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-CLIFFS MINERALS, INC.
EASTERN GAS SHALES PROJECT Lincoln
WEST VIRGINIA #4 WELL - JACKSON COUNTY
PHASE III REPORT
SUMMARY OF LABORATORY ANALYSES AND
MECHANICAL CHARACTERIZATION RESULTS
NOVEMBER 1982

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Summary of Mechanical Characterization Results

The purpose of mechanical characterization of samples from the EGSP-West Virginia #4 core is to determine the orientation of preferred planes of weakness in the Devonian gas shales at the Lincoln County well site.

The physical property tests employed were: 1) directional ultrasonic P wave measurements; 2) point load induced fracturing; and 3) directional tensile strength tests.

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 indicate N45°E+30° as the preferred direction of fracturing in a sum of 146 out of 263 total induced fractures in the well composite.

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 P wave measurements indicate N45°E+30° as the preferred direction of fracturing in a sum of 12 out of 15 total samples in the well composite.

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. The 215 directional tensile strength measurements indicate N60oE+15° as the preferred plane of weakness in this well.

INTRODUCTION

The purpose of mechanical characterization of samples from the EGSP-West Virginia #4 core is to determine the direction of preferred planes of weakness in the Devonian gas shales at the Lincoln County well site.

A series of samples, representing about a thousand feet of core taken from the West Virginia #4 well, were tested by other contractors through MERC in Morgantown, West Virginia. The raw lab data was interpreted and put into report form by the Rock Mechanics Research Facility at Michigan Technological Unlversi.ty., Houghton, Michigan. The tested core intervals extend from 2,655 feet to 3,977 feet below surface and are summarized in Table 1.

TABLE 1

EGSP-West Virginia #4
Lincoln County

Formations Tested

Lithology	Depth Log	Depth Tested	Type of Test
OHIO SHALE			
Undifferentiated	3,317'	2,762.0'-3,032.5'	Velocity
		2,658.0'3,317.6'	Point Load
		2,655.1'-3,054.5'	DTS
Middle Huron	3,317'-3,357'	3,334.2'-3,351.3'	Point Load
		3,336.9'-3,349.2'	DTS
Lower Huron	3,357'-3,596'	3,421.7'-3,573.0'	Velocity
		3,362.0'-3,588.2'	Point Load
		3,358.7'-3,587.6'	DTS
JAVA FORMATION			
Hanover	3,596'-3,700	None	
WEST FALLS FORMATION			
Angola	3,700'-3,896'	3,889.0'	Velocity
		3,818.7'-3,894.4'	Point Load
Rhinestreet	3,896'-3,977'	3,898.0'-3,967.0'	Velocity
		3,897.2'-3,976.1'	Point Load
		3,916.7'-3,964.5'	DTS
Onondaga Group	3,977'	3,986.0'	Point Load

RESULTS

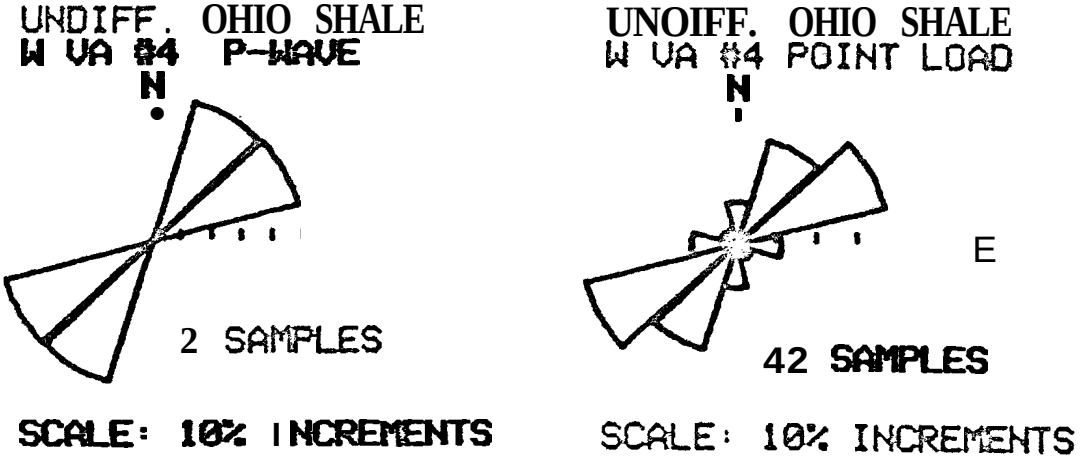
The results of the physical property measurements of directional ultrasonic P wave, point load induced fracturing, and directional tensile strength tests are compiled in Appendices A, Band C respectively. Table 2 is a summary of the mechanical property testing results for each stratigraphic formation.

Undifferentiated Ohio Shale; 2.655-3.317 feet tested:

The two ultrasonic P wave measurements indicate N4SoE+30o as the preferred direction of fracturing. Point load induced fractures occur most frequently in the N4SoE+30° orientation (a sum of 28 out of 42 induced fractures). The 41 directional tensile strength measurements in the six orientations indicate N60oE+15° as the preferred plane of weakness. Figure 1 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Undifferentiated Ohio Shale. Tabulated results are presented in Appendices A. Band C.

FIGURE 1

Undifferentiated Ohio Shale
Frequency Distribution Rose Diagrams of Results

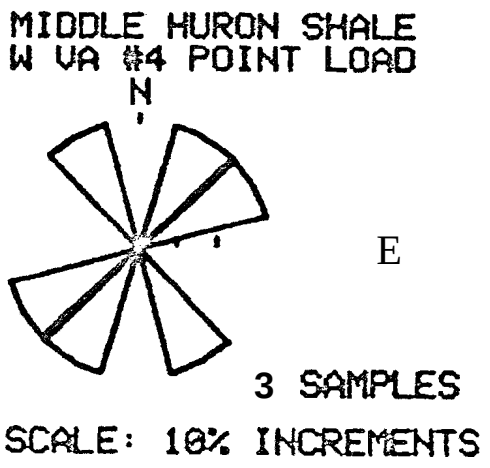


Middle Huron Shale; 3,334 to 3,351 feet tested:

The three point load induced fractures indicate N30oE±15°, N60oE+15° and N150oE+15° as the preferred directions of fracturing. The six directional tensile strength measurements in the six orientations indicate N30°E±15° and N150oE+15° as the preferred planes of weakness. Figure 2 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Middle Huron Shale. Tabulated results are presented in Appendices Band C.

FIGURE 2

Middle Huron Shale
Frequency Distribution Rose Diagram of Results

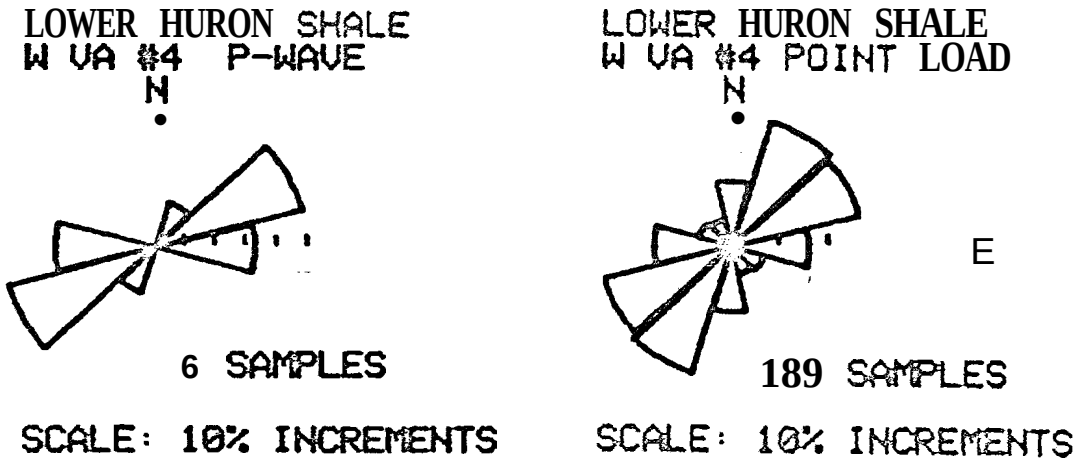


Lower Huron Shale; 3,358 to 3,588 feet tested:

Three out of the six ultrasonic P wave measurements indicate N60°E+15° as the preferred direction of fracturing. Point load induced fractures occur most frequently in the N45°E+30° direction (a sum of'lOS out of 189 induced fractures). Directional tensile strength measurements of 150 sam-p1es in the six orientations indicate N60°E+1S° as the preferred plane of weakness. Figure 3 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Lower Huron Shale. Tabulated results are presented in Appendices A, Band C.

FIGURE 3

Lower Huron Shale
Frequency Distribution Rose Diagrams of Results

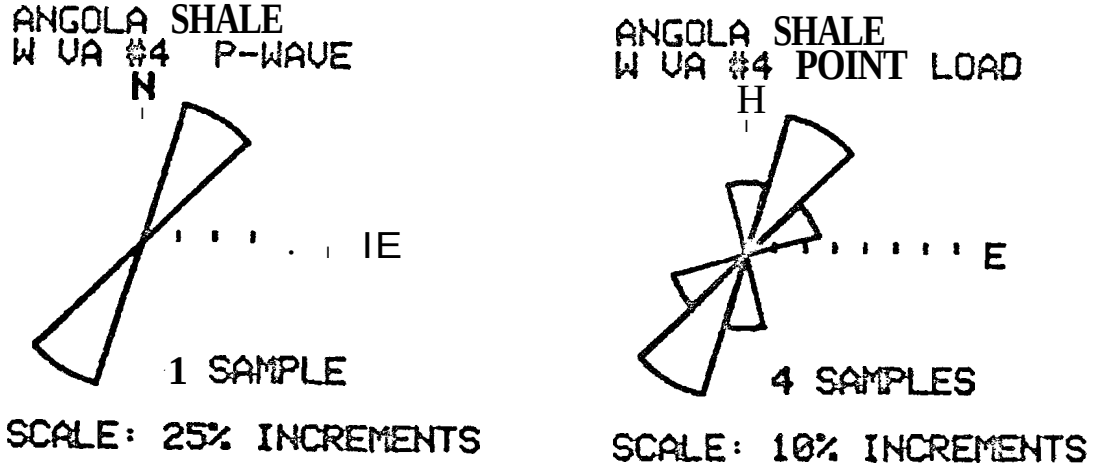


Angola Shale; 3,818 to 3,894 feet tested:

The one ultrasonic P wave measurement indicates N30oE+15° as the preferred direction of fracturing. Point load induced fractures occur most frequently in the N30oE±15° orientation (Two out of four induced fractures). Figure 4 illustrates the frequency distribution rose diagram of preferred direction of fracturing in the Angola Shale. Tabulated results are presented in Appendices A and **B.**

FIGURE 4

Angola Shale
Frequency Distribution Rose Diagrams of Results

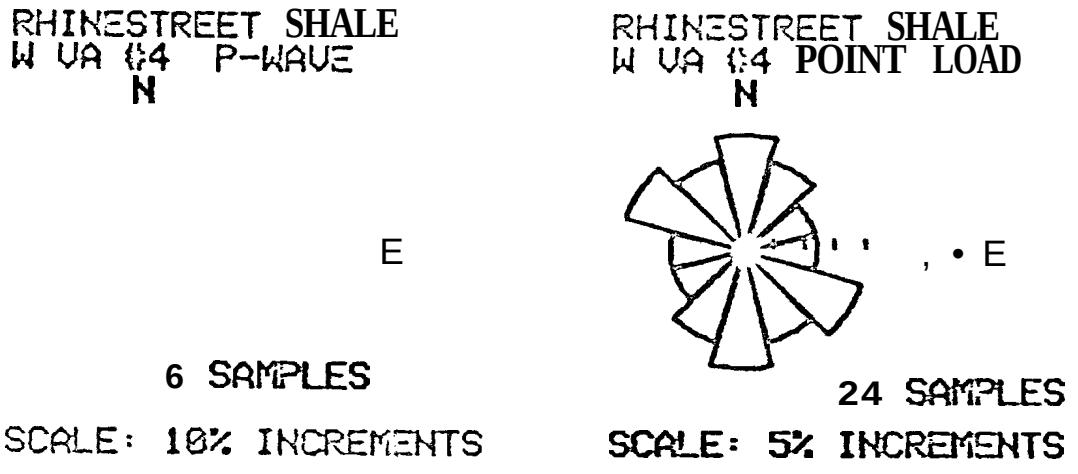


Rhinestreet Shale; 3,897 to 3.976 feet tested:

Three out of the six ultrasonic P wave measurements indicate *N30oE+1So* as the preferred direction of fracturing. The 24 point load induced fractures do not indicate statistically significant preferred direction of fracturing. The 18 directional tensile strength measurements in the six orientations indicate *N60oE+lSo* as the preferred plane of weakness. Figure 5 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the Rhinestreet Shale. Tabulated results are presented in Appendices A. Band C.

FIGURE 5

Rhinestreet Shale
Frequency Distribution Rose Diagrams of Results



Onondaga Group; 3,977' one sample tested:

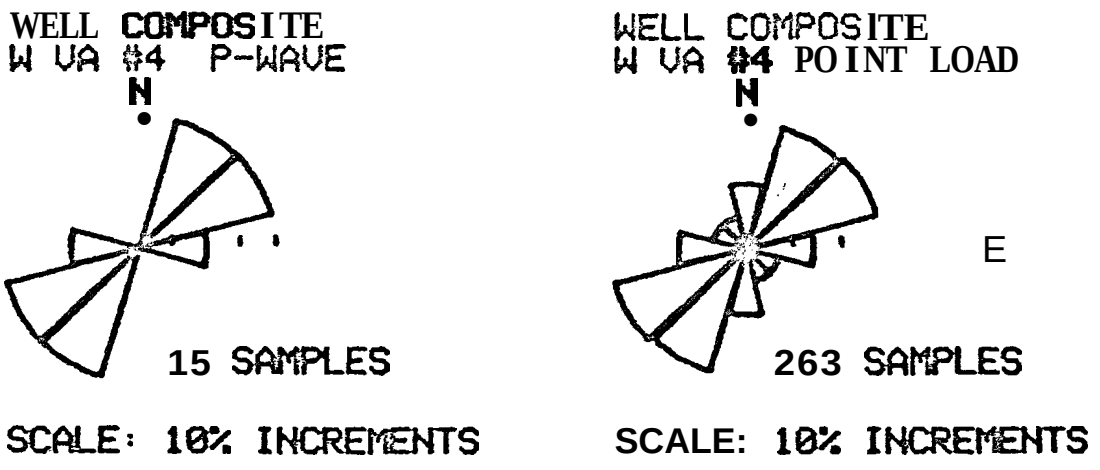
The one point load induced fracture occurs in the N60°E+15° direction. Tabulated results are presented in Appendix B.

West Virginia #4 Well Composite; 2,655 to 3,977 feet tested:

Ultrasonic P wave measurements and point load induced fractures indicate N45Eo+30° as the preferred direction of fracturing (a sum of 12 out of 15 total velocity samples; and a sum of 146 out of 263 total induced fractures). The calculated average in the six orientations of 215 directional tensile strength samples indicate N60oE±15° as the preferred plane of weakness. Figure 6 illustrates the frequency distribution rose diagrams of preferred direction of fracturing in the EGSP-West Virginia #4 Lincoln County well composite. Tabulated results are presented in Appendices A, B and C.

FIGURE 6

West Virginia #4 Well Composite; 2,655' - 3,977' Tested
Frequency Distribution Rose Diagrams of Results



CONCLUSIONS

The data presented in this report indicate that core samples from the EGSP-West Virginia #4 well exhibit a directional variation in physical properties. Prediction of the preferred direction of induced fracturing at the Lincoln County well site was based on inherent weaknesses in the core samples found by: (1) point load induced fractures; (2) directional tensile strength measurements; and (3) normality to measured ultrasonic P wave transit time maximums. These tests were performed by other contractors through the Morgantown Energy Technology Center (MERC). The raw lab data was interpreted and put into report form by the Rock Mechanics Research Facility at Michigan Technological University, Houghton, Michigan. 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 data:

(1) The preferred direction of fracturing in the Undifferentiated Ohio Shale (2,655 to 3,317 feet tested) is N45°E+30° as indicated by point load induced fracturing and ultrasonic P wave measurements and directional tensile strength measurements.

(2) The preferred direction of fracturing in the Middle Huron Shale (3,334 to 3,351 feet tested) is N30oE+lSo and N150oE+lSo as indicated by directional tensile strength measurements and point load induced fractures. There was a statistically small number of samples tested from this depth interval.

CONCLUSIONS Continued

(3) The preferred direction of fracturing in the Lower Huron Shale (3,358 to 3,588 feet tested) is N60°E+15° as indicated by the ultrasonic P wave measurements, point load induced fracturing and directional tensile strength measurements.

(4) The preferred direction of fracturing in the Angola Shale (3,818 to 3,894 feet tested) is N30°E+15° as indicated by point load induced fracturing and ultrasonic P wave measurements.

(5) The preferred direction of fracturing in the Rhinestreet Shale (3,897 to 3,976 feet tested) is N30°E+15° as indicated by directional ultrasonic P wave measurements and N60°E+15° as indicated by directional tensile strength measurements.

(6) The preferred direction of fracturing in the Onondaga Group (3,977 feet; one sample) is N60°E+15° as indicated by the one point load induced fracture.

TABLE A-I

EGSP-West Virginia #4
Lincoln County

Directional Ultrasonic P Wave Transit Times

	Orientation in Degrees East of North					
Depth	0°	30°	60°	90°	120°	150°
Undifferentiated Ohio Shale						
2,762.0'	19.639	19.357	19.376	19.461	19.702	19.760*
3,032.5'	21.800	21.760	21.965	21.257	22.350*	22.317
Lower Huron Shale						
3,421.7'	23.300	23.170	23.320	23.506	23.514	23.675*
3,431.3'	19.616	19.393	19.486	19.917	19.778	19.994*
3,434.0'	19.971	19.709	19.623	19.882	20.131	20.203*
3,459.0'	23.161*	22.727	22.820	23.000	23.000	23.087
3,554.3'	21.519	21.449	21.533	21.649	21.666*	21.456
3,573.0'	23.623*	23.621	23.601	24.362	24.524	24.389
Angola Shale						
3,889.0'	23.401	22.614	22.609	24.047	24.048*	23.761
Rhinestreet Shale						
3,898.0'	22.192	21.987	21.864	22.481	22.604*	21.745
3,918.6'	23.303	23.472	23.400	23.614	23.793	23.915*
3,927.0'	20.784	20.774	21.088	21.083	21.223*	21.001
3,954.0'	23.182	22.387	22.456	22.567	23.371	23.508*
3,958.4'	23.124*	22.604	22.427	22.298	22.531	22.505
3,967.0'	21.838	21.417	21.531	22.126	22.461*	22.024

* Maximum transit time

Note: The diameters were not recorded; if all diameters were equal in each sample, the maximum transit time would yield the minimum calculated velocity (preferred direction of fracturing is perpendicular minimum velocity).

TABLE B-1

EGSP-West Virginia #4
Lincoln County

Frequency of Fractures Induced by Point Load
Depth is Midpoint of 10 ft. Interval

	Orientation in Degrees East of North						
Depth	0°	30°	60°	90°	120°	150°	Total
Undifferentiated Ohio Shale							
2,658.0'	1	0	1	0	1	0	2
2,663.7'	0	0	0	0	1	0	1
2,674.4'	0	3	1	0	0	0	4
2,685.0'	2	1	1	0	0	0	4
2,698.1'	0	0	1	0	0	0	1
2,705.0'	0	0	3	1	0	1	5
2,718.2'	0	1	0	0	0	0	1
2,721.0'	0	0	0	0	0	1	1
2,730.7'	0	1	1	0	0	0	2
2,745.0'	0	1	2	0	1	0	4
2,755.0'	0	1	0	1	0	0	2
2,765.0'	0	2	3	0	0	0	5
2,808.4'	0	0	0	1	0	0	1
2,959.6'	0	0	0	1	0	0	1
3,007.4'	0	0	1	0	0	0	1
3,022.7'	0	0	0	1	0	0	1
3,085.0'	0	1	2	0	0	0	3
3,103.0'	1	0	0	0	0	0	1
3,315.6'	1	1	0	0	0	0	2
Total	5	12	16	5	2	2	42
Middle Huron							
3,334.2'	0	1	0	0	0	0	1
3,349.5'	0	0	1	0	0	0	1
3,351.3'	0	0	0	0	0	1	1
Total	0	1	1	0	0	1	3
Lower Huron							
3,362.0'	0	1	0	0	0	0	1
3,375.0'	1	6	4	2	2	0	15
3,385.0'	2	4	8	8	1	2	25
3,395.0'	1	0	3	1	0	1	6
3,408.5'	2	1	0	0	0	0	3
3,411.0'	0	0	0	2	0	1	3
3,425.0'	0	2	0	2	1	0	5
3,435.0'	1	2	2	0	0	1	6
3,445.0'	3	4	6	1	3	0	17
3,455.0'	1	3	1	0	0	1	6
3,460.0'	2	2	3	0	1	0	8
3,478.9'	1	0	0	0	0	0	1

TABLE B-1 Continued

EGSP-West Virginia #4
Lincoln County

Frequency of Fractures Induced by Point Load
Depth is Midpoint of 10 ft. Interval

	Orientation in Degrees East of North						
Depth	0°	30°	60°	90°	120°	150°	Total
Lower Huron cont.							
3,480.5'	1	0	0	2	0	0	3
3,495.0'	0	1	0	1	0	0	2
3,505.0'	2	2	0	0	0	0	4
3,515.0'	3	3	4	2	1	2	15
3,525.0'	1	2	4	1	2	1	11
3,535.0'	2	5	4	2	1	0	14
3,545.0'	2	4	1	2	0	1	10
3,555.0'	2	1	1	1	0	0	5
3,565.0'	0	4	6	1	0	1	12
3,575.0'	0	2	3	2	1	0	8
3,585.0'	0	4	2	1	1	1	9
Total	27	53	52	31	14	12	189
Angola							
3,818.7'	1	0	0	0	0	0	1
3,877.2'	0	1	0	0	0	0	1
3,894.0'	0	1	1	0	0	0	2
Total	1	2	1	0	0	0	4
Rhinestreet							
3,897	0	1	0	0	0	2	3
3,901.0'	0	0	0	1	0	0	1
3,915.0'	0	2	0	1	0	0	3
3,926.1'	0	0	0	0	3	1	4
3,930.6'	0	0	1	0	0	0	1
3,945.8'	0	1	0	1	1	0	3
3,955.0'	2	0	2	0	1	0	5
3,965.0'	3	0	0	0	0	0	3
3,976.1'	0	0	0	0	0	1	1
Total	5	4	3	3	5	4	24
ONONDAGA GROUP							
3,986.•8'	0	0	1	0	0	0	1
Total	0	0	1	0	0	0	1
Well Composite	38	72	74	39	21	19	263

The point load index was not calculated; the distance between load platens at failure had not been recorded.

FIGURE C-1

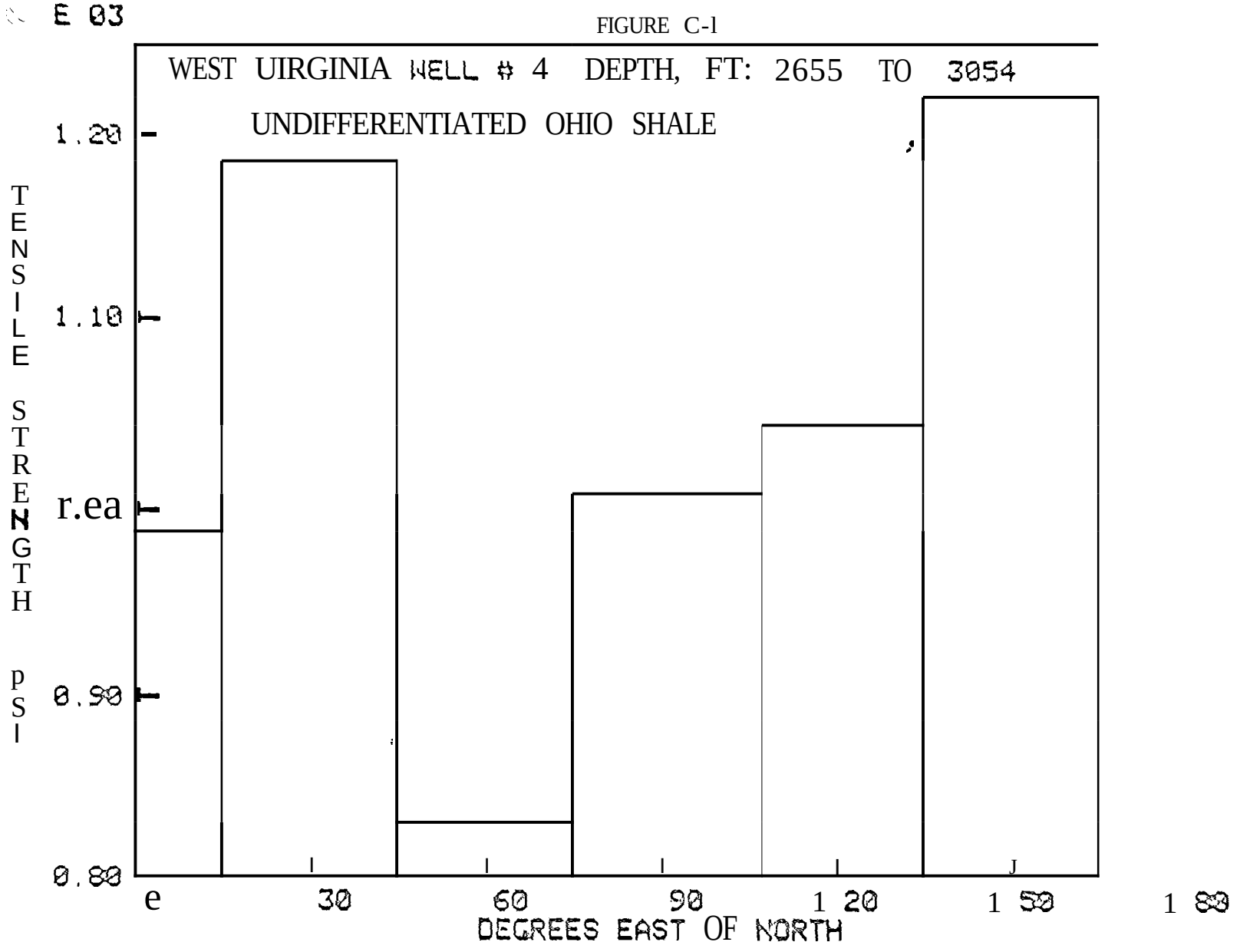

E 03
WEST UIRGINIA WELL # 4 DEPTH, FT: 2655 TO 3054
UNDIFFERENTIATED OHIO SHALE
TENSILE STRENGTH PSI
1.20
1.10
r.ea
0.90
0.80
e
30
60
90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE C-2

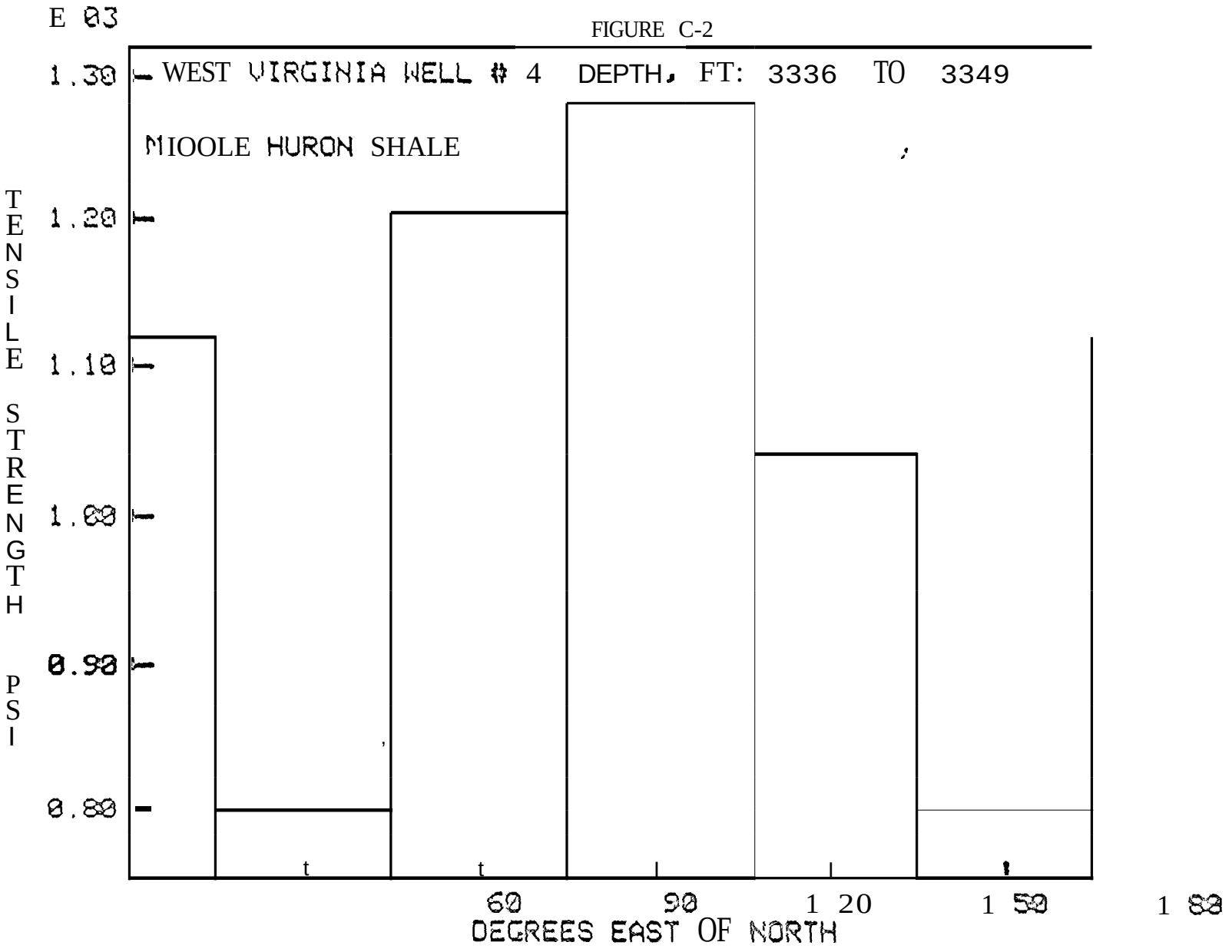

E 03
WEST VIRGINIA WELL # 4 DEPTH, FT: 3336 TO 3349
MIOOLE HURON SHALE
TENSILE STRENGTH PSI
1.30
1.20
1.10
1.00
0.90
0.80
60
90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE C-3

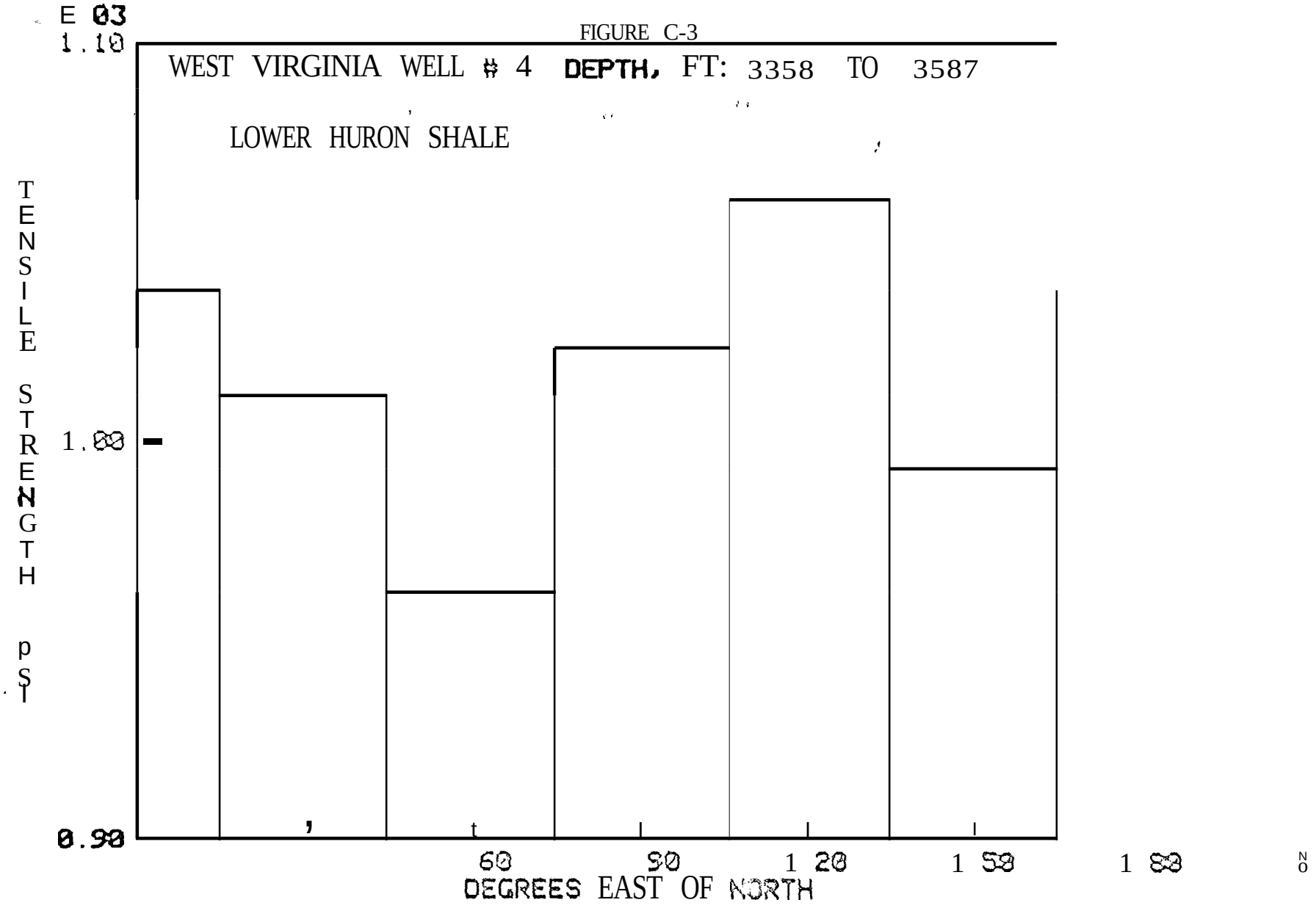

WEST VIRGINIA WELL # 4 DEPTH, FT: 3358 TO 3587
LOWER HURON SHALE
E 03
1.10
1.00
0.90
TENSILE STRENGTH psi
60
90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE G-4

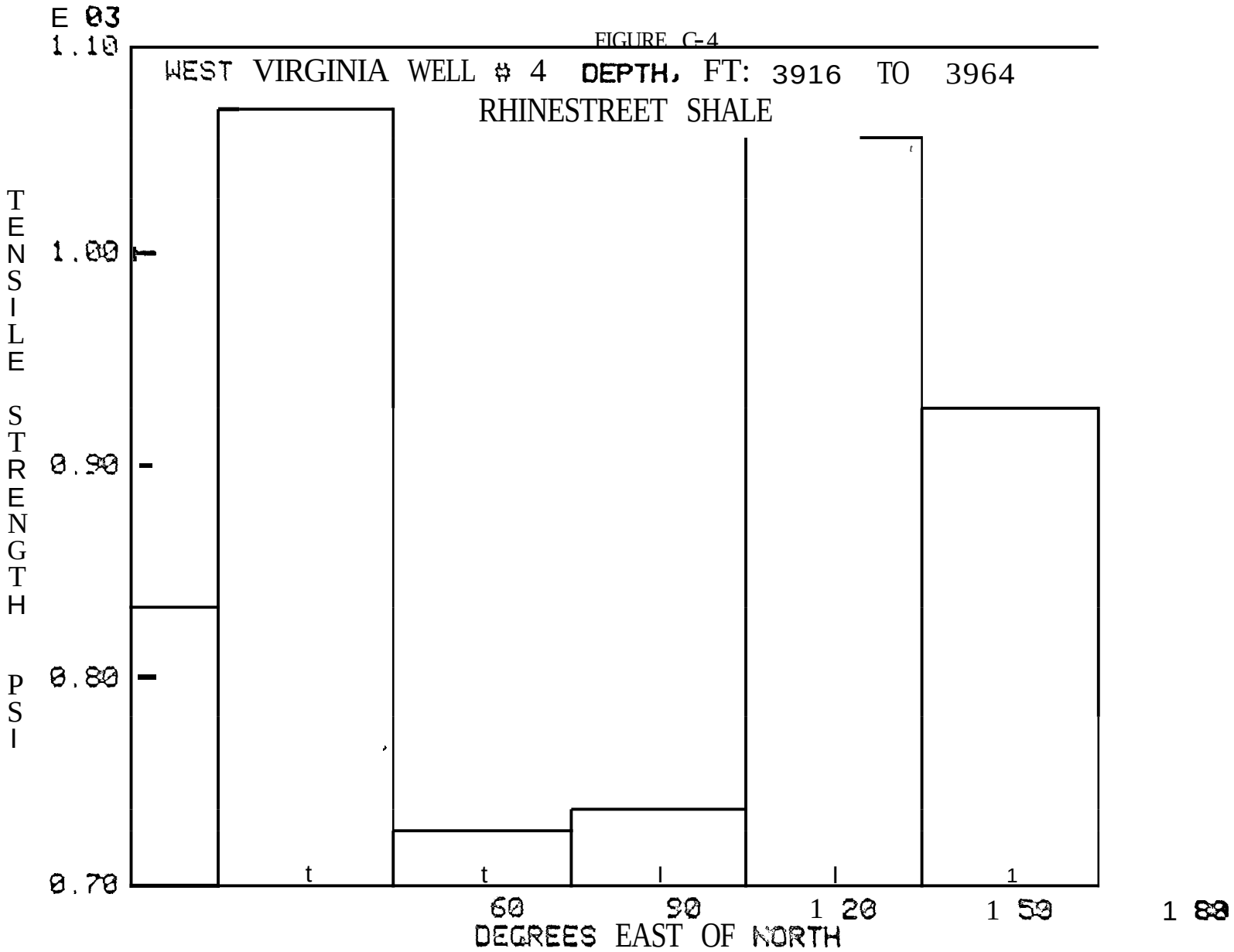
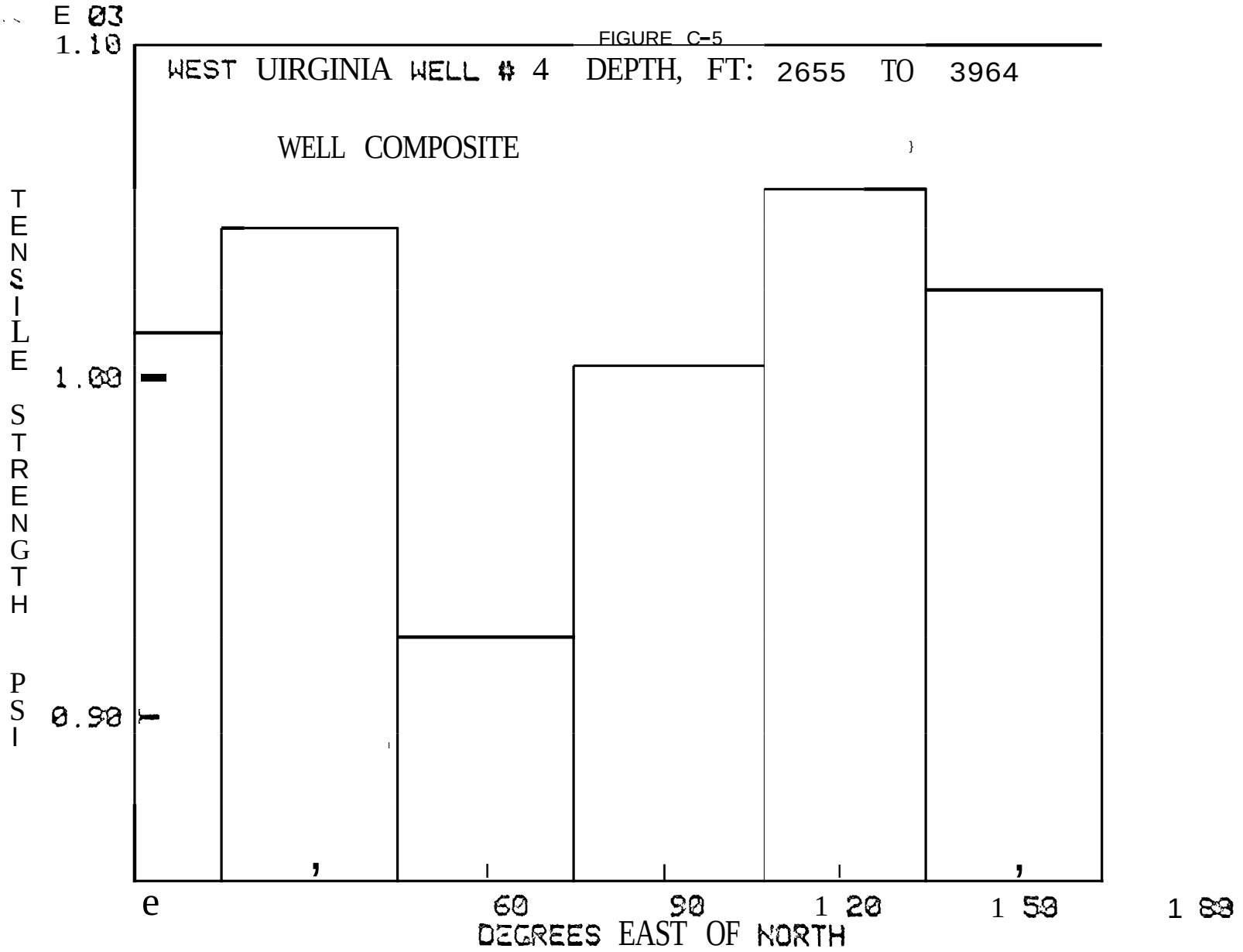

WEST VIRGINIA WELL # 4 DEPTH, FT: 3916 TO 3964
RHINESTREET SHALE
E 03
1.10
1.00
0.90
0.80
0.70
TENSILE STRENGTH PSI
60
90
1 20
1 50
1 80
DEGREES EAST OF NORTH

FIGURE C-5


E 03
1.10
WEST UIRGINIA WELL # 4 DEPTH, FT: 2655 TO 3964
WELL COMPOSITE
TENSILE STRENGTH PSI
1.00
0.90
e
60
90
1 20
1 50
1 80
DEGREES EAST OF NORTH