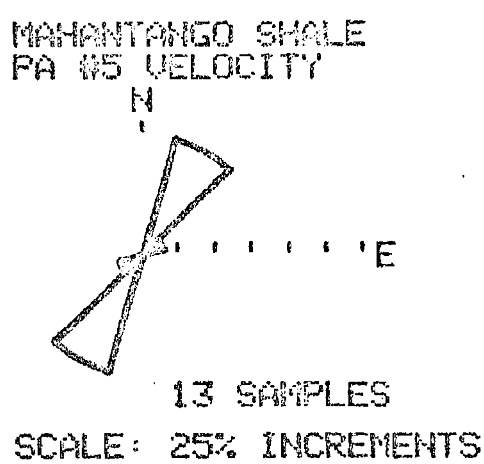
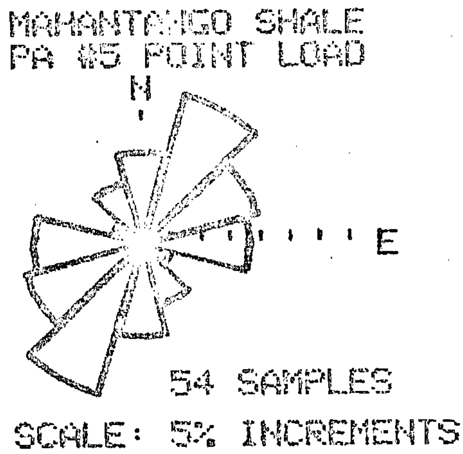
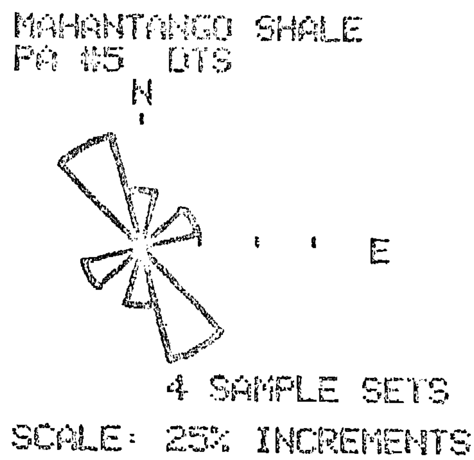


FIGURE 9
(continued)



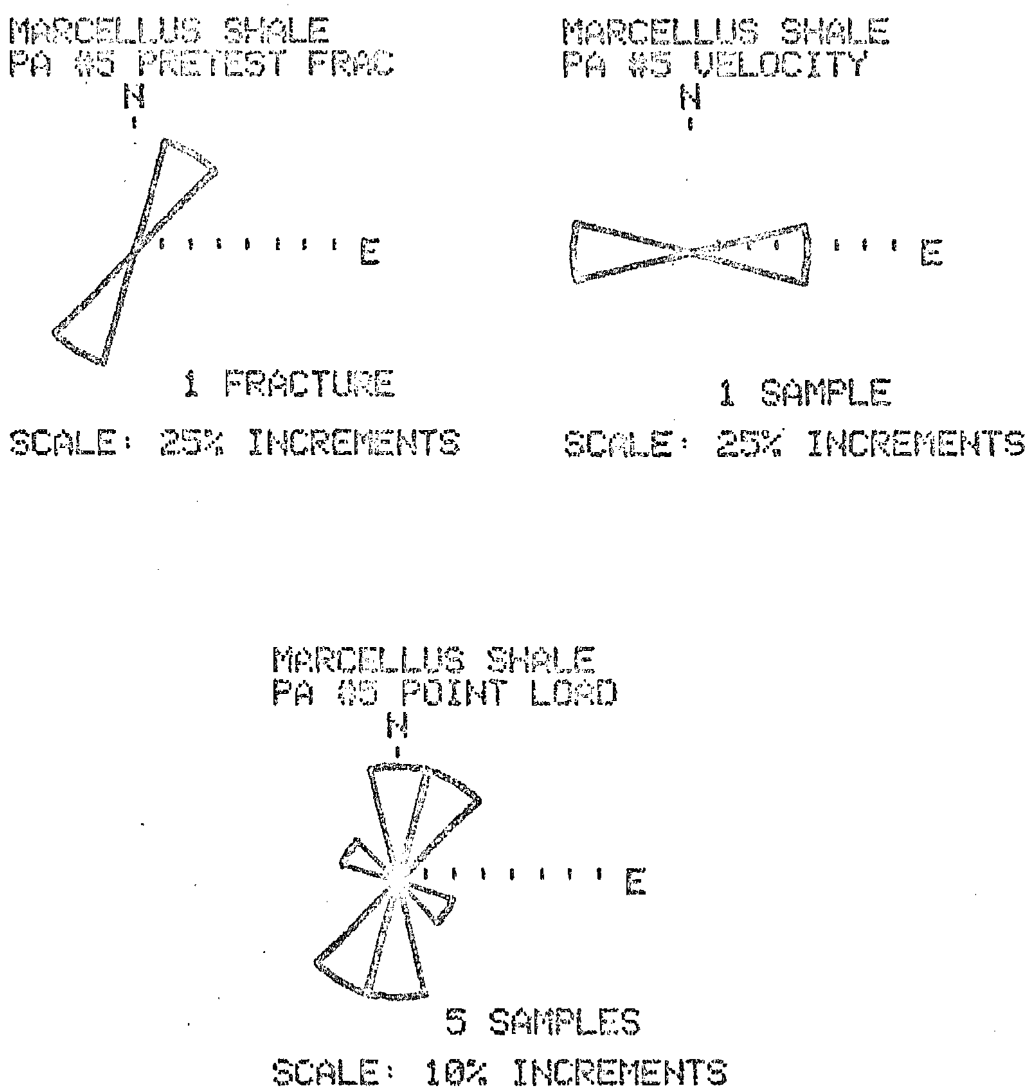


Marcellus Shale in the Hamilton Group; 4,113'-4,124' tested:

A statistically small number of samples were received from this interval. The one pretest fracture identified in this depth interval occurs in the N30°E ± 15° direction. The one ultrasonic velocity sample indicates N90°E ± 15° as the preferred direction of fracturing. Four of the five point load induced fractures occur in the due North ± 15° and N30°E ± 15° directions. Figure 10 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Marcellus Shale in the Hamilton Group. Tabulated results are presented in Appendices A, B and C.

FIGURE 10

Marcellus Shale in the Hamilton Group
Frequency Distribution Rose Diagrams of Results



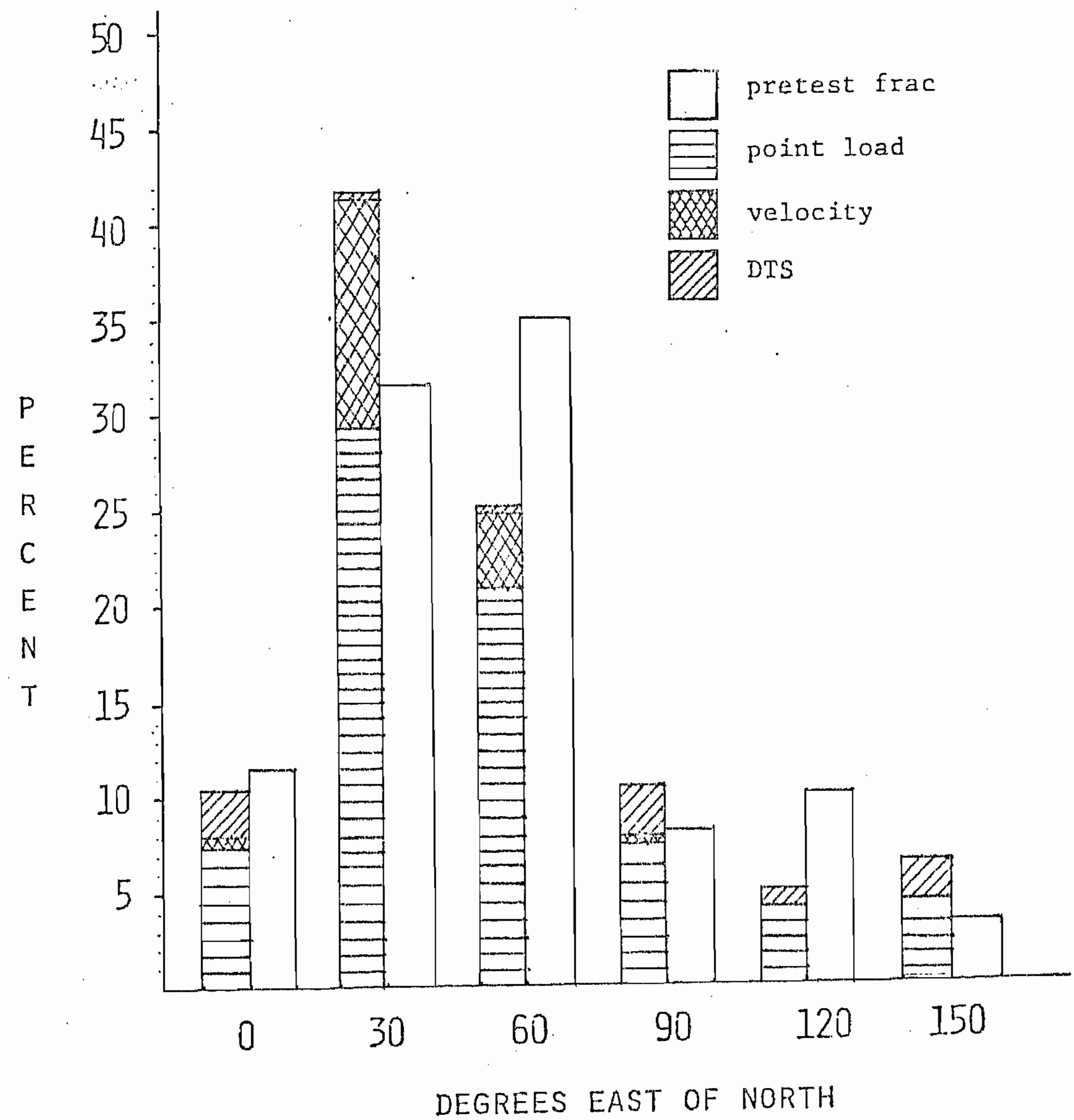
WELL COMPOSITE

Well Composite; 3,522'-4,124' tested:

Figure 11 is a grouped histogram comparing the frequency distribution of all mechanical test results with the frequency distribution of pretest fractures.

FIGURE 11

Well Composite
Grouped Histogram Comparing Frequency Distribution of
Mechanical Test Results (n = 353) with Pretest
Fractures (n = 60)



Pretest fractures occur most frequently in the N60°E ± 15° direction (21 out of 60 total pretest fractures) and the N30°E ± 15° direction (19 out of 60 total pretest fractures). Ultrasonic velocity measurements indicate N30°E ± 15° as the preferred direction of fracturing (42 out of 58 total velocity samples). Point load induced fractures occur most frequently in the N30°E ± 15° direction (105 out of 265 total induced fractures). Directional tensile strength measurements do not indicate a statistically significant preferred plane of weakness. Figure 12 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Pennsylvania #5 Well Composite. Tabulated results are presented in Appendices A, B, C and D.

FIGURE 12

Pennsylvania #5, Lawrence County Well Composite
Frequency Distribution Rose Diagrams of Results

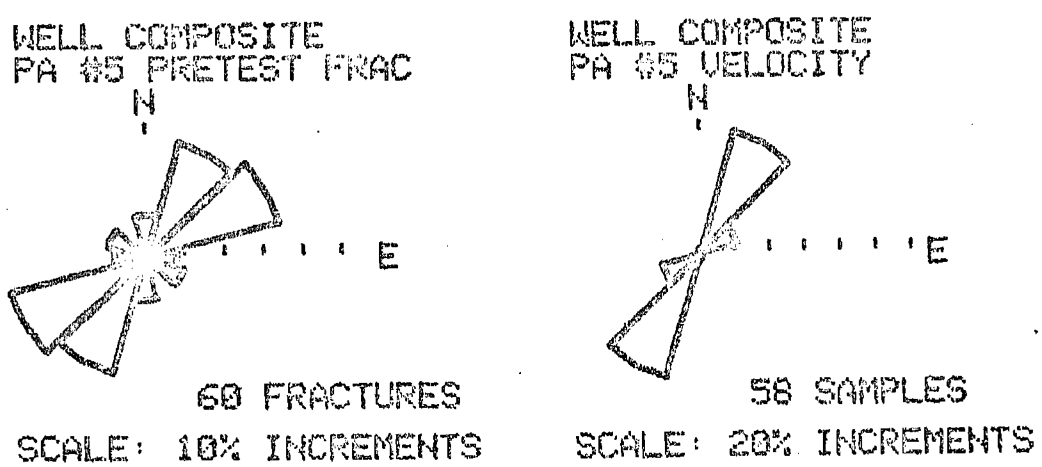
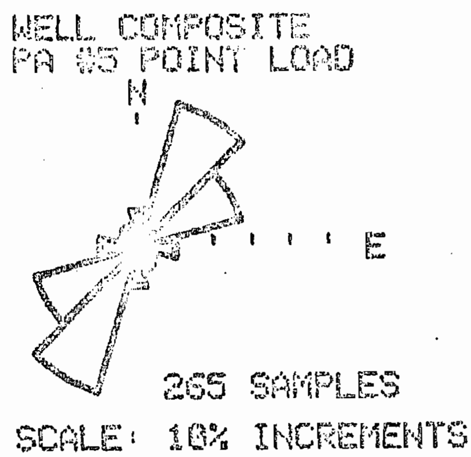
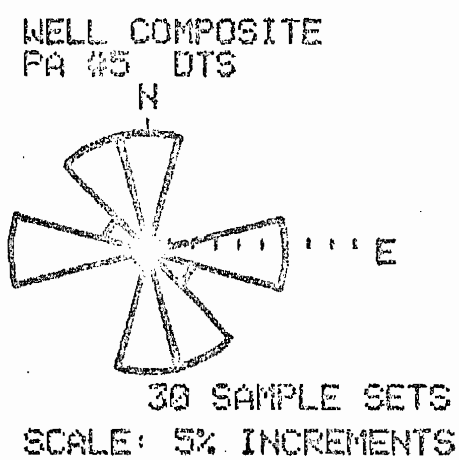


FIGURE 12
(continued)





CONCLUSIONS

The data presented in this report indicate that core samples from EGSP-Pennsylvania #5 well exhibit a directional variation in physical properties. Prediction of the preferred direction of induced fracturing at the Lawrence 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 suggest that these physical property measurements do indicate a preferred direction of fracturing in these core samples.

The following conclusions may be drawn from this investigation:

1) The preferred direction of fracturing for the Rhinestreet Shale Member of the West Falls Formation (3,522'-3,846' tested) is N30°E ± 15° as indicated by ultrasonic velocity measurements, point load induced fractures and the directional trend of pretest fractures. A secondary preferred direction of fracturing of N60°E ± 15° is also indicated.

2) The preferred direction of fracturing for the Cashaqua Shale Member of the Sonyea Formation (3,853'-3,909' tested) is N30°E ± 15° as indicated by ultrasonic velocity measurements and point load induced fractures. Three of the four pretest fractures in the Cashaqua Shale occur in the due North ± 15° direction. A secondary preferred direction of fracturing of N60°E ± 15° is also indicated.

3) The preferred direction of fracturing in the Middlesex Shale Member of the Sonyea Formation (3,910'-3,925' tested) is N30°E ± 15° as indicated by ultrasonic velocity measurements and point load induced fractures. Pretest fractures in the Middlesex Shale occur most frequently in the N60°W ± 15° direction. A possible secondary preferred direction of fracturing of N60°E ± 15° is indicated by point load induced fractures.

4) The preferred direction of fracturing in the Undifferentiated Members of the Genesee Formation (3,937'-3,967' tested) is N60°E ± 15° as indicated by ultrasonic velocity measurements, point load induced fractures and the directional trend of pretest fractures. A possible secondary preferred direction of fracturing of N30°E ± 15° is also indicated.

5) The preferred direction of fracturing for the Mahantango Shale in the Hamilton Group (3,988'-4,103' tested) is N30°E ± 15° as indicated by ultrasonic velocity measurements, point load induced fractures and the directional trend of pretest fractures. A secondary preferred direction of fracturing of N60°E ± 15° is also indicated.

6) The preferred direction of fracturing for the Marcellus Shale in the Hamilton (4,113'-4,124' tested) cannot be determined because of the statistically small number of samples received from this interval. The one velocity sample indicates N90°E ± 15° as the preferred direction of fracturing while four of the five point load induced fractures indicate due North ± 15° and N30°E ± 15° as the preferred direction of fracturing. The one pretest fracture identified in the Marcellus Shale Core occurs in the N30°E ± 15° direction.

7) The overall preferred direction of fracturing for the Pennsylvania #5 well core (3,522'-4,124' tested) is N30°E ± 15° as indicated by ultrasonic velocity measurements and point load induced fractures. A secondary preferred direction of fracturing of N60°E ± 15° is also indicated. Pretest fractures in the well core occur most frequently in the N60°E ± 15° and N30°E ± 15° directions.

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. In-situ 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.

APPENDICES

APPENDICES
(continued)

APPENDIX A

RESULTS OF PRETEST FRACTURE MEASUREMENTS

TABLE A-1

EGSP-Pennsylvania #5 Core

Orientation of Scribe Cuts in Velocity Samples*

Depth ft.	Groove Orientation Degrees East of North				
3,525	70	205	355		
3,533	65	185	335		
3,546	30	165	315		
3,553	15	95	230		
3,573	60	190	345		
3,589	100	180	345		
3,593	90	245	325		
3,604	70	220	300		
3,613	50	135	265		
3,628	30	110	240		
3,633	20	105	135		
3,646	30	110	240		
3,653	10	90	220		
3,665	60	190	340		
3,671	50	180	330		
3,688	100	180	310		
3,690	100	180	305		
3,704	0	80	210		
3,714	35	165	315		
3,721	20	150	300		
3,736	120	270	345		
3,746	20	150	300		
3,752	15	145	290		
3,765	40	175	320		
3,773	110	190	320		
3,785	105	185	345		
3,794	100	180	310		
3,801	95	180	305		
3,816	70	220	300		
3,822	65	220	300		
3,833	55	210	290		
3,842	25	105	235		
3,856	40	195	270		
3,864	60	190	340		
3,877	70	200	285		
3,888	105	255	340		
3,891	90	100	250	300	335
3,905	90	170	300		
3,914	90	170	300		
3,920	85	165	295		
3,937	70	150	280		
3,947	65	150	280		
3,952	70	150	280		
3,963	10	170	250		
3,988	75	230	305		
3,997	100	250	330		
4,008	95	245	330		
4,012	95	250	330		
4,026	70	225	305		
4,033	60	230	310		
4,046	15	140	300		
4,056	0	75	105		
4,061	0	80	210		
4,070	5	90	215		
4,080	65	145	275		
4,090	15	140	295		
4,103	25	155	305		
4,121	10	90	220		

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

TABLE A-2

EGSP-Pennsylvania #5

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

Depth ft.	0°	30°	Degrees East of North 60°	90°	120°	150°	Total
WEST FALLS FORMATION Rhinestreet Shale Member							
3,525		1.0*					1
3,533	1.0*						1
3,589		3.5,.7, .5,1.3*					4
3,604			1.0*				1
3,613				.5*	.7*		2
3,628			.5*				1
3,633		.6*	.9*				2
3,646			.6*	.3*			2
3,653			1.0*				1
3,665	1.2*	1.1*					2
3,704			.6*,.7*				2
3,714		.4*				.5*	2
3,721	.6*					1.0*	2
GENESEE FORMATION Undifferentiated							
3,937		1.0	1.3,1.3, 1.3*,.4*				5
HAMILTON GROUP Marcellus Shale							
4,121		.6*					1
WELL COMPOSITE Total Frequency							
	3	10	11	2	1	2	29

*Fracture originated at orientation groove; note only 6 out of 29 fractures did not originate at an orientation groove.

TABLE A-3

EGSP-Pennsylvania #5

Orientation and Length of Pretest Fractures in Point Load Samples measured in inches

Depth (ft.)	0°	30°	Degrees East of North 60°	90°	120°	150°	Total
WEST FALLS FORMATION Rhinestreet Shale Member							
3,805				.5,.7,.5			3
SONYEA FORMATION Cashaqua Shale Member							
3,875	.6	.6					2
GENESEE FORMATION Undifferentiated							
3,935			1.4				1
3,945			.7				1
WELL COMPOSITE Total Frequency							
	1	1	2	3	0	0	7

TABLE A-4

ECSP-Pennsylvania #5

Orientation and Length of Pretest Fractures in
Directional Tensile Strength Samples
measured in inches

Depth (ft.)	0°	30°	60°	90°	120°	150°	Total
			Degrees East of North				
WEST FALLS FORMATION Rhinestreet Shale Member							
3,665	.2	.2,.3					3
SONYEA FORMATION Cashaqua Shale Member							
3,875	.6,.5						2
Middlesex Shale Member							
3,915			.5,.4,.6		.4,.5,.5, .5,.4		8
GENESEE FORMATION Undifferentiated							
3,935		1.6	1.6				2
3,945		2.0	.5,.6, .5,.7				5
HAMILTON GROUP Mahantango Shale							
4,055		.7,.7, .5,.4					4
WELL COMPOSITE Total Frequency							
	3	8	8	0	5	0	24

TABLE A-5

EGSP-Pennsylvania #5

Frequency Distribution of Pretest Fractures

Formation	Test	Degrees East of North 0°	30°	60°	90°	120°	150°	Total
WEST FALLS FORMATION								
Rhinestreet Shale Member	Velocity	3	8	7	2	1	2	23
	Point Load	0	0	0	3	0	0	3
	DTS	1	2	0	0	0	0	3
	Total	4	10	7	5	1	2	29
SONYEA FORMATION								
Cashaqua Shale Member	Point Load	1	1	0	0	0	0	2
	DTS	2	0	0	0	0	0	2
	Total	3	1	0	0	0	0	4
Middlesex Shale Member	DTS	0	0	3	0	5	0	8
GENESEE FORMATION								
Undifferentiated	Velocity	0	1	4	0	0	0	5
	Point Load	0	0	2	0	0	0	2
	DTS	0	2	5	0	0	0	7
	Total	0	3	11	0	0	0	14
HAMILTON GROUP								
Mahantango Shale	DTS	0	4	0	0	0	0	4
Marcellus Shale	Velocity	0	1	0	0	0	0	1
WELL COMPOSITE	Velocity	3	10	11	2	1	2	29
	Point Load	1	1	2	3	0	0	7
	DTS	3	8	8	0	5	0	24
	Total	7	19	21	5	6	2	60

APPENDIX B

RESULTS OF DIRECTIONAL ULTRASONIC VELOCITY MEASUREMENTS

TABLE B-1

WELL # 5 IN PENNSYLVANIA, LAWRENCE COUNTY

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
WEST FALLS INFORMATION							
Rhinestreet	3525	5.187	5.246	5.289	5.192	5.181	5.17
Shale Member	3533	5.332	5.433	5.367	5.274	5.226	5.151
	3546	5.364	5.397	5.374	5.311	5.251	5.279
	3553	5.031	5.082	5.063	4.985	4.937	4.964
	3573	5.123	5.227	5.233	5.14	5.069	5.035
	3589	4.795	4.784	4.791	4.744	4.72	4.737
	3593	4.702	4.745	4.657	4.661	4.637	4.649
	3604	5.275	5.322	5.287	5.243	5.142	5.168
	3613	4.833	4.878	4.835	4.813	4.758	4.768
	3628	5.074	5.066	5.021	5.015	4.937	4.975
	3633	4.862	5.185	5.098	4.74	4.286	4.567
	3646	5.092	5.028	5.087	5.039	4.977	5.001
	3653	5.146	5.177	5.165	5.123	5.085	5.104
	3665	4.596	4.584	4.576	4.517	4.497	4.584
	3671	4.562	4.625	4.594	4.532	4.494	4.437
	3688	4.613	4.667	4.646	4.557	4.531	4.554
	3690	4.439	4.511	4.496	4.395	4.359	4.384
	3704	5.088	5.141	5.176	5.077	4.962	4.976
	3714	5.243	5.286	5.289	5.21	5.139	5.141
	3721	4.986	5.077	5.1	5.021	4.855	4.845
	3736	4.539	4.588	4.575	4.493	4.469	4.478
	3746	5.175	5.225	5.222	5.162	5.053	5.072
	3752	5.227	5.295	5.305	5.305	5.221	5.148
	3765	5.158	5.226	5.203	5.11	5.043	5.033
	3773	5.123	5.159	5.128	5.066	5.032	5.056
	3785	4.506	4.543	4.759	4.467	4.448	4.469

TABLE B-1
(continued)

	3794	4.893	4.884	4.882	4.795	4.746	4.757
	3801	5.302	5.329	5.31	5.23	5.249	5.253
	3816	5.102	5.14	5.117	5.057	5.082	5.026
	3822	5.063	5.087	5.099	5.051	5	5.097
	3833	5.131	5.187	5.167	5.099	5.039	5.031
	3842	4.509	4.583	4.582	4.516	4.441	4.45
SONYEA FM	3856	4.987	5.057	5.05	4.963	4.922	4.933
Cashaqua	3864	4.903	4.969	4.928	4.881	4.816	4.766
Shale Member	3877	4.924	4.968	4.976	4.941	4.89	4.878
	3888	5.014	5.056	5.033	4.978	4.949	4.961
	3891	5.059	5.111	5.107	4.981	4.94	4.953
	3905	5.003	5.077	5.024	4.923	4.897	4.94
Middlesex	3914	4.914	4.975	4.966	4.846	4.824	4.856
Shale Member	3920	4.764	4.827	4.827	4.747	4.689	4.714
GENESEE FM	3937	4.955	4.976	4.971	4.944	4.915	4.878
Undiff.	3947	5.002	5.031	5.017	4.937	4.969	4.937
	3952	5.002	5.042	5.039	4.994	4.944	4.949
	3963	4.889	4.862	4.829	4.731	4.765	4.844
HAMILTON GR	3988	5.269	5.296	5.237	5.204	5.199	5.22
Mahantango	3997	5.13	5.163	5.158	5.134	5.104	5.09
Shale Member	4008	4.592	4.659	4.634	4.558	4.496	4.508
	4012	4.854	4.899	4.839	4.759	4.722	4.757
	4026	4.856	4.876	4.911	4.851	4.773	4.778
	4033	4.857	4.925	4.915	4.839	4.759	4.774
	4046	4.967	4.995	4.982	4.909	4.832	4.87
	4056	4.755	4.91	4.985	4.82	4.749	4.763
	4061	4.785	4.892	4.911	4.827	4.757	4.779
	4070	4.797	4.911	4.924	4.815	4.782	4.771
	4080	4.823	4.858	4.772	4.748	4.718	4.75
	4090	4.897	4.937	4.949	4.895	4.818	4.842
	4103	4.839	4.982	4.981	4.822	4.734	4.74
Marcellus Sh	4121	4.132	4.181	4.209	4.168	4.159	4.176
	AVERAGE VELOCITY	4.93	4.982	4.974	4.9	4.943	4.856

TABLE B-2

ORIENTATION OF ULTRASONIC VELOCITY MINIMUM
WELL # 5 IN PENNSYLVANIA, LAWRENCE COUNTY

DEGREES EAST OF NORTH

	DEPTH IN FEET	0	30	60	90	120	150
WEST FALLS FORMATION Rhinestreet	3525						MIN
Shale Member	3533						MIN
	3546					MIN	
	3553					MIN	
	3573						MIN
	3589					MIN	
	3593					MIN	
	3604					MIN	
	3613					MIN	
	3628					MIN	

1

FREQUENCY VS ORIENTATION

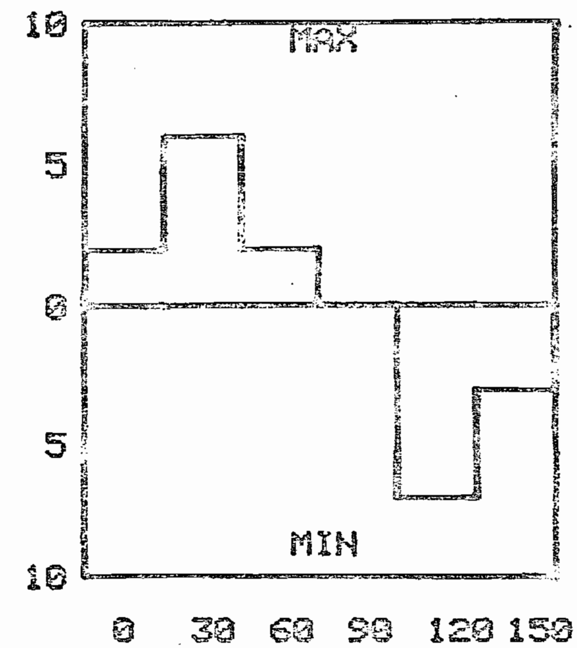


TABLE B-2
(continued)

ORIENTATION OF ULTRASONIC VELOCITY MINIMUM
WELL # 5 IN PENNSYLVANIA, LAWRENCE COUNTY

2

DEPTH IN FEET	0	30	60	90	120	150
3633					MIN	
3646					MIN	
3653					MIN	
3665					MIN	
3671						MIN
3688					MIN	
3690					MIN	
3704					MIN	
3714					MIN	
3721						MIN

FREQUENCY VS ORIENTATION

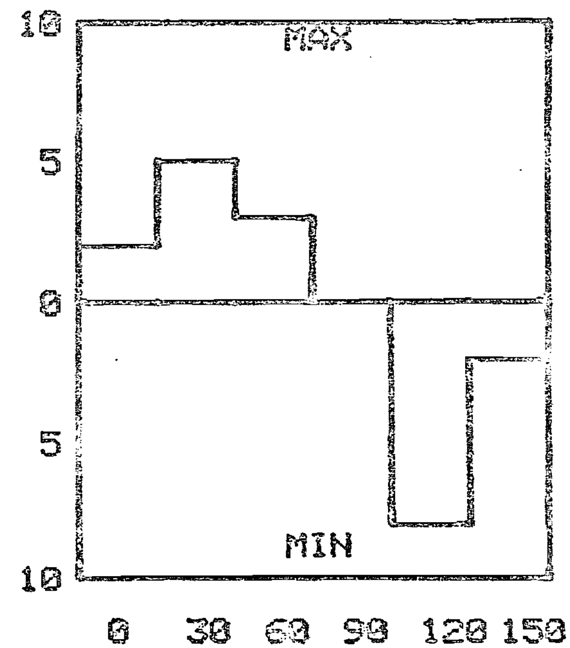


TABLE B-2
(continued)

ORIENTATION OF ULTRASONIC VELOCITY MINIMUM
WELL # 5 IN PENNSYLVANIA, LAWRENCE COUNTY

3

DEPTH IN FEET	0	30	60	90	120	150
3736					MIN	
3746					MIN	
3752						MIN
3765						MIN
3773					MIN	
3785					MIN	
3794					MIN	
3801				MIN		
3816					MIN	
3822					MIN	

(Column headings: DEGREES EAST OF NORTH)

FREQUENCY VS ORIENTATION

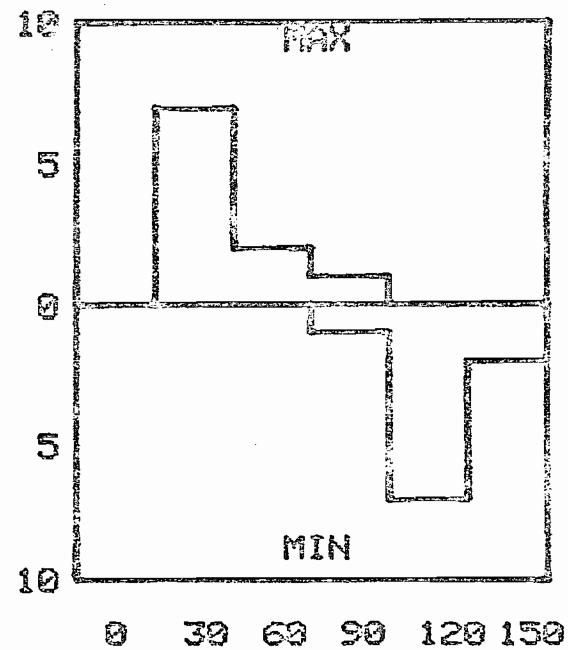


TABLE B-2
(continued)

ORIENTATION OF ULTRASONIC VELOCITY MINIMUM
WELL # 5 IN PENNSYLVANIA, LAWRENCE COUNTY

	DEPTH IN FEET	0	30	60	90	120	150
		DEGREES EAST OF NORTH					
SONYEA FM	3856					MIN	
Cashaqua	3864						MIN
Shale Member							
	3877						MIN
	3888					MIN	
	3891					MIN	
	3905					MIN	
Middlesex	3914					MIN	
Shale Member	3920					MIN	
GENESEE FM	3937						MIN
Undiff.	3947						MIN
	3952					MIN	
	3963				MIN		

4

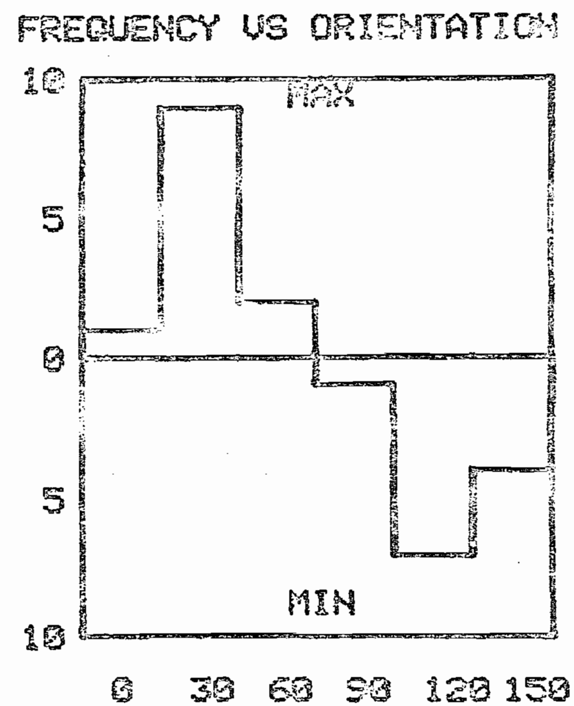


TABLE B-2
(continued)

ORIENTATION OF ULTRASONIC VELOCITY MINIMUM
WELL # 5 IN PENNSYLVANIA, LAWRENCE COUNTY

5

	DEPTH IN FEET	0	30	60	90	120	150
HAMILTON GR	3988					MIN	
Mahantango	3997						MIN
Shale Member	4008					MIN	
	4012					MIN	
	4026					MIN	
	4033					MIN	
	4046					MIN	
	4056					MIN	
	4061					MIN	
	4070						MIN
	4080					MIN	
	4090					MIN	
	4103					MIN	
Marcellus Sh	4121	MIN					

(Column heading: DEGREES EAST OF NORTH)

FREQUENCY VS ORIENTATION

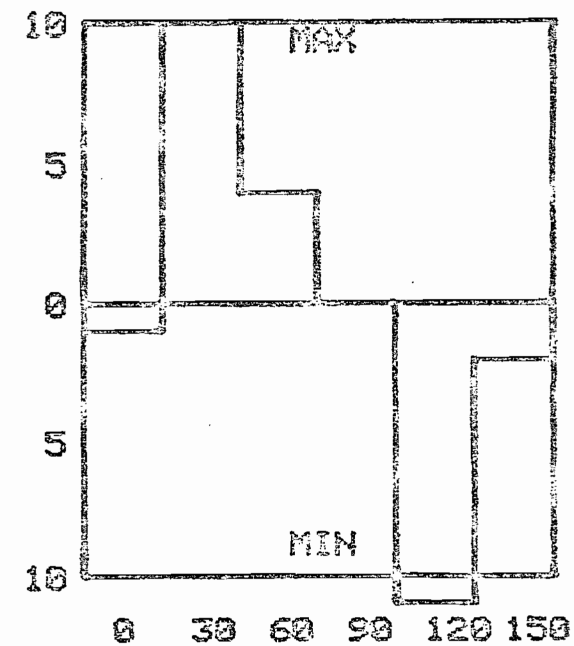


FIGURE B-1

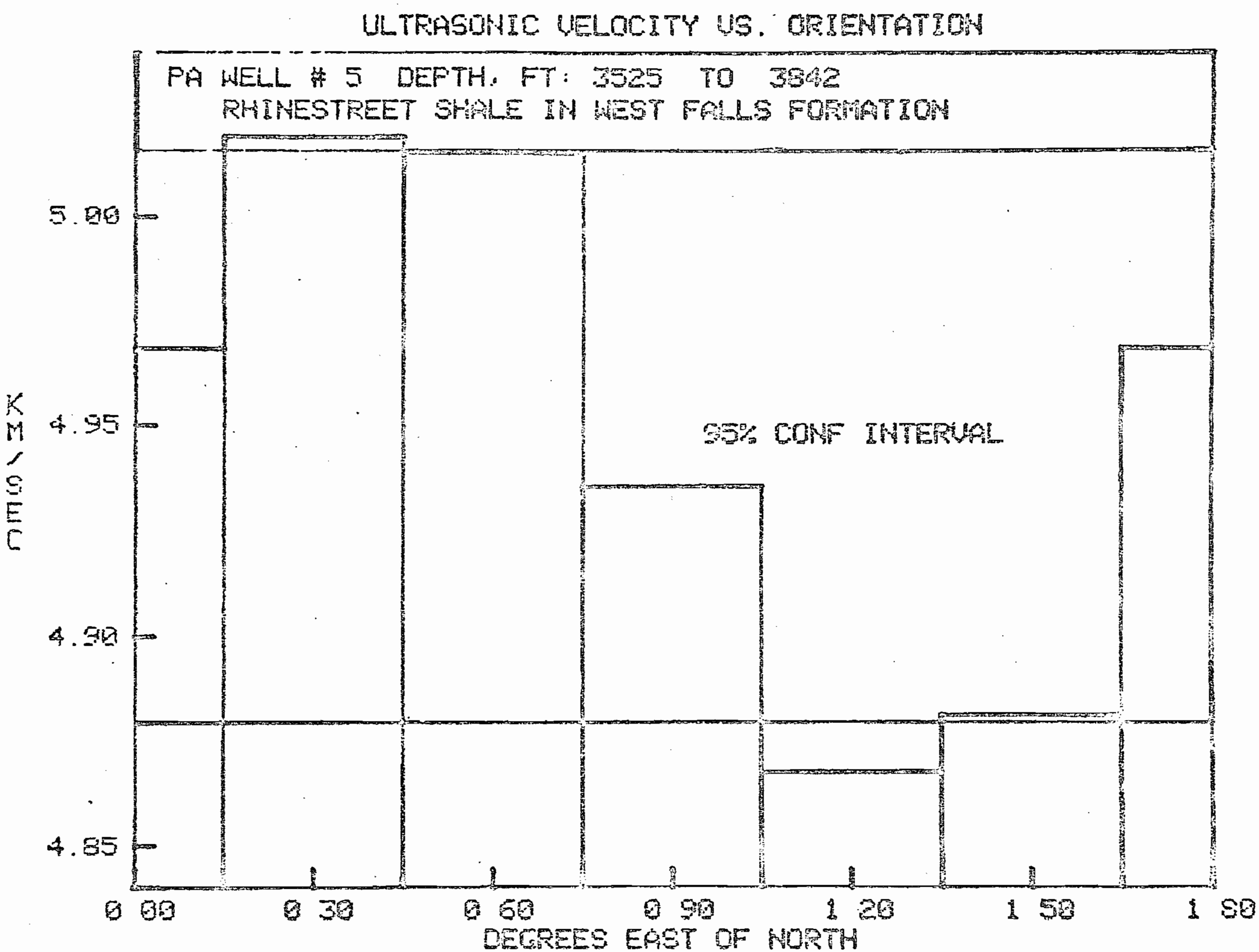

ULTRASONIC VELOCITY VS. ORIENTATION
PA WELL # 5 DEPTH, FT: 3525 TO 3842
RHINESTREET SHALE IN WEST FALLS FORMATION
95% CONF INTERVAL
KM/SEC
5.00
4.95
4.90
4.85
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE B-2

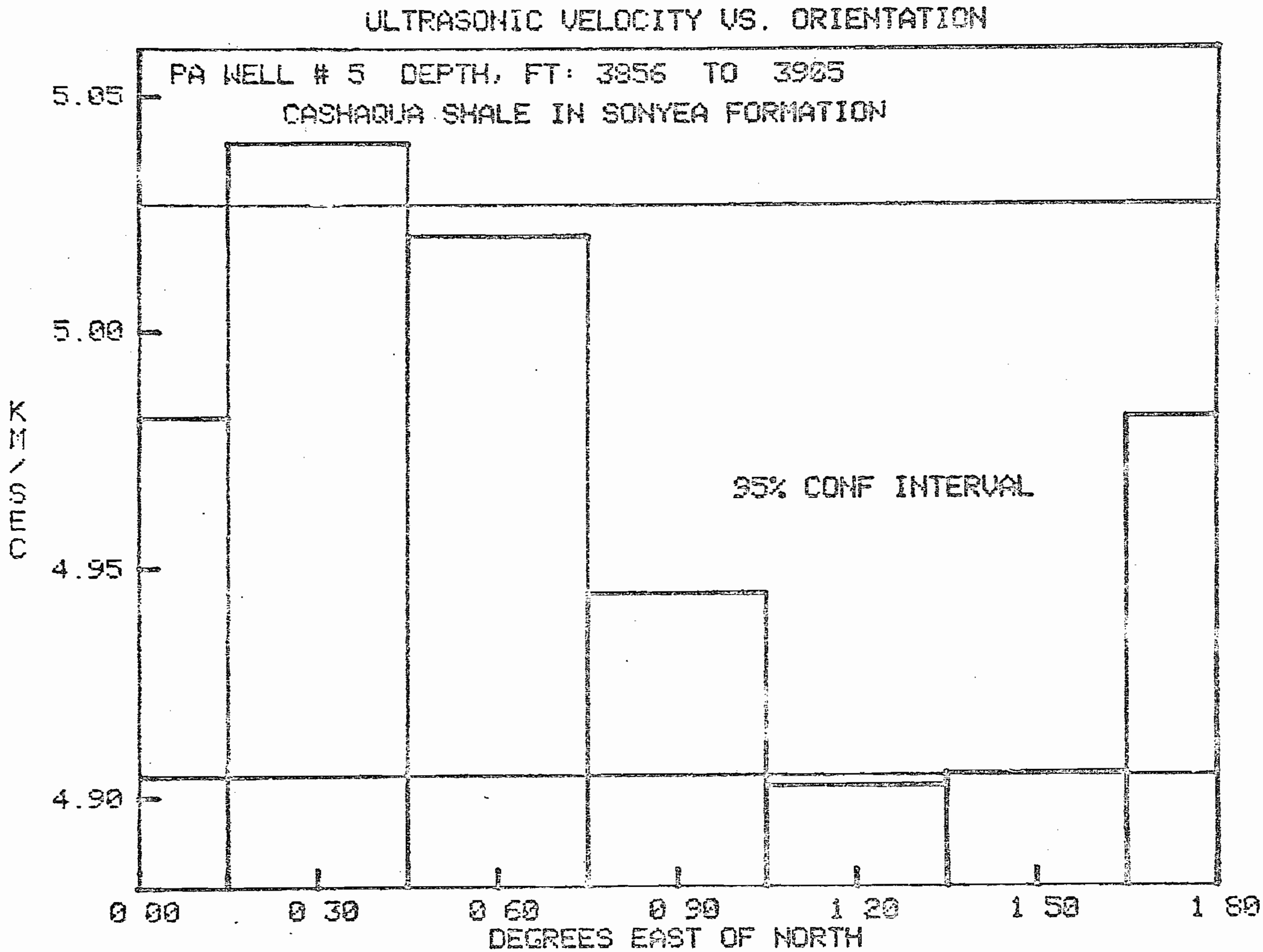
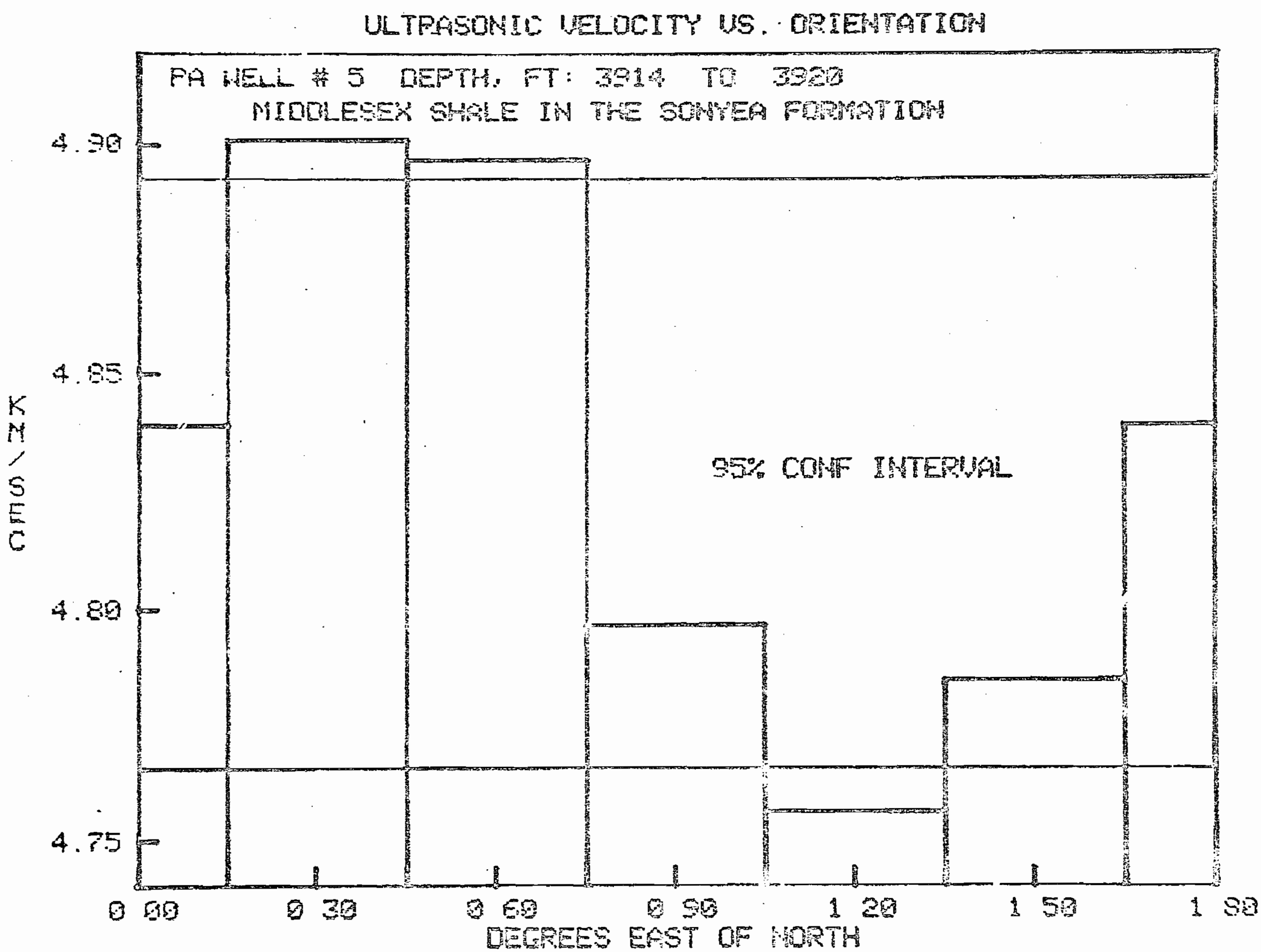

ULTRASONIC VELOCITY VS. ORIENTATION
PA WELL # 5 DEPTH, FT: 3856 TO 3905
CASHAQUA SHALE IN SONYEA FORMATION
95% CONF INTERVAL
5.05
5.00
4.95
4.90
KM/SEC
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE B-3



ULTRASONIC VELOCITY VS. ORIENTATION
PA WELL # 5 DEPTH, FT: 3914 TO 3920
MIDDLESEX SHALE IN THE SONYEA FORMATION
95% CONF INTERVAL
KM/SEC
4.90
4.85
4.80
4.75
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE B-4

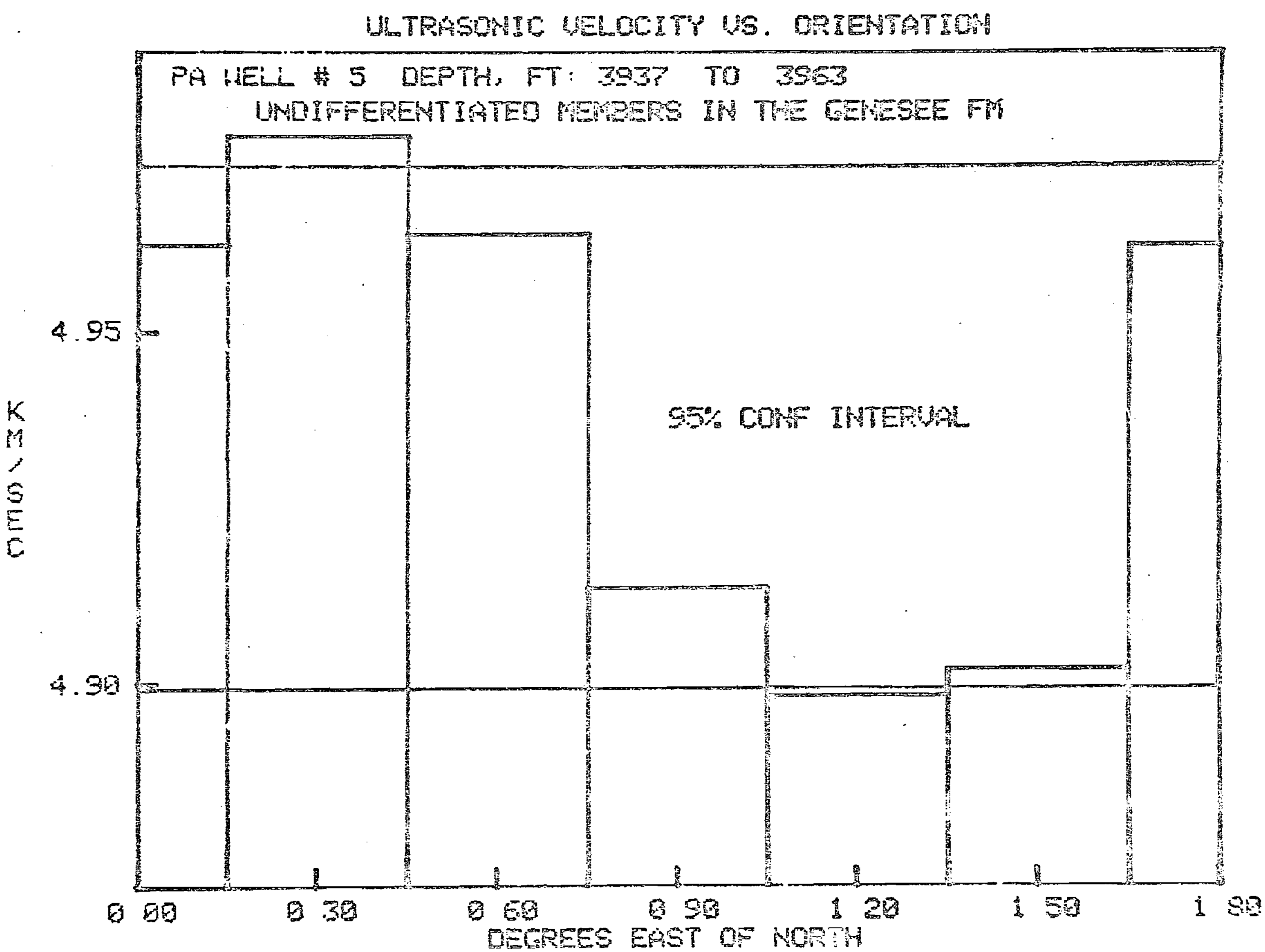

ULTRASONIC VELOCITY VS. ORIENTATION
PA WELL # 5 DEPTH, FT: 3937 TO 3963
UNDIFFERENTIATED MEMBERS IN THE GENESEE FM
95% CONF INTERVAL
4.95
4.90
KM/SEC
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE B-5

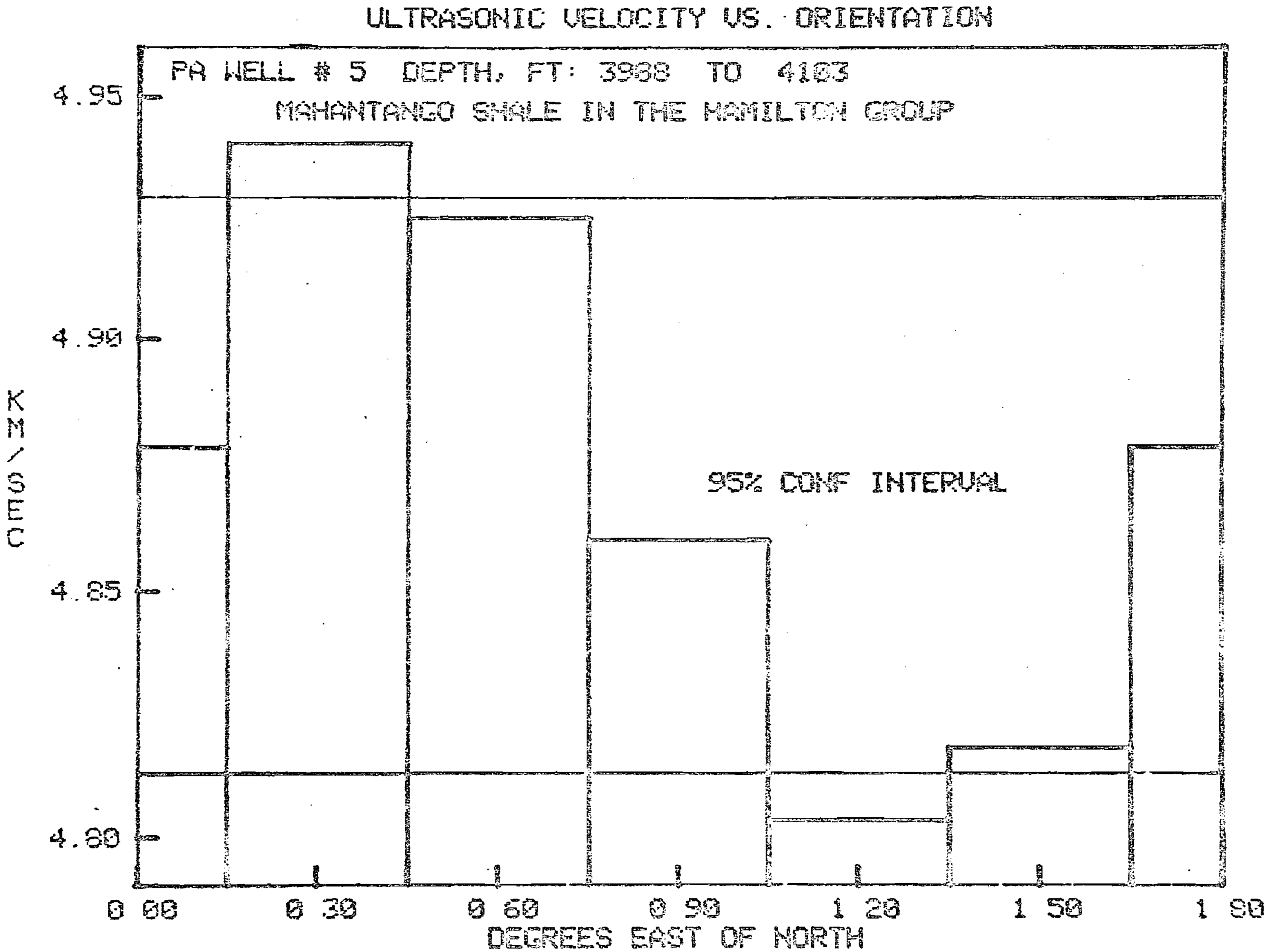

ULTRASONIC VELOCITY VS. ORIENTATION
PA WELL # 5 DEPTH, FT: 3988 TO 4103
MAHANTANGO SHALE IN THE HAMILTON GROUP
95% CONF INTERVAL
4.95
4.90
4.85
4.80
KM/SEC
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE B-6

ULTRASONIC VELOCITY VS. ORIENTATION

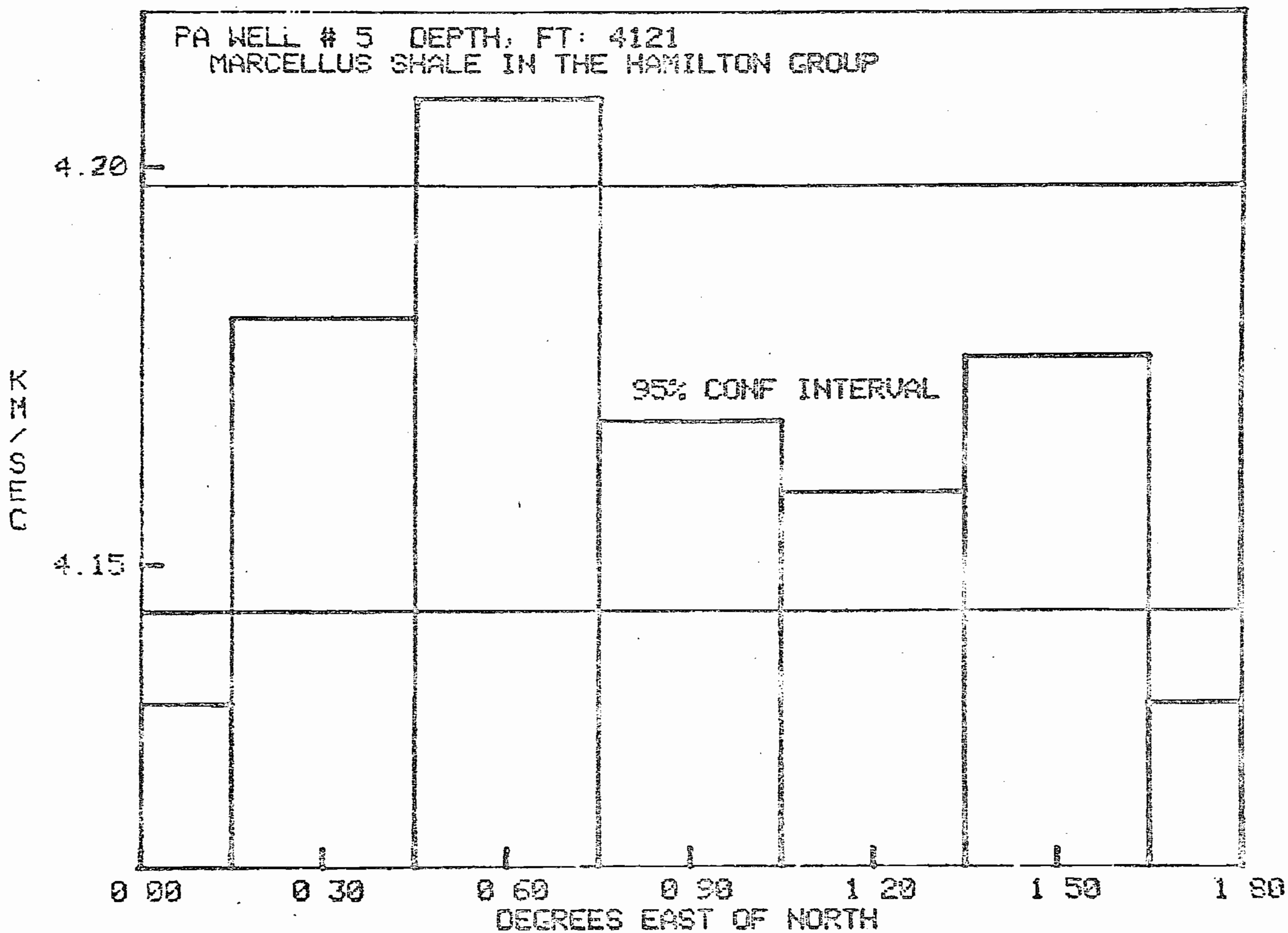
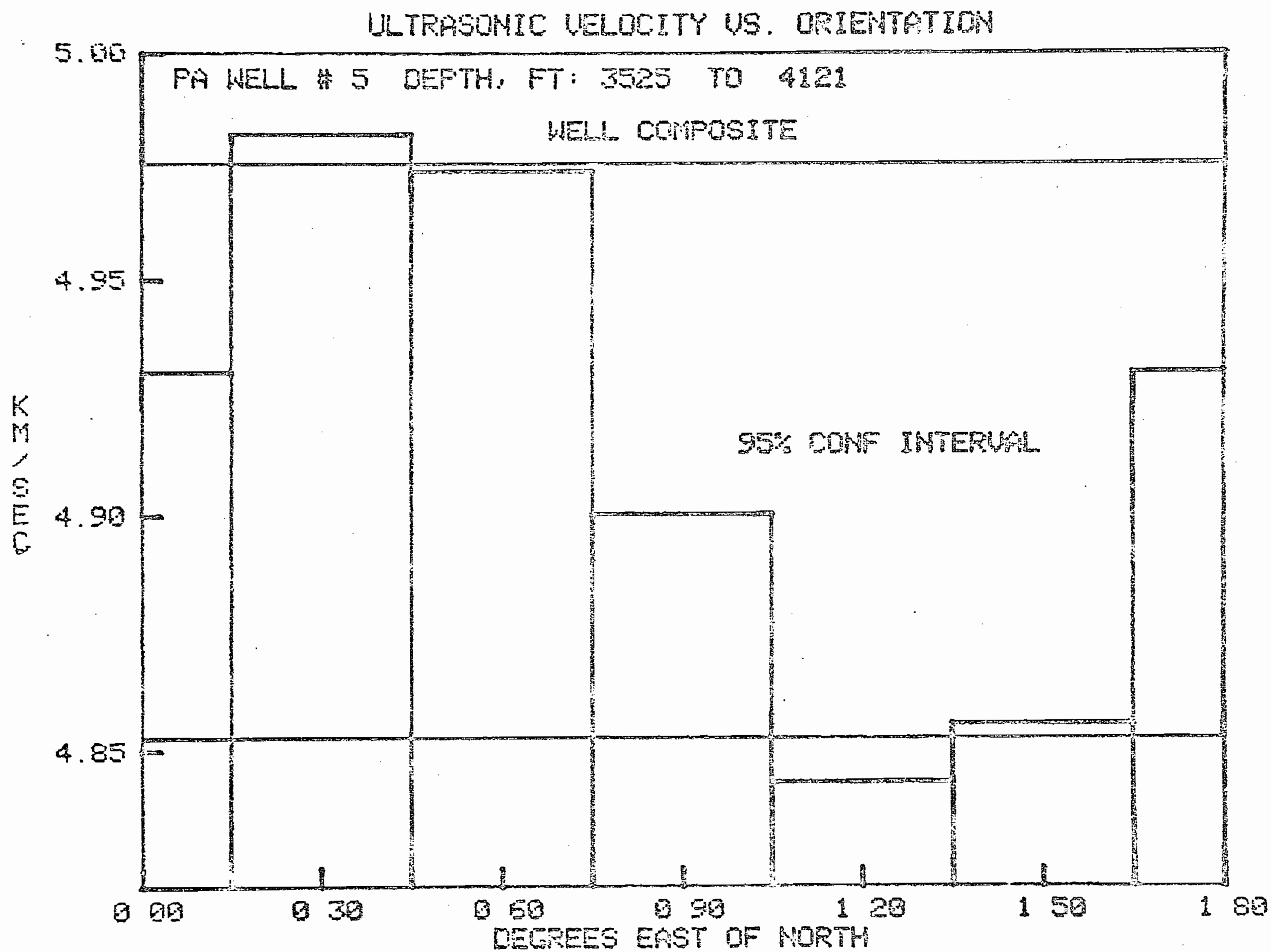


FIGURE B-7


ULTRASONIC VELOCITY VS. ORIENTATION
PA WELL # 5 DEPTH, FT: 3525 TO 4121
WELL COMPOSITE
95% CONF INTERVAL
KM/SEC
5.00
4.95
4.90
4.85
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 # 5 IN PENNSYLVANIA, LAWRENCE COUNTY

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
WEST FALLS FORMATION Rhinestreet	3663	2	1	0	2	1	2	8
Shale Member	3675	2	3	2	1	0	0	8
	3685	0	7	2	0	0	1	10
	3695	1	1	2	1	1	0	6
	3715	1	1	3	1	0	0	6
	3725	0	3	3	0	1	0	7
	3735	0	4	4	1	1	0	10
	3745	0	7	2	0	0	0	9
	3755	0	4	0	0	1	0	5
	3763	1	3	1	0	0	1	6
	3778	0	1	3	0	0	1	5
	3782	1	6	2	0	0	0	9
	3794	0	5	1	0	1	0	7
	3804	0	1	2	1	1	0	5
	3814	1	5	3	0	0	0	9
	3826	0	3	2	0	1	0	6
	3835	0	2	4	0	0	0	6
	3841	0	1	0	0	0	0	1
SONYEA FM	3853	0	1	2	1	0	0	4
Cashaqua	3865	1	2	2	1	0	1	7
Shale Member	3875	1	3	3	0	0	0	7
	3886	0	6	1	0	0	0	7
	3895	1	0	3	0	0	0	4
	3905	0	4	3	1	0	1	9
Middlesex	3915	1	1	3	0	0	0	5
Shale Member	3925	0	5	1	1	1	0	8
GENESEE FM	3938	0	1	4	2	0	1	8

TABLE C-1
(continued)

Undiff.	3945	1	1	3	3	0	0	8
	3955	1	2	2	1	1	2	9
	3964	1	4	1	0	1	0	7
HAMILTON GR	3994	2	2	4	1	0	1	10
Mahantango	4004	3	4	1	2	0	0	10
Shale Member	4015	1	1	2	2	1	2	9
	4025	0	1	0	4	0	1	6
	4045	1	1	0	0	2	0	4
	4055	2	0	1	0	0	0	3
	4065	0	4	1	0	0	1	6
	4074	0	0	2	1	0	0	3
	4085	0	2	0	0	0	1	3
Marcellus Sh	4116	2	2	0	0	1	0	5
	TOTAL FREQ	27	105	75	27	15	16	265

TABLE C-2

WELL # 5 IN PA

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

WEST FALLS FORMATION

	DEPTH FEET	POINT LOAD INDEX 1	2	3	4	5	6	7	8	9	10
Rhinestreet	3663	2892	3643	4961	3014	3501	4673	4772	3130	0	0
Shale Member	3675	5037	5273	5883	4218	4767	3637	3711	3445	0	0
	3685	7942	2348	7183	5190	4018	6233	6134	7488	6193	5389
	3695	4912	4332	4850	4584	2221	2055	0	0	0	0
	3715	2956	2553	5170	3595	4257	3326	0	0	0	0
	3725	4658	4555	5797	4195	5234	2577	4899	0	0	0
	3735	4133	3918	3719	4234	3880	4462	3234	5539	4520	4175
	3745	3811	6110	5450	3570	6015	4820	5173	5793	6308	0
	3755	4566	5570	6671	5365	4349	0	0	0	0	0
	3763	6285	5627	3022	4570	3586	9007	0	0	0	0
	3778	4471	6218	4491	5783	5631	0	0	0	0	0
	3782	6861	5810	5870	4769	5533	3999	5791	4285	5761	0
	3794	4835	6859	8035	6595	7976	2468	6961	0	0	0
	3804	5147	2538	4150	5862	3944	0	0	0	0	0
	3814	2946	5926	5870	7113	5109	5591	4991	4335	6258	0
	3826	5269	8817	9937	3260	8891	6341	0	0	0	0
	3835	3441	3293	5596	3642	1126	4226	0	0	0	0
	3841	3372	0	0	0	0	0	0	0	0	0
SONYEA FM	3853	2578	5246	5163	3752	0	0	0	0	0	0
Cashaqua	3865	4869	7184	6210	3263	4324	5077	7453	0	0	0
Shale Member	3875	8035	4634	9244	8337	3836	4197	3320	0	0	0
	3886	3123	7072	4428	3416	3224	3706	6876	0	0	0
	3895	6686	4365	5587	3932	0	0	0	0	0	0
	3905	4027	4923	3338	4740	3489	5761	5946	3223	4283	0
Middlesex	3915	3197	2254	2509	1711	4273	0	0	0	0	0
Shale Member	3925	4183	4917	3311	3659	5243	3318	3571	4032	0	0
GENESEE FM	3938	4178	2704	6260	2583	1945	2248	1819	4263	0	0
Undiff.	3945	4466	3352	1974	4647	4886	4822	2426	2951	0	0

TABLE C-2
(continued)

	3955	4935	4638	4308	3547	3097	2203	3501	2969	6203	0
	3964	5583	4881	3581	4001	4458	5598	5036	0	0	0
HAMILTON GR	3994	4758	4402	5179	4846	3826	3224	3195	3561	4410	4168
Mahantango	4004	4675	4367	5158	3713	3743	4641	3972	4057	2678	5021
Shale Member	4015	4259	4728	4904	2401	3258	4990	2336	3881	3353	0
	4025	5453	3186	2613	6063	6129	2282	0	0	0	0
	4045	4031	3020	2459	2569	0	0	0	0	0	0
	4055	5770	5698	3393	0	0	0	0	0	0	0
	4065	4980	4118	5425	3802	3053	5019	0	0	0	0
	4074	3920	2797	1687	0	0	0	0	0	0	0
	4085	4583	1933	1850	0	0	0	0	0	0	0
Marcellus Sh	4118	6838	3650	2354	3332	6465	0	0	0	0	0

APPENDIX D

RESULTS OF DIRECTIONAL TENSILE STRENGTH TESTS

TABLE D-1

WELL NUMBER 5 IN PENNSYLVANIA, LAWRENCE COUNTY

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 DFG	120 DEG	150 DEG
WEST FALLS FORMATION							
Rhinestreet	3665	497	561	687	725	510	699
Shale Member	3675	644	691	677	695	758	670
	3688	558	912	802	806	549	665
	3696	596	493	402	285	476	417
	3729	582	797	754	587	457	528
	3764	585	602	645	569	652	600
	3778	704	554	438	224	538	388
	3780	1289	1472	1442	1209	1293	1532
	3790	1615	1935	1802	1833	1534	1711
	3806	1540	1432	1677	1517	1518	1361
	3818	1527	1360	1454	1314	1050	654
	3825	1376	1593	1603	1564	1532	1523
	3833	1330	1667	1627	1570	1444	1380
	3845	1422	1371	1365	1040	1251	1571
SONYEA FM	3854	1243	1472	1258	1271	1329	1142
Cashaqua	3863	1473	1400	1449	1357	1281	1194
Shale Member	3874	1088	1715	1574	1247	1737	1869
	3886	1314	1589	1553	1423	1535	1444
	3893	1528	1365	1283	1181	1210	1327
	3901	1147	1429	1195	1364	1227	1051
Middlesex	3911	1256	1738	1574	1183	1597	1474
Shale Member	3925	1778	1466	1533	1841	2030	1754
GENESEE FM	3938	1276	1645	1453	1552	1299	1513
Undiff.	3941	1671	947	596	894	1103	1514
	3953	1639	1628	1580	1499	1536	1685
	3961	1538	1580	1554	1617	1553	1428

TABLE D-1
(continued)

HAMILTON GROUP							
Mahantango	3991	1464	1436	1390	1406	1600	1200
Shale Member	4000	1397	1574	2034	2171	2033	1649
	4052	801	877	712	991	956	855
	4063	1158	1181	1042	1198	1164	1034
	AVERAGE STRENGTH	1201	1275	1252	1207	1226	1191

TABLE D-2

ORIENTATION OF DIRECTIONAL TENSILE STRENGTH MINIMUM
WELL # 5 IN PENNSYLVANIA, LAWRENCE COUNTY

	DEPTH IN FEET	0	30	60	90	120	150
WEST FALLS FORMATION	3665	MIN					
Rhinestreet Shale Member	3675	MIN					
	3688					MIN	
	3696				MIN		
	3729					MIN	
	3764				MIN		
	3778				MIN		
	3788				MIN		
	3790					MIN	
	3806						MIN
	3818						MIN
	3825	MIN					
	3833	MIN					
	3845				MIN		

(Column headings: DEGREES EAST OF NORTH)

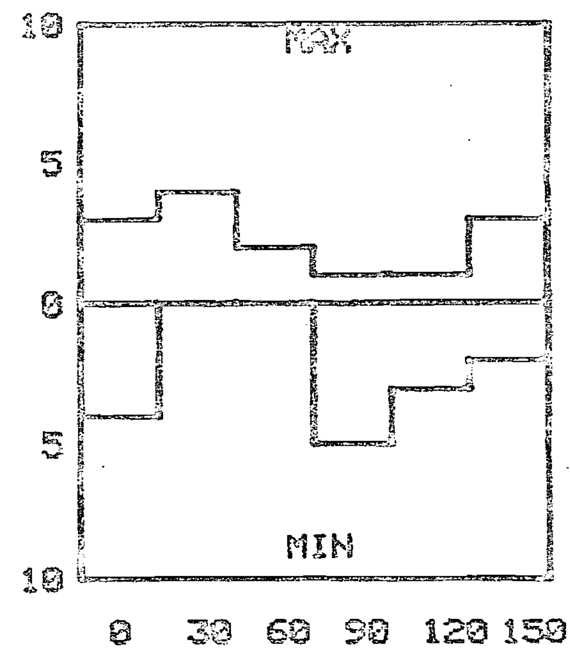


TABLE D-2
(continued)

ORIENTATION OF DIRECTIONAL TENSILE STRENGTH MINIMUM
WELL # 5 IN PENNSYLVANIA, LAWRENCE COUNTY

	DEPTH IN FEET	0	30	60	90	120	150
		DEGREES EAST OF NORTH					
SONYEA FM	3854						MIN
Cashaqua	3863						MIN
Shale Member	3874	MIN					
	3886	MIN					
	3893				MIN		
	3901						MIN
Middlesex	3911				MIN		
Shale Member	3925		MIN				
GENESEE FM Undiff.	3938	MIN					
	3941				MIN		
	3953				MIN		
	3961						MIN
HAMILTON GROUP Mahantango	3991						MIN
Shale Member	4000	MIN					
	4052			MIN			
	4063						MIN

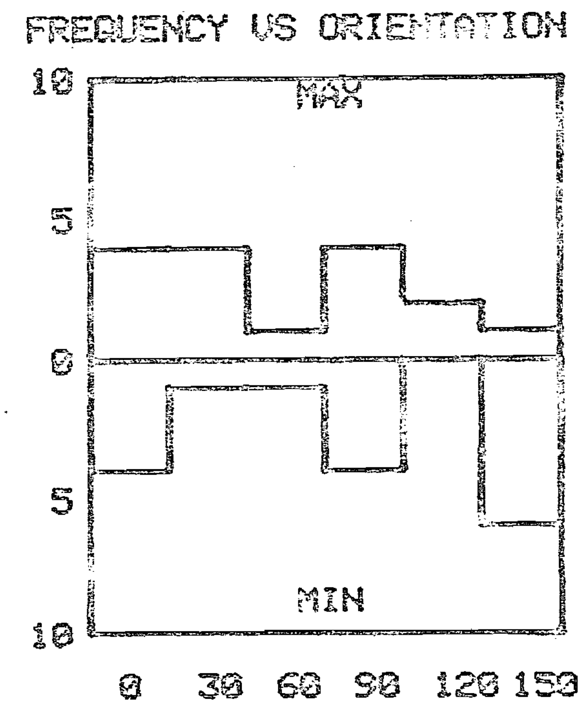


FIGURE D-1

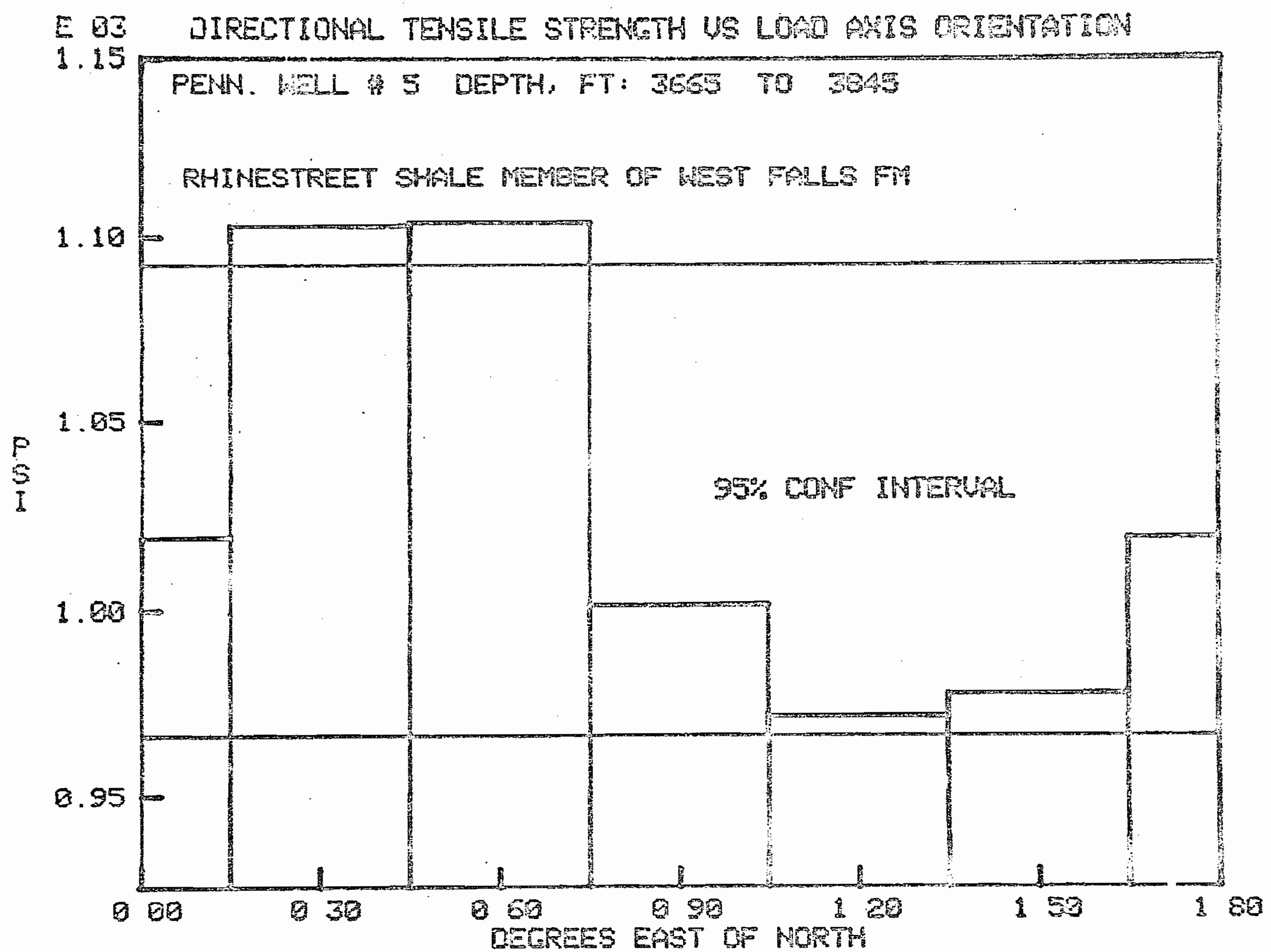

E 03
DIRECTIONAL TENSILE STRENGTH VS LOAD AXIS ORIENTATION
PENN. WELL # 5 DEPTH, FT: 3665 TO 3845
RHINESTREET SHALE MEMBER OF WEST FALLS FM
95% CONF INTERVAL
1.15
1.10
1.05
1.00
0.95
PSI
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE D-2

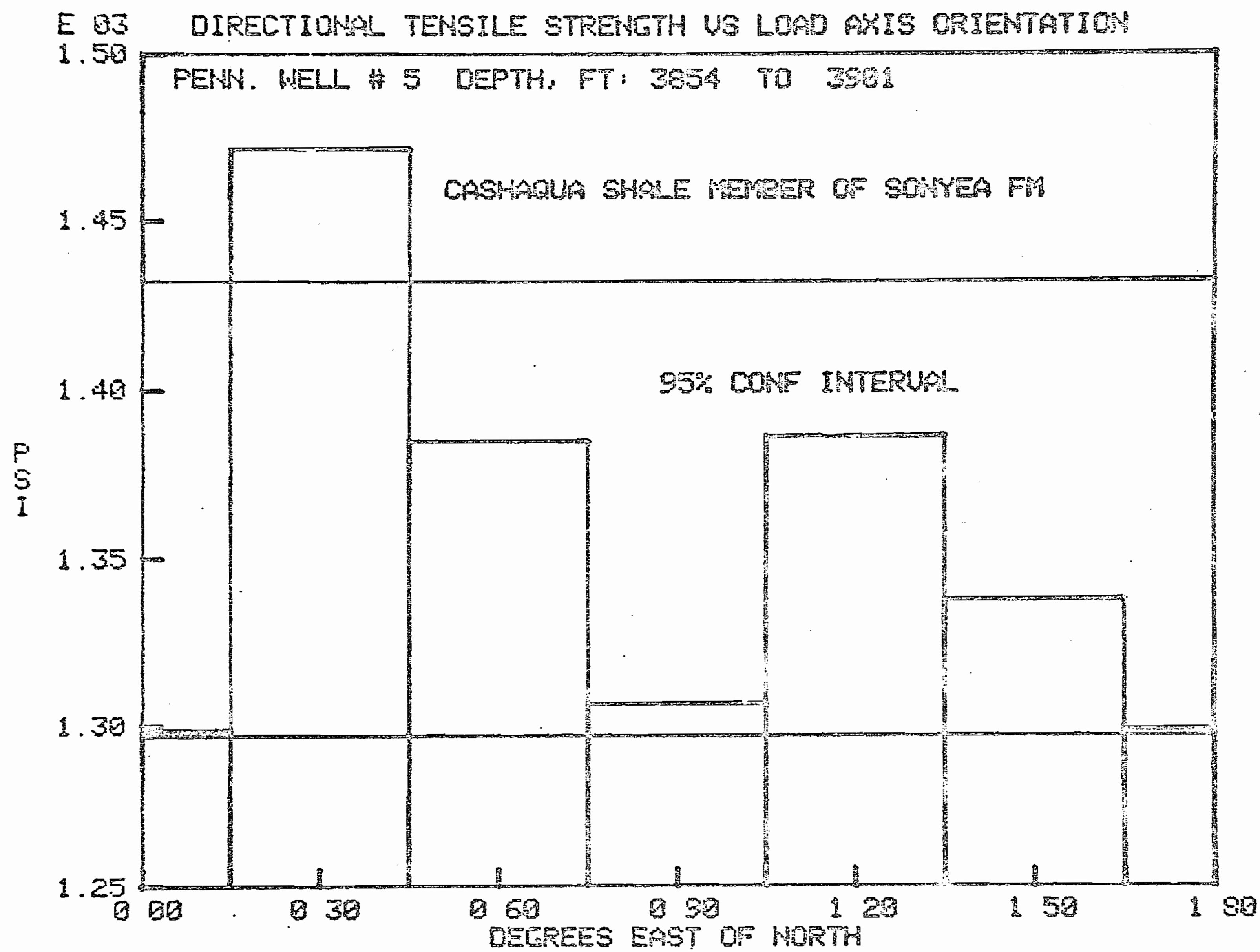

E 03
DIRECTIONAL TENSILE STRENGTH VS LOAD AXIS ORIENTATION
PENN. WELL # 5 DEPTH, FT: 3854 TO 3901
CASHAQUA SHALE MEMBER OF SONYEA FM
95% CONF INTERVAL
1.50
1.45
1.40
1.35
1.30
1.25
P S I
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE D-3

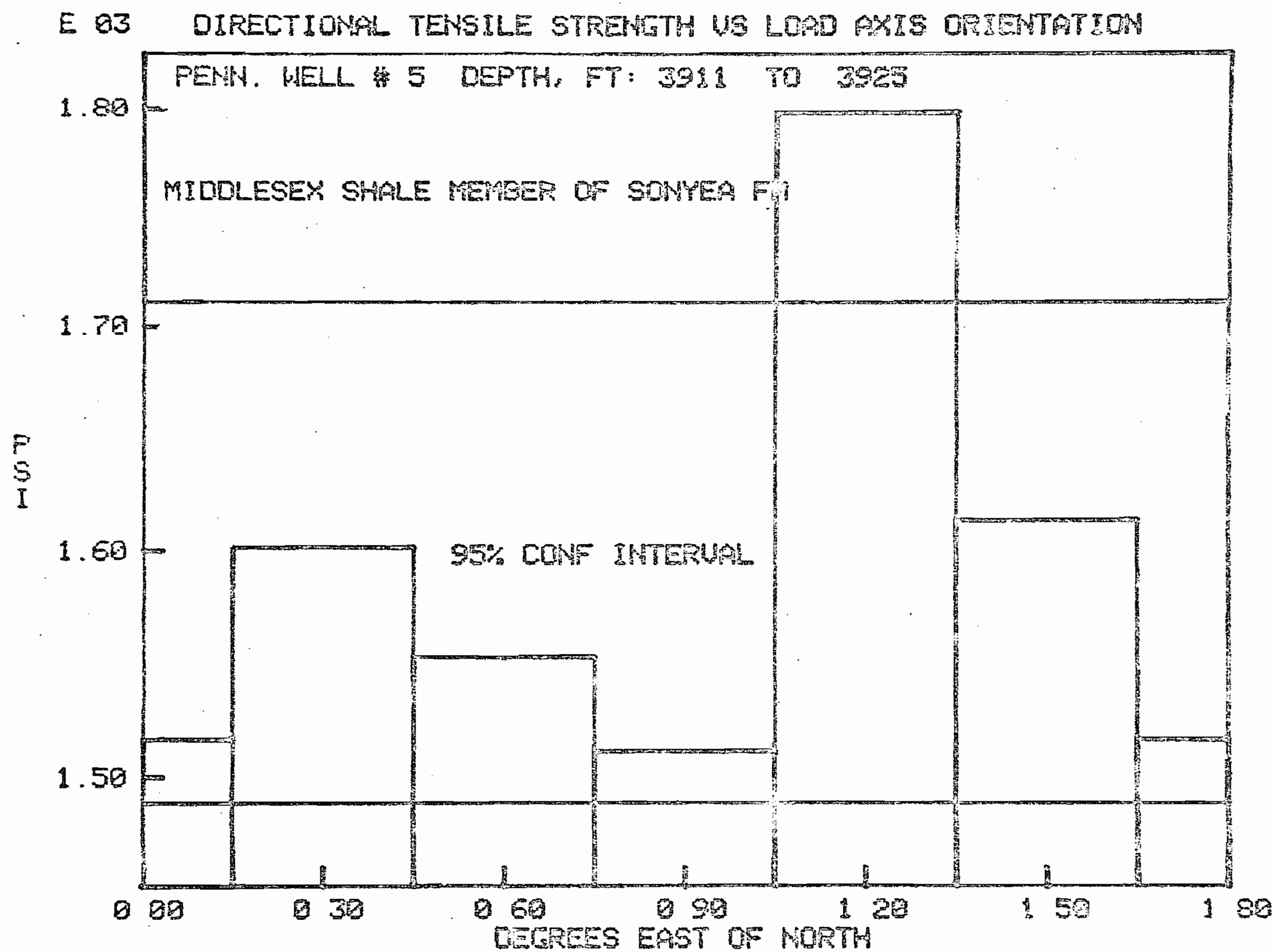

E 03
DIRECTIONAL TENSILE STRENGTH VS LOAD AXIS ORIENTATION
PENN. WELL # 5 DEPTH, FT: 3911 TO 3925
MIDDLESEX SHALE MEMBER OF SONYEA FM
95% CONF INTERVAL
1.80
1.70
1.60
1.50
PSI
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE D-4

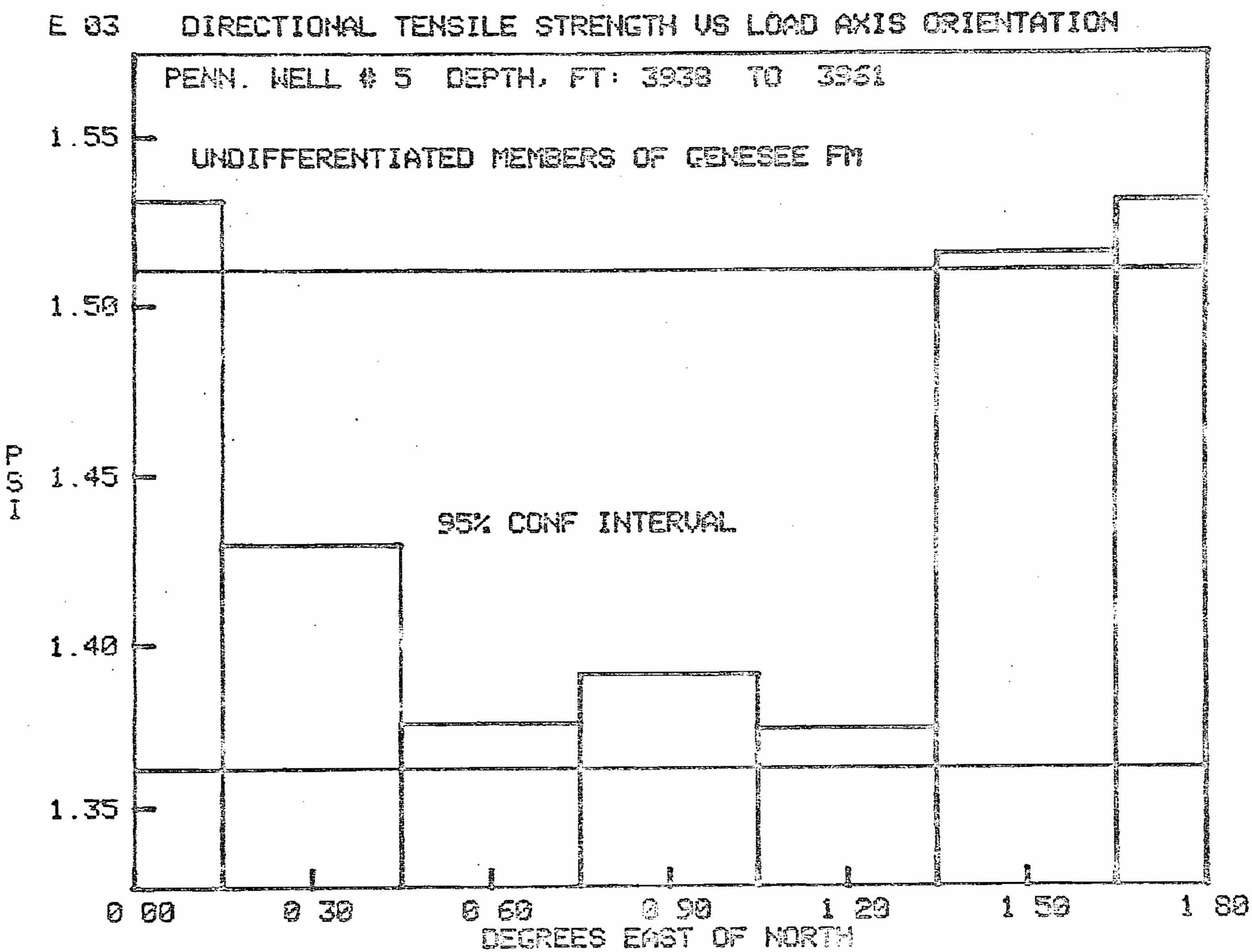

E 03
DIRECTIONAL TENSILE STRENGTH VS LOAD AXIS ORIENTATION
PENN. WELL # 5 DEPTH, FT: 3938 TO 3961
UNDIFFERENTIATED MEMBERS OF GENESEE FM
95% CONF INTERVAL
P S I
1.55
1.50
1.45
1.40
1.35
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE D-5

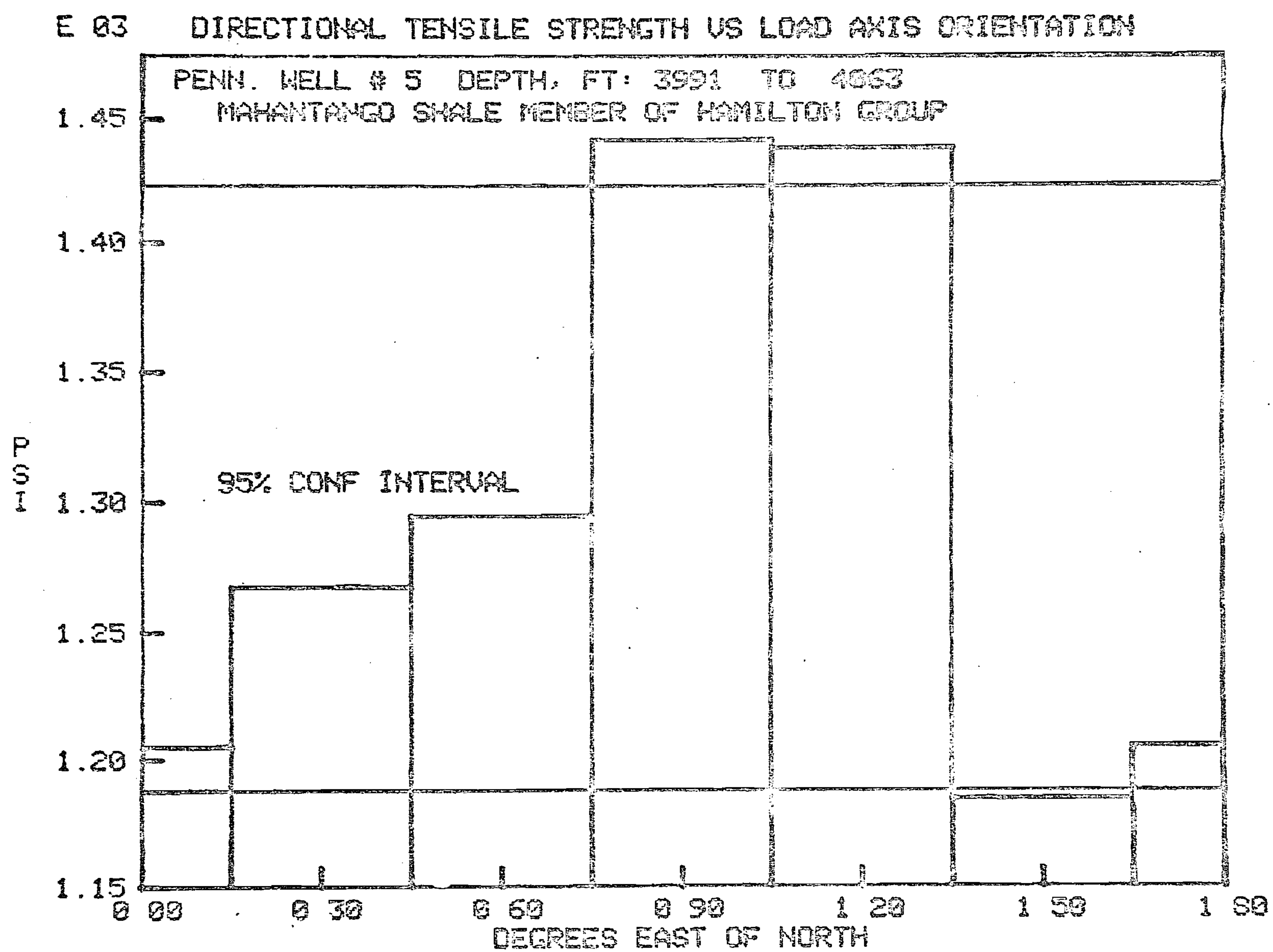
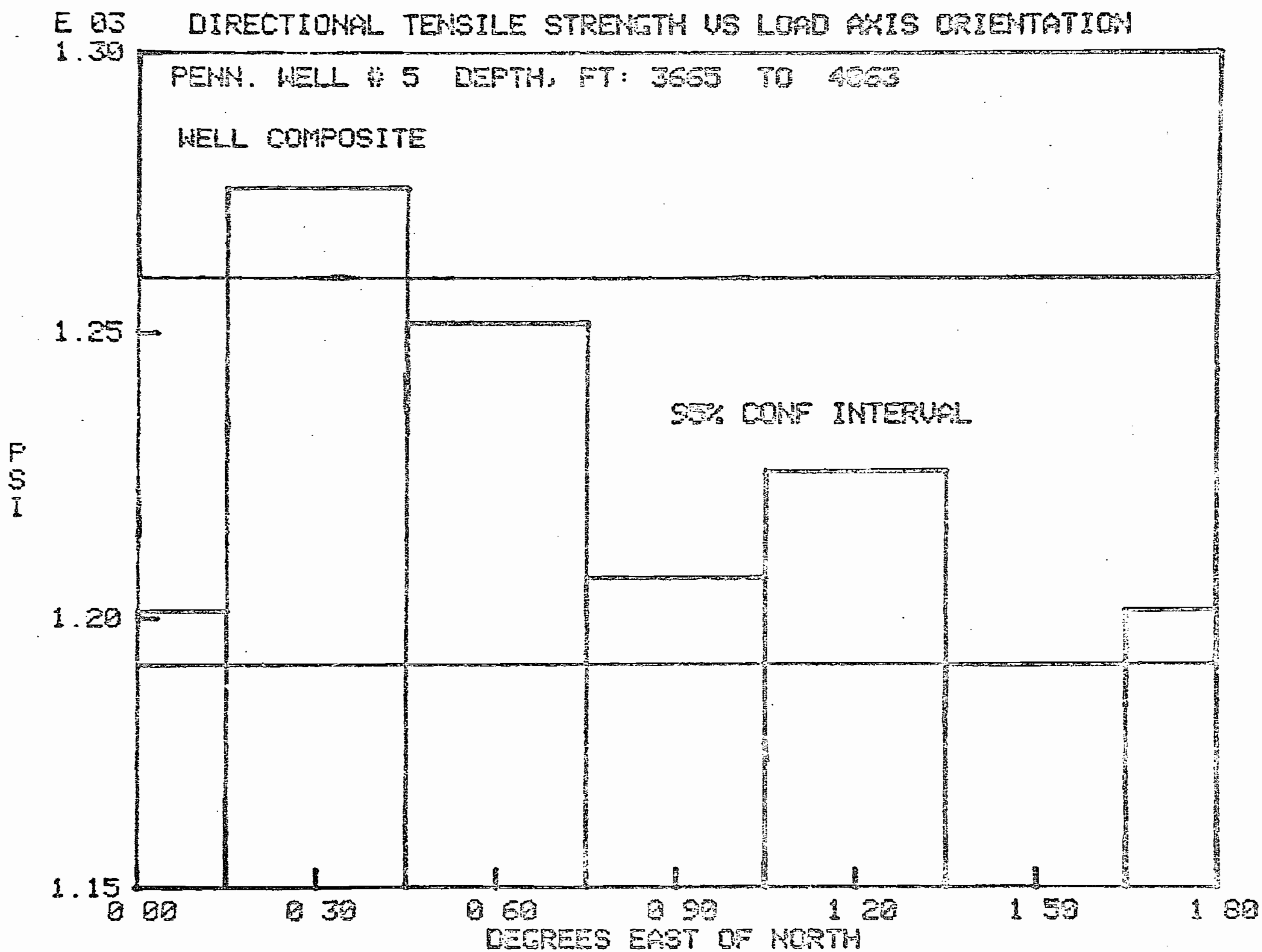

E 03
DIRECTIONAL TENSILE STRENGTH VS LOAD AXIS ORIENTATION
PENN. WELL # 5 DEPTH, FT: 3991 TO 4063
MAHANTANGO SHALE MEMBER OF HAMILTON GROUP
95% CONF INTERVAL
PSI
1.45
1.40
1.35
1.30
1.25
1.20
1.15
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE D-6



E 03
DIRECTIONAL TENSILE STRENGTH VS LOAD AXIS ORIENTATION
PENN. WELL # 5 DEPTH, FT: 3665 TO 4063
WELL COMPOSITE
95% CONF INTERVAL
1.30
1.25
1.20
1.15
PSI
0 00
0 30
0 60
0 90
1 20
1 50
1 80
DEGREES EAST OF NORTH