SSCL-SR-1099

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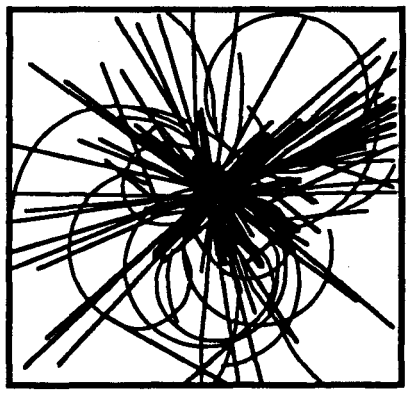
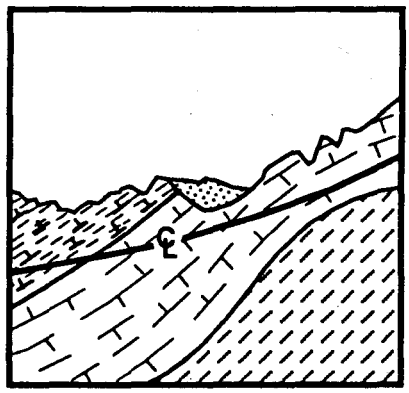
Project No. 87-888-0017
Report No. SSC-GR-40
July 1990

GR-40

Data Report for Corehole BE 5





Prepared by: The Earth Technology Corporation
Long Beach, California

Prepared for: RTK a joint venture
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FOREWORD

The goal of the geotechnical studies at the Texas Superconducting Super Collider (SSC) site is to allow the geologist and engineer to build their level of knowledge and confidence about the geologic structures and geotechnical properties of the site materials to the point at which there remains only a realistically small risk of encountering geotechnical conditions during construction that would significantly increase construction costs or delay construction schedules. To do this, a characterization program has been designed to meet the following objectives:

- To confirm the site's suitability and optimize the ring location (the "footprint") and hall positions on the ring
- To provide data for a preliminary structural design
- To provide a rational framework within which construction contracts and schedules can be formulated
- To maximize the use of the site-specific data already gathered by the proposer.

The geotechnical program to meet these objectives has been divided into the following three phases of study:

- Footprint location data
- Structure-specific data
- Global data.

This is one in a series of data reports prepared for the global data phase of geotechnical characterization at the SSC site. Data collection for this study phase focused on drillhole-based geological, geohydrological, geophysical, and geotechnical tests in the near vicinity of the E and F access shaft sites. The global data set has three key attributes: (1) uniform geographic distribution over the site footprint, (2) complete coverage of all of the strata through which the SSC tunnels and shafts will pass, and (3) consistency of the data from sampling site to sampling site throughout the SSC site. In combination with data from the other phases, these data will allow conceptual designs of construction methods. Each data report includes the results of both field and laboratory tests for specific drilling and sampling site(s).

DATA REPORT

Site Designator: BE 5

Objective: Drill a corehole at the proposed shaft location and determine geotechnical conditions through in-situ hydrological testing and laboratory geomechanical testing. The corehole extended at least 35 feet deeper than tunnel depth.

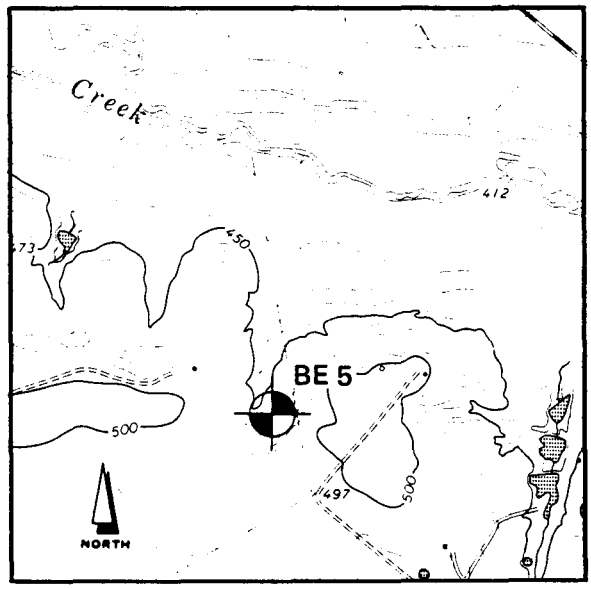
Location:

North 278,967 feet

East 2,245,051 feet

Surface Elevation 462.5 feet

BE 5 is located on the northeastern portion of the proposed tunnel alignment, approximately 0.6 mile north of FM 878 and 0.9 mile east of Rutherford Road.



SCALE 1:24,000

0 1000 2000 3000 4000 Feet

CONTOUR INTERVAL 10 FEET

Scope and Schedule:

Coring (full depth)	January 10 to 13, 1990
Wire-line Logging	January 16 and 25, 1990
Hydraulic Fracture Testing	January 26 to 30, 1990
Laboratory Testing	January 21 to March 15, 1990
Well Construction	February 8 to 13, 1990

Conditions Encountered: (see lithologic log, Appendix A)

Total Hole Depth:	335.0 feet
Soil:	0.0 to 9.0 feet
Weathered Taylor Marl:	9.0 to 15.0 feet
Fresh Taylor Marl:	15.0 to 120.4 feet
Austin Chalk:	120.4 to 335.0 feet (bottom of hole)
Static Water Level:	Water level in the well probably has not reached static condition. It was last measured at 389.4 feet above MSL (73.1 feet below ground surface) on June 25, 1990, 130 days after the well had been air-lifted to approximately 156.5 feet above MSL.

Geophysical Logging: (see wire-line logs, Appendix B)

Spontaneous Potential (SP)
Normal Resistivity (short and long)
Guard Resistivity
Point Resistance
Natural Gamma
Short and Long Gamma
Compensated Density (caliper)
Sonic Velocity (full wave)

Hydraulic Fracture Testing: (see also Appendix C).

Vertical Depth (feet)	Formation/ Lithology	Breakdown Pressure (psi)	Average Instantaneous Shut-in Pressure (psi)	
			Vertical Fractures	Horizontal Fractures
107	Taylor Marl	336	215	178
127	Austin Chalk	368	250	250
152	Austin Chalk	365	300	–
162	Austin Chalk	410	300	250
192	Austin Chalk	418-462	328	251
204	Austin Chalk	710	462	302
210	Austin Chalk	397-524	283	–

Bulk and Clay Mineralogy Test Results:

Formation: Taylor Marl Depth: 115.6 feet

Whole Rock Composition:

Mineral	Percent
quartz	27
K feldspar	1
plagioclase	1
calcite	29
dolomite	1
siderite	1
pyrite	2
total clay	38
Total	100

Relative Clay Abundance:

Mineral	Percent
illite	14
kaolinite	22
Fe-chlorite	9
mixed layer (illite/smectite)	55
Total	100

Formation: Austin Chalk Depth: 319.0 feet

Whole Rock Composition:

Mineral	Percent
quartz	6
calcite	80
pyrite	1
total clay	13
Total	100

Relative Clay Abundance:

Mineral	Percent
illite	18
mixed layer (illite/smectite)	82
Total	100

Laboratory Geomechanical Test Results Summary: (see also Appendix D)

Vertical Depth (ft)	Formation/ Lithology	Moisture Content (%)	Dry Density (pcf)	Unconfined Compressive Strength (psi)	Tangent Young's Modulus E_{50} (psi x 10^5)	Brazil Tensile Strength (psi)
25-26	Taylor Marl	18	111-112	285	0.22-0.33	
49-50	Taylor Marl	17	112-115	313	0.31-0.53	
75-76	Taylor Marl	16-17	117			
100-101	Taylor Marl	16-17	113-114			
115-117	Taylor Marl	17	114			
145	Austin Chalk	10	130-131	2708	3.23-5.40	
171-172	Austin Chalk	10-12	129	2540	4.90	
178	Austin Chalk	11	128			
195	Austin Chalk	10	132	2983	3.20	
223	Austin Chalk	11	130			
233	Austin Chalk	10	131			
243	Austin Chalk	10	128			
271	Austin Chalk	8-13	126	2172	4.20	222
319-321	Austin Chalk	10-28	131	2280	3.20	

Hole Status: A monitoring well log was installed in the boring on February 13, 1990 (see Appendix E).

APPENDIX A

LITHOLOGIC LOG

NOTE: Shading has been added in the column labeled "Standard Penetration Test Per 6 inches" to show the hydraulic fracturing test intervals.

LOG OF BORING

PROJECT: Superconducting Supercollider

CLIENT: The Earth Technology Corporation

TASK NO.: 17

BORING NO: BE 5 PG 1 OF 9

LOCATION: N 278,967 feet
E 2, 245,051 feet

GROUND EL: 462.5 feet

DATE: 1/10-13/90 TYPE: NX Core CASED TO: 21'.0' CONTRACTOR: SwL 89-192

SAMPLE LEGEND

S= SPLIT SPOON
T= 2" THIN WALL TUBE
U= 3" THIN WALL TUBE
C= NX ROCK CORE

WATER INFORMATION

Begin drilling with air rotary to 15'. No seepage encountered. Begin drilling with water at 15'. Unable to determine parameters of subsurface water table.

DEPTH IN FEET	SYMBOL	SAMPLE TYPE & NUMBER	DEPTH RANGE TOP	DEPTH RANGE BOT.	PERCENT REC.	PERCENT RQD.	STANDARD PENETRATION TEST PER 6 INCHES	HAND PEN. TSF.	DESCRIPTION OF STRATUM
									1.5 CLAY, soft, dark brown, organics, wood, moist
									3.5 CLAY, soft, brown, pebbles, organics, moist some medium sand
5									6.0 CLAY, soft, light brown, fine to medium sand, small pebbles
									9.0 CLAY, soft, yellowish tan, fine sand, moist
10									CALCAREOUS SHALE (Taylor Marl), soft brown, trace of fine sand, moist, weathered
15									15.0
		C-1	15.0	18.0	66	66			CALCAREOUS SHALE (Taylor Marl), soft to medium, fresh, calcareous, dark gray with trace fossils
20		C-2	18.0	22.0	62	62			
25		C-3	22.0	32.0	99	99			fossil parting at 29.5'
30									
35		C-4	32.0	42.0	98	98			
40									
			42.0						

DRILLING GEOLOGIST Ron Randall ASSISTANT Dale Brown CHECKED BY Clem Bommarito

Shawn Wood
(3-7-90)

LOG OF BORING

PROJECT: Superconducting Supercollider

CLIENT: The Earth Technology Corporation

TASK NO.: 17

BORING NO: BE 5 PG 2 OF 9

LOCATION: N 278,967 feet
E 2, 245,051 feet

GROUND EL: 462.5 feet

DATE: 1/10-13/90 TYPE: NX Core CASED TO: 21.0' CONTRACTOR: SwL 89-192

SAMPLE LEGEND
S= SPLIT SPOON
T= 2" THIN WALL TUBE
U= 3" THIN WALL TUBE
C= NX ROCK CORE

WATER INFORMATION
See p. 1 of 9

DEPTH IN FEET	SYMBOL	SAMPLE TYPE & NUMBER	DEPTH RANGE TOP	DEPTH RANGE BOT.	PERCENT REC.	PERCENT RQD.	STANDARD PENETRATION TEST PER 6 INCHES	HAND PEN. TSF.	DESCRIPTION OF STRATUM
									CALCAREOUS SHALE (Taylor Marl), soft to medium, fresh, calcareous, dark gray, with trace fossils.
45		C-5	42.0	52.0	100	100			
50									
55		C-6	52.0	62.0	97	97			
60									
65		C-7	62.0	72.0	100	100			fossil at 70.1'
70									
75		C-8	72.0	82.0	100	100	Hydrofracture Test J		
80									

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Shawn Wood
(3-7-90)

LOG OF BORING

PROJECT: Superconducting Supercollider

CLIENT: The Earth Technology Corporation

TASK NO.: 17

BORING NO: BE 5 PG 3 OF 9

LOCATION: N 278,967 feet
E 2,245,051 feet

GROUND EL: 462.5 feet

DATE: 1/10-13/90 TYPE: NX Core CASED TO: 21.0' CONTRACTOR: SwL 89-192

SAMPLE LEGEND

S= SPLIT SPOON
T= 2" THIN WALL TUBE
U= 3" THIN WALL TUBE
C= NX ROCK CORE

WATER INFORMATION

See p. 1 of 9

DEPTH IN FEET	SYMBOL	SAMPLE TYPE & NUMBER	DEPTH RANGE TOP	DEPTH RANGE BOT.	PERCENT REC.	PERCENT RQD.	STANDARD PENETRATION TEST PER 6 INCHES	HAND PEN. TSF.	DESCRIPTION OF STRATUM
									CALCAREOUS SHALE (Taylor Marl), soft to medium, fresh, calcareous, dark gray with trace fossils and occasional thin limestone seams
85		C-9	82.0	92.0	97	97			-calcareous parting at 86.9'
90									-fossil parting at 90.6'
95		C-10	92.0	102.0	97	97			-thin limestone layer at 94.1'
105		C-11	102.0	112.0	100	100			
115		C-12	112.0	121.0	100	100			
120									120.4 -sharp contact-
									LIMESTONE (Ausin Chalk), medium,fresh, sound, light gray

DRILLING GEOLOGIST Ron Randall ASSISTANT Dale Brown CHECKED BY Clem Bommarito

Shawn Wood
(3-7-90)

LOG OF BORING

PROJECT: Superconducting Supercollider

CLIENT: The Earth Technology Corporation

TASK NO.: 17

BORING NO: BE 5 PG 4 OF 9

LOCATION: N 278,967 feet
E 2,245,051 feet

GROUND EL: 462.5 feet

DATE: 1/10-13/90 TYPE: NX Core CASED TO: 21.0' CONTRACTOR: SwL 89-192

SAMPLE LEGEND

S= SPLIT SPOON
T= 2" THIN WALL TUBE
U= 3" THIN WALL TUBE
C= NX ROCK CORE

WATER INFORMATION

See p. 1 of 9

DEPTH IN FEET	SYMBOL	SAMPLE TYPE & NUMBER	DEPTH RANGE TOP	DEPTH RANGE BOT.	PERCENT REC.	PERCENT RQD.	STANDARD PENETRATION TEST PER 6 INCHES	HAND PEN. TSF.	DESCRIPTION OF STRATUM
			121.0						LIMESTONE (Austin Chalk), moderately to medium hard, fresh, light gray to dark gray with 0.5' to 7' thick slightly, moderately argillaceous limestone interbeds 7' to 11' apart. Also shale layers 0.1' thick, fossil partings, bentonite layer.
125					100	100	Hydrofracture Test H		-fossil partings at 125.3' and 129.4'
130				131.0					-slightly argillaceous layer, gradational contact at 131.0' to sharp contact at 133.7'
			131.0						
135		C-14			100	100			-fossil parting at 137.3'
									-moderately argillaceous layer, gradational contact at 141.0' to sharp contact at 148.0'
140				141.0					
			141.0						
145		C-15			100	100			
									-1" shale layer at 148.0'
150				151.0					-fossil parting at 149.6'
			151.0				Hydrofracture Test G		
155		C-16			100	100			-slightly fossilifereous limestone at 156.0'-160.0'
									-fossil partings at 157.8' and 158.6'
									-bentonite layer at 159.7'
									-moderately argillaceous layer, gradational contact at 159.2' to sharp contact at 159.7'
160				161.0					

DRILLING GEOLOGIST Ron Randall ASSISTANT Dale Brown CHECKED BY Clem Bommarito

Shawn Wood
(3-7-90)

LOG OF BORING

PROJECT: Superconducting Supercollider
CLIENT: The Earth Technology Corporation
TASK NO.: 17

BORING NO: BE 5 PG 5 OF 9
LOCATION: N 278,967 feet, E 2,245,051 feet
GROUND EL: 462.5 feet

DATE: 1/10-13/90 TYPE: NX Core CASED TO: 21.0' CONTRACTOR: SwL 89-192

SAMPLE LEGEND:
S= SPLIT SPOON
T= 2" THIN WALL TUBE
U= 3" THIN WALL TUBE
C= NX ROCK CORE

WATER INFORMATION: See p. 1 of 9

DEPTH IN FEET	SYMBOL	SAMPLE TYPE & NUMBER	DEPTH RANGE TOP	DEPTH RANGE BOT.	PERCENT REC.	PERCENT RQD.	STANDARD PENETRATION TEST PER 6 INCHES	HAND PEN. TSF.	DESCRIPTION OF STRATUM
			161.0				Hydrofracture Test F		LIMESTONE (Austin Chalk), moderately to medium hard. fresh, light gray to dark gray with 0.3' to 1' thick slightly, moderately argillaceous limestone interbeds 6' to 26' apart. Also shale layers 1' thick fossil partings, medium, high angle fractures.
165		C-17			100	100			-slightly argillaceous layer, gradational contacts at 164.5'-165.4' -fossil partings at 165.1', 169.0' and 169.3'
170				171.0					-argillaceous layer, gradational contacts at 171.1' to sharp contact at 171.4' -fossil partings at 172.6', 173.7', 175.6' and 180.7'
			171.0						
175		C-18			100	100			-60° grooved, closed, slickensided fracture at 182.0' -60° grooved, planar, closed, slickensided fracture at 179.0'
180				181.0					-2-75° calcite filled (¼") healed, fractures at 181.0' -2-60° grooved, closed, slickensided fractures at 182.7'
			181.0						
185		C-19			100	96			-very argillaceous layer, gradational contact at 186.1' to sharp contact at 186.8'; and gradational contact at 189.2' to sharp contact at 189.6' -shale layer at 188.0'-189.0'
190				191.0					
			191.0				Hydrofracture Test E		
195		C-20			100	100			-fossiliferous layer (3/4"), at 196.0' -argillaceous layer, gradational contacts at 198.0'-199.0'
200				201.0					

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Shawn Wood
(3-7-90)

LOG OF BORING

PROJECT: The Superconducting Supercollider

CLIENT: The Earth Technology Corporation

TASK NO.: 17

BORING NO: BE 5 PG 6 OF9

LOCATION: N 278,967 feet
E 2,245,051 feet

GROUND EL: 462.5 feet

DATE: 1/10-13/90 TYPE: NX Core CASED TO: 21.0' CONTRACTOR: SwL 89-192

SAMPLE LEGEND

S= SPLIT SPOON
T= 2" THIN WALL TUBE
U= 3" THIN WALL TUBE
C= NX ROCK CORE

WATER INFORMATION

See p.1 of 9

DEPTH IN FEET	SYMBOL	SAMPLE TYPE & NUMBER	DEPTH RANGE TOP	DEPTH RANGE BOT.	PERCENT REC.	PERCENT RQD.	STANDARD PENETRATION TEST PER 6 INCHES	HAND PEN. TSF.	DESCRIPTION OF STRATUM
		C-21	201.0	211.0	100	100	Hydrofracture Test C		LIMESTONE (Austin Chalk), moderately to medium hard, fresh, light gray to dark gray with 0.3' to 2' thick moderately, extremely argillaceous limestone interbeds 2' to 15' apart. Also fossil partings, medium, high angle fractures. -60° grooved, planar, closed slickensided fractures at 202.3' and 203.3'
205									
210									
		C-22	211.0	221.0	99	94			-70° grooved, planar, closed, slickensided fracture at 216.3' -60° grooved, planar, closed, slickensided fractures at 219.8'
215									
220									
		C-23	221.0	231.0	100	100			-45° grooved, planar, closed, slickensided fracture at 224.2' -moderately argillaceous layer, gradational contact at 226.0' to sharp contact at 227.4'
225									
230									
		C-24	231.0	241.0	99	99			-2-60° grooved, planar, closed, slickensided fractures at 232.5' -45° grooved, planar, closed, slickensided fractures at 233.7' -very argillaceous layer, gradational contact at 238.8'to sharp contact at 239.8' -fossiliferous layer at 239.8'-240.0' -very argillaceous layer, gradational contact at 242.8' to sharp contact at 243.8' -very argillaceous layer, gradational contact at 245.5' to sharp contact at 245.8' -very argillaceous layer, gradational contact at 247.1' to sharp contact at 247.6'
235									
240									

DRILLING GEOLOGIST Ron Randall ASSISTANT Dale Brown CHECKED BY Clem Bommarito

Shawn Wood
(3-7-90)

LOG OF BORING

PROJECT: Superconducting Supercollider

CLIENT: The Earth Technology Corporation

TASK NO.: 17

BORING NO: BE 5 PG 7 OF 9

LOCATION: N 278,967 feet
E 2,245,051 feet

GROUND EL: 462.5 feet

DATE: 1/10-13/90 TYPE: NX Core CASED TO: 21.0' CONTRACTOR: SwL 89-192

SAMPLE LEGEND
S= SPLIT SPOON
T= 2" THIN WALL TUBE
U= 3" THIN WALL TUBE
C= NX ROCK CORE

WATER INFORMATION
See p. 1 of 9

DEPTH IN FEET	SYMBOL	SAMPLE TYPE & NUMBER	DEPTH RANGE TOP	DEPTH RANGE BOT.	PERCENT REC.	PERCENT RQD.	STANDARD PENETRATION TEST PER 6 INCHES	HAND PEN. TSF.	DESCRIPTION OF STRATUM
245, 250		C-25	241.0	251.0	100	100			LIMESTONE (Austin Chalk), moderately to medium hard, fresh, light gray to dark gray with 1' to 4' thick moderately, extremely argillaceous to shaley limestone interbeds 1' apart. Also shale layers 0.2' thick, fossiliferous layers and medium, high angle fractures. -very argillaceous layer at 243.0'-243.7' -moderately fossiliferous limestone at 243.0'-250.4' -30° healed fracture at 244.0' -60° fracture at 248.9' -pyrite nodule at 245.6'
255, 260		C-26	251.0	261.0	100	100			-argillaceous gradational contacts, at 251.0' to 255.0' -pyrite nodule at 252.0' -fossil partings at 253.4', 255.3', 257.3', 258.2', 258.8', 259.3', and 260.0' -very argillaceous layers with thin shale layers, sharp contacts at 255.4'-256.0' -fossil parting at 256.1' -numerous broken fossil fragments at 258.0'-262.0' -60° calcite filled fracture at 262.0'-272.0' -70° closed, healed, planar, fracture at 263.1' -45° planar fracture at 263.2' -numerous fossil debris at 263.3'-265.5'
265		C-27	261.0	268.2	97.5	82			-moderately fossiliferous at 269.0'-278.0' -fossil partings at 268.6', 269.0', 269.8', 271.1' 273.2', 275.0', 275.8', 276.3, 277.1', and 277.7' -fossiliferous layers (½"), at 270.2' and 275.0' -bioturbated sediment, light gray at 269.0'-278.0' -shale layer (1½") at 275.8'
270, 275, 280		C-28	268.2	278.0	99	99			

DRILLING GEOLOGIST Ron Randall ASSISTANT Dale Brown CHECKED BY Clem Bommarito

Shawn Wood
(3-7-90)

LOG OF BORING

PROJECT: Superconducting Supercollider

CLIENT: The Earth Technology Corporation

TASK NO.: 17

BORING NO: BE 5 PG 8 OF 9

LOCATION: N 278,967 feet
E 2,245,051 feet

GROUND EL: 462.5 feet

DATE: 1/10-13/90 TYPE: NX Core CASED TO: 21.0' CONTRACTOR: SwL 89-192

SAMPLE LEGEND:
S= SPLIT SPOON
T= 2" THIN WALL TUBE
U= 3" THIN WALL TUBE
C= NX ROCK CORE

WATER INFORMATION: See p. 1 of 9

DEPTH IN FEET	SYMBOL	SAMPLE TYPE & NUMBER	DEPTH RANGE TOP	DEPTH RANGE BOT.	PERCENT REC.	PERCENT RQD.	STANDARD PENETRATION TEST PER 6 INCHES	HAND PEN. TSF.	DESCRIPTION OF STRATUM
285		C-29		288.0	100	100	Hydrofracture Test B		LIMSTONE (Austin Chalk), moderately to medium hard, fresh, light gray to dark gray with 0.3' to 1.5' thick moderately, extremely argillaceous to shaley limestone interbeds 5' to 13' apart. Also shale layers 0.6' thick, fossil partings, bentonite layers, medium angle fractures. -fossil partings at 278.0', 279.5', 280.0' and 282.0' -numerous fossils and sediment filled borings, gray to light gray at 281.1'-298.9' -3/4" broken fossil layer at 281.0' -very argillaceous layer, gradational contact at 281.5' to sharp contact at 282.5' -fossil partings at 288.9', 289.8', 292.6', 293.7', 293.9', 295.3', 297.4' and 297.8'
290			288.0						
295		C-30		298.0	100	100			-very argillaceous layer, gradational contact at 295.4' to sharp contact 295.7' -45° planar, grooved, closed fracture at 295.7' -bentonite layer (1½") at 295.7'
300			298.0						-very argillaceous layer, gradational contact at 300.0' to sharp contact at 300.4' -shale layer at 300.4'-301.0' -fossil partings at 298.5', 301.1', 301.5', 301.8', 305.5', 306.8', and 307.4'
305		C-31		308.0	100	100	Hydrofracture Test D		
310			308.0						-moderately argillaceous layer, gradational contacts at 313.0'-314.5' -fossil partings at 308.8', 310.5', 311.0', 313.6', 314.0', 315.2' and 317.2'
315		C-32		318.0	100	100			-bentonitic shale, gradational contact at 318.6' to sharp contact at 319.4' -bentonitic shale, gradational contact at 319.9' to sharp contact at 320.1' -trace bentonite at 318.7' -bentonite layer (½"), gradational contact at 320.1'
320			318.0						

DRILLING GEOLOGIST ~~Ron Randall~~ ASSISTANT ~~Dale Brown~~ CHECKED BY Clem Bommarito

Shawn Wood
(3-7-90)

LOG OF BORING

PROJECT: Superconducting Supercollider

CLIENT: The Earth Technology Corporation

TASK NO.: 17

BORING NO: BE 5 PG 9 OF 9

LOCATION: N 278,967 feet
E 2,245,051 feet

GROUND EL: 462.5 feet

DATE: 1/10-13/90 TYPE: NX Core CASED TO: 21.0' CONTRACTOR: SwL 89-192

SAMPLE LEGEND

S= SPLIT SPOON
T= 2" THIN WALL TUBE
U= 3" THIN WALL TUBE
C= NX ROCK CORE

WATER INFORMATION

See p. 1 of 9

DEPTH IN FEET	SYMBOL	SAMPLE TYPE & NUMBER	DEPTH RANGE TOP	DEPTH RANGE BOT.	PERCENT REC.	PERCENT RQD.	STANDARD PENETRATION TEST PER 6 INCHES	HAND PEN. TSF.	DESCRIPTION OF STRATUM
-325		C-33		328.0	91	91	Hydrofracture Test A		LIMESTONE (Austin Chalk), moderately to medium hard, fresh, light gray to dark gray with 0.2' thick extremely, argillaceous limestone interbeds. Also fossil partings, and medium angle fractures. -45° planar, grooved, closed, slickensided fracture at 320.0' -fossil partings at 321.7' and 324.0'
-330		C-34	328.0	335.0	97	97			-30° irregular fracture at 330.0' -very argillaceous layer at 331.0'-331.3'
-335									335.0
-340									Bottom of exploration at 335.0 feet Monitor Well Installed Upon Completion
-345									
-350									
-355									
-360									

DRILLING GEOLOGIST Ron Randall ASSISTANT Dale Brown CHECKED BY Clem Bommarito

Shawn Wood
(3-7-90)

APPENDIX B

WIRE-LINE LOGS

WIRE-LINE LOGGING PARAMETERS

Hole No. BE 5

Log Measured From: Ground Level

Drilling Parameters

Depth 335.0 feet

Bit Diameter 6.75 inches

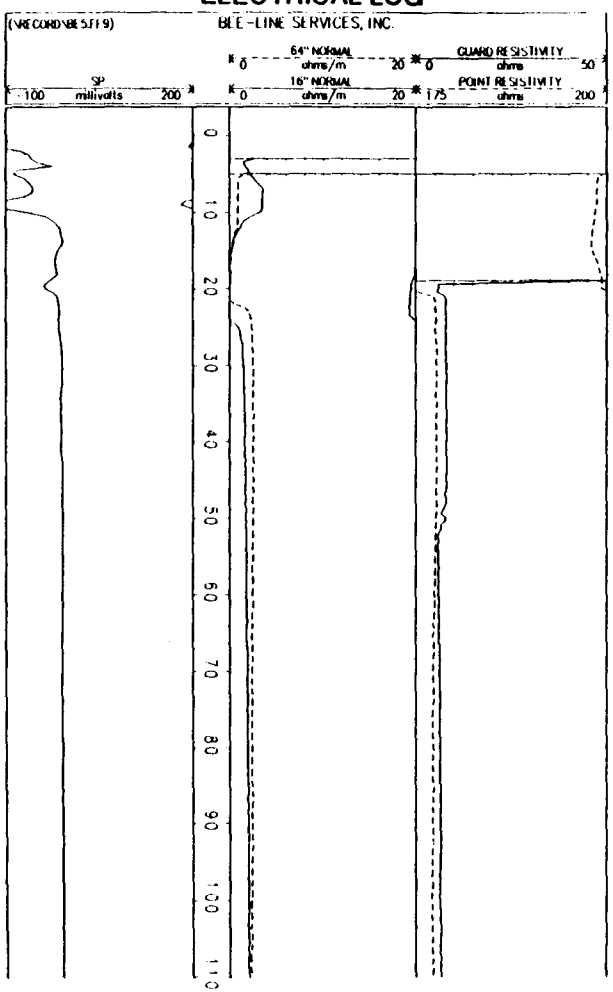
Logging Parameters	Electrical Log	Gamma Log	Sonic Log
Date	January 16, 1990	January 16 and 25*, 1990	January 16, 1990
Bottom Log Interval	335.0 feet	332.5 feet	328.4 feet
Top Log Interval	surface	surface	surface
Type of Fluid in Hole	drilling mud	drilling mud	drilling mud
Time Since Circulation Stop	30 minutes	30 minutes, 9 days*	30 minutes
Probe Type/S.N.	ALP-4979	XAP-4383	CLP-4877A
Module Type/S.N.	ALM-4979	XAM-4383	CLM-4877A
Logging Speed	40 feet/min.	20 feet/min.	20 feet/min.
Sample Interval	0.5 foot	0.5 foot	0.5 foot

*** Note:** Density log only was run on January 25, 1990

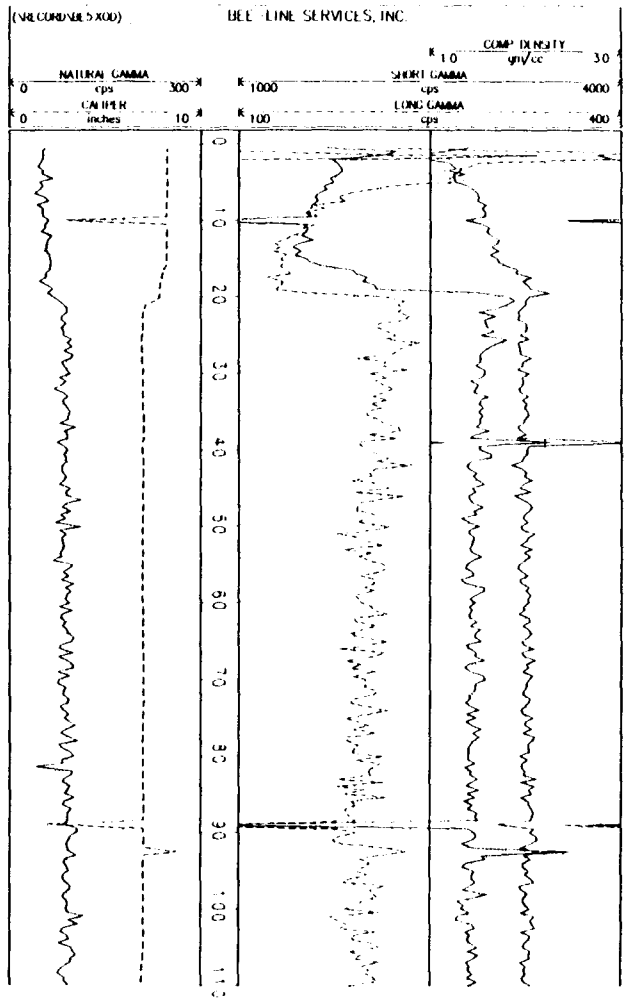
Logged by: BEE-LINE SERVICES, INC.
P. O. Box 2096
Corsicana, TX 75151

BE 5 Wire-line logs run January 16 and 25, 1990. Surface elevation 462.5 feet.

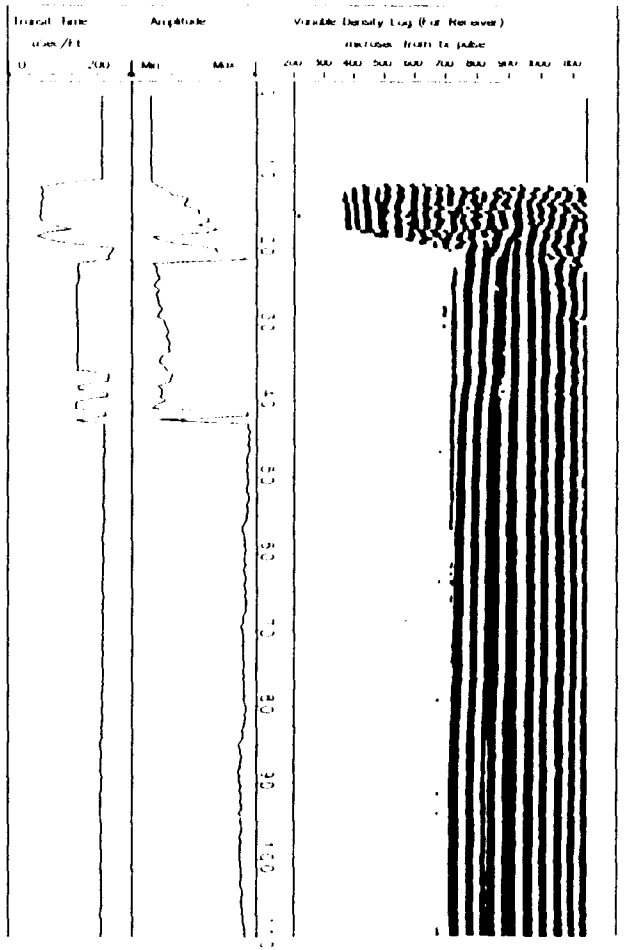
ELECTRICAL LOG



GAMMA LOG

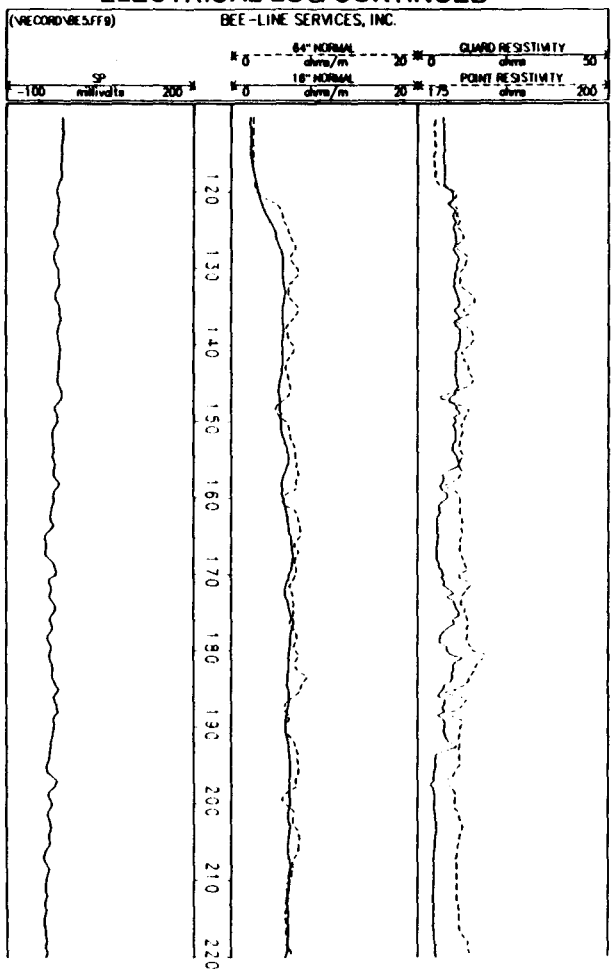


SONIC LOG



BE 5 Wire-line logs run January 16 and 25, 1990 (Continued). Surface elevation 462.5 feet.

ELECTRICAL LOG CONTINUED



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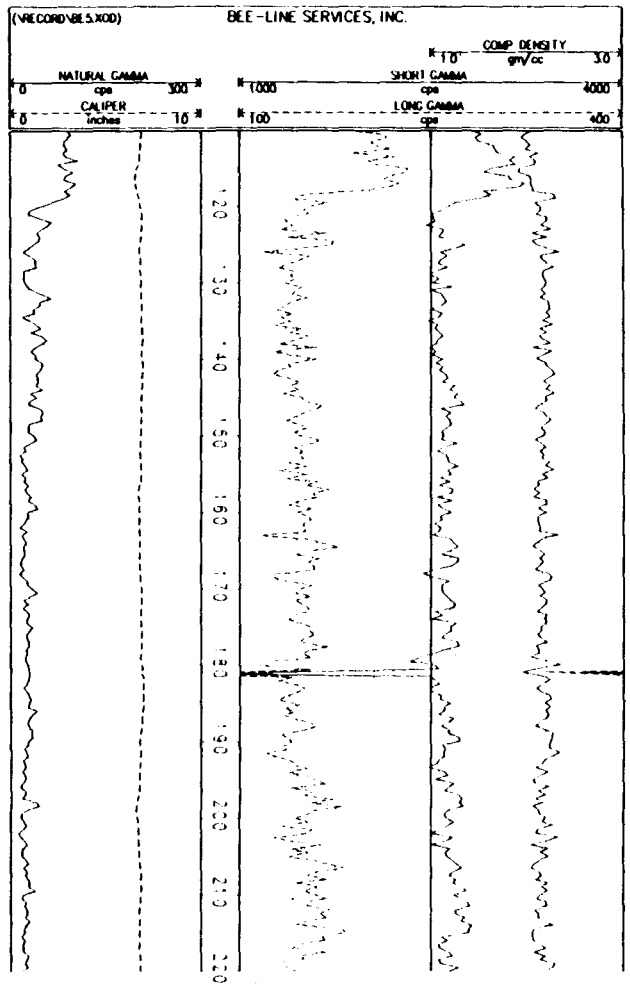

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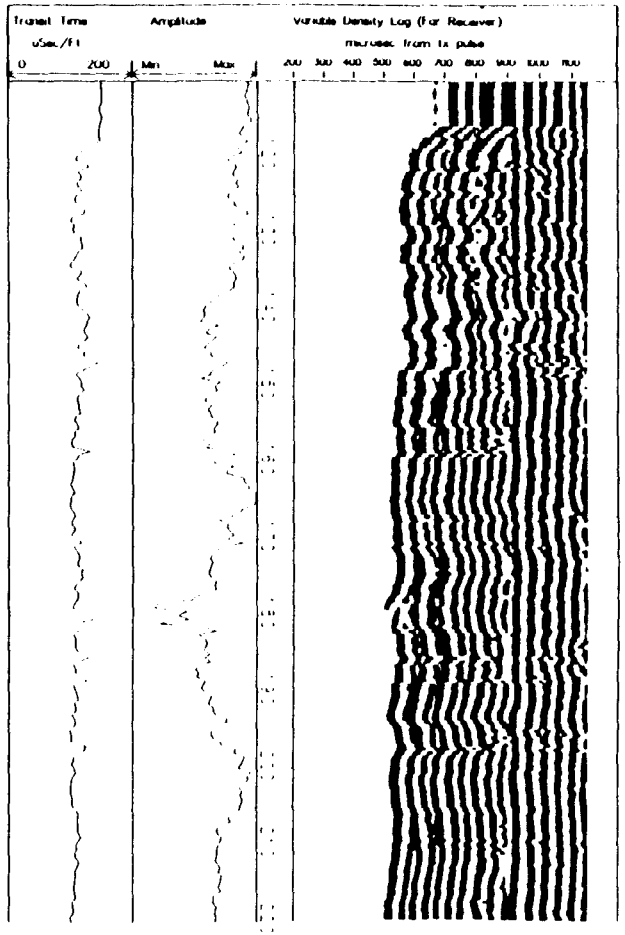
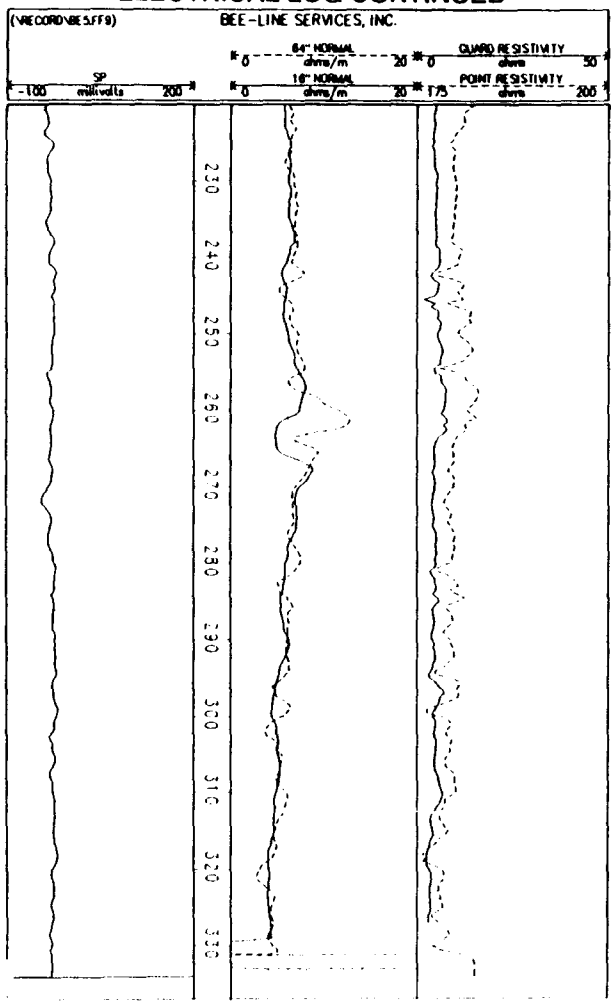


BE 5 Wire-line logs run January 16 and 25, 1990 (Continued). Surface elevation 462.5 feet.

ELECTRICAL LOG CONTINUED



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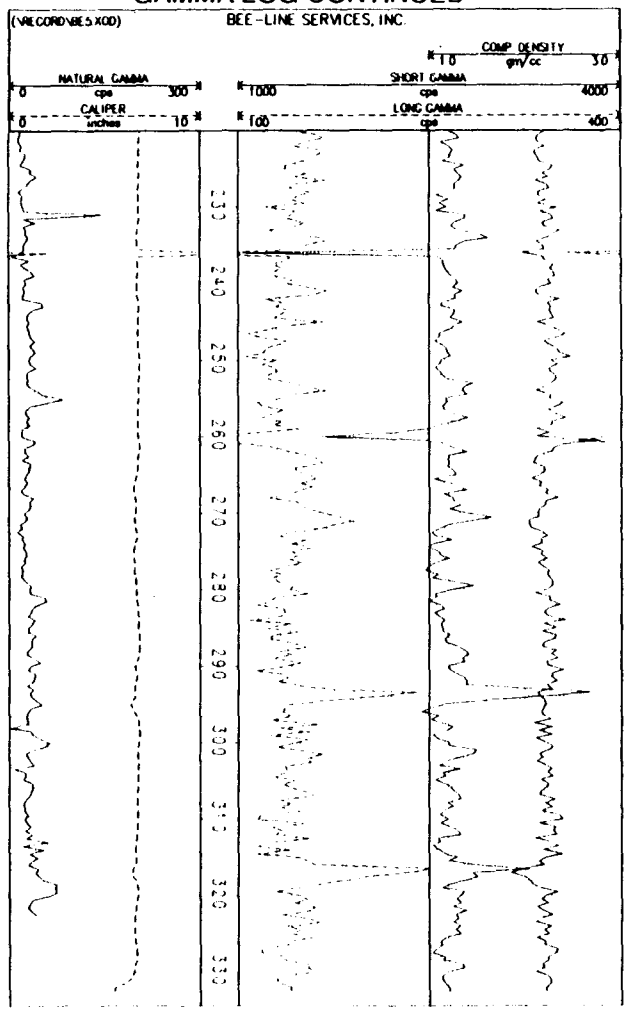

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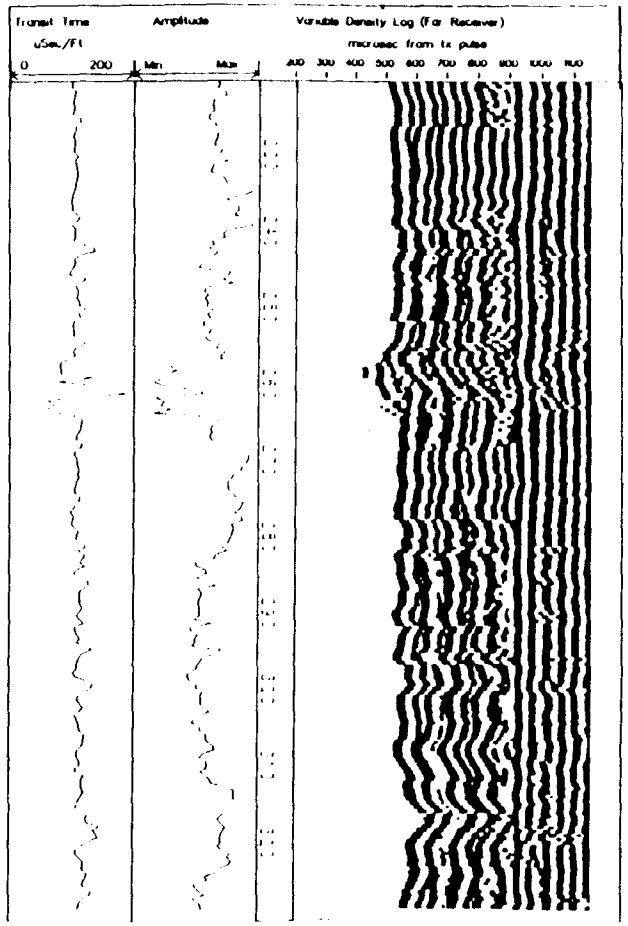

APPENDIX C

HYDROLOGIC TEST RESULTS

SwL SOUTHWESTERN LABORATORIES

Materials, environmental and geotechnical engineering, nondestructive, metallurgical and analytical services

2575 Lone Star Drive • P. O. Box 224227, Dallas, Texas 75222 • 214/631-2700

April 25, 1990

The Earth Technology Corporation
275 West Hospitality Lane, Suite 200
San Bernardino, California 92408

Attention: Matt Werner, Project Manager

Re: Hydraulic Fracturing Test Report
Texas SSC Site

Gentlemen:

Transmitted herewith is the final copy of the referenced report which we received from Re/Spec earlier today. The final report includes revisions to the preliminary report (March, 1990) based on our conference call discussions April 6, 1990.

We appreciate the opportunity to be of service. If you have any questions about information in this report, or if we can be of further assistance, please call.

Sincerely,

SOUTHWESTERN LABORATORIES, INC.

Bruce Bailey, Ph.D., P.E.
Geotechnical Division

Ralph B. Barnes, Jr., P.E.
Manager
Geotechnical Division

RBB/BB/jf
encl:

cc: (1) Priscilla Nelson, SSC Laboratory
(1) Chris Laughton, SSC Laboratory

RE/SPEC Inc.
RESEARCH/SPECIALISTS
Rapid City, South Dakota • Albuquerque, New Mexico

April 24, 1990

Dr. Bruce Bailey
Geotechnical Division
Southwestern Laboratories
2575 Lone Star Drive
P.O. Box 224227
Dallas, TX 75222

Dear Dr. Bailey:

Enclosed are five copies of our revised report entitled *Geotechnical Characterization of the Texas Superconducting Super Collider Site: Hydraulic Fracturing Tests - Boring BE5.* I believe our revision covers each of the points iterated in our earlier correspondence.

I could not replicate Appendix C because our previous report contained the material received from Schlumberger. Nothing in Appendix C changes, so you can insert the *old* Appendix C in its entirety.

Thank you for working with us to make the report as informative as possible such that the merits of additional hydraulic fracturing tests can be properly judged. As always, call if you have any questions.

Sincerely,

Leo L. Van Sambeek /AJL

Leo L. Van Sambeek
Manager, Mine and Field Services

LVS:ajl

Enclosures

3824 Jet Drive, P.O. Box 725, Rapid City, South Dakota 57709 • (605) 394-6400 • TLX 3791625 RESPEC • FAX (605) 394-6456

GEOTECHNICAL CHARACTERIZATION OF THE TEXAS SUPERCONDUCTING SUPER COLLIDER SITE

HYDRAULIC FRACTURING TESTS – BORING BE5

Topical Report RSI–0369

by

Leo L. Van Sambeek
RE/SPEC Inc.
and
Jean–Claude Roegiers
University of Oklahoma

prepared for

Southwestern Laboratories
2575 Lone Star Drive
Dallas, TX 75222

April 1990

EXECUTIVE SUMMARY

An in situ stress profile was completed in one of the exploratory holes of the Superconducting Super Collider (SSC) project near Waxahachie, Texas. A series of microhydraulic fracturing tests were conducted from a depth of 326 feet to a horizon as shallow as 76 feet. Two different formations were targeted: the Austin Chalk and the Taylor Marl. The data interpretation revealed a consistent picture and the tests were considered successful in that five of them resulted in both vertical and horizontal hydraulic fractures.

In both formations, the vertical overburden stress is the minimum stress component. Both horizontal stresses are larger (more compressive) than the vertical stress. The maximum horizontal stress is approximately twice as large as the vertical, and the minimum horizontal stress is approximately 30 percent larger than the vertical.

The stress measurement campaign did not result in an accurate determination of stress orientation. The stress orientation can be inferred from the structural geology but should be measured in the future.

Laboratory hydraulic fracture tests revealed that the Austin Chalk displays a remarkable strength size effect. The strength size effect of the Austin Chalk should be considered in all past and future property measurement projects.

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1.0 INTRODUCTION

The design of the underground openings for the Superconducting Super Collider (SSC) project requires knowledge of the virgin state of stress at depth. Although the weight of the overburden can easily be determined from the integration of the density logs, the horizontal principal stress components need to be determined via experimental techniques. This report describes an in situ measurement campaign to determine the stress profile in an exploratory hole (BE5) drilled near Palmer, Texas, situated about 12 miles west of Waxahachie, Texas.

North Central Texas is underlain by a thick sequence of sedimentary rocks that dip gently southeastward toward the Gulf of Mexico. The outcropping units in Ellis County belong to the Upper Cretaceous Gulf Series including the Taylor, Austin, Eagle Ford, and Woodbine Groups. The Austin Chalk and the Taylor Marl groups outcrop at the SSC site, and the majority of the tunnel would be in these two rocks. Figure 1-1 shows the general arrangement of the tunnels and the BE5 borehole location.

The Taylor Marl is characteristically a green-gray to blue-gray, fine-grained, laminated, calcareous claystone with interbedded chalk. Although it contains 60 to 70 percent of illite and montmorillonite clays, the cores are of good quality when fresh. The permeability of this formation is of the order of 10^{-8} cm/sec, corresponding to 100 md. The contact between the Taylor Marl and the underlying Austin Chalk is unconformable and marked by a few inches of reddish-brown clay containing reworked fossils and phosphate nodules.

The Austin Chalk is primarily light to medium gray chalk (microgranular calcite) with interbedded calcareous claystone. The average calcium carbonate content of the chalk is about 85 percent, and its physical characteristics are quite uniform. The permeability of this formation is of the order of $1.6(10^{-8})$ cm/sec, or 170 md.

Stress measurements were attempted in the Austin Chalk and the Taylor Marl; the contact being at 120.4 feet. The horizons to be fractured were determined after careful inspection of the core logs: zones of fracturing, more argillaceous chalk, and vugular regions were avoided to minimize packer problems and to fracture in as homogeneous a rock interval as possible (see core logs in Appendix A).

The stress measurement campaign relied on the microhydraulic fracturing technique (μHF). The tests were performed using mechanically expanded straddle packers. Because of the shallow depth of the measurements, it was critical that every attempt be made to initiate vertical fractures instead of horizontal fractures, which lift the overburden. Horizontal fractures do not allow the determination of the principal horizontal stress components. The use of mechanically expanded packers allowed the introduction of an additional vertical stress component, which was hoped to be sufficient to allow vertical fractures to initiate.

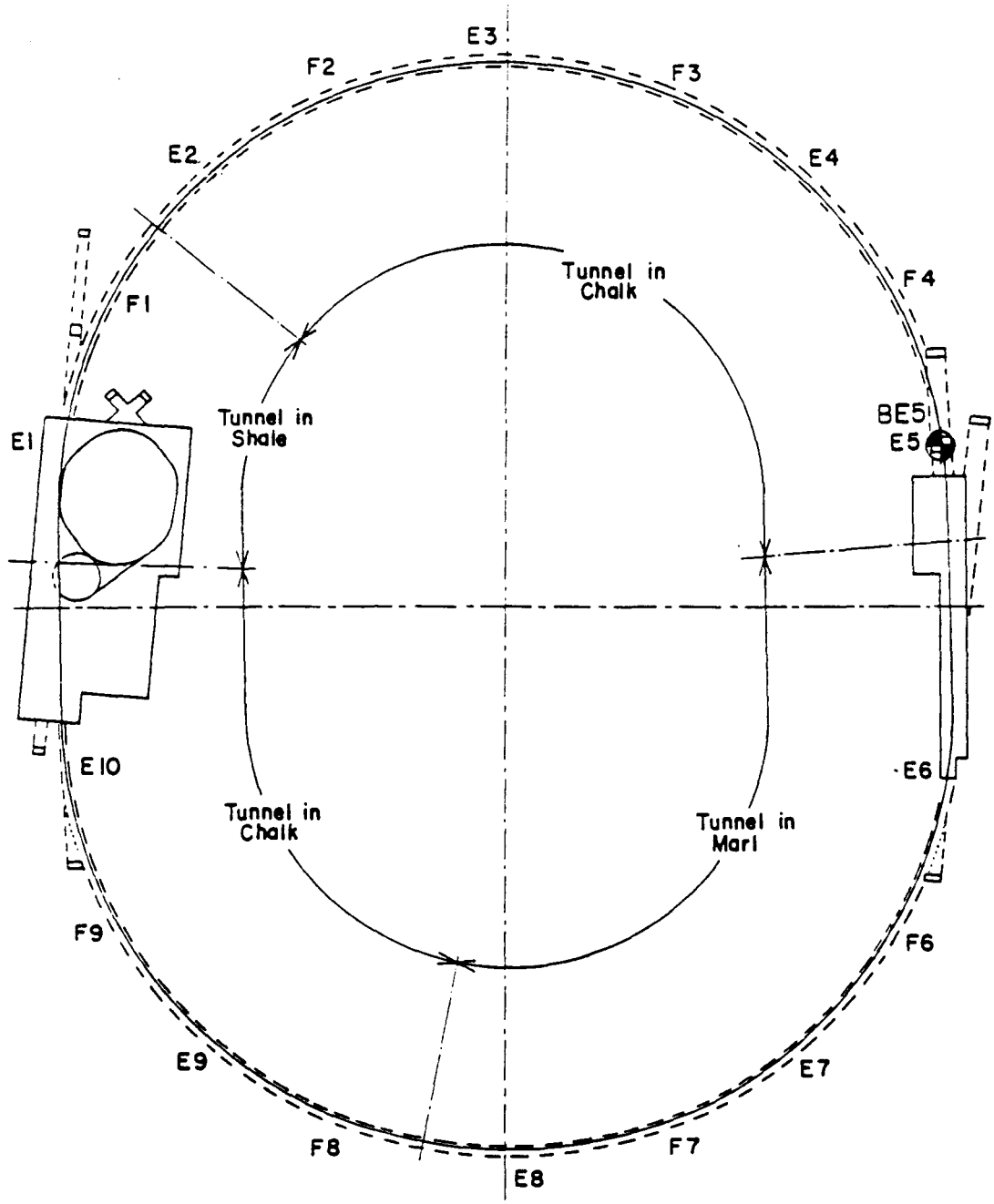

Figure 1-1. General Layout of Superconducting Super Collider Site and Borehole BE5.

After the vertical fracture was propagated, it would reorient itself to become perpendicular to the minimum principal stress component, the vertical overburden stress. When this happened, a second set of pertinent pressures was recorded in order to complete the full stress tensor.

Following the microhydraulic fracturing measurements, the hole was logged with a Schlumberger Formation MicroScanner (FMS) to obtain fracture location/orientations. The FMS also measures borehole ellipticity and breakouts.

Chapter 2 of this report presents the chronology and equipment used during the field testing effort. Chapter 3 reviews the microhydraulic fracturing technique, the results of the fracturing tests, and the results of the Formation MicroScanner logging. Chapter 4 provides a summary of the results in the form of conclusions and recommendations.

2.0 CHRONOLOGY AND EQUIPMENT

2.1 INTRODUCTION

Borehole BE5 near Palmer, Ellis County, Texas, was drilled by Southwestern Laboratories between January 10 and January 13, 1990. After core drilling, the hole was reamed to nominally 6.75-inch diameter on January 15. Wireline logging (including sonic, electrical, and gamma logs) was performed the evening of January 15. Microhydraulic fracturing tests were originally scheduled to begin the morning of January 16; however, heavy rains were forecast for the next several days, and the measurement campaign was postponed several times until it began the morning of January 27. Caliper logging was repeated on January 25 and confirmed that the condition of the borehole had not deteriorated.

Microhydraulic fracturing tests were made on January 27 (one), January 29 (four), and January 30 (five). Only one microhydraulic fracturing test was completed on January 27 because the drill rig could not free the packer assembly after the first test. Late in the evening, a hydraulic crane was mobilized at the site and used to free the packer. On January 28, the packer was being lowered into the borehole when an unforecasted rain storm forced cancellation of further testing. Testing began again on January 29 and concluded on January 30. Eight microhydraulic fracturing tests were made in the Austin Chalk (lower formation) and two microhydraulic fracturing tests were made in the Taylor Marl. A summary of the test locations is given in Table 2-1.

Table 2-1. Summary of Microhydraulic Fracturing Tests in Borehole BE5

Test I.D.	Depth (feet)	Formation	Date	Time	
				Start	Stop
BE5-A	326	Austin Chalk	Jan. 27	11:30	11:55
BE5-B	285	Austin Chalk	Jan. 29	11:00	11:30
BE5-C	210	Austin Chalk	Jan. 29	13:45	14:00
BE5-D	304	Austin Chalk	Jan. 29	16:45	16:54
BE5-E	192	Austin Chalk	Jan. 29	19:30	19:45
BE5-F	162	Austin Chalk	Jan. 30	9:49	10:30
BE5-G	152	Austin Chalk	Jan. 30	11:30	12:08
BE5-H	127	Austin Chalk	Jan. 30	13:40	14:15
BE5-I	107	Taylor Marl	Jan. 30	15:25	15:45
BE5-J	77	Taylor Marl	Jan. 30	16:38	16:56

2.2 EQUIPMENT

2.2.1 Packer Assembly

The packer assembly used in the testing was a Haliburton Services *open hole compression straddle packer* with Duro 50 packer rubbers. The length of the test interval was 36 inches. With one exception, an equalizing tube was used to avoid pressurizing the annulus below the lower packer. The proximity of the hole bottom precluded use of the equalization tube at the lowest test interval centered at 326 feet. A schematic drawing of the packer is shown in Figure 2-1.

The open hole compression straddle packer relies on the weight of the drill pipe to compress the packer rubbers and expand them against the borehole wall. Because of the shallow depth, thick-walled pipe (drill collars) was used to increase the weight above that of standard pipe. For the shallower tests, the weight was supplemented with 4,000 to 6,000 pounds of pull down from the drill rig. After 10 tests the packer rubbers showed no indications of damage or wear.

The rationale for selecting mechanically compressed straddle packers rather than inflatable straddle packers involves several interrelated lines of reasoning which include depth, fracture propagation, and packer-induced stresses. These items are discussed in the remainder of this section.

The depths at which tests were contemplated are unusually shallow for the microhydraulic fracturing technique. Indeed, previous experience in in situ stress measurements has shown that below about 1,000 feet to 1,500 feet, the minimum principal stress is horizontal. At shallower depths, a reversal in the principal stress directions occurs, and the overburden stress becomes the minimum principal stress component (refer to Figure 2-2).

Fractures always propagate "the easiest way," that is, they will tend to run parallel to the minimum stress direction. At shallow depths, horizontal fractures will usually be induced. If this occurs, the unfortunate consequence is that the field pressure records only allow the determination of the overburden pressure, a rather expensive way to integrate the density log. Consequently, to determine the horizontal stress components at shallow depths, one needs to either initiate a vertical fracture or initiate both a horizontal and vertical fracture, knowing very well that the vertical fractures will reorient themselves and become horizontal. Both of these options are discussed in this report. The first option is discussed here, and the second option is discussed in Section 2.2.2.

The theory of microhydraulic fracturing for in situ stress determination relies on the elasticity solution for stress around an infinitely long pressurized cylindrical cavity [Scheidegger, 1962]. Kehle [1964] introduced the effects of longitudinally rigid packers and a finite pressurized length. In actuality, the packers used in hydraulic fracturing are neither longitudinally rigid nor radially bonded to the rock. Inflatable packers, because of their length and tremendous expansion capabilities, are allowed to slide along a central mandril. This sliding reduces the tensile stress increment

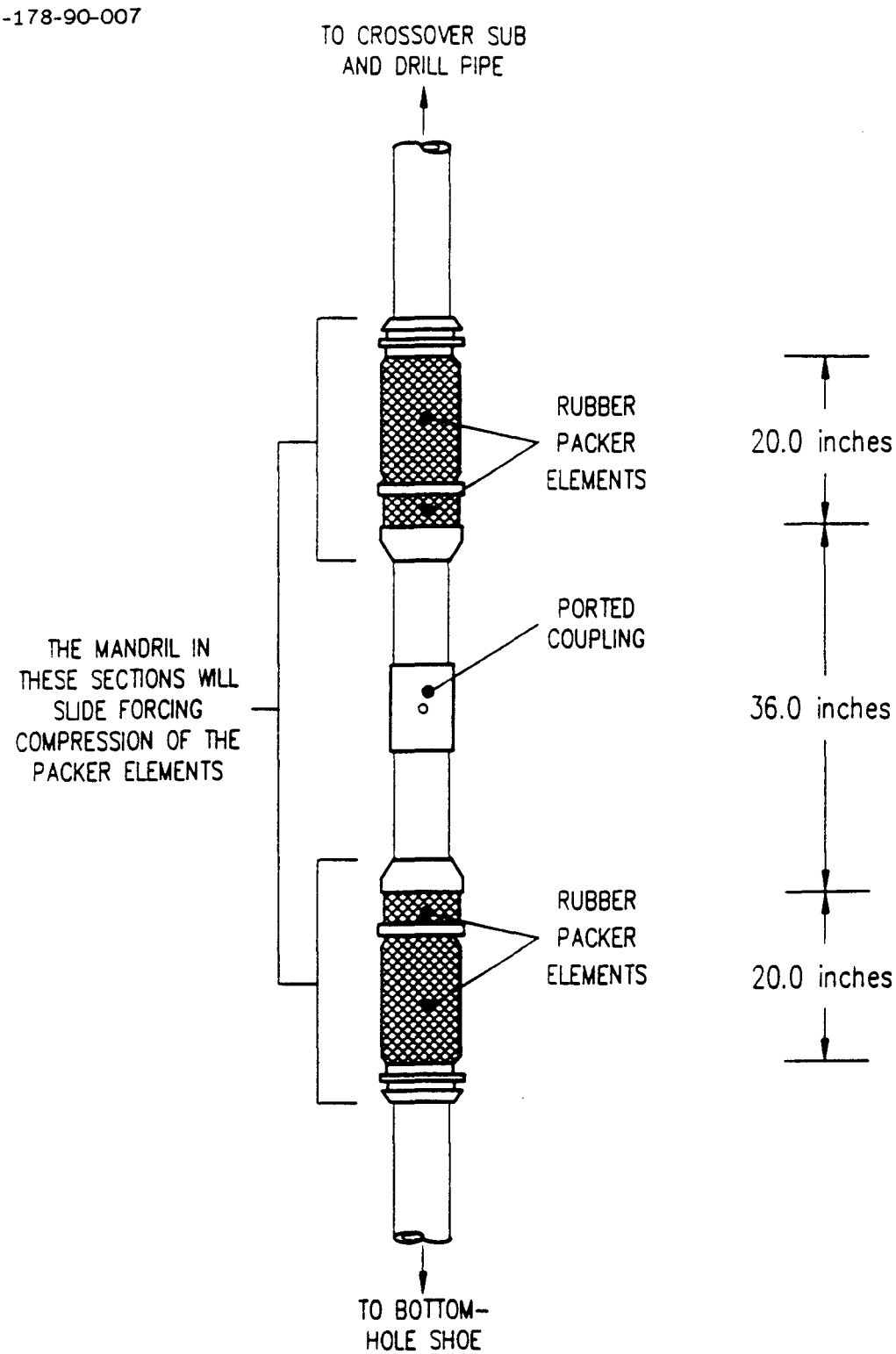

Figure 2-1. Schematic of Open Hole Compression Straddle Packer.

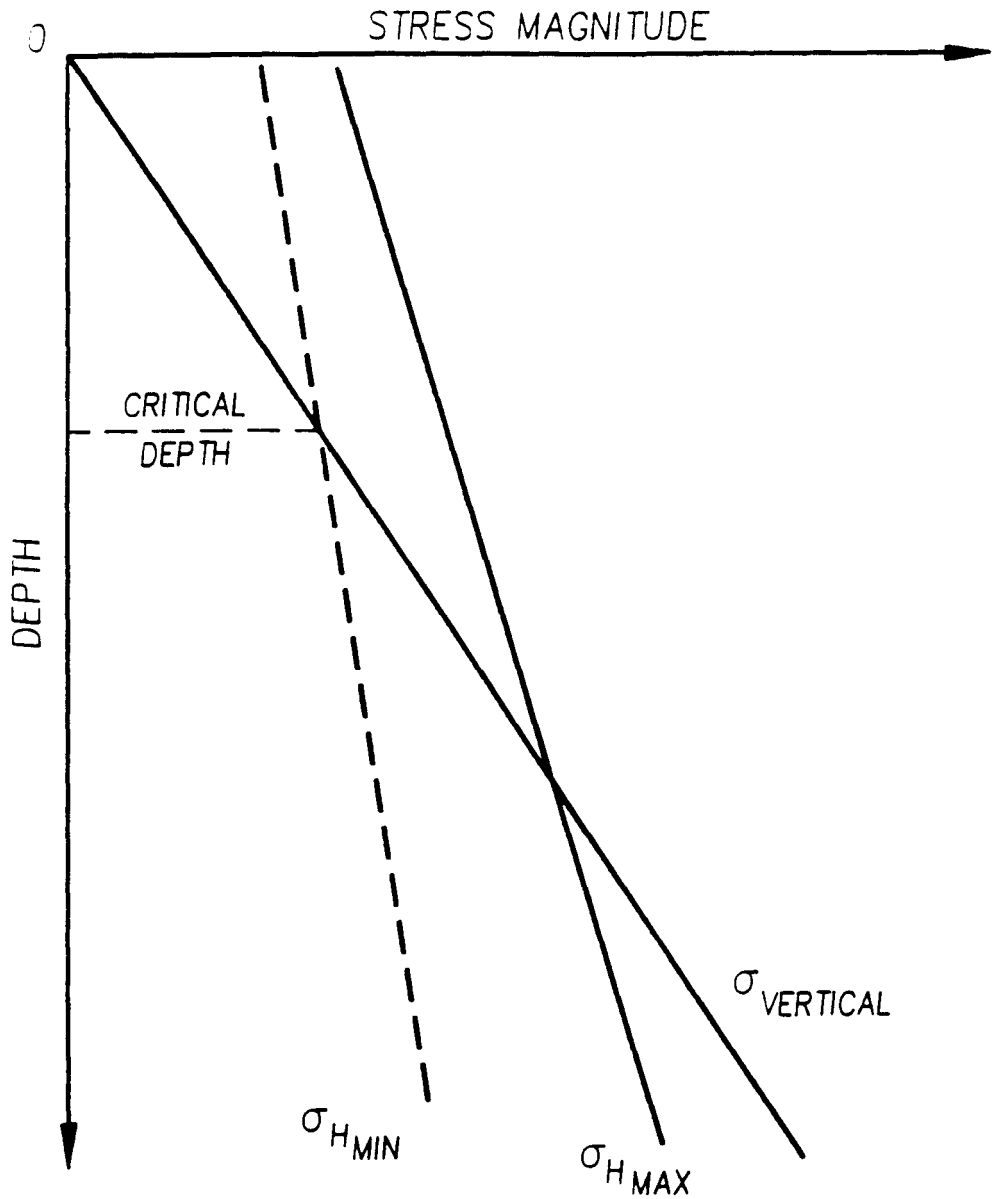

Figure 2-2. Typical In Situ Stress Profiles.

introduced in the rock surrounding the borehole when the packers are inflated. The mechanical-expansion straddle packer, however, has the opposite reaction. Rather than introducing an axial tensile stress increment, a compressive stress increment is induced in the rock between the packer elements. The combination of the compressive stress increment and the axial rigidity of the straddle section resists the formation of a horizontal fracture. Essentially, the packer assembly "pins" the rock together. Additional aspects of packer selection are discussed by Roegiers, et al. [1973] and Roegiers [1974].

2.2.2 Pump and Data Logging

The pump used in the testing was a Haliburton Services RCM cementing truck. A special conversion kit was installed to reduce the pump piston diameter to 1 inch (from the standard 4-inch diameter). The pumping rate could be controlled from about 0.5 gpm to more than 10 gpm. Radio contact was maintained between the test operator and the pump operator, such that shut-in instructions and flow rate changes could be instantly communicated.

Flow rates were measured using several impeller-type flowmeters with throat sizes between 0.5- and 2-inch diameter. Considerable problems were encountered in maintaining the small-diameter meters. When flow meter problems were encountered, the flow rates were calculated by the pump operator based on volume removal from the calibrated supply tank. The test records included in Appendix B sometimes show peaks in flow rate. Such a transient is sensed at the surface because of either switching gears on the pumping unit or closing valves in the surface piping. For example, when the hydraulically driven fractures were shut-in, a spike will be seen in the flow rate. This spike is inherent in the use of turbine flowmeters which will record a positive flow rate when spinning in either direction.

Pressures were measured using strain-gaged pressure transducers. Originally, a 0–1,000 psi transducer was intended to be the primary transducer. During the second microhydraulic fracturing test, it was obvious that this transducer was in error (possibly because of being frozen during the previous night). The transducer was replaced with a 0–15,000 psi transducer for Tests B through E. For the final five tests, 0–1,000 psi and 0–300 psi transducers were simultaneously used.

Both the Haliburton Services Compuvan and Compupack data loggers were used during the tests. The Compuvan allowed playback of selected portions of the test cycles and rigorous inspection of the data in the field. The Compupack records the same information, but is less versatile in terms of in-the-field plotting and data inspection.

The apparently over-sized pumping unit was selected because we were uncertain whether or not it would be possible to initiate a vertical hydraulic fracture. If a horizontal fracture is initiated and propagated, then the only remaining option is to attempt to initiate a second vertical fracture while propagating the horizontal fracture. This can only be achieved if a large pumping capacity is available.

For example, assume that a horizontally fractured borehole is pressurized and that pumping has resumed (i.e., the horizontal fracture is being propagated). A relationship exists between the pressure in the borehole and the width of the horizontal fracture, but this relationship is nonlinear (i.e., doubling the pressure does not double the fracture width at the borehole). Consequently, if water is pumped into the borehole at a rate faster than the fracture can accommodate, a choke will be introduced. The pressure in the borehole will increase and hopefully a second vertical fracture will be induced. Upon shut-in, two instantaneous shut-in pressures will be recorded: one for the vertical fracture followed by one for the horizontal fracture.

2.2.3 Fracture Detector

The Schlumberger Formation MicroScanner (FMS) Service was used to log the borehole after the microhydraulic fracturing tests. The FMS provides a high resolution image of the borehole surface using a dense array of electrical sensors. Major applications of the FMS are in fracture identification, analyzing thinly bedded formations, recognizing secondary porosity developments in carbonates, and defining sedimentary structures and depositional environments.

Ideally, the FMS should be used both before and after microhydraulic fracturing. Because of budget limitations, the FMS was used only after the microhydraulic fracturing tests. The location of fractures existing in the borehole before the tests were based on the core logs.

3.0 STRESS DETERMINATIONS

3.1 INTRODUCTION

A series of microhydraulic fracturing tests were performed in a single borehole in an attempt to determine the in situ stress field prevailing in the Austin Chalk and in the Taylor Marl. It was recognized beforehand that the tests would be performed at depths where horizontal fractures are usually induced. An attempt was made to increase the longitudinal (i.e., along the borehole axis) stress concentration by using mechanical-expansion packers. It was hoped that this axial stress increment would resist a *horizontal* fracture from forming at the borehole wall.

3.2 MICROHYDRAULIC FRACTURING

3.2.1 Introduction

The microhydraulic fracturing technique consists of sealing off a section of an open hole and pressuring it until the borehole wall fails in tension (i.e., a hydraulically induced fracture occurs). The hydraulic fracture is then propagated and shut-in to record the pressure that just holds the fracture open. Several pressurization/propagation cycles provide data which can be related to the in situ stress field.

3.2.2 Theoretical Background

If one assumes that rock behaves as a linear elastic solid, and that the borehole is drilled parallel to one of the principal stress directions, the following expressions can be obtained for the stresses around a vertical borehole.

$$\sigma_r = \tfrac{1}{2}(\sigma_{Hmax} + \sigma_{Hmin})(1 - \tfrac{a^2}{r^2}) + \tfrac{1}{2}(\sigma_{Hmax} - \sigma_{Hmin})(1 - \tfrac{4a^2}{r^2} + \tfrac{3a^4}{r^4}) \cos 2\theta$$

$$\sigma_\theta = \tfrac{1}{2}(\sigma_{Hmax} + \sigma_{Hmin})(1 + \tfrac{a^2}{r^2}) - \tfrac{1}{2}(\sigma_{Hmax} - \sigma_{Hmin})(1 + 3\tfrac{a^4}{r^4}) \cos 2\theta$$

$$\tau_{r\theta} = -\tfrac{1}{2}(\sigma_{Hmax} - \sigma_{Hmin})(1 + 2\tfrac{a^2}{r^2} - 3\tfrac{a^4}{r^4}) \sin 2\theta$$

where a is the radius of the borehole, r is the radial distance from the center of the borehole, and σ_4 represents the horizontal or in plane principal stresses. The angle θ defines the direction relative to the σ_{Hmin} direction.

If one is interested only in what happens at the borehole wall then, with $r \rightarrow a$, the following expressions are obtained:

$$\begin{cases} \sigma_r = 0 \\ \sigma_\theta = (\sigma_{Hmax} + \sigma_{Hmin}) - 2(\sigma_{Hmax} - \sigma_{Hmin}) \cos 2\theta \\ \tau_{r\theta} = 0 \end{cases}$$

Considering only the directions parallel and perpendicular to the minimum horizontal stress direction (i.e., $\theta = 0$ and $\theta = \frac{\pi}{2}$, respectively), these expressions further simplify to:

$$\sigma_\theta \Big|_{\theta=0} = 3\sigma_{Hmin} - \sigma_{Hmax}$$

$$\sigma_\theta \Big|_{\theta=\pi/2} = 3\sigma_{Hmax} - \sigma_{Hmin}$$

If one provides hydraulic pressure to a sealed-off interval of the borehole, a radial fracture initiates as soon as the hydraulic pressure exceeds the tensile strength of the rock and the circumferential stress concentration (the breakdown pressure, P_b). It should be noted that the stress concentration diminishes rapidly to zero away from the wellbore. Consequently, the stress concentration affects the pressure to induce a fracture, but not the pressure to propagate the fracture away from the wellbore wall (the fracture reopening pressure, P_r).

The following expression can be written for the breakdown pressure of an uncased, smooth wellbore:

$$P_b = 3\sigma_{Hmin} - \sigma_{Hmax} - p + T \quad \text{with} \quad \sigma_{Hmax} \geq \sigma_{Hmin}$$

or, in terms of effective stresses, σ'_{Hmin} and σ'_{Hmax},

$$P_b = 3\sigma'_{Hmin} - \sigma'_{Hmax} + T$$

where p is the formation pore pressure and T is its tensile strength.

This equation is valid only in the case of no fluid penetration; hence, it actually gives an *upper bound* for the breakdown pressure. Also, it assumes that the initiation and propagation directions are identical.

It should be noted that an increase in the pore pressure in the vicinity of the well corresponds to a decrease in the breakdown pressure [Bredehoeft et al., 1976]. Therefore, the use of low-viscosity fluids and/or low pumping rates will decrease the pressure for breakdown.

After the fracture has propagated, the pumps are stopped and an instantaneous shut-in pressure, P_{ISIP}, is recorded. Based on the action/reaction principle, this pressure should only be slightly above the magnitude of the minimum principal stress (assuming the influence of the borehole is negligible). Hence, a second equation can be written as follows:

$$P_{\text{ISIP}} \approx \sigma_{Hmin}$$

The last unknown, T, is obtained by letting the pressure bleed off and starting a second cycle of pressurization using the same fracturing fluid and the same pumping rate as for the first cycle. The tensile strength of the rock is effectively nullified by the presence of the fracture, and the fracture reopening pressure can be expressed as

$$P_r = 3\sigma_{Hmin} - \sigma_{Hmax} - p$$

The stress-state solution requires a knowledge of the pore pressure, p. For this testing, the pore pressure is assumed to be equal to the calculated downhole hydrostatic pressure shown in Table 3-1.

Table 3-1. Microhydraulic Fracturing Testing Horizons and Hydrostatic Pressures

Formation	Test Identification	Depth to Center of Pressurized Interval (ft)	Date of Test	Hydrostatic Pressure (psi)
Austin Chalk	BE5-A	326	1/27	141
	BE5-B	292	1/29	123
	BE5-C	210	1/29	91
	BE5-D	303	1/29	132
	BE5-E	192	1/29	83
	BE5-F	162	1/30	70
	BE5-G	152	1/30	66
	BE5-H	127	1/30	55
Taylor Marl	BE5-I	107	1/30	46
	BE5-J	77	1/30	33

The system of three equations and three unknowns allows the determination of both in situ stresses, σ_{Hmax} and σ_{Hmin}, and the tensile strength of the formation, T. One should note that these expressions assume smooth, openhole conditions which are rarely the case in practice. However, the data from a microhydraulic fracturing test always give, at least, the value of the minimum principal stress.

The calculated values for the in situ stresses should be used cautiously because they are only approximations. Sources of error include effects of leakoff, stress concentrations, pore pressure, and rock strength. For instance, one must make sure that the pore pressure is not altered during the test period; otherwise, the shut-in pressure will increase as has been reported in the literature. These problems are minimized when high-viscosity fluids are used.

In practice, several pump/shut-in cycles are performed, involving the injection of progressively larger volumes of fluid. However, in most cases, the instantaneous shut-in pressure (taken as the pressure at which the downhole pressure curve departs

from the initial drop immediately following the shut-in) are sometimes observed to change from cycle to cycle. This procedure should be repeated until subsequent instantaneous shut-in pressures are repeatable.

Because it was felt that vertical fractures would eventually turn horizontal as they were propagated, it was essential to "capture" this feature. Hence, the usual microhydraulic fracturing procedure was modified in the sense that the fracture was shut-in (pumping was stopped) as soon as breakdown was indicated. If the shut-in is preformed fast enough, the instantaneous shut-in pressure may reflect the attitude of the fracture close to the borehole wall. A number of pressurization cycles were performed. Careful monitoring of the instantaneous shut-in pressure values until they became repetitive, reveals when the fracture attitude has stopped changing. Consequently, the following possibilities are contemplated:

- Fracture starts horizontal and stays horizontal

  Uniform instantaneous shut-in pressures from first breakdown cycle on.

- Fracture starts vertical and stays vertical

  Uniform instantaneous shut-in pressures from first breakdown cycle on. The difference with the previous case is that, in general, the breakdown peak is sharper than for the horizontal case and propagation will usually occur at pressures below the overburden stress magnitude.

- Fracture starts vertical and turns horizontal

  Definite higher instantaneous pressure in first breakdown cycle with a tendency to lower P_{ISIP} as number of cycle increases. Finally, constant shut-in pressures are recorded that are consistent with the overburden pressure.

- Fracture starts horizontal and turns vertical

  Impossible unless a major structural discontinuity is encountered by the propagating hydraulic fracture.

- Both horizontal and vertical fractures are initiated and propagated

  After shut-in, two changes in slope of pressure decay curve are observed; two definite plateaus, P_{ISIP}, will be recorded.

3.2.3 Procedure

The same basic steps were followed in each test:

- Determine the test interval based on the core log.
- Position the packer at the interval and circulate clear water for 5 minutes.
- Isolate a 3-foot section of a borehole, using a mechanical straddle packer assembly.

- Inject into the formation at minimum rate[1] until fracture occurs.
- After short propagation, shut-in the well and observe the pressure decline.
- Open the valves and flow back under controlled conditions (i.e., constant rate) and note any breaks in the pressure decline curve.
- Monitor the well head for flow-back, which indicates either packer failure or vertical fracturing around the packer.
- Repeat pressurization cycles until consistent *picture* emerges. The last cycle can be carried out at higher pumping rate.

3.2.4 Field Data

Ten microhydraulic fracturing tests were attempted, starting from the bottom of the hole. Table 3-1 summarizes the tested intervals and the assumed hydrostatic pressure at the test interval. The raw pressure/time curves from the field are included in Appendix B.

Table 3-2 summarizes the data interpretation and Table 3-3 gives the in situ stress values obtained from the pressure data. To illustrate how breakdown and instantaneous shut-in pressures were determined, a few field pressure-time plots will be discussed. Figure 3-1 shows the pressure-time plot from Test BE5-A. Two curves are shown: the tubing pressure and the bottom hole treatment pressure (BHTP). For these tests, the two curves are offset from each other by the hydrostatic pressure produced by the water column in the borehole (see Table 3-1). Pumping began at 11:21 and continued intermittently until about 11:43 when an apparent breakdown occurred (P_b = 510 psi). The pumping was erratic because the flow meter was not responding and several start/stops occurred while attempting to fix it. After the apparent breakdown, a shut-in pressure of 338 psi was detected (Point B in Figure 3-1). The P_{ISIP} = 338 psi suggested a horizontal fracture was induced. At 11:53, a very high pumping rate (20 gpm) was started. An apparent breakdown occurred at 685 psi and was followed by a shut-in pressure of 338 psi. This suggests that the same horizontal fracture was shut-in and that the high pumping rate failed to induce a vertical fracture.

Figure 3-2 shows the pressure-time plot for Test BE5-C. Five successful cycles of pressurization were performed. Unfortunately, the pressure transducer momentarily stopped recording at 400 psi during the first cycle (Point A); hence the peak pressure was missed. The P_{ISIP} for the first cycle was 291 psi (Point B). The next four cycles suggest that a vertical fracture had been induced and that it remained vertical because the P_{ISIP} for each cycle is about the same (range 291 to 321 psi). The breaks in pressure during cycles 2 and 3 (Point C) correspond to a change in gear on the pumping unit.

[1] Just sufficient to overcome the natural formation permeability.

Table 3-2. Microhydraulic Fracture Data

Test I.D.	P_b (psi)	P_r (psi)	T (psi)	Number of Shut-Ins	P_{ISIP}, Average (psi)		Comments
					Horizontal Fractures	Vertical Fractures	
BE5-A	510	—	—	2	338	—	Started horizontally
BE5-B	—	—	—	—	—	—	Bad data, problems with pressure transducers
BE5-C	397/524[a]			5	—	283	Ignored first two pressurization cycles
BE5-D	710	547	163	4	302	462	Vertical fracture turning horizontal
BE5-E	418/462[b]	—	—	7	251	328	Vertical fracture turning horizontal
BE5-F	410	400	10	4	250	300	Vertical fracture turning horizontal
BE5-G	365	365	0	3	—	300	Vertical fracture
BE5-H	368	342	26	4	250[c]	250[c]	Vertical or horizontal fracture
BE5-I	336	307	29	4	178	215	Vertical fracture turning horizontal
BE5-J	133	100	33	4	93	—	Horizontal fracture

Notes: (*a*) 397 psi corresponds to the first breakdown, but later cycles revealed higher pressures.

(*b*) 418 psi corresponds to the first breakdown, but later cycles revealed higher pressures.

(*c*) No way to know if vertical or horizontal fracture was induced.

Table 3-3. Interpreted Instantaneous Shut-In Pressures for Each Test Cycle

Test Identification	Depth In Ft.	No. of Cycles	No. of P_{ISIP}	ISIP's In psi
BE5-A	326	1	1	338
BE5-B	285	0	0	
BE5-C	210	5	5	291, 321, 311, 291, 311
BE5-D	304	4	3	462, 302, 302
BE5-E	192	7	5	323, 293, 253, 248, 253
BE5-F	162	4	4	300, 252, 250, 250
BE5-G	152	3	2	300, 300
BE5-H	127	4	4	240, 250, 253, 258
BE5-I	107	4	3	215, 180, 175
BE5-J	77	4	4	100, 95, 95, 80

Figure 3-3 shows the four pressurization cycles for Test BE5-D. The breakdown pressure (Point A) is very distinct at 710 psi. The shut-in pressure for the first cycle occurred at 462 psi (Point B). The second cycle revealed a distinct fracture reopening pressure (Point D) at 547 psi. The pressure difference between Points A and D reflect a tensile strength of 163 psi. No clear P_{ISIP} shows up on the second cycle. The third and fourth cycles reveal a distinct and repeatable P_{ISIP} of 302 psi. This suggests that an initially vertical fracture has turned horizontal.

Figure 3-4 shows seven pressurization cycles performed in Test BE5-E. In this test, very low pumping rates were used: 0.05 to 0.15 gpm. The breakdown pressure (Point A) was 418 psi on the first cycle. The fracture reopening pressure increased to about 460 psi (Point C) on each of the later cycles. The shut-in pressures dropped from an initial 323 psi to 293, 253, 248, and 253 psi on subsequent cycles. Again, this behavior is suggestive of an initially vertical fracture turning horizontal.

3.2.5 Discussion

Ten microhydraulic fracturing tests were carried out in borehole BE5. Eight of the tests were in the Austin Chalk, and two tests were in the Taylor Marl. One of the tests, BE5-B did not produce any usable data because the pressure transducers did not work properly. In two of the tests, BE5-A and BE5-J, it is believed that a horizontal fracture was initiated from the borehole wall. Four of the tests are believed to have initially produced a vertical fracture at the borehole wall, which subsequently turned horizontal as it was propagated. Two of the remaining tests resulted in vertical fractures initiating from the borehole wall which were not detected to have turned horizontal. The orientation of the fracture in test BE5-H could not be resolved.

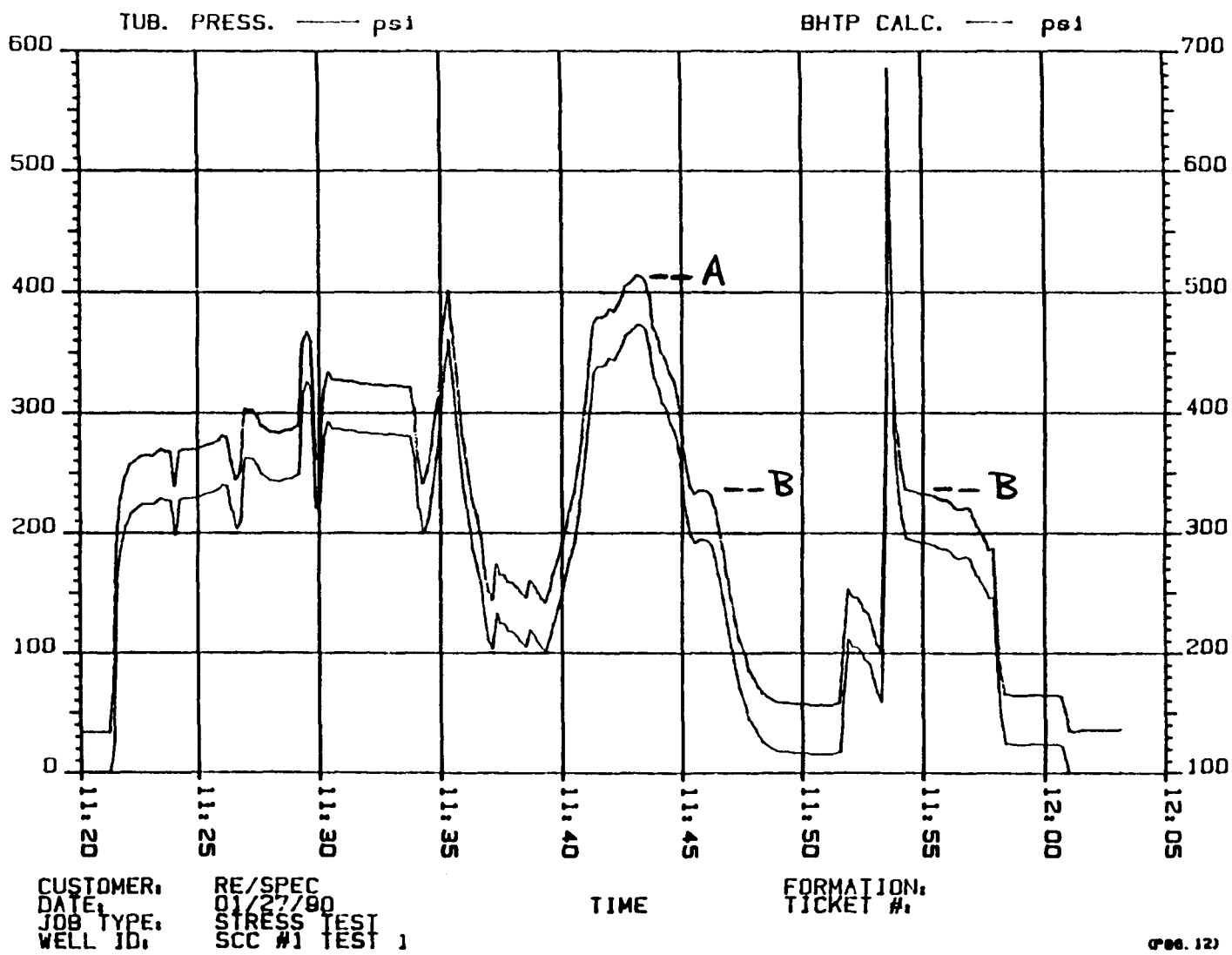

Figure 3-1. Photocopy of Pressure-Time Plot For Test BE5-A.

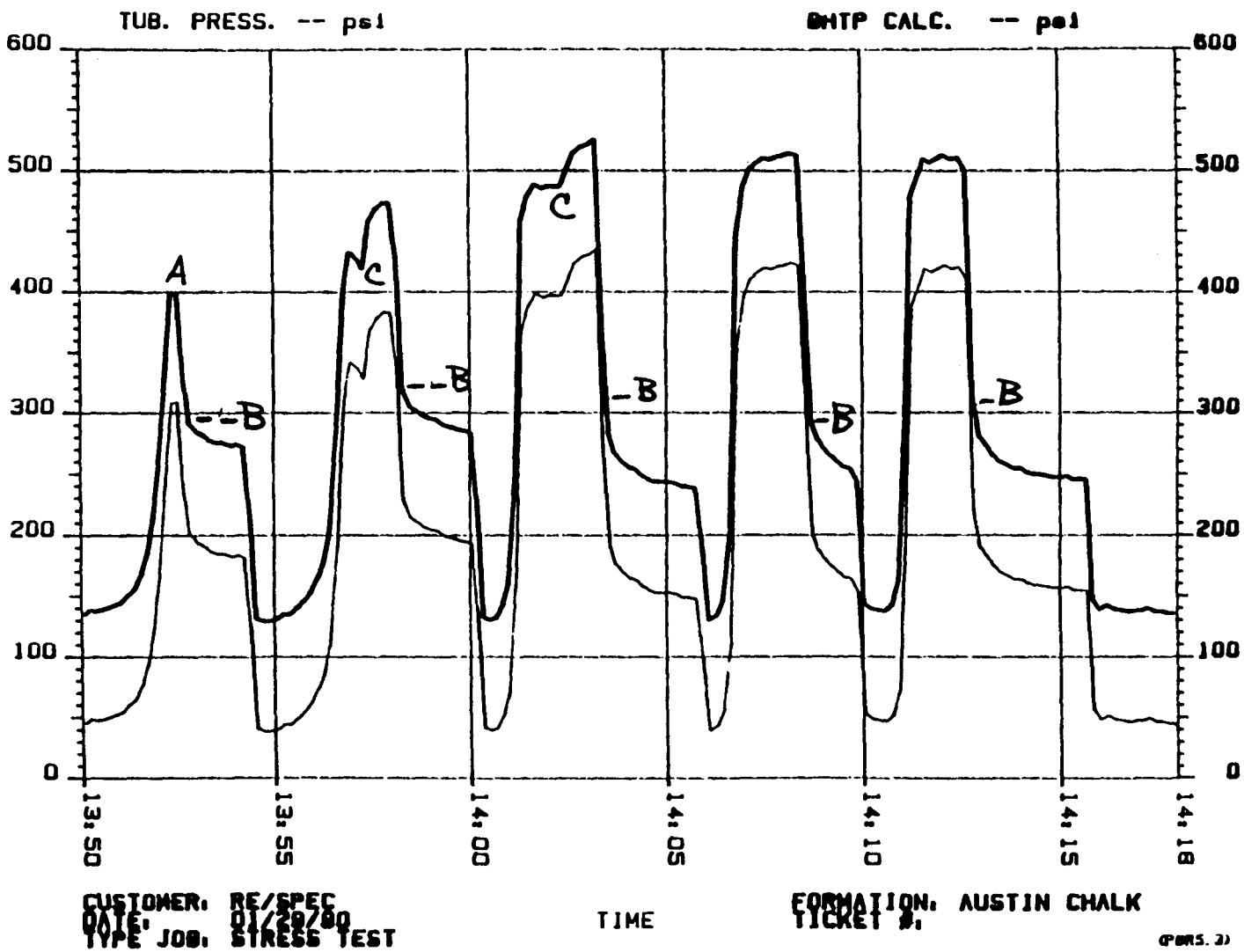

Figure 3-2. Photocopy of Pressure-Time Plot For Test BE5-C.

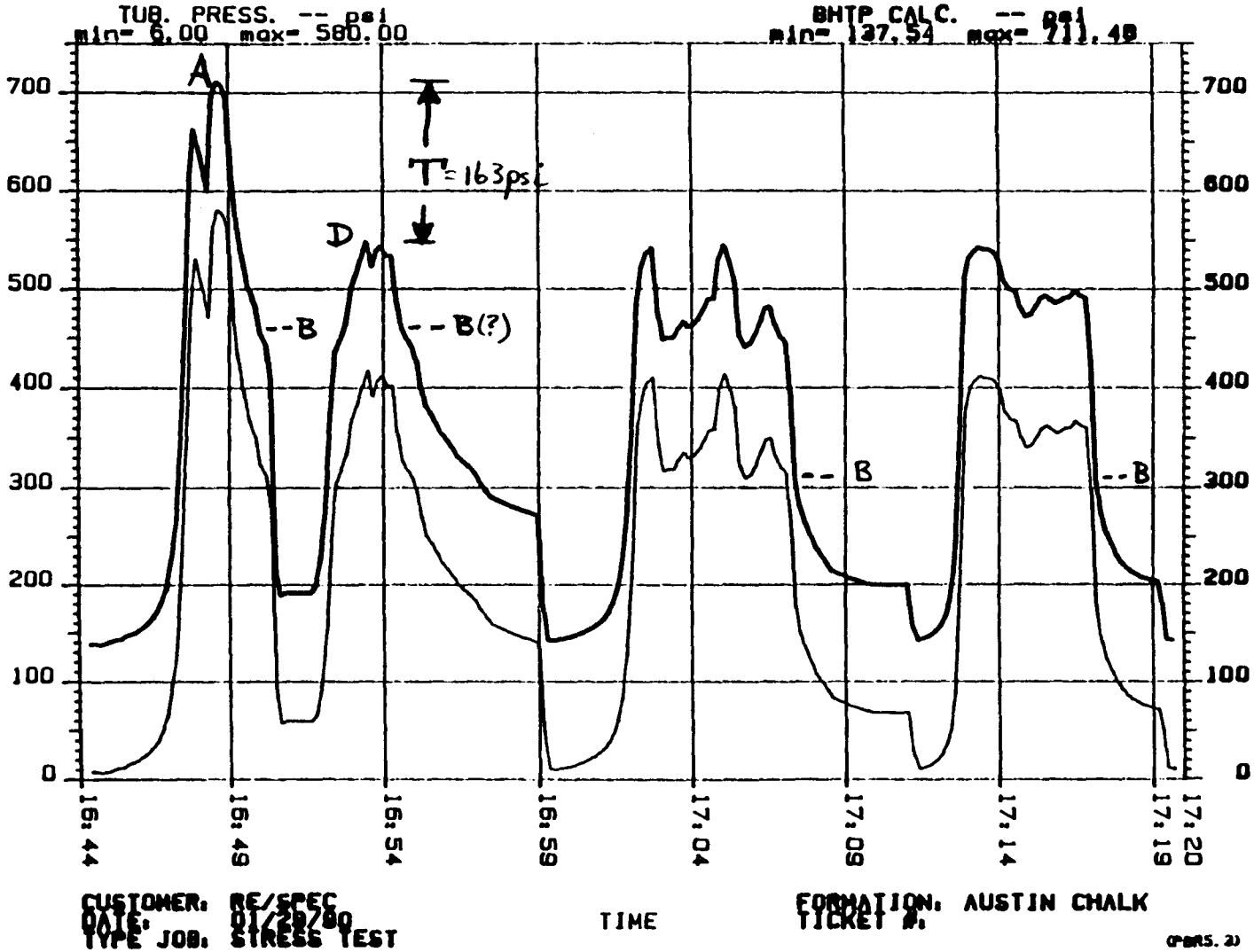

Figure 3-3. Photocopy of Pressure-Time Plot For Test BE5-D.

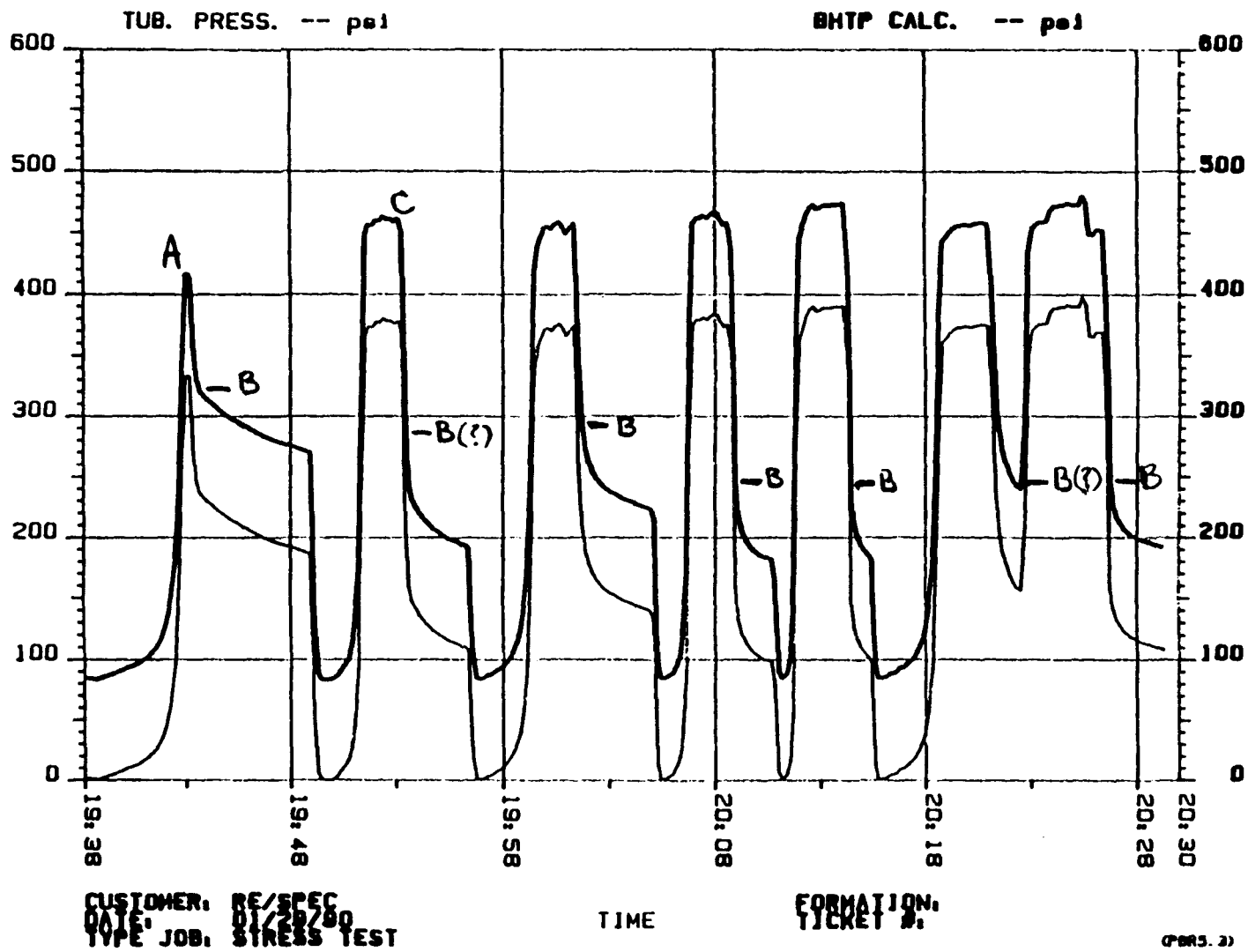

Figure 3-4. Photocopy of Pressure-Time Plot For Test BE5-E.

Table 3-3 supplements Table 3-2 by listing the interpreted instantaneous shut-in pressure for each test cycle. The stress profile information is summarized in Table 3-4 and Figure 3-5.

Table 3-4. Calculated Stresses From the Micro-hydraulic Fracturing Tests

Test I.D.	Depth ft.	Calculated Stresses (psi)		
		Vertical	Minimum Horizontal	Maximum Horizontal
BE5-A	326	338	—	—
BE5-B	285	—	—	—
BE5-C	210	—	283	—
BE5-D	304	302	462	707
BE5-E	192	251	328	—
BE5-F	162	250	300	430
BE5-G	152	—	300	469
BE5-H	127	250	250	—
BE5-I	107	178	215	292
BE5-J	77	93	—	—

The vertical stress was obtained from the instantaneous shut-in pressures in horizontal fractures (Tests BE5-A, -D, -E, -F, -I, and -J). The resulting stress gradient in the Taylor Marl is higher than would be indicated from the density of Taylor Marl. However, there are only two measurements in this unit and any error in one of the measurements could result in a significant error in the gradient. The vertical stress gradient in the Austin Chalk resulting from the measurements is 0.87 psi/ft. This stress gradient compares remarkably well with that which would result from the density of the Austin Chalk.

The minimum horizontal stress was resolved at six test intervals in borehole BE5; five in the Austin Chalk and one in the Taylor Marl. The minimum horizontal stress is approximately 30 percent larger (more compressive) than the vertical stress in the Austin Chalk. The minimum horizontal stress gradient in the Austin Chalk is 1.08 psi/ft.

The maximum horizontal stress can be resolved at four of the test intervals. In the Austin Chalk, the maximum horizontal stress is approximately double the vertical stress and exhibits a gradient of 1.73 psi/ft.

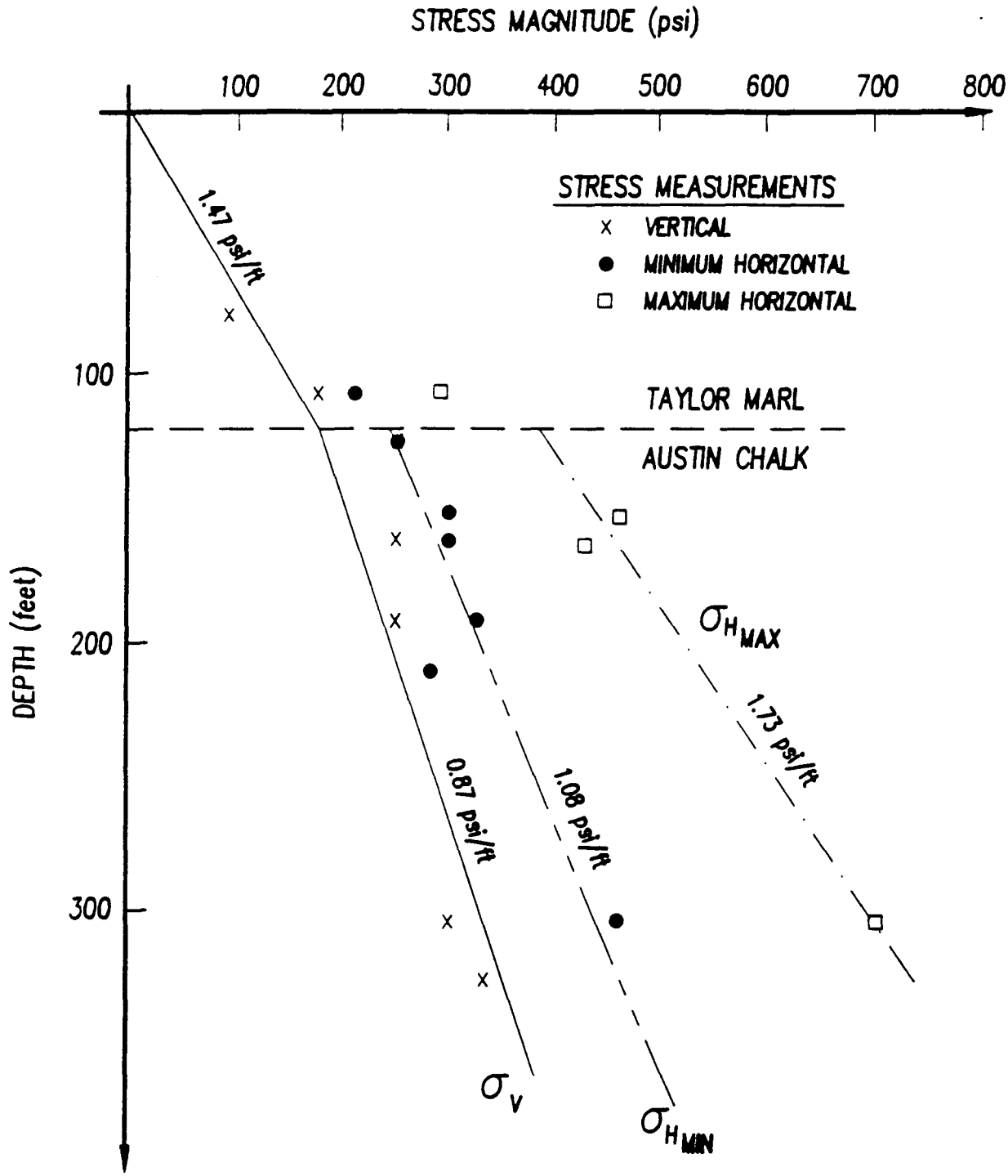

Figure 3-5. In Situ Stresses as a Function of Depth in Borehole BE5.

These relatively large and unequal horizontal stresses in the Austin Chalk are consistent with the hypotheses of Gough and Bell [1981]. These investigators evaluated borehole breakouts in the Austin Chalk in south Texas and stress measurements by others in various locations throughout south and south central Texas. The occurrence of horizontal stresses greater than the vertical stress at shallow depth is commonly accepted (e.g., Brady and Brown [1985]). Surface topography, erosion, residual and tectonic stresses, and fracture sets and discontinuities can all affect horizontal stresses.

Based on experience from the oil and gas industry, it is also common for the magnitudes and orientations of the stresses to be quite different when going from one lithology to another. Many reasons have been suggested but thus far, none has gained overwhelming acceptance.

3.3 FORMATION MICROSCANNER

3.3.1 Introduction

The Formation MicroScanner tool represents a recent advance in borehole imaging. The instrument is essentially a conventional two- or four-pad dipmeter, but the tool has the added capability of producing high resolution images of the borehole wall using a dense array of electrical sensors. The high resolution of this tool allows the identification and orientation of testing-induced fractures.

3.3.2 Principle

Basically, the Formation MicroScanner produces a continuous record of the electrical conductivity of the borehole wall. After processing, the electrical conductivity image is displayed on a variable intensity gray scale or optional color image. For our purposes, changes in the conductivity of the borehole wall, caused by the presence of a fluid filled or healed fracture, are easily identified on the displayed images. Depending on the conductivity contrasts, fractures with apertures as small as $10\mu m$ to 1 mm can be identified.

The tool used for this logging contained four sets of imaging sensors, and was run several times hoping for better coverage. The imaging sensors produce four, 7-cm-wide oriented records of the borehole wall per pass. All pads contain electrical sensors for the dipmeter measurements, and therefore, the tool can simultaneously acquire dipmeter data while imaging.

3.3.3 Field Data

The Formation MicroScanner was run after the hydraulic fracturing tests were completed. A copy of the variable intensity gray scale image, as well as enhanced color images, are provided in Appendix C.

In reviewing the color-enhanced images, two types of images are apparent:

i. *Bedding planes* Based on 75 independent measurements of the thousands available, these planes were almost horizontal, gently dipping at 3° toward the S80°*irc*E. As seen on the color-enhanced images, each of these bedding planes is fitted with an oriented sine curve in green.

ii. *Natural fractures* Two sets of steeply dipping fractures were detected via stereographic projections, the poles being respectively (Figure 3-6):

$$P_1(54/269) \text{ and } P_2(67, 100)$$

As seen on the color-enhanced images, the ten natural fractures were fitted with an oriented sine wave in yellow.

No hydraulically induced fractures from the tests were detected by the Formation MicroScanner. This is possibly explained by the fact that we were unable to rotate the pads during successive FMS loggings; hence, only 50 percent of the borehole circumference was covered. Apparently, the FMS followed a drill-bit groove in the borehole despite repeated efforts to reorient the tool.

3.3.4 Discussion

No induced fractures were detected by the Formation MicroScanner. It is possible that the device simply missed the vertical fractures, because only one half of the borehole wall was actually logged. Any induced horizontal fractures would have been obscured by the bedding planes. Since the fractures were not detected, stress orientation could not be determined. The Formation MicroScanner did detect fractures revealed in the core (including a fault not specifically identified) and provided information on their apparent strike and dip.

3.4 BOREHOLE BREAKOUTS

3.4.1 Introduction

Borehole ellipticity sometimes allows the determination of the orientation of the stresses acting in a plane perpendicular to the borehole axis. Numerous papers describing borehole breakouts are available in the literature [e.g., Gough and Bell, 1981].

3.4.2 Principle

The existence of differential stresses will deform a circular borehole. Whenever the resultant stress concentrations overcome the strength of the rock, typical *dog-ear*

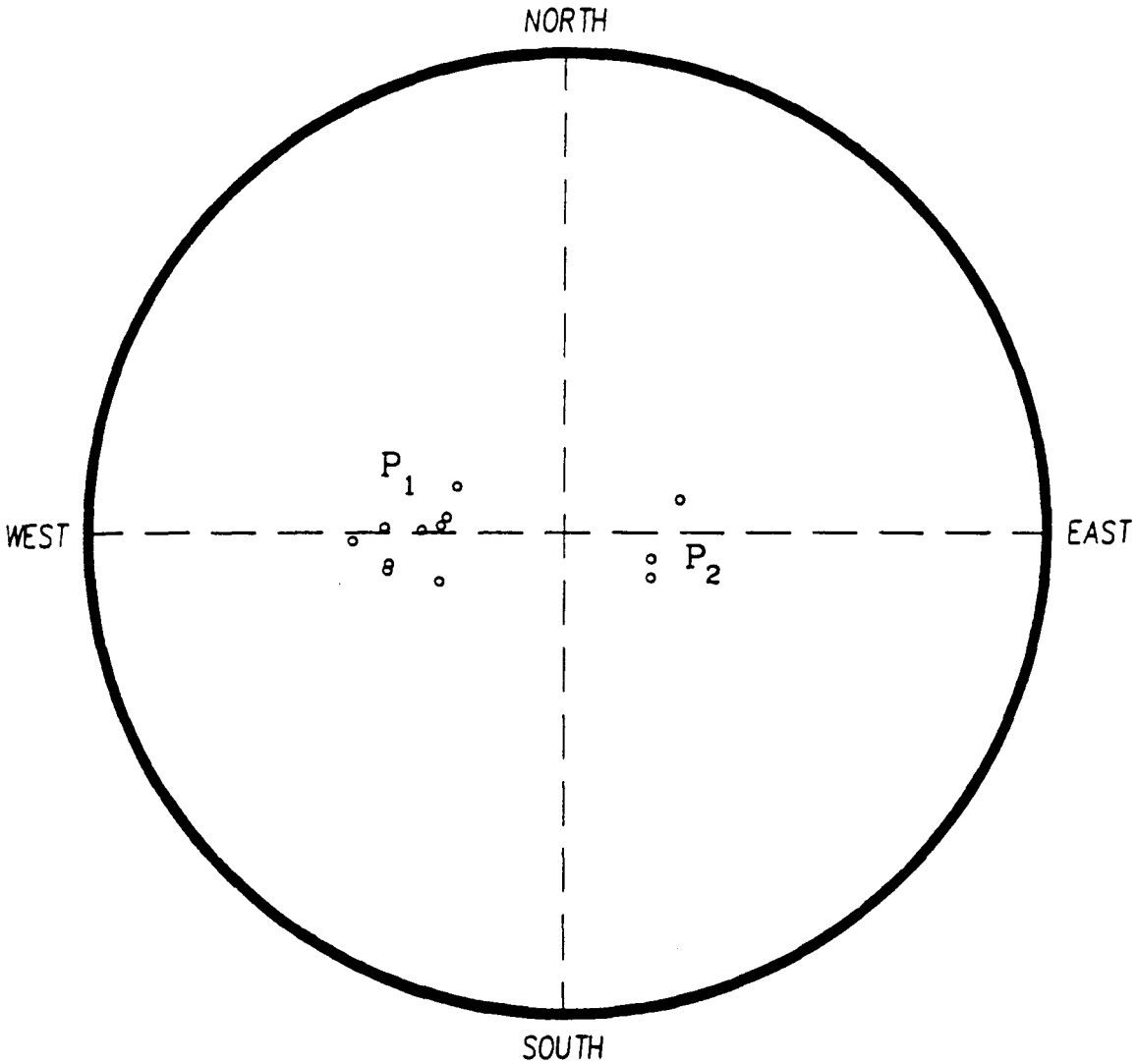

Figure 3-6. Stereographic Projection of Natural Fracture Poles.

breakouts will appear. These breakouts have, therefore, the tendency to align with the direction of the maximum in situ component acting in a plane perpendicular to the borehole. Consequently, an accurate caliper survey may reveal the in situ stress orientation.

One should note that breakouts will only occur if the strength has been exceeded. Hence, only in weak formations, or at great depths, or in locations where large differential stress conditions prevail will this technique work. Any attempts to correlate the geometry of such breakouts with the magnitude of the stresses, or stress differential, is futile unless the failure mechanisms are fully understood, especially the influence of the stress redistributions upon fracture propagation.

3.4.3 Field Data

Appendix C contains the traces of the FMS borehole caliper. Three regions of the borehole exhibit ellipticity: between 40 and 95 feet; between 120 and 166 feet; and between 280 and 340 feet.

The magnitude of the ellipticity reached 0.50 inches in the nominally 6.75-inch-diameter borehole at 314 feet. However, it should be recognized that a single logging run with a four-arm caliper may not result in the sampling of the maximum ellipticity amount and orientation.

3.4.4 Discussion

Three regions of small magnitude ellipticity developed in borehole BE5 in the Austin Chalk. However, because of the potential that the maximum ellipticity location was not sampled, ellipticity (and therefore, stress) orientation is difficult to establish from these measurements.

4.0 CONCLUSIONS AND RECOMMENDATIONS

- In situ stress determinations both in the Austin Chalk and in the Taylor Marl were quite successful and indicated minimum and maximum horizontal stress magnitudes 30 percent and 100 percent greater (more compressive) than the vertical stress.

- The magnitudes of the horizontal stresses and the resulting stress differential seem to be quite high. This finding will need to be taken into consideration when designing both tunnels and shafts.

- Based on the experience gained in this first exploratory hole, microhydraulic fracturing tests should definitely be considered as a technique to determine the in situ stress tensor in future boreholes associated with the Superconducting Super Collider site. Indeed, by judiciously selecting the straddle packer configuration it has been possible — in at least 50 percent of the cases — to induce vertical and horizontal fractures.

- Although inflatable packers might speed up the stress profiling, one needs to determine the induced secondary stress field by inflating them in an instrumented steel cylinder and compare the induced stress field to the mechanically activated system used in BE5.

- MicroScanner imaging is not recommended in the future as the direction of those exploratory holes coincide exactly with the vertical fracture traces; hence, unless 100 percent coverage is guaranteed (for example by 8 pads), the chances to detect the orientation of the induced fractures is only as good as the percentage of coverage. Consequently, the orientation of the stress field ought to be determined by other independent techniques such as Differential Strain Curve Analysis (DSCA) and/or Anelastic Strain Recovery (ASR) which are conducted on oriented core.

- Based on the assumption that both the Austin Chalk and the Taylor Marl are believed to be massive homogeneous formations, similar in situ stress determination campaigns should be carried out at the boundaries of the property (i.e., most northern, southern, and eastern exploratory boreholes).

5.0 REFERENCES

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APPENDIX A

FIELD CORE LOG

FIELD CORE LOG

FURNISHED IN APPENDIX A OF

"DATA REPORT FOR COREHOLE BE 5"

APPENDIX B

RAW DATA FROM MICROHYDRAULIC FRACTURING TESTS

Test BE5-A

Test BE5-B

Test BE5-C

Test BE5-D

Test BE5-E

Test BE5-F

Test BE5-G

Test BE5-H

Test BE5-I

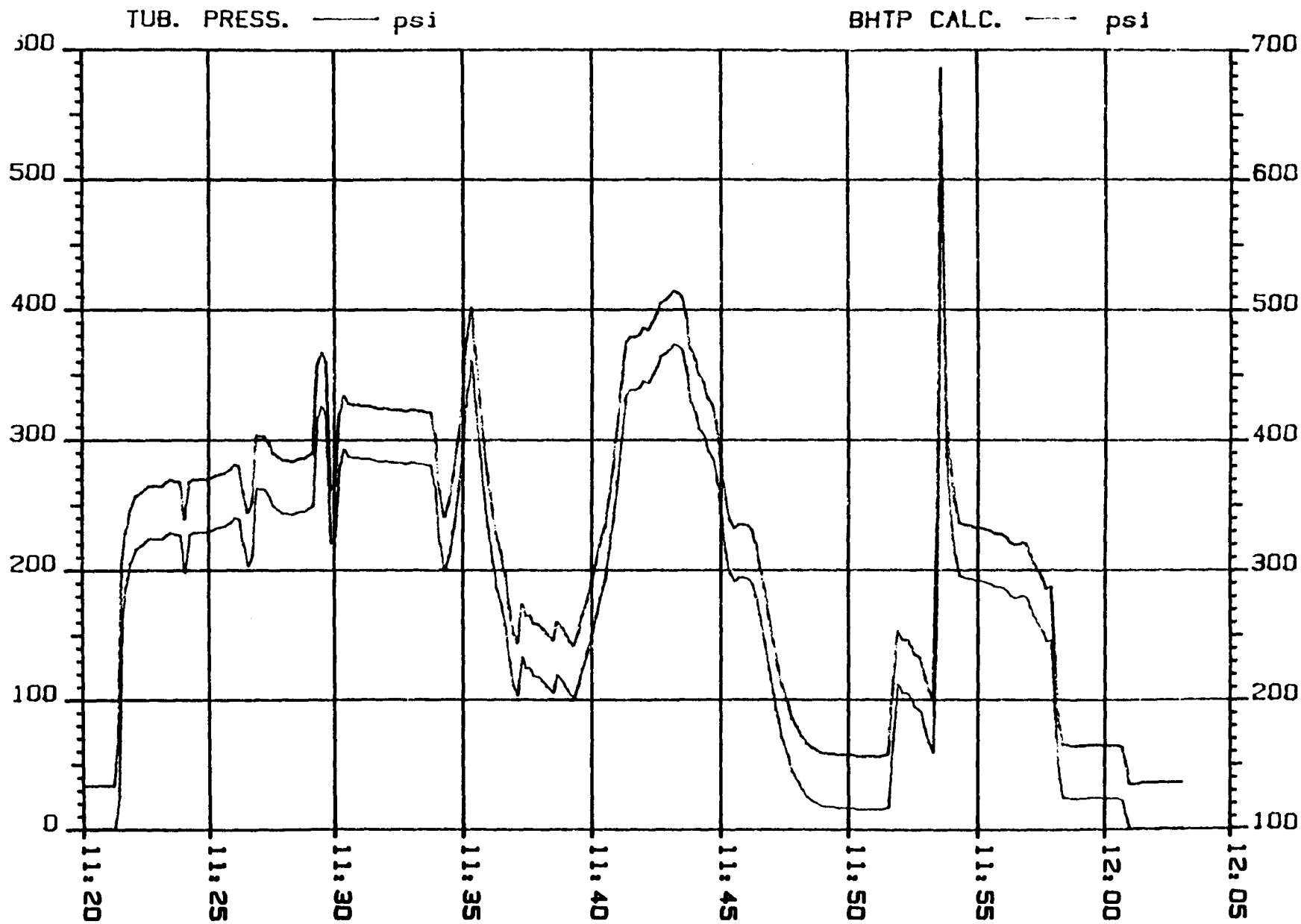
Test BE5-J

TEST: BE5-A

FORMATION: Austin Chalk

DEPTH: 326 feet

DATE OF FIELD TEST: January 27, 1990



CUSTOMER: RE/SPEC
DATE: 01/27/90
JOB TYPE: STRESS TEST
WELL ID: SCC #1 TEST 1

FORMATION:
TICKET #:

(PG. 12)

TEST: BE5-B

FORMATION: Austin Chalk

DEPTH: 292 feet

DATE OF FIELD TEST: January 29, 1990

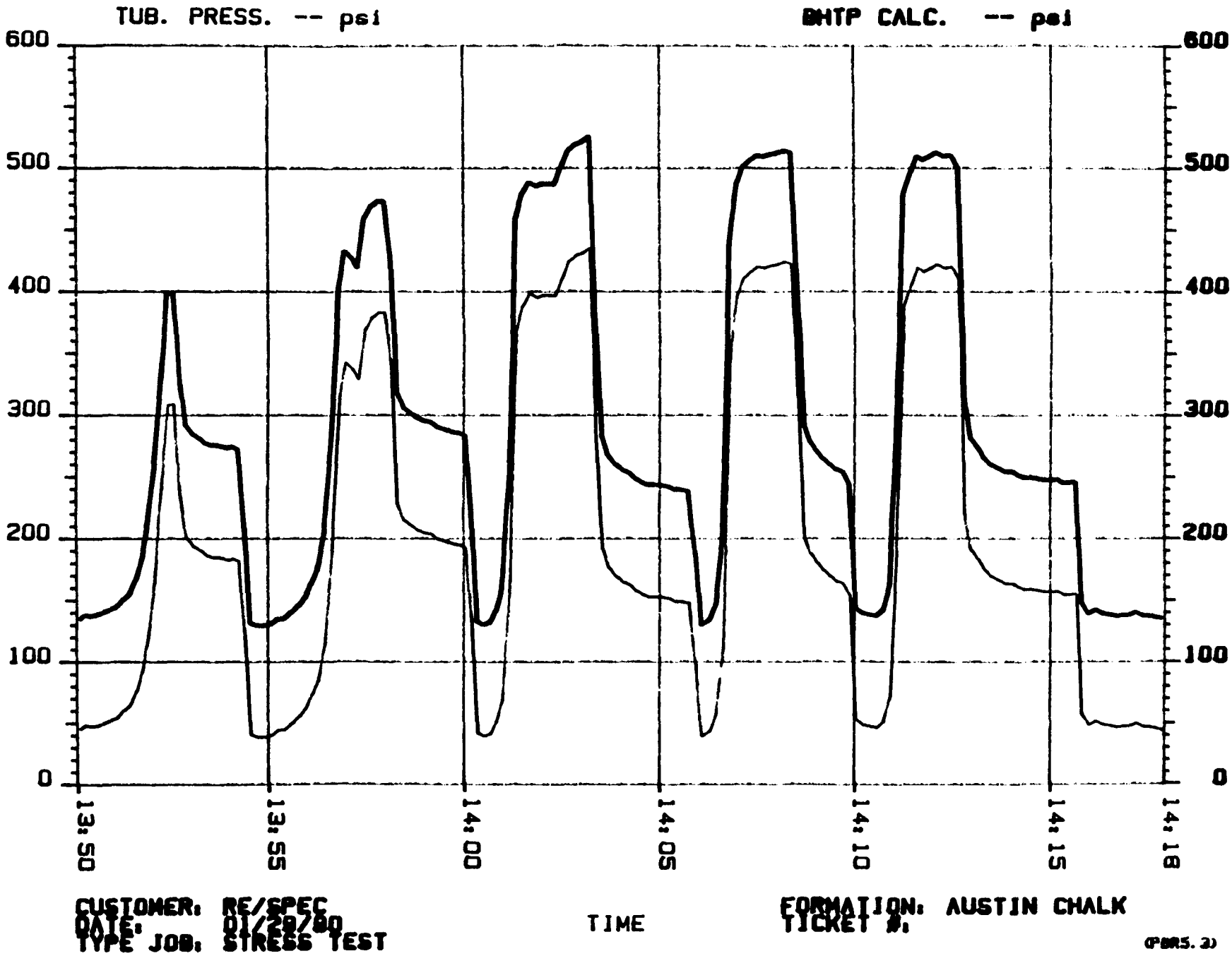
This test was unsuccessful because of pressure transducer problems.

TEST: BE5-C

FORMATION: Austin Chalk

DEPTH: 210 feet

DATE OF FIELD TEST: January 29, 1990

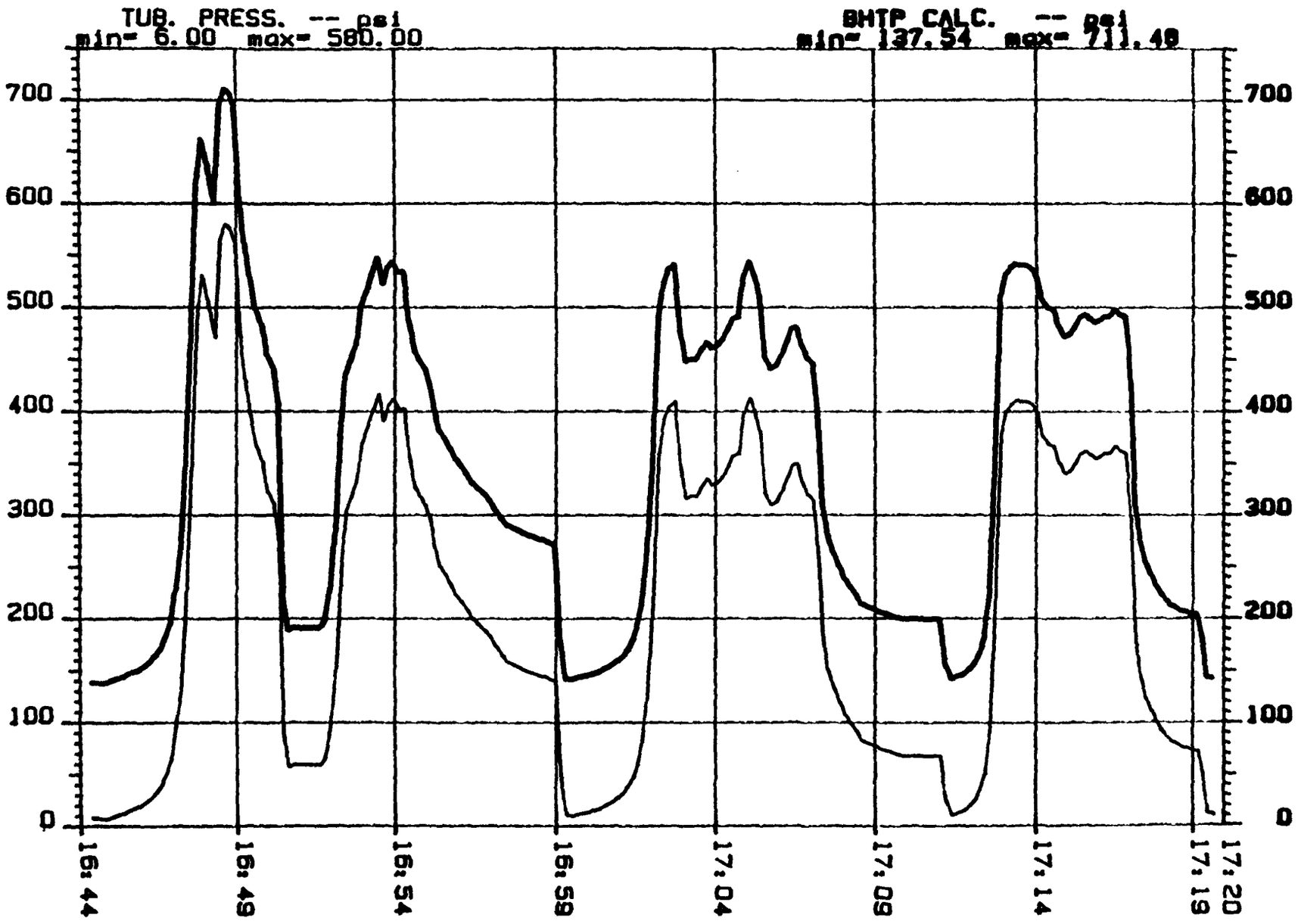

TUB. PRESS. -- psi
BHTP CALC. -- psi
600
500
400
300
200
100
0
13:50
13:55
14:00
14:05
14:10
14:15
14:18
TIME
CUSTOMER: RE/SPEC
DATE: 01/20/90
TYPE JOB: STRESS TEST
FORMATION: AUSTIN CHALK
TICKET #:
(PGM5.2)

TEST: BE5-D

FORMATION: Austin Chalk

DEPTH: 303 feet

DATE OF FIELD TEST: January 29, 1990



CUSTOMER: RE/SPEC
DATE: 01/29/90
TYPE JOB: STRESS TEST

FORMATION: AUSTIN CHALK
TICKET #:

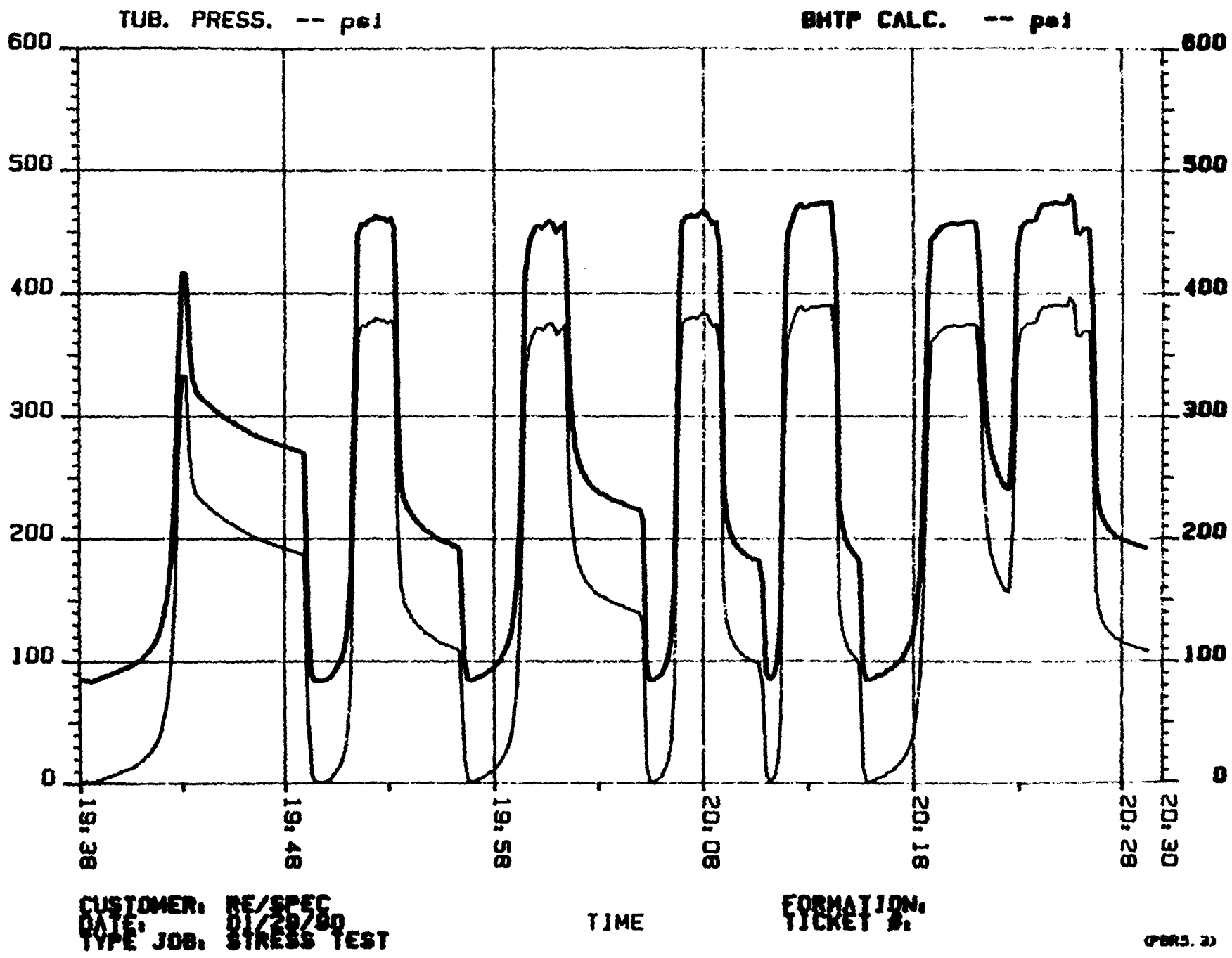
(PGRS. 2)

TEST: BE5-E

FORMATION: Austin Chalk

DEPTH: 192 feet

DATE OF FIELD TEST: January 29, 1990

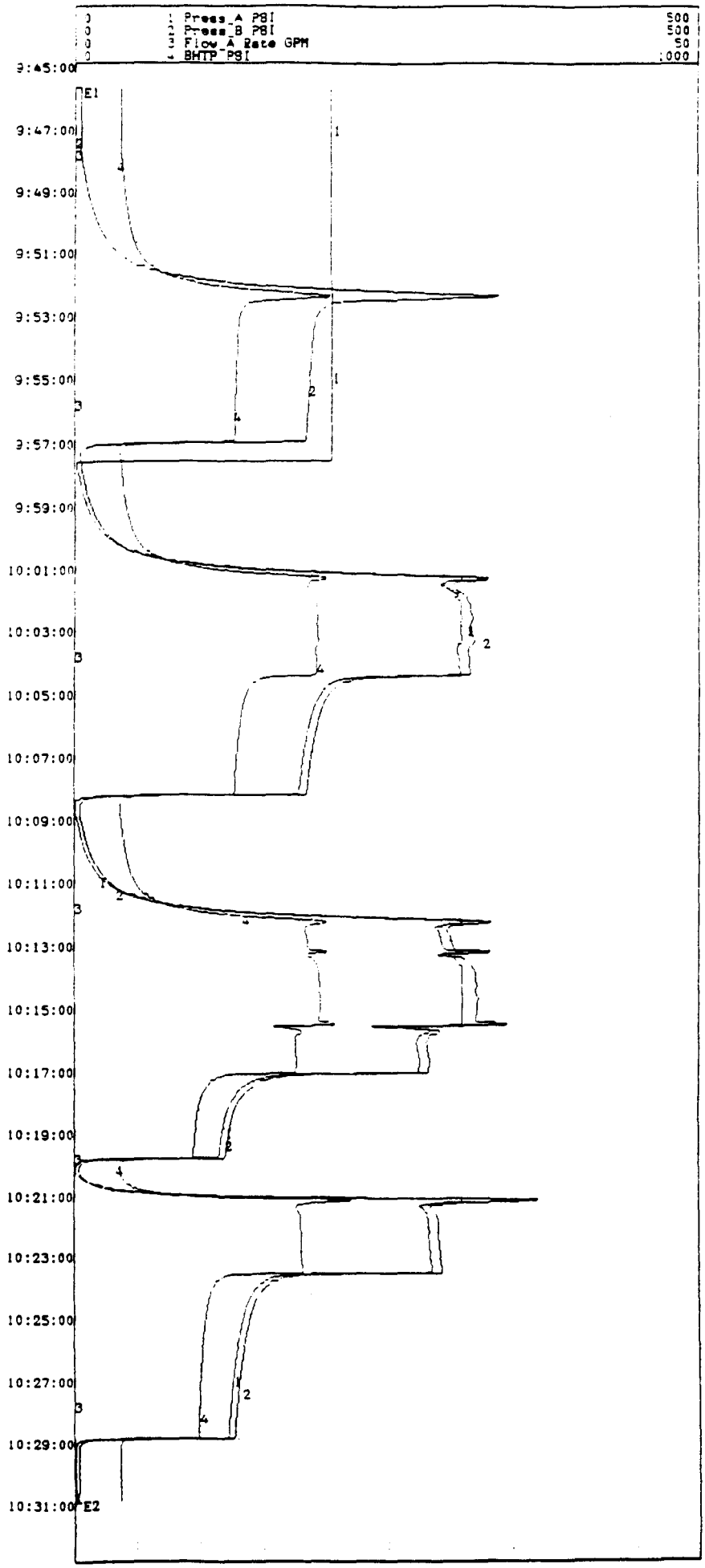

TUB. PRESS. -- psi
BHTP CALC. -- psi
600
500
400
300
200
100
0
19:38
19:48
19:58
20:08
20:18
20:28
20:30
TIME
CUSTOMER: RE/SPEC
DATE: 01/29/80
TYPE JOB: STRESS TEST
FORMATION:
TICKET #:
(PBR5. 2)

TEST: BE5-F

FORMATION: Austin Chalk

DEPTH: 162 feet

DATE OF FIELD TEST: January 30, 1990

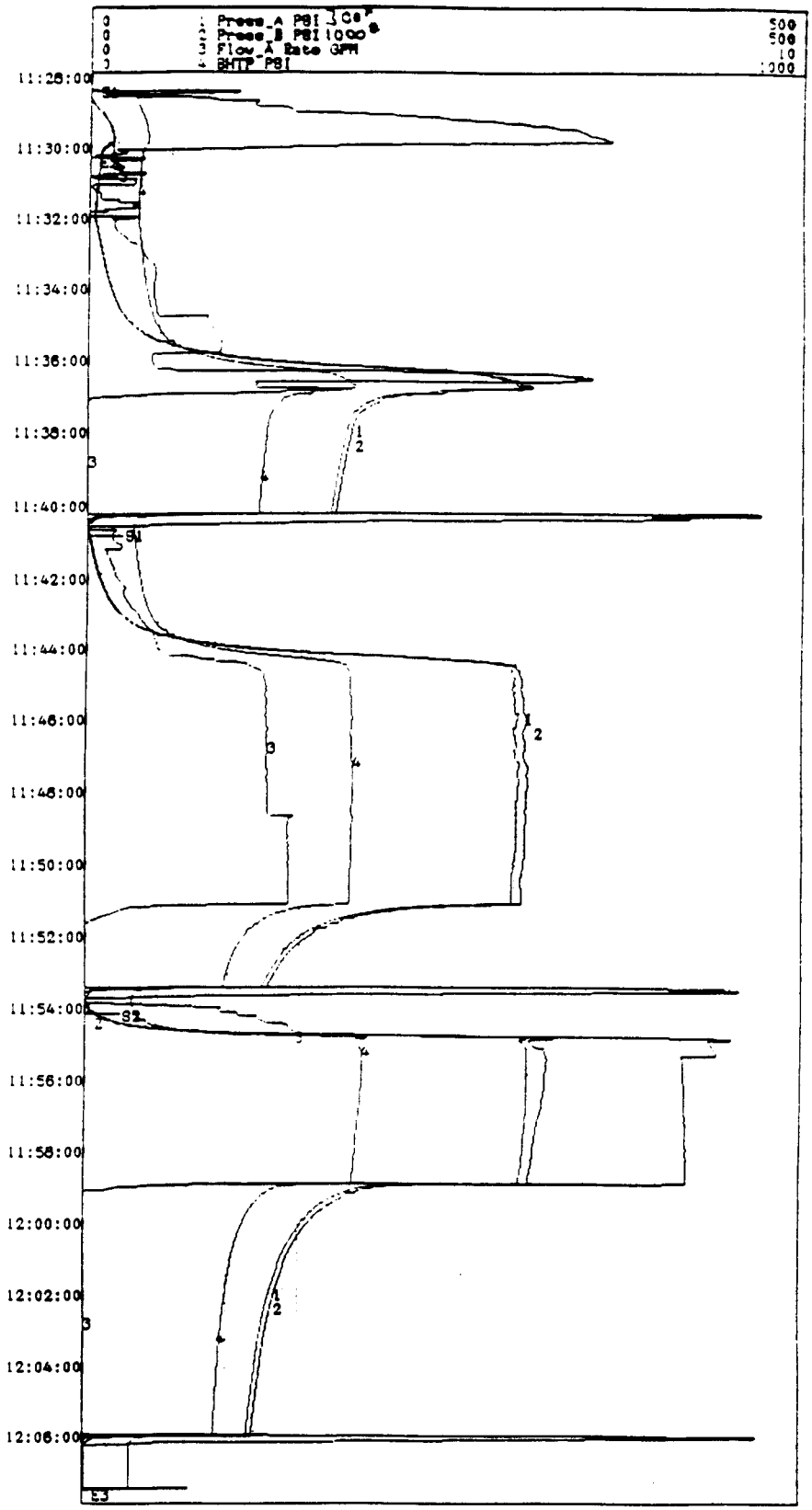

1 Press_A PSI
2 Press_B PSI
3 Flow_A Rate GPM
4 BHTP PSI
500
500
50
1000
9:45:00
9:47:00
9:49:00
9:51:00
9:53:00
9:55:00
9:57:00
9:59:00
10:01:00
10:03:00
10:05:00
10:07:00
10:09:00
10:11:00
10:13:00
10:15:00
10:17:00
10:19:00
10:21:00
10:23:00
10:25:00
10:27:00
10:29:00
10:31:00
E1
E2

TEST: BE5-G

FORMATION: Austin Chalk

DEPTH: 152 feet

DATE OF FIELD TEST: January 30, 1990

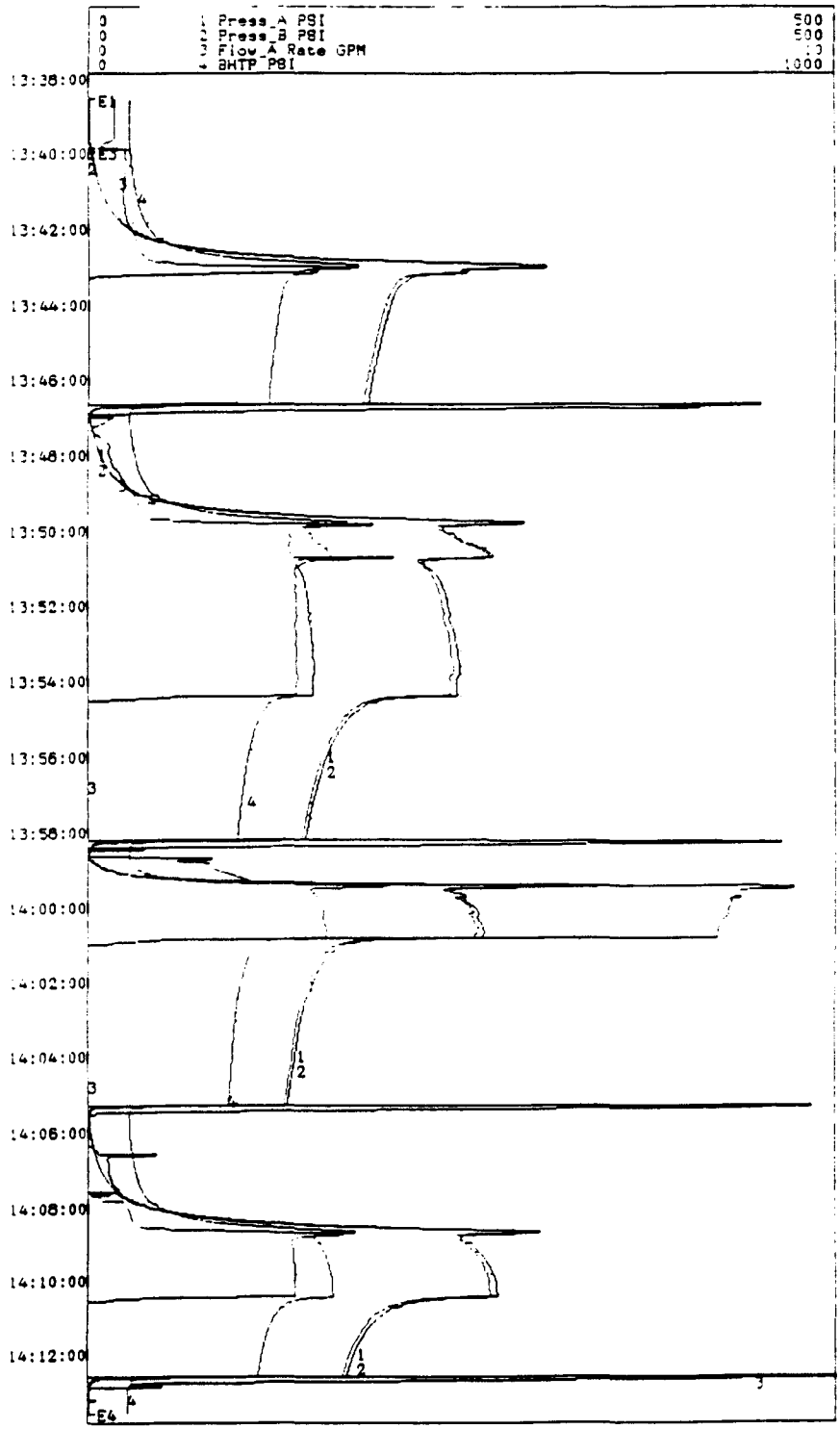

0 1 Press_A PSI 100
0 2 Press_B PSI 1000
0 3 Flow_A Rate GPM
0 4 BHTP PSI
500
500
10
1000
11:28:00
11:30:00
11:32:00
11:34:00
11:36:00
11:38:00
11:40:00
11:42:00
11:44:00
11:46:00
11:48:00
11:50:00
11:52:00
11:54:00
11:56:00
11:58:00
12:00:00
12:02:00
12:04:00
12:06:00

TEST: BE5-H

FORMATION: Austin Chalk

DEPTH: 127 feet

DATE OF FIELD TEST: January 30, 1990

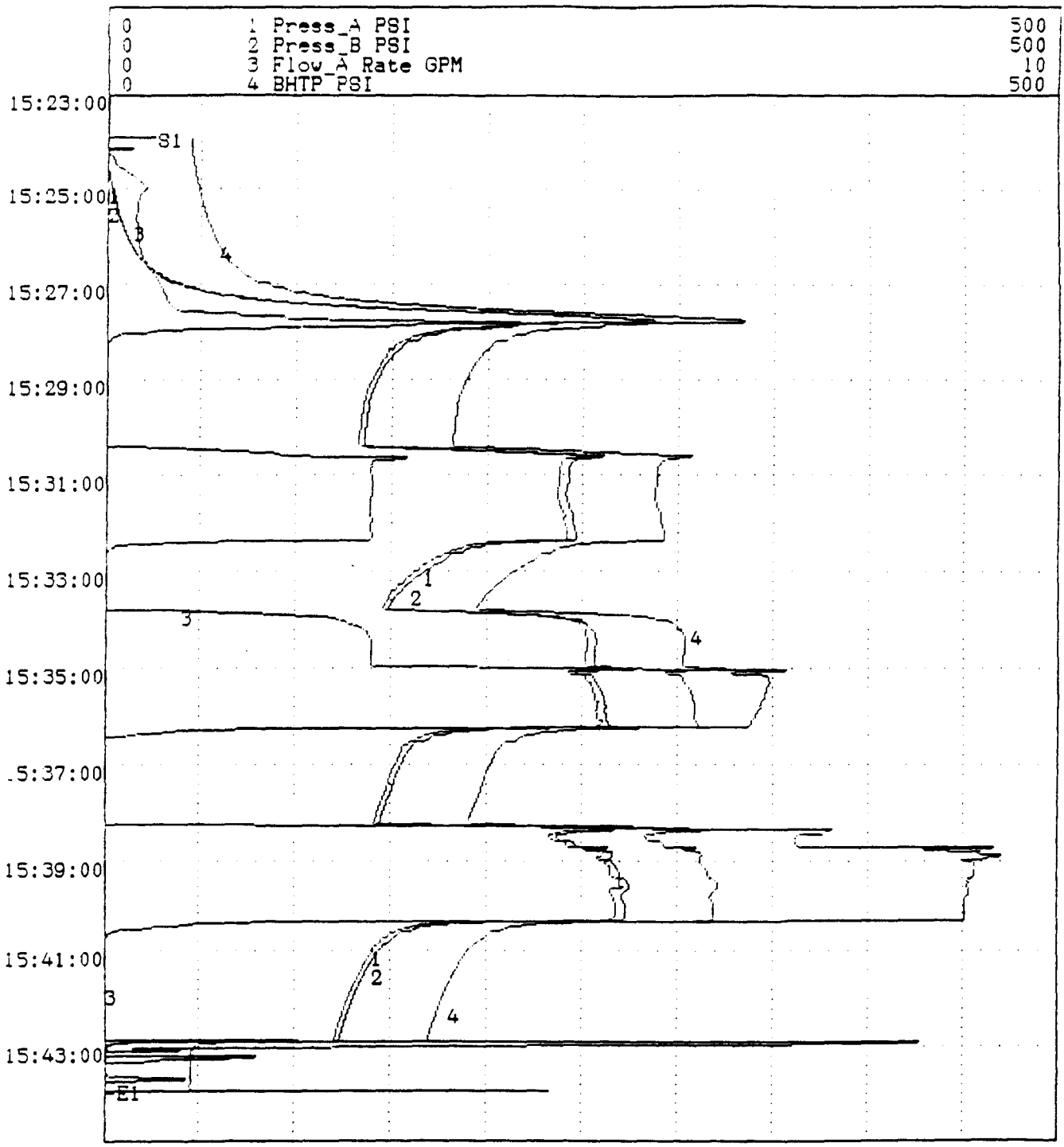

0 1 Press_A PSI 500
0 2 Press_B PSI 500
0 3 Flow_A Rate GPM 10
0 4 BHTP PSI 1000
13:38:00
13:40:00
13:42:00
13:44:00
13:46:00
13:48:00
13:50:00
13:52:00
13:54:00
13:56:00
13:58:00
14:00:00
14:02:00
14:04:00
14:06:00
14:08:00
14:10:00
14:12:00
E1
E3
E4

TEST: BE5-I

FORMATION: Taylor Marl

DEPTH: 107 feet

DATE OF FIELD TEST: January 30, 1990

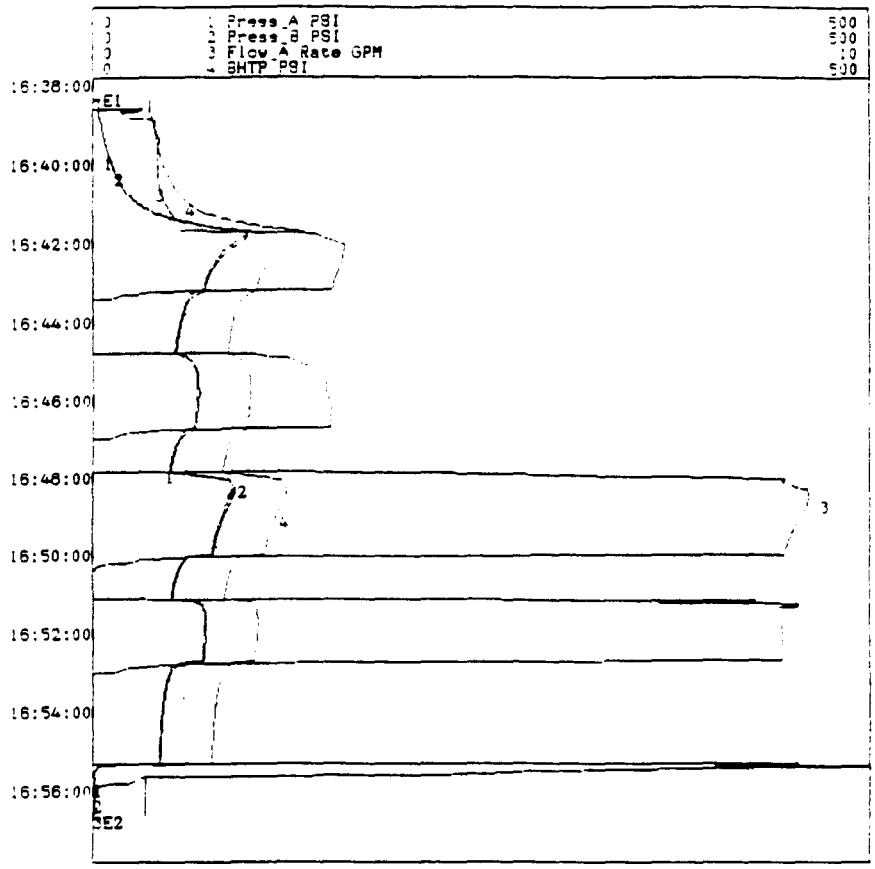

0 1 Press_A PSI 500
0 2 Press_B PSI 500
0 3 Flow_A Rate GPM 10
0 4 BHTP PSI 500
15:23:00
15:25:00
15:27:00
15:29:00
15:31:00
15:33:00
15:35:00
15:37:00
15:39:00
15:41:00
15:43:00
S1
E1

TEST: BE5-J

FORMATION: Taylor Marl

DEPTH: 77 feet

DATE OF FIELD TEST: January 30, 1990



16:38:32 Event # 1 Start Job
16:56:51 Event # 2 End Job

APPENDIX C

FORMATION MICROSCANNER DATA

VARIABLE INTENSITY GRAY SCALE FMS, INTERPRETED VIA FLIP

Note: The depths mentioned on the enclosed FMS logs are 5.3 feet deeper than the depths recorded by the driller.

RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5

ORIENTATION: NORTH

0 45 90 135 180 225 270 315 360

ORIENTATION: NORTH

0 45 90 135 180 225 270 315 36

60.0
80.0
100.0
120.0
140.0
160.0
180.0
200.0
220.0
240.0
260.0
280.0
300.0
320.0

105.0

106.0

TD:4/284

define depth zone

reset depth zone

stop zone depth :41.53 F

start zone depth :337.49 F

plot mode : Azimuth directions

75 dips processed for this plot

N

E

W

Dip types

- ☐ No type
- ☐ Cross bed
- ☐ Fracture
- ☐ Fault
- ☑ Bed boundary
- ☐ Unconformity
- ☐ Others

Plot

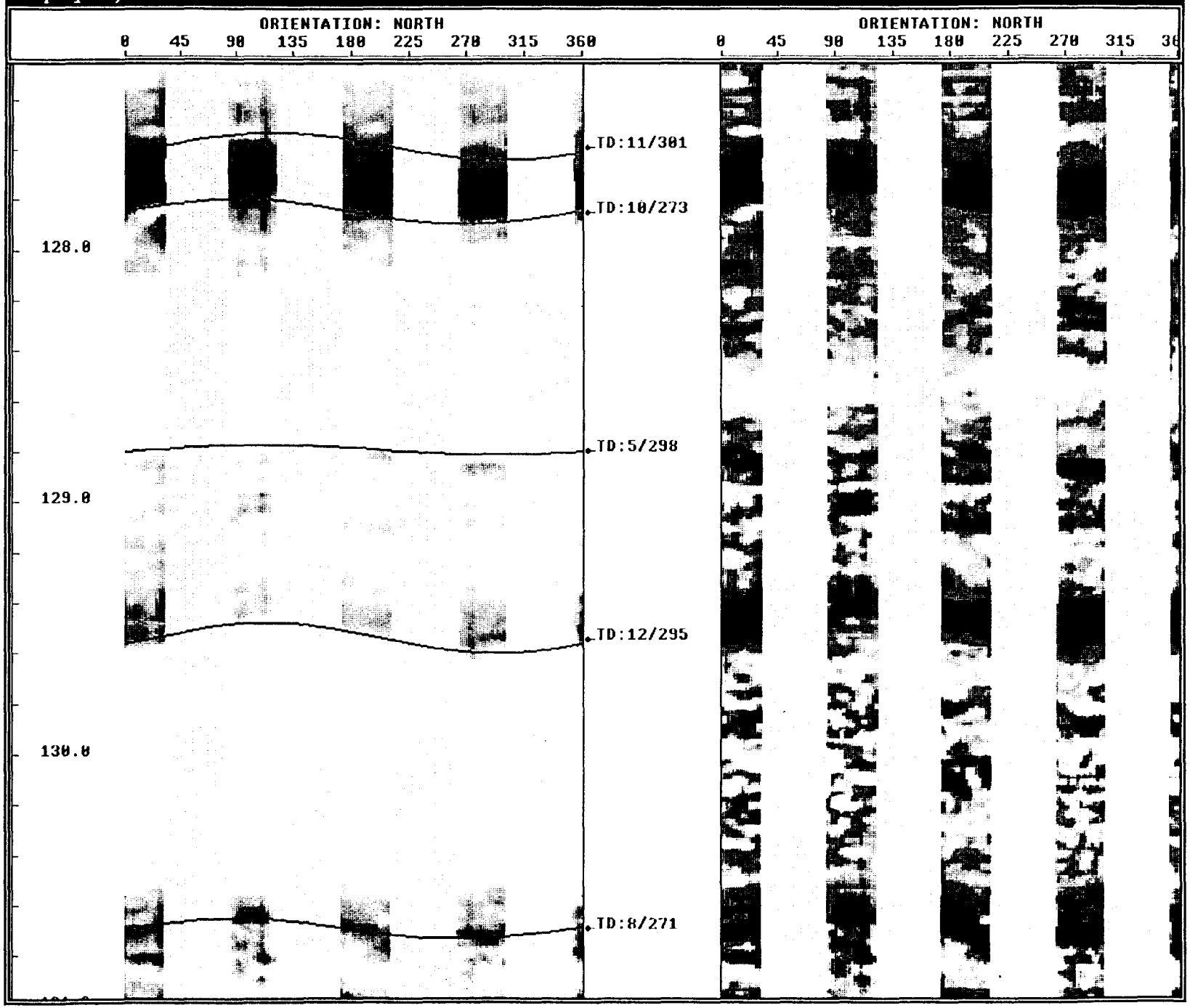
Quit

RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5

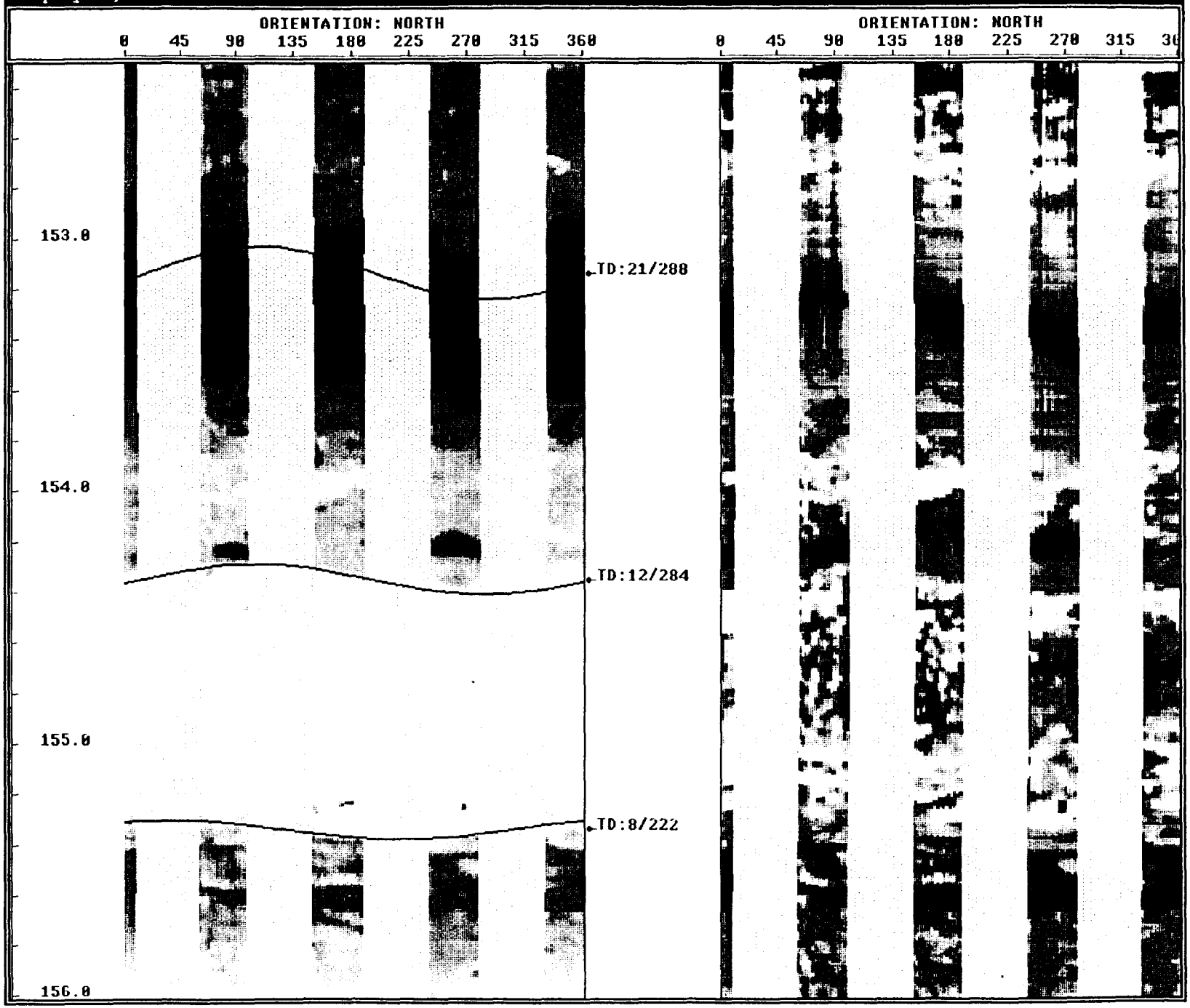


RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5

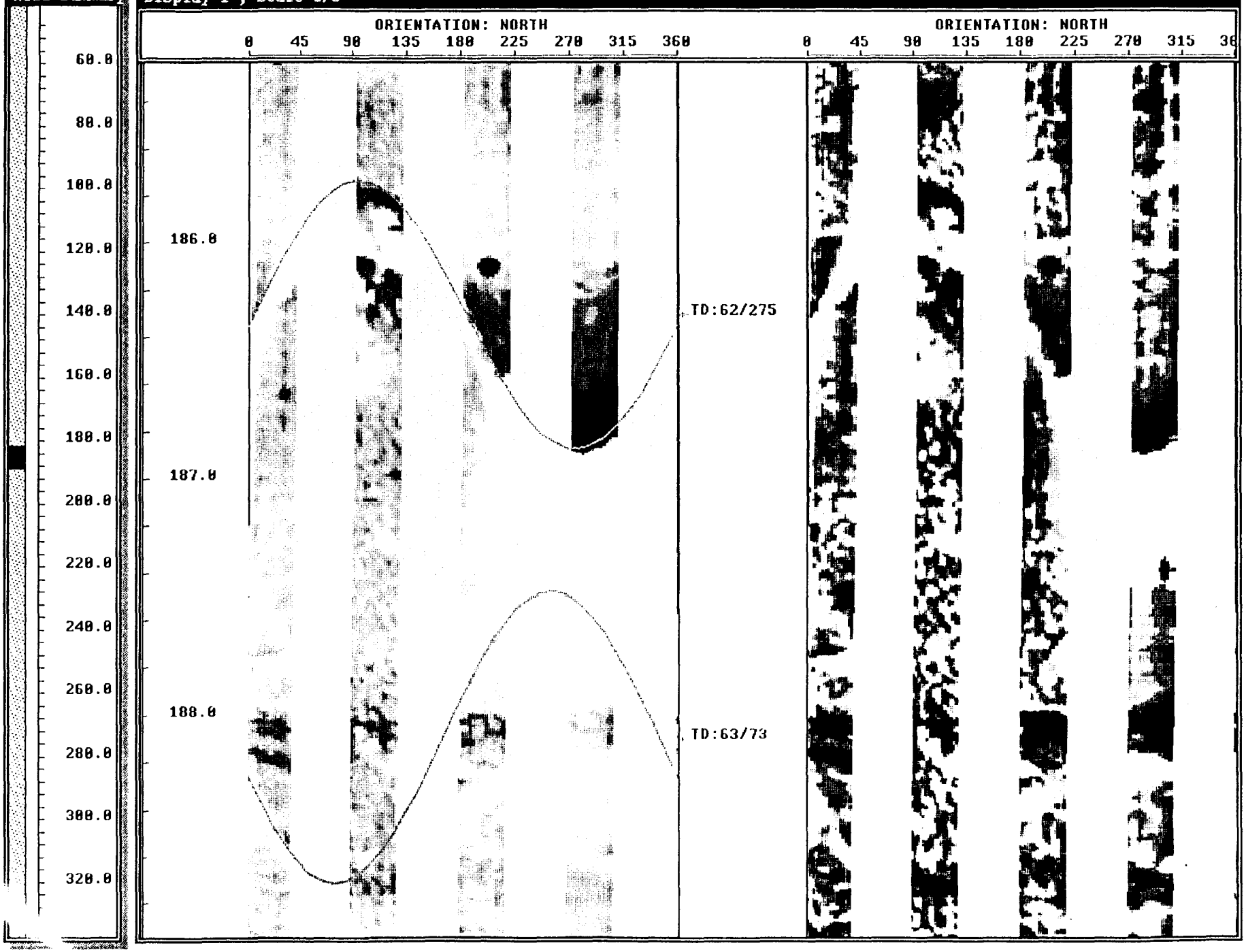


RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5

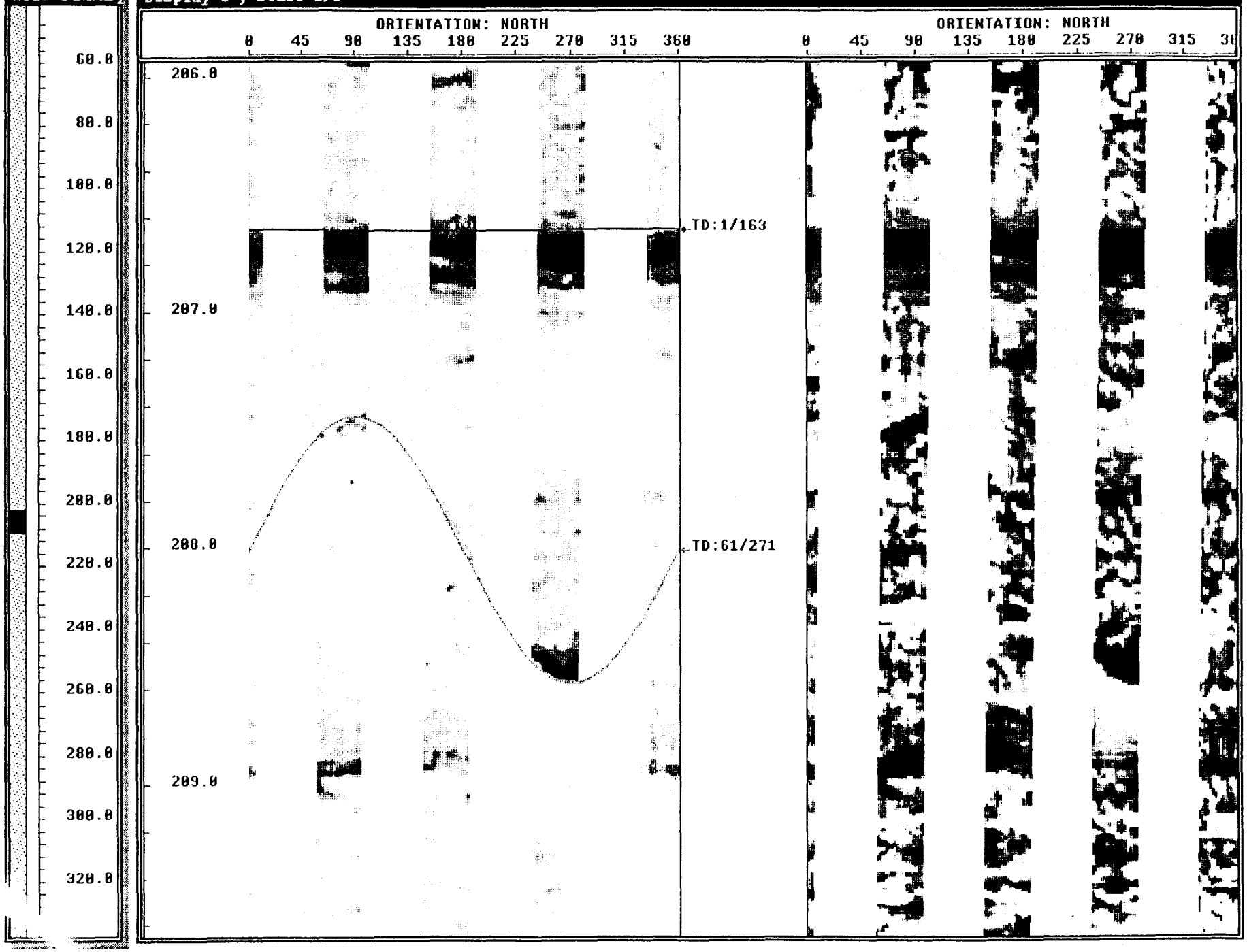


RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5



RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5

ORIENTATION: NORTH

0 45 90 135 180 225 270 315 360

60.0 80.0 100.0 120.0 140.0 160.0 180.0 200.0 220.0 240.0 260.0 280.0 300.0 320.0

207.0 208.0 209.0 210.0

TD:1/163

TD:61/271

ORIENTATION: NORTH

0 45 90 135 180 225 270 315 360

define depth zone

reset depth zone

stop zone depth :41.53 F

start zone depth :337.49 F

plot mode : Azimuth directions

10 dips processed for this plot

N E S W

Dip types

- No type
- Cross bed
- Fracture
- Fault
- Bed boundary
- Unconformity
- Others

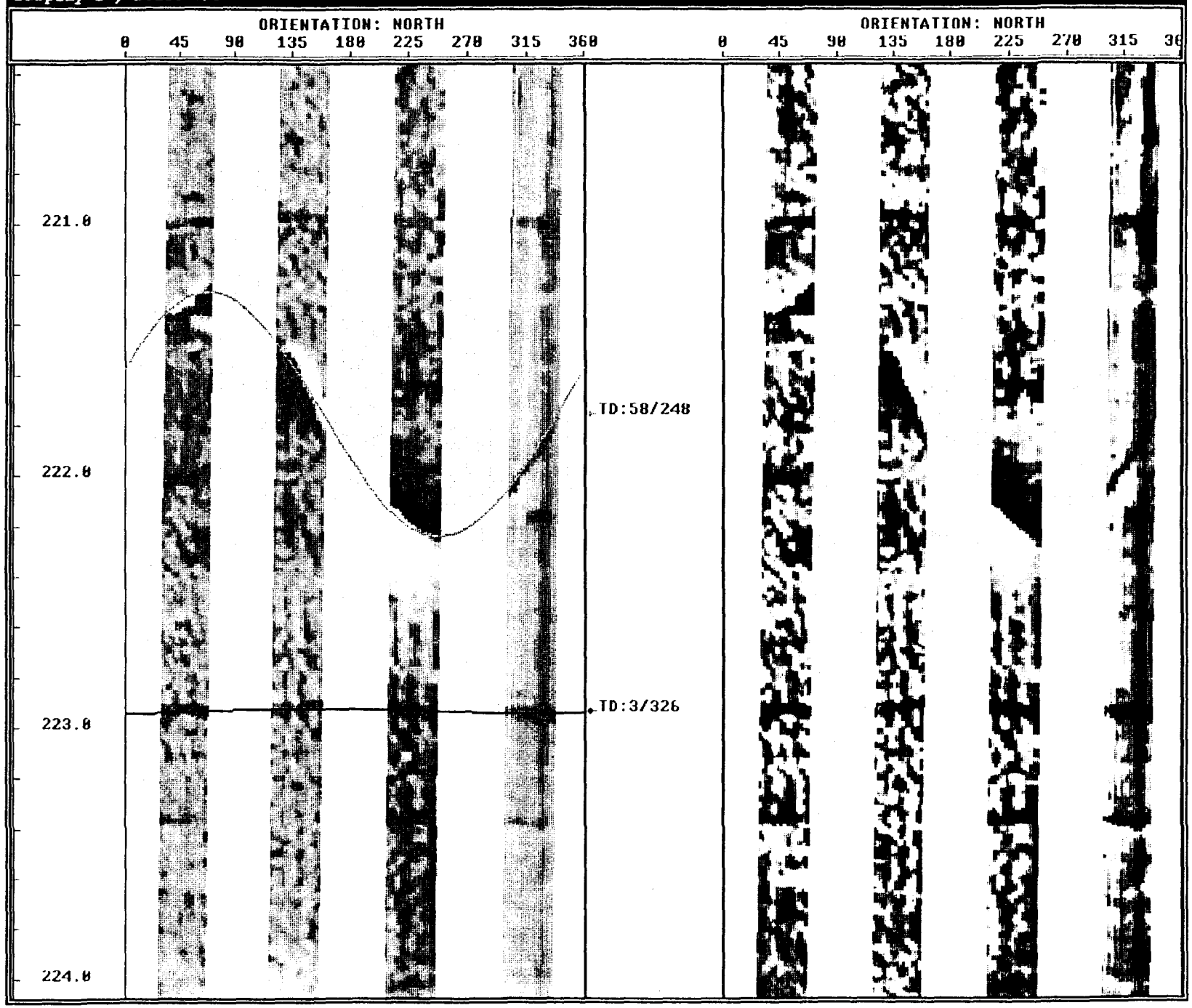
Plot Quit

RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5

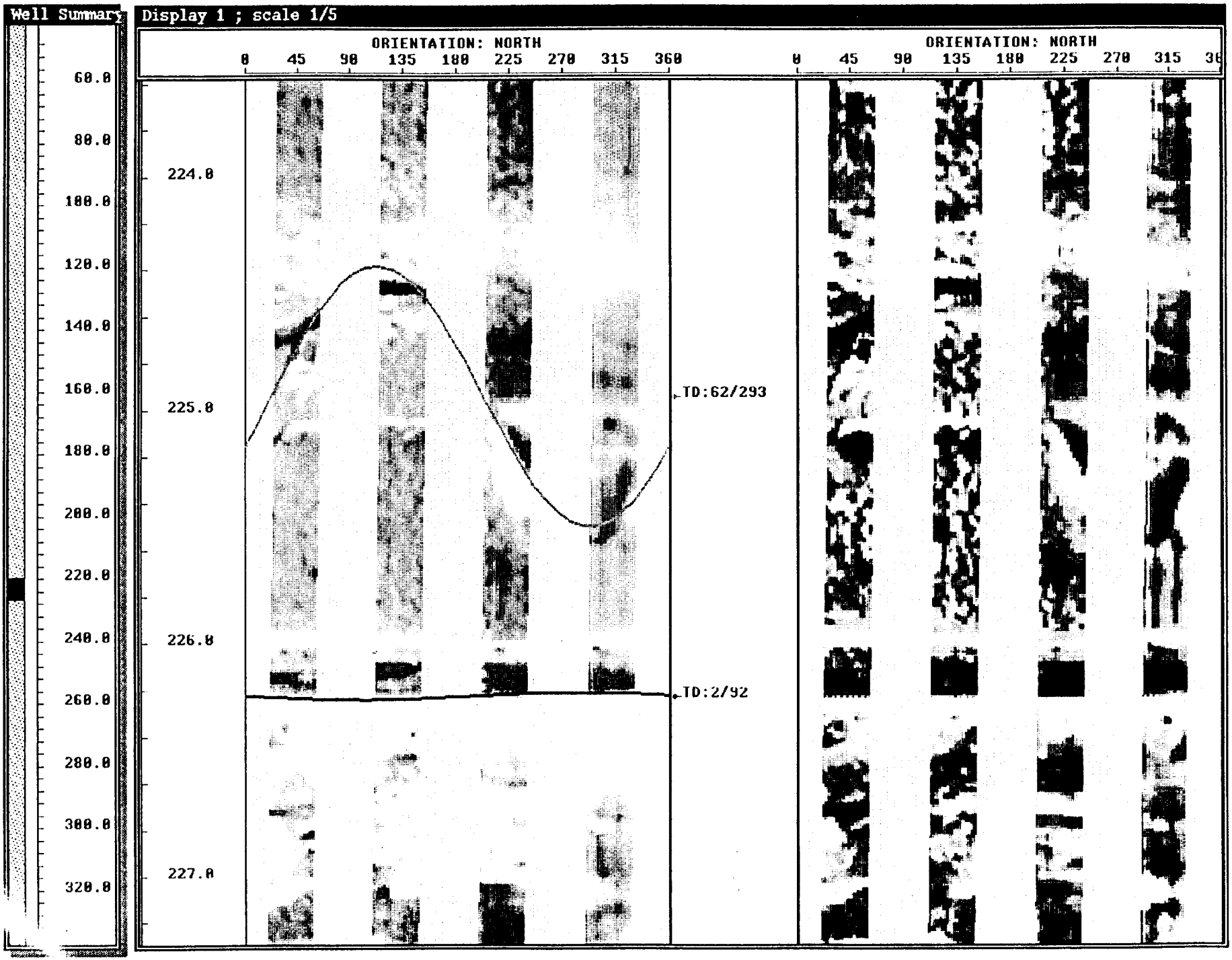


RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5

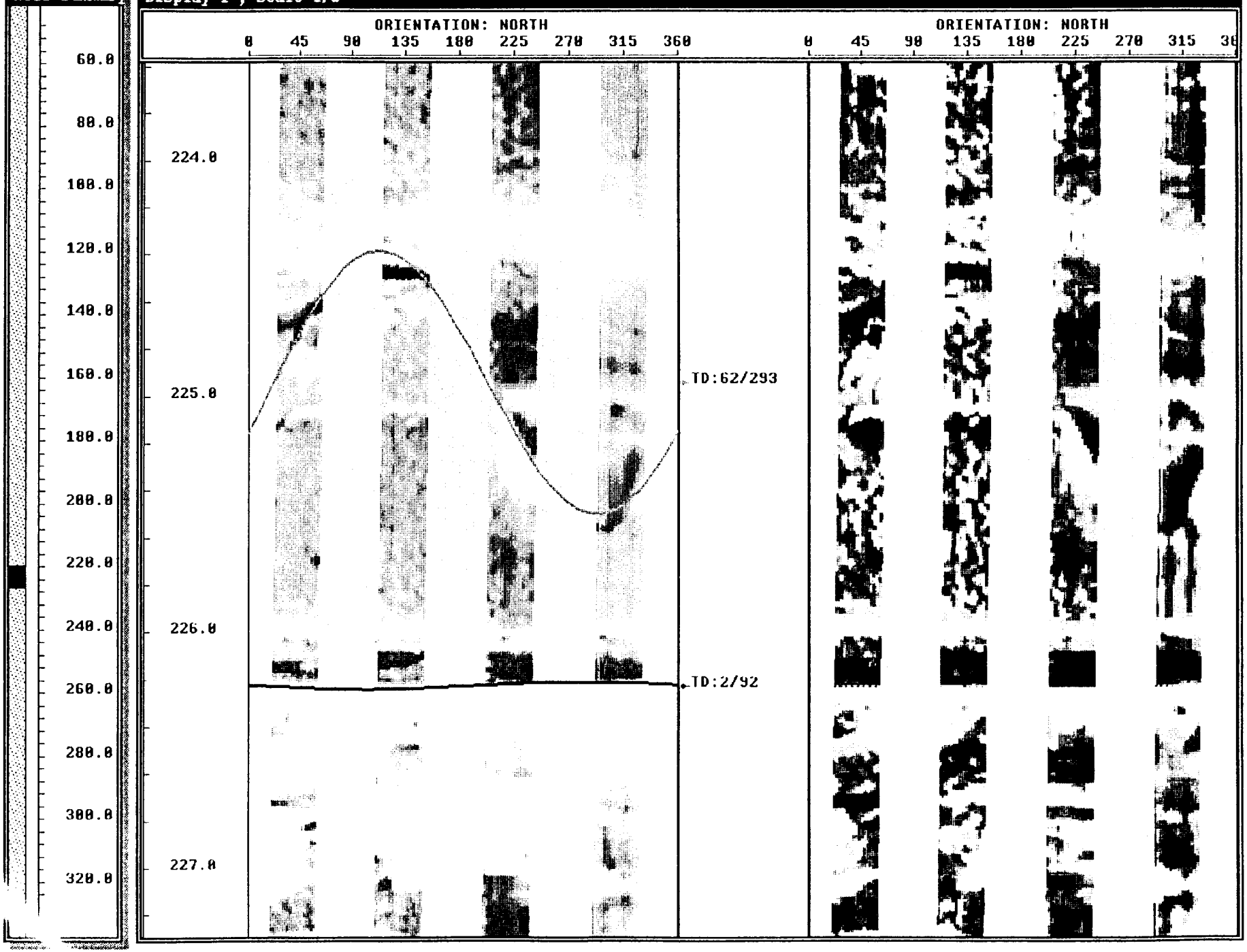


RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5

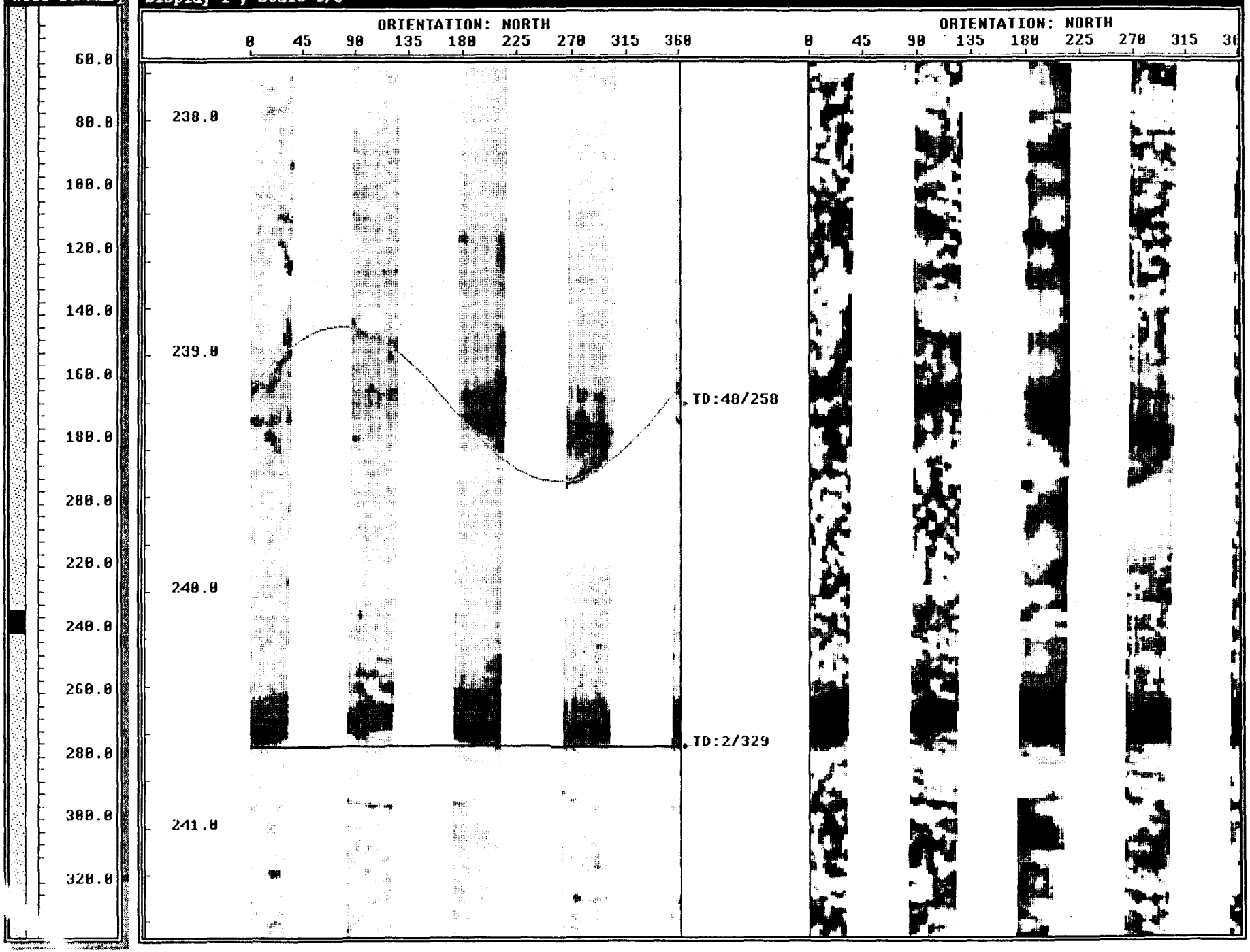


RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5

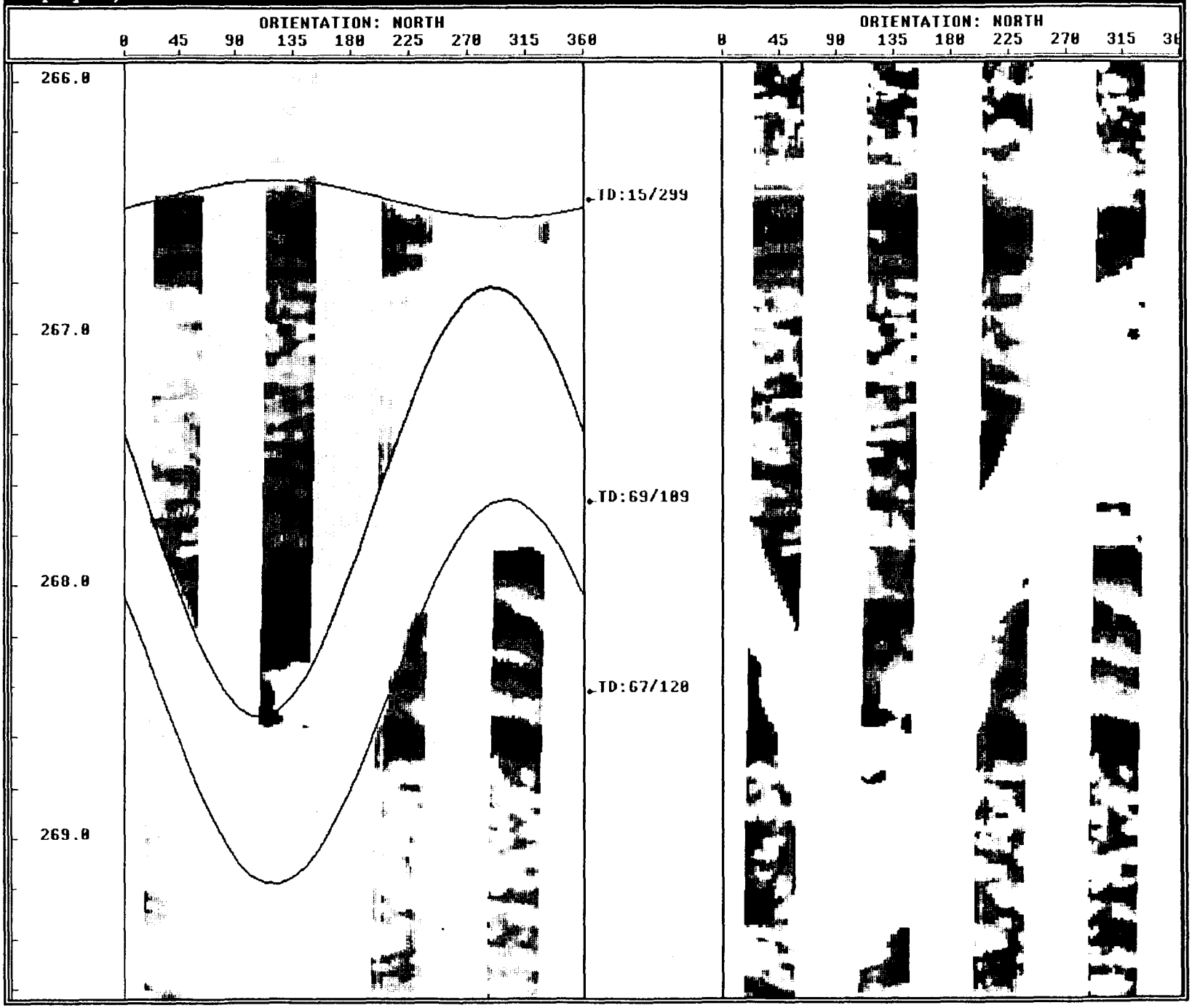


RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5

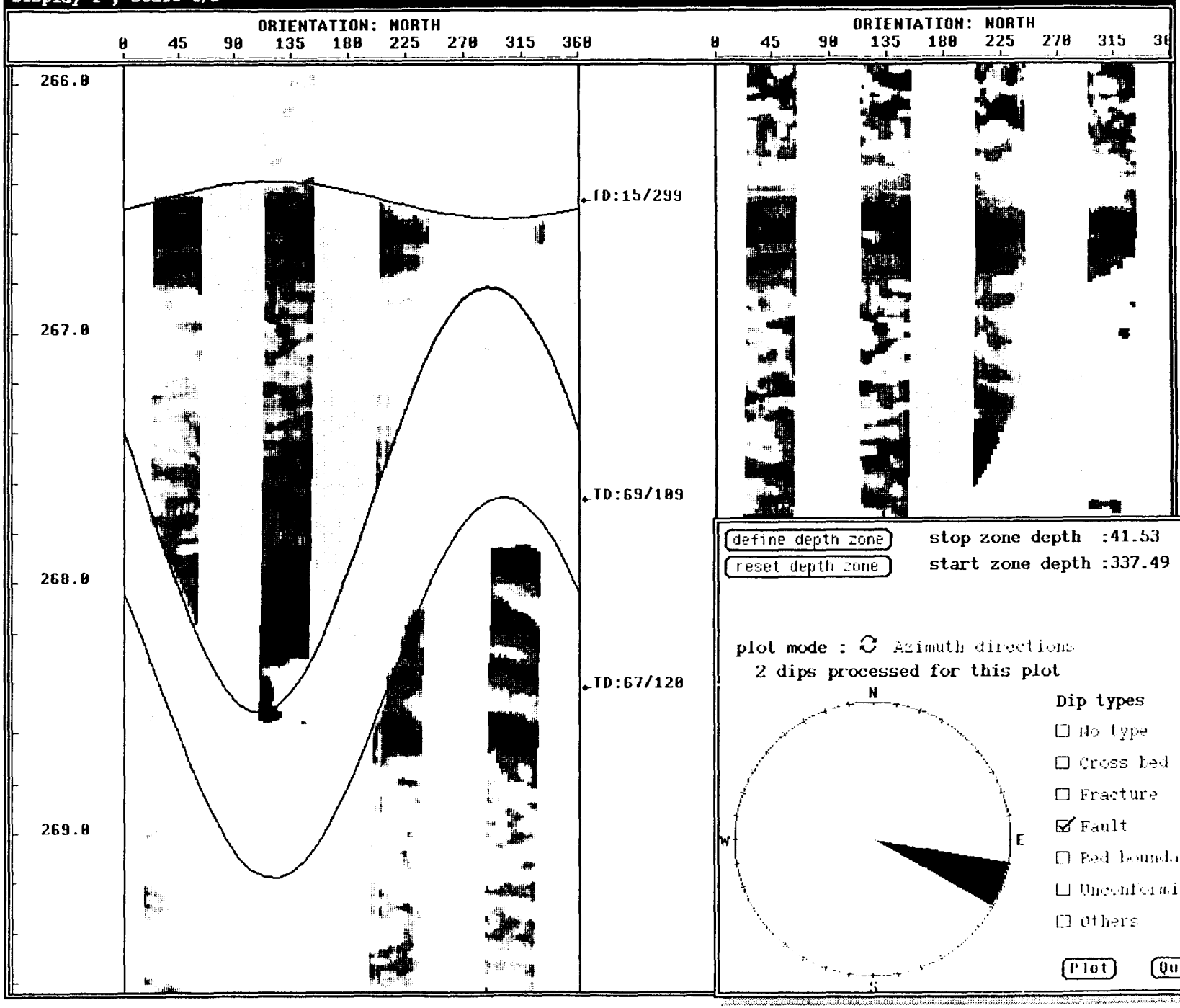


RE SPEC INC. B.E. 5 DALLAS JOB #4621 - FLIP Version 4.1 - (C) Schlumberger 1989

File browser

Well Summary

Display 1 ; scale 1/5



define depth zone

reset depth zone

stop zone depth :41.53 F

start zone depth :337.49 F

plot mode : Azimuth directions

2 dips processed for this plot

N

E

W

S

Dip types

- ☐ No type
- ☐ Cross bed
- ☐ Fracture
- ☑ Fault
- ☐ Bed boundary
- ☐ Unconformity
- ☐ Others

Plot Quit

APPENDIX D

LABORATORY HYDRAULIC FRACTURE TESTS

D.1 INTRODUCTION

Each microhydraulic fracturing tests involved several cycles of pressurization and depressurization. The difference between the fracture reopening pressure, P_r, and the initial breakdown pressure, P_b, is a measure of the apparent in situ tensile strength, T, of the rock mass. In order to compare the field-deduced tensile strength with laboratory data, a series of laboratory hydraulic fracturing tests were conducted on representative samples.

D.2 TENSILE STRENGTH SIZE EFFECT

Rocks are known to exhibit a strength *size-effect* in the laboratory hydraulic fracture test [e.g., Haimson, 1968; Ratigan, 1982]. Size effects in the microhydraulic fracture test are discussed in Ratigan [1990]. Laboratory testing of the rock specimens was performed with two different sized pressurized boreholes. The Austin Chalk was the only rock type tested in the laboratory.

When intact rock samples are taken into the laboratory and tested to determine tensile strength, three observations are invariably made.

1. The apparent tensile strength depends upon the sample size (the larger the specimen, the smaller the strength).
2. The apparent tensile strength depends upon the type of test being performed.
3. With any given test and specimen size, a scatter (usually skewed) about the mean is obtained.

The first dilemma (commonly referred to as the *size effect*) is also observed with respect to compressive strength and an apparent Young's Modulus, although to a lesser extent than with tensile strength (i.e., Heuze [1980]). However, the observation has prompted many investigators to recognize that tensile strength of brittle rock at the usual laboratory scale for many rocks is not a material property (e.g., Hudson and Fairhurst [1969]). The second observation noted above has been brushed away by using different names to refer to the strength observed in different tests. For example, the apparent tensile strength in bending is referred to as the Modulus of Rupture. The tensile strength determined by indirect tension tests is often referred to with an adjective taken from the test; for example, the Brazilian tensile strength or the split cylinder tensile strength. The third observation above is often totally neglected in the reporting of test results. Scatter about the mean is often attributed to testing methodology and/or sample inhomogeneity. Thus, more often than not, the only result of the tensile testing may be the mean without the standard deviation or any of the other statistical moments.

D.3 LABORATORY HYDRAULIC FRACTURING TESTS

The specimens used in the laboratory hydraulic fracture test were fabricated from nominally 2-inch-diameter core to lengths of approximately 4 inches. All samples tested were identified with a unique identification. A typical identification number is

BE-5/161/3/1

where

BE-5	=	location of coring (Borehole BE5)
161	=	depth (feet) from which core was removed
3	=	sequential number of piece of core
1	=	the portion of the original piece/piece number resulting from preparation process

Each specimen was sawn to length and the ends were lapped until smooth and parallel. An internal borehole was drilled (axially) part way through the center of the specimen. A distance of approximately 1 inch was maintained between the bottom of the internal borehole and the end of the specimen. A steel tube, which extended about 1 inch above the specimen, was epoxied in the borehole. The end of the tubing fitted into the loading platen and an O-ring provided a hydraulic seal.

The laboratory specimen was loaded axially with a load sufficient to resist horizontal fracturing. An axial stress of approximately 300 psi was used when testing the Austin Chalk. The borehole was pressurized at a nearly constant rate of approximately 250 psi/minute. All specimens were monitored with acoustic emission instrumentation to determine if fracturing occurred before the peak pressure was attained.

Two internal borehole diameters were tested; 0.25 inch and 0.50 inch. The results of the testing are shown in Table D-1. The strength size effect (decrease in strength with increasing borehole size) illustrated is dramatic. An increase in borehole diameter from 0.25 inches to 0.50 inches resulted in a decrease in strength by a factor of about 2. In comparison, Haimson [1968] found a strength decrease of less than 20 percent for a similar increase in borehole size when testing Tennessee Marble. Ratigan [1981] found a strength decrease of about 10 percent for a similar increase in borehole diameter for Stripa granite. Clearly, the laboratory strengths in Table D-1 are far greater than the strengths that are exhibited in situ. The laboratory hydraulic fracture strengths are also significantly larger than the typical Brazilian tensile strength of Austin Chalk, approximately 250 psi [Bailey, 1990] and the tensile strength inferred from the field tests, between 0 and 163 psi.

Table D-1. Laboratory Hydraulic Fracture Tests

Specimen	Internal Borehole (inches)	Burst Pressure (psi)	Tensile Strength (psi)
BE-5/161/2/1	0.5	539	611
BE-5/108/5	0.5	294[a]	333[a]
BE-5/209/6/1	0.5	390	442
BE-5/161/1/1	0.25	869	897
BE-5/161/3/1	0.25	882	910
BE-5/161/3/2	0.25	919	948

(*a*) Horizontal fracture.

D.4 REFERENCES

Bailey, B., 1990. Personal communication with Leo L. Van Sambeek, RE/SPEC Inc., April.

Haimson, B. C., 1968. *Hydraulic Fracturing in Porous and Nonporous Rock and its Potential for Determining In-Situ Stresses at Great Depth*, Missouri River Division Corps of Engineers, Technical Report No. 4-68.

Hudson, J. A. and C. Fairhurst, 1969. "Tensile Strength, Weibull's Theory and a General Statistical Approach to Rock Failure," in *Proceedings of the Southampton 1969 Civil Engineering Material's Conference,* Wiley-Interscience.

Heuze, F. E. 1980. "Scale Effects in the Determination of Rock Mass Strength and Deformability," *Rock Mechanics, 12*, No. 3-4, pp. 167-192.

Ratigan, J. L., 1981. "A Statistical Fracture Mechanics Approach to the Strength of Brittle Rock," *Ph.D. Thesis*, Department of Civil Engineering, University of California, Berkeley, CA.

Ratigan, J. L., 1982. "A Statistical Fracture Mechanics Determination of the Apparent Tensile Strength in Hydraulic Fracture," *Proceedings of Workshop XVII, Workshop on Hydraulic Fracturing Stress Measurements*, U.S.G.S. Open-File Report 82-1075.

Ratigan, J. L., 1990. "Scale Effects in the Hydraulic Fracture Test Associated With the Estimation of Tensile Strength," *Proceedings of the First International Workshop on Scale Effects in Rock Mechanics*, Loen. Norway, June.

APPENDIX D

LABORATORY RESULTS

GEOMECHANICAL TEST RESULTS-BORING BE 5

GENERAL LITHOLOGY	BORING DEPTH feet	MOISTURE CONTENT percent	DRY DENSITY pcf	SPECIFIC GRAVITY	ATTERBERG LIMITS LL	ATTERBERG LIMITS PI	FRACTION FINER THAN # 200 SIEVE percent	CARBONATE CONTENT percent	SAMPLE DIMENSION RATIO L/D	SAMPLE FAILURE MODE/ DEGREES*	UNCONFINED COMPRESSIVE STRENGTH psi	TRIAXIAL COMPRESSION CONFINING PRESSURE σ_3 psi	TRIAXIAL COMPRESSION DEVIATOR STRESS $\sigma_1-\sigma_3$ psi	FAILURE STRAIN percent	TANGENT YOUNG'S MODULUS E50 (psi)x10E5	TANGENT YOUNG'S MODULUS σ_3 psi	POISSON'S RATIO	BRAZIL TENSILE STRENGTH psi	2ND CYCLE SLAKE DURABILITY INDEX percent	SWELL PRESSURE INDEX psi	COMMENTS
TAYLOR MARL	25.0	18.2	111.7	2.72	57	31	98.9	22.9	2.2	D		50	285	1.40	0.33	50					
TAYLOR MARL	25.0														0.31		0.31				DEFORMATION JACKET
TAYLOR MARL	25.4	18.3	111.5																		
TAYLOR MARL	25.7	18.5	111.9		63	34	98.3	21.2	2.3	D	285			1.37	0.22	0					
TAYLOR MARL	48.9				66	39	96.8	24.6													
TAYLOR MARL	49.1	16.7	115.1	2.73	62	36	98.8	26.3	2.4	B-1/50		100	372	0.81	0.53	100					
TAYLOR MARL	49.1														0.65		0.35				DEFORMATION JACKET
TAYLOR MARL	49.9	17.3	114.3																		
TAYLOR MARL	50.5	17.4	111.6						2.4	D	313			1.20	0.31	0					
TAYLOR MARL	75.0	16.1	116.9																		
TAYLOR MARL	75.2	17.2			89	56															
TAYLOR MARL	75.7							23.3													
TAYLOR MARL	99.8	16.9	114.4																		
TAYLOR MARL	100.0	17.4			100	62		18.1											32.7		
TAYLOR MARL	101.1	16.1	114.2																	14.4	
TAYLOR MARL	101.3	16.2	112.7																	14.5	
TAYLOR MARL	115.4	17.0	114.0																		
TAYLOR MARL	117.0	17.5			96	61															
TAYLOR MARL	117.1			2.65																	
AUSTIN CHALK	145.0	10.4	129.4	2.69					2.2	B-1/20		100	2160	0.74	3.91	100					
AUSTIN CHALK	145.0														5.14		0.12				DEFORMATION JACKET
AUSTIN CHALK	145.1	10.5	131.4						2.3	E	2708			0.59	5.40	0					
AUSTIN CHALK	145.5	10.1	130.8						2.3	B-1/20		200	2546	0.77	3.23	200					
AUSTIN CHALK	145.5														4.43		0.01				DEFORMATION JACKET
AUSTIN CHALK	171.4	10.4	129.0						2.3	A	2540			0.72	4.90	0					
AUSTIN CHALK	171.9	11.6																			
AUSTIN CHALK	178.5	11.2	128.4																		
AUSTIN CHALK	195.4	10.2																			
AUSTIN CHALK	195.5	10.1	131.7	2.68					2.3	E	2983			1.24	3.20	0					
AUSTIN CHALK	223.4	10.7	130.3																		
AUSTIN CHALK	233.3	10.3	130.6																		
AUSTIN CHALK	243.2	10.0	127.6																		
AUSTIN CHALK	271.1	12.9																			
AUSTIN CHALK	271.2	8.2																222			
AUSTIN CHALK	271.3	12.1	126.2	2.68					2.4	A	2172			0.89	4.20	0					
BENTONITE	318.6	27.8																			
BENTONITE	318.7	21.2			172	115															
AUSTIN CHALK	320.7	10.9																			
AUSTIN CHALK	320.8	10.2	131.0						2.4	E	2280			0.81	3.20	0					
PROCEDURE		ASTM-D2216		ASTM-D854	ASTM-D4318		ASTM-D422				ASTM-D2938	ASTM-D2664			ASTM-D3148		ASTM-D3148	ISRM	ISRM	ISRM	

* EXPLANATION OF SAMPLE FAILURE MODE AS FOLLOWS.

SYMBOL	Failure Type
A	No discernible failure plane
B	Well defined shear plane @ "X" angle (deg) to vertical or to long axis of core
B-1	Shear plane
B-2	Bedding plane shear
B-3	Shear plane along pre-existing fracture, shear zone, etc.

SYMBOL	Failure Type
B-4	Combination
C	Barreling/Bulging
D	Longitudinal (axial) splitting
E	Conical
F	No information

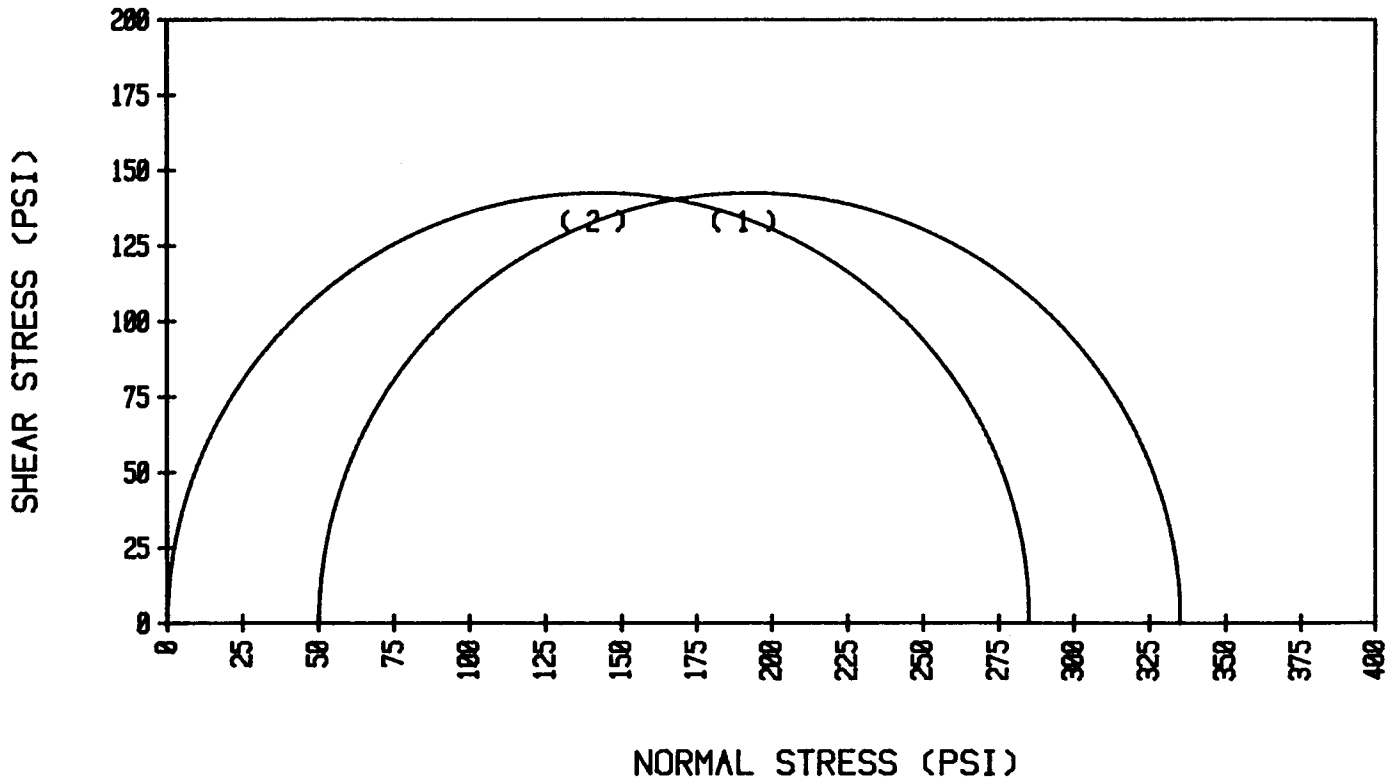
Note: Some values in this table may be revised based on reviews of test procedures and individual test results. The reader should refer to the latest revision of the gINT geotechnical data base (geotechnical report GR-70).

BESPRT.WK1
REVISION:1.1
DATE 4/1/90

PRELIMINARY (Subject to Revision)

BORING NO.: BE5
DEPTH RANGE (FT): 25.0-26.1
TAYLOR MARL

BORING INCLINATION (DEG): VERTICAL
TEST TYPE: UNCONFINED COMPRESSION (ASTM D2938)
TRIAXIAL COMPRESSION (ASTM D2664)



SEE STRESS - STRAIN PLOTS
FOR INDIVIDUAL SAMPLE DATA

(1) DEPTH (FT): 25.0
(2) DEPTH (FT): 25.7

TEXAS SSC SITE

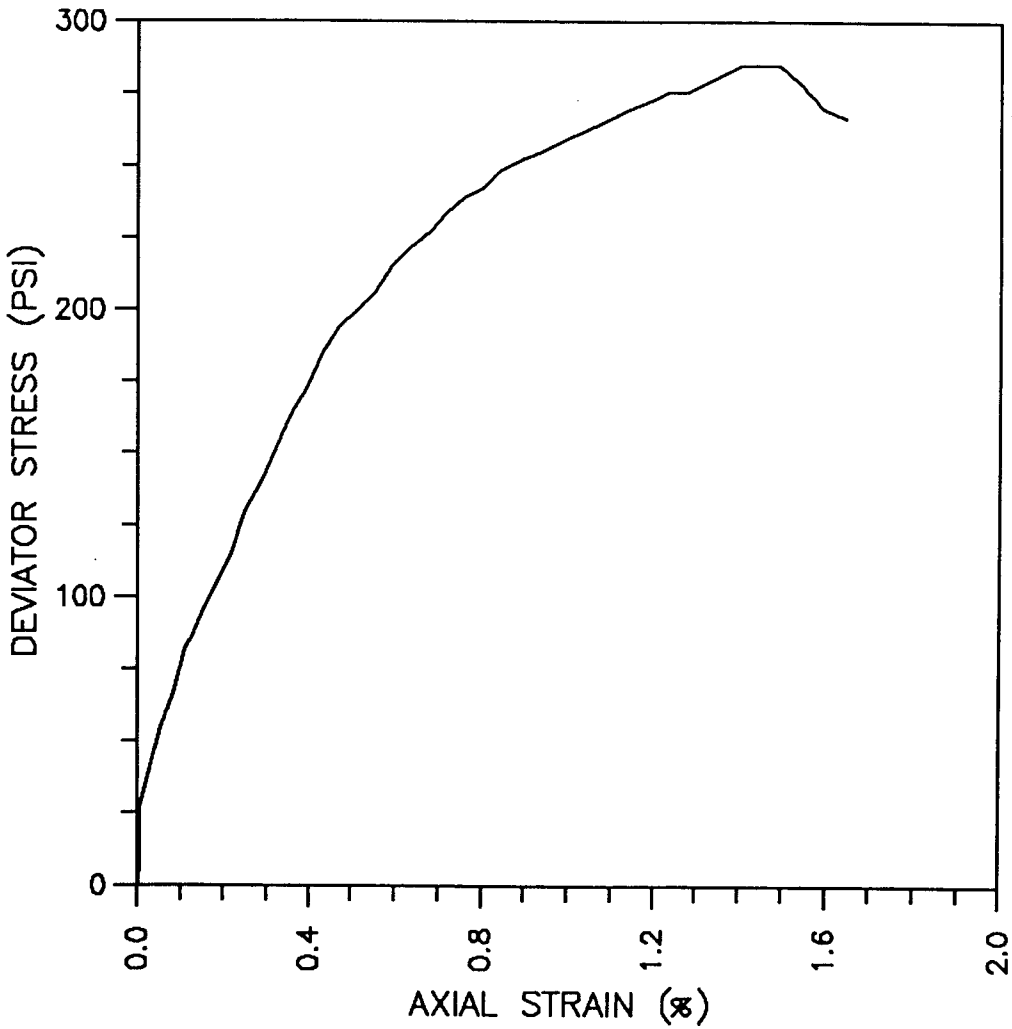
MOHR CIRCLE PLOT

MASON-JOHNSTON & ASSOCIATES, INC.
GEOLOGISTS-ENGINEERS

JOB NO.: 5530.17

FIGURE

BORING NO.: BE5
DEPTH (FT): 25.0
TAYLOR MARL



INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 18.2
DRY UNIT WEIGHT (PCF): 111.7
DEG. OF SATURATION (%): 95.5
ASSUMED SPECIFIC GRAVITY: 2.72
CONFINING PRESSURE (PSI): 50
TEST TYPE: TRIAXIAL COMPRESSION
(ASTM D 2664)

TANGENT MODULUS AT 50%
ULTIMATE STRESS:
0.325 x10E5 PSI

FAILURE MODE:
AXIAL SPLITTING

TEXAS SSC SITE

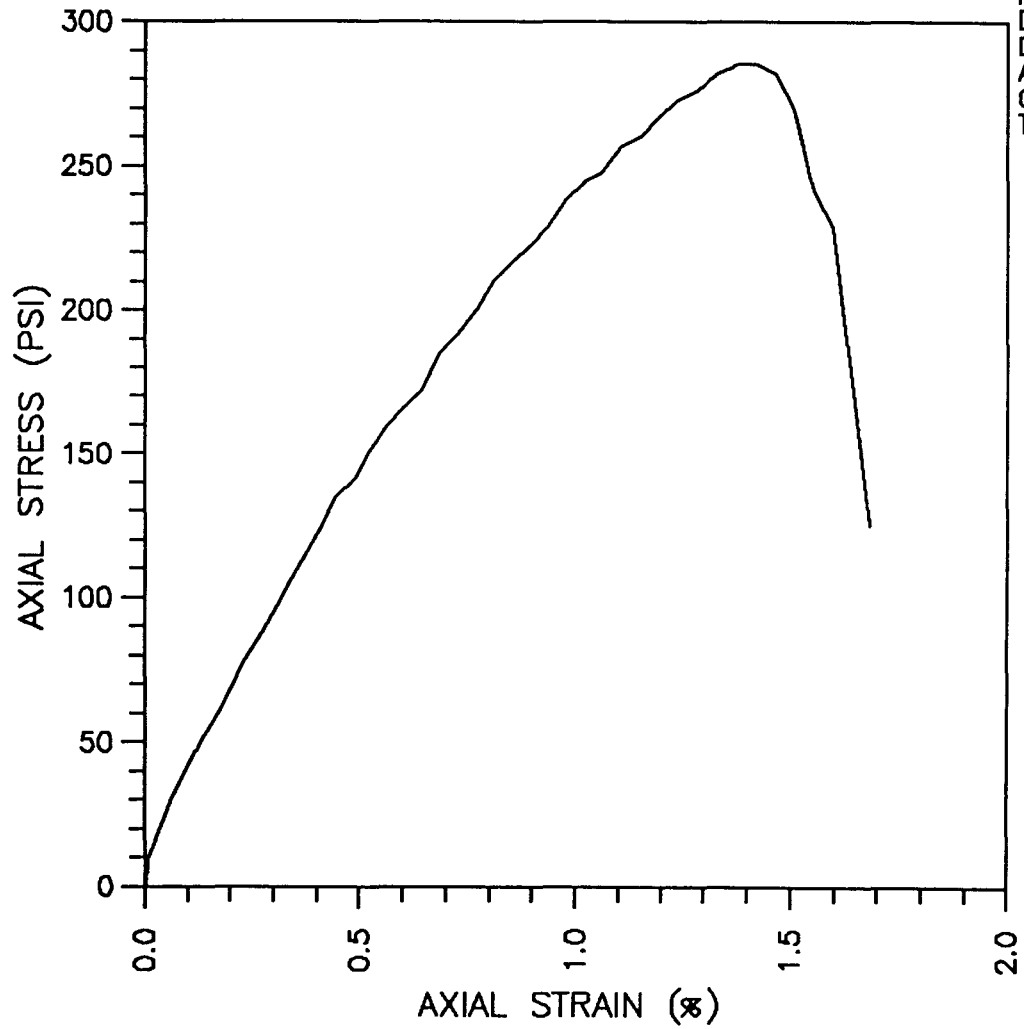
STRESS-STRAIN PLOT

MASON-JOHNSTON & ASSOCIATES,INC.
GEOLOGISTS-ENGINEERS

JOB NO.: 5530.17

FIGURE

BORING NO.: BE5
DEPTH (FT): 25.7
TAYLOR MARL



INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 18.5
DRY UNIT WEIGHT (PCF): 111.9
DEG. OF SATURATION (%): 97.5
ASSUMED SPECIFIC GRAVITY: 2.72
CONFINING PRESSURE (PSI): 0
TEST TYPE: UNCONFINED COMPRESSION
(ASTM D 2938)

TANGENT MODULUS AT 50%
ULTIMATE STRESS:
0.219 x10E5 PSI

FAILURE MODE:
AXIAL SPLITTING

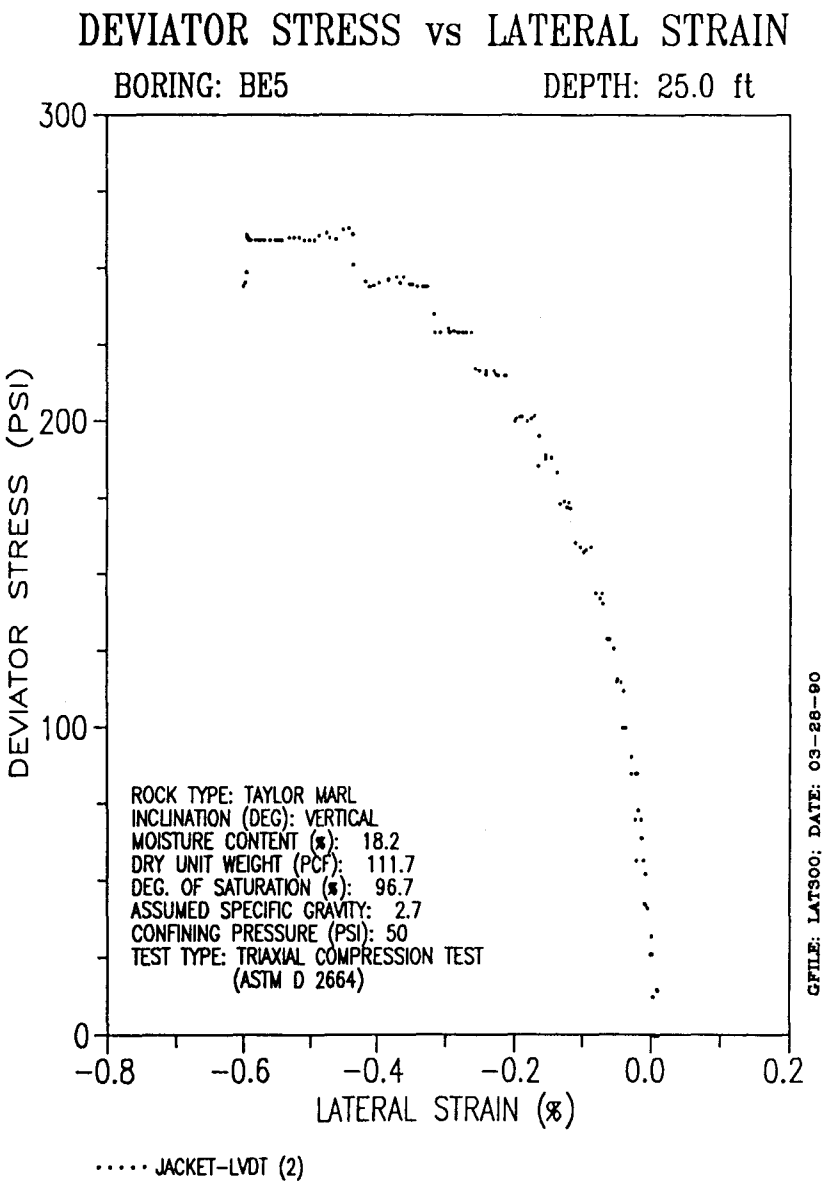
TEXAS SSC SITE

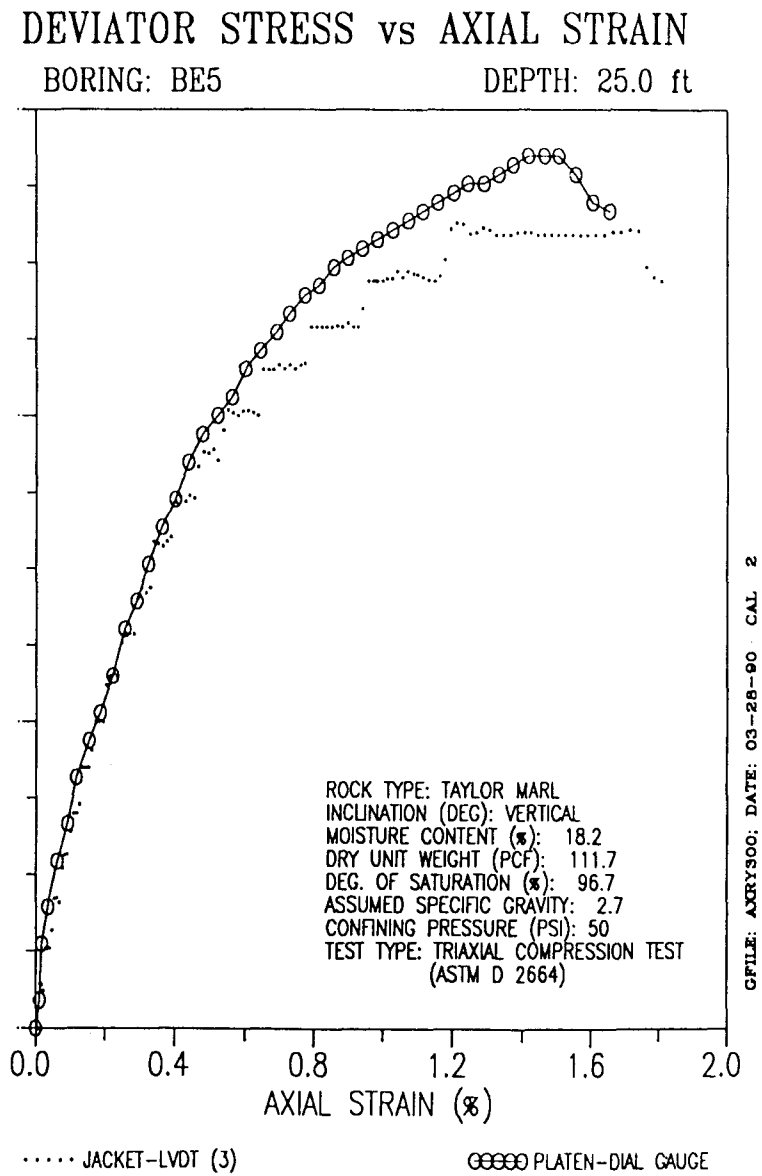
STRESS-STRAIN PLOT

MASON-JOHNSTON & ASSOCIATES,INC.
GEOLOGISTS-ENGINEERS

JOB NO.: 5530.17

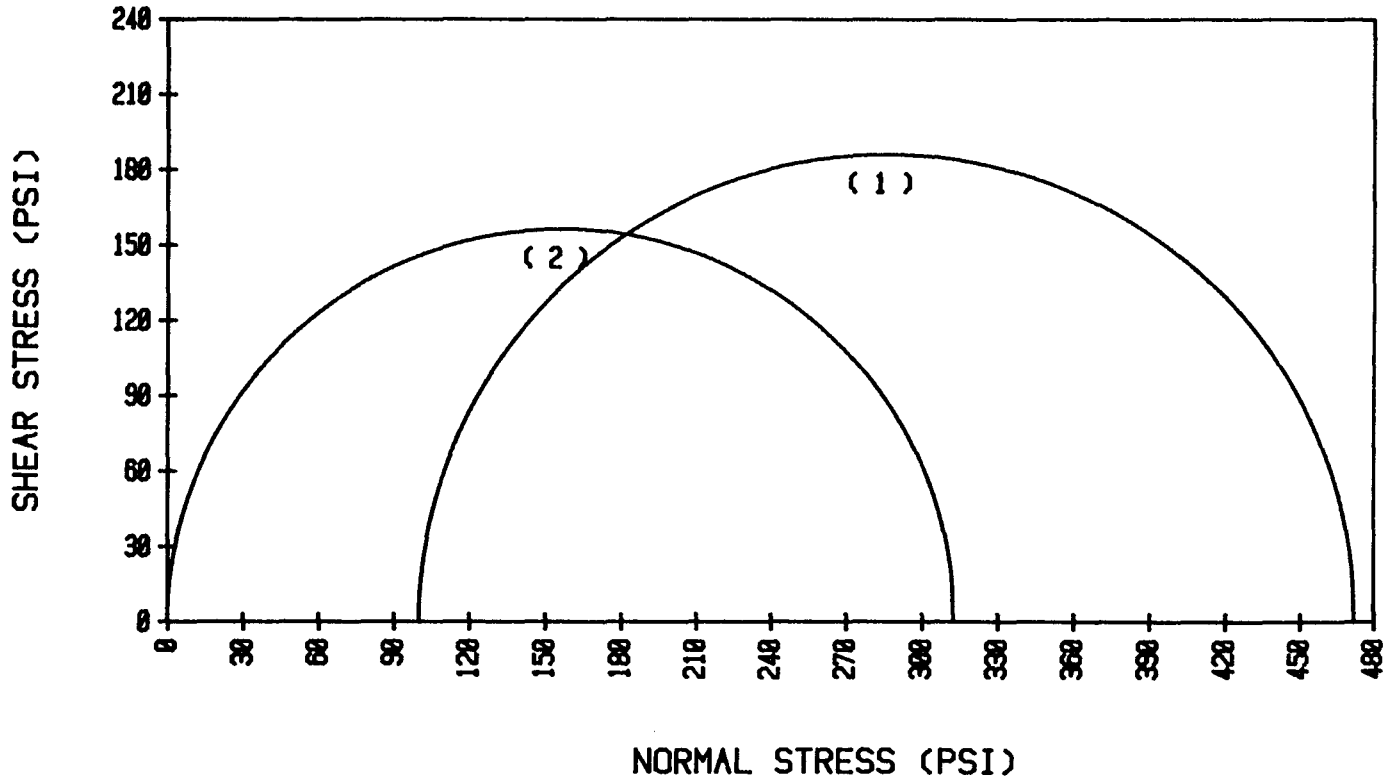
FIGURE


DEVIATOR STRESS vs LATERAL STRAIN
BORING: BE5
DEPTH: 25.0 ft
DEVIATOR STRESS (PSI)
300
200
100
0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
LATERAL STRAIN (%)
ROCK TYPE: TAYLOR MARL
INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 18.2
DRY UNIT WEIGHT (PCF): 111.7
DEG. OF SATURATION (%): 96.7
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 50
TEST TYPE: TRIAXIAL COMPRESSION TEST
(ASTM D 2664)
GFILE: LAT300; DATE: 03-28-90
JACKET-LVDT (2)


DEVIATOR STRESS vs AXIAL STRAIN
BORING: BE5
DEPTH: 25.0 ft
0.0
0.4
0.8
1.2
1.6
2.0
AXIAL STRAIN (%)
ROCK TYPE: TAYLOR MARL
INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 18.2
DRY UNIT WEIGHT (PCF): 111.7
DEG. OF SATURATION (%): 96.7
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 50
TEST TYPE: TRIAXIAL COMPRESSION TEST
(ASTM D 2664)
GFILE: AXRY300; DATE: 03-28-90 CAL 2
JACKET-LVDT (3)
PLATEN-DIAL GAUGE

BORING NO.: BE5
DEPTH RANGE (FT): 49.1-50.9
TAYLOR MARL

BORING INCLINATION (DEG): VERTICAL
TEST TYPE: UNCONFINED COMPRESSION (ASTM D2938)
TRIAXIAL COMPRESSION (ASTM D2664)

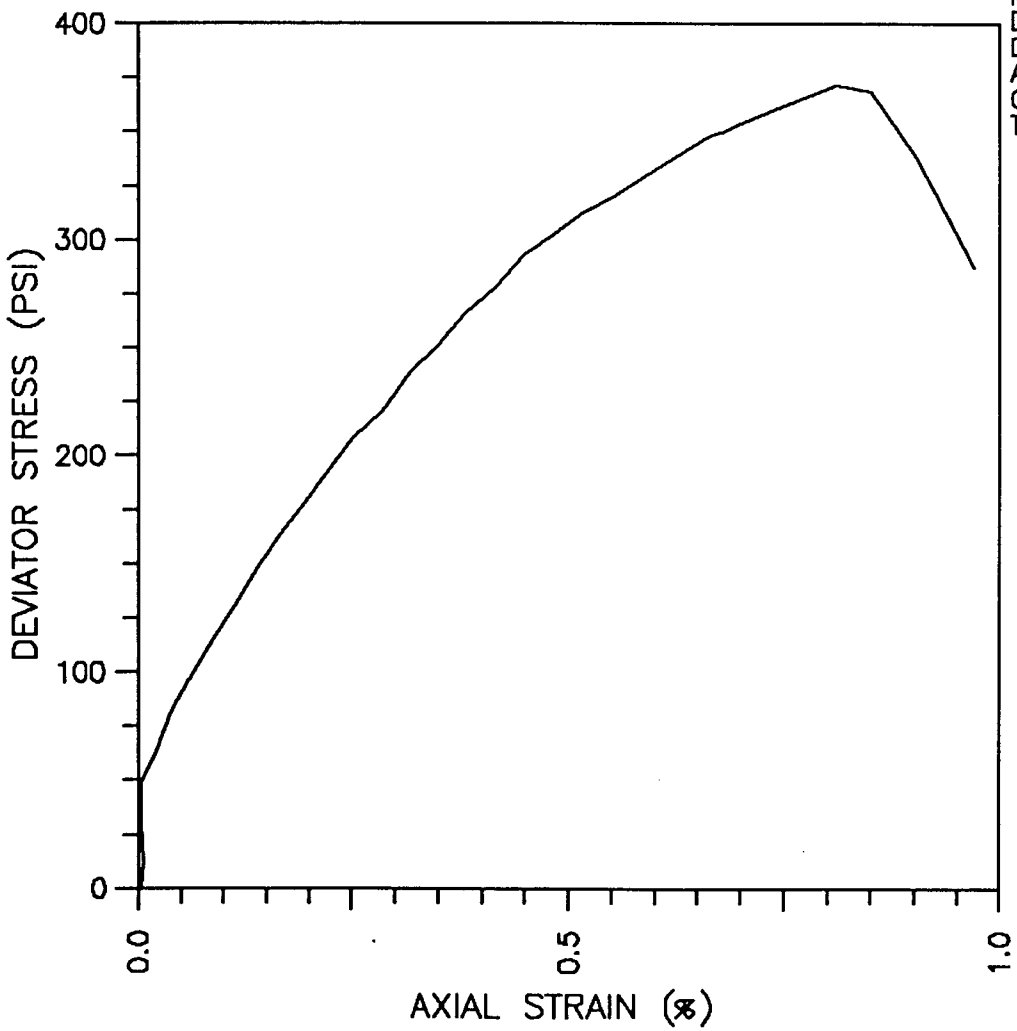


SEE STRESS - STRAIN PLOTS
FOR INDIVIDUAL SAMPLE DATA

(1) DEPTH (FT): 49.1
(2) DEPTH (FT): 50.5

TEXAS SSC SITE	
MOHR CIRCLE PLOT	
MASON-JOHNSTON & ASSOCIATES, INC. GEOLOGISTS-ENGINEERS	
JOB NO.: 5530.17	FIGURE

BORING NO.: BE5
DEPTH (FT): 49.1
TAYLOR MARL



INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 16.7
DRY UNIT WEIGHT (PCF): 115.1
DEG. OF SATURATION (%): 95.3
ASSUMED SPECIFIC GRAVITY: 2.73
CONFINING PRESSURE (PSI): 100
TEST TYPE: TRIAXIAL COMPRESSION
(ASTM D 2664)

TANGENT MODULUS AT 50%
ULTIMATE STRESS:
0.529 x10E5 PSI

FAILURE MODE:
SHEAR PLANE AT 50 DEG.

TEXAS SSC SITE

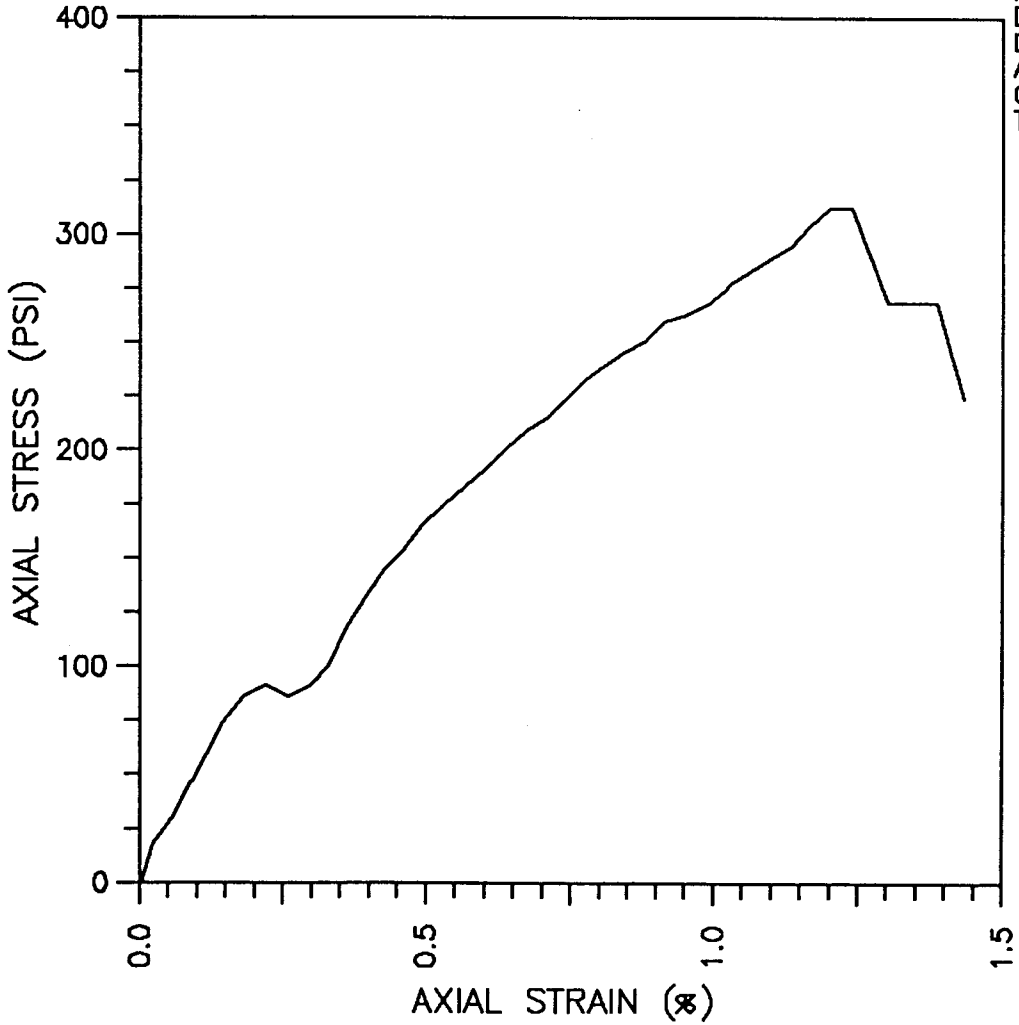
STRESS-STRAIN PLOT

MASON-JOHNSTON & ASSOCIATES, INC.
GEOLOGISTS-ENGINEERS

JOB NO.: 5530.17

FIGURE

BORING NO.: BE5
DEPTH (FT): 50.5
TAYLOR MARL



INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 17.4
DRY UNIT WEIGHT (PCF): 111.6
DEG. OF SATURATION (%): 90.2
ASSUMED SPECIFIC GRAVITY: 2.73
CONFINING PRESSURE (PSI): 0
TEST TYPE: UNCONFINED COMPRESSION
(ASTM D 2938)

TANGENT MODULUS AT 50%
ULTIMATE STRESS:
0.310 x10E5 PSI

FAILURE MODE:
AXIAL SPLITTING

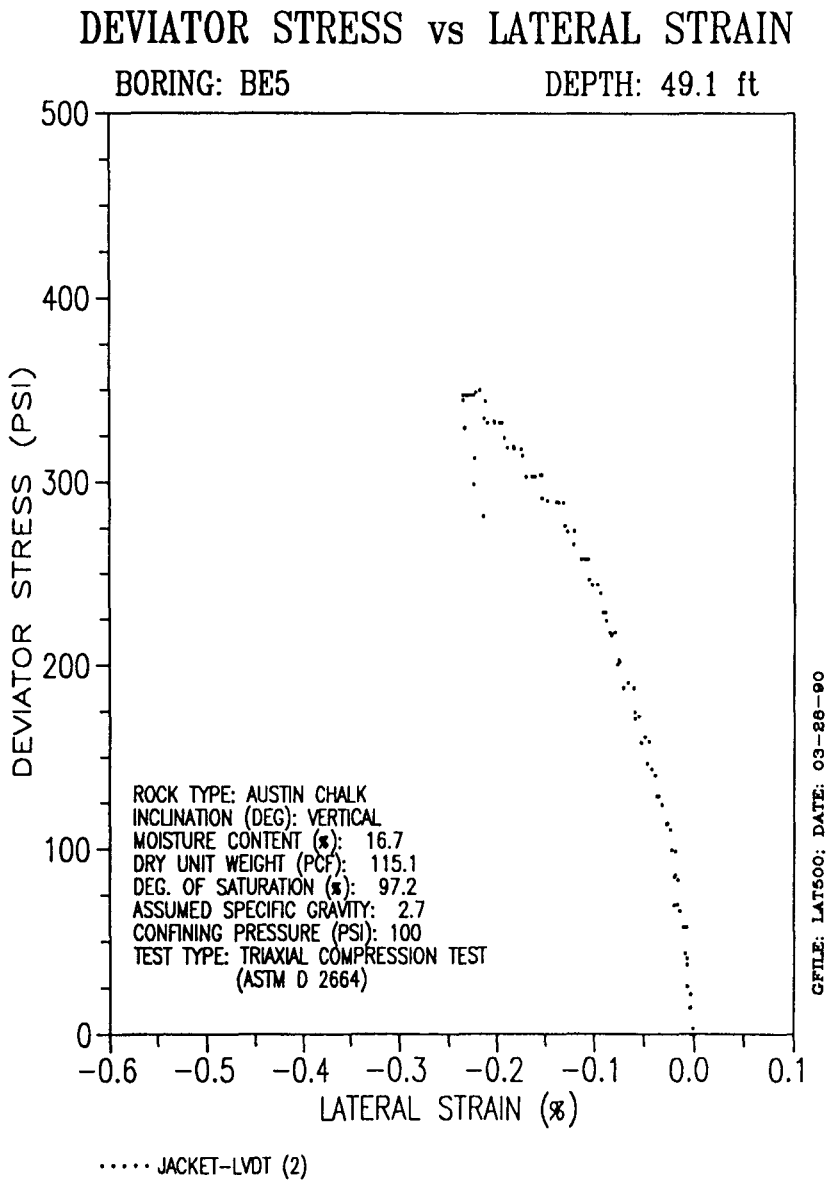
TEXAS SSC SITE

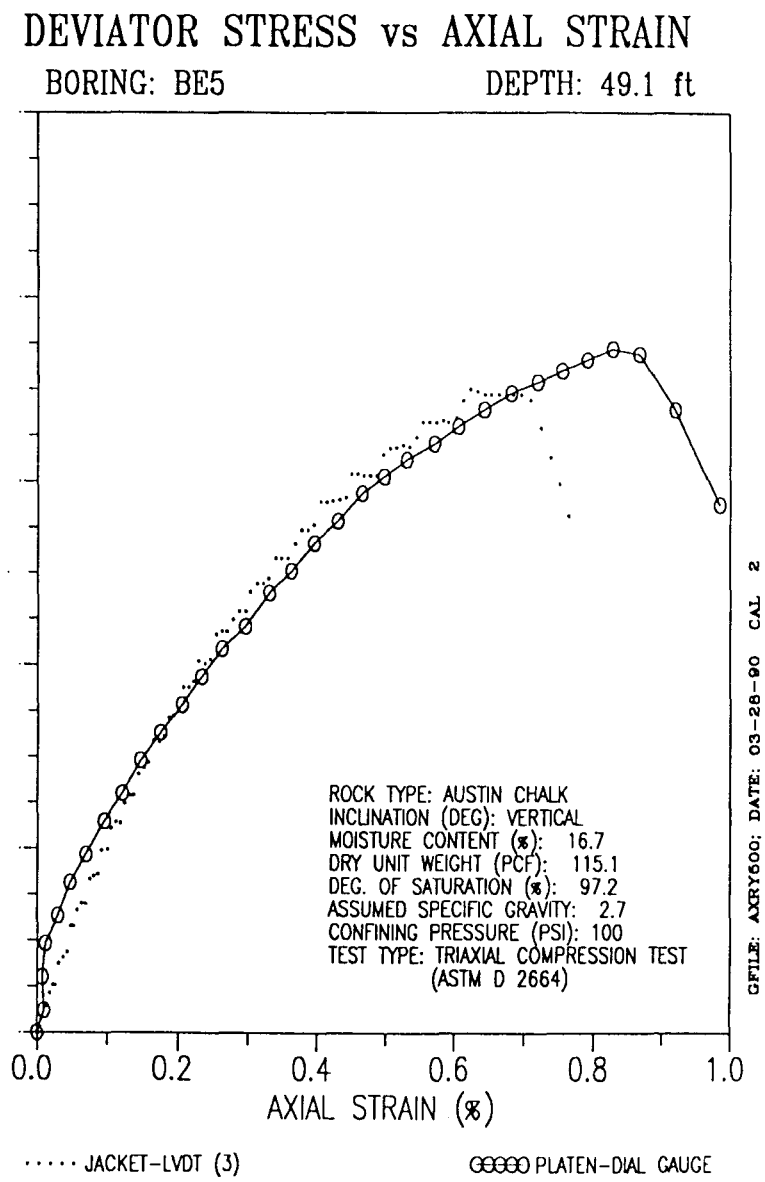
STRESS-STRAIN PLOT

MASON-JOHNSTON & ASSOCIATES, INC.
GEOLOGISTS-ENGINEERS

JOB NO.: 5530.17

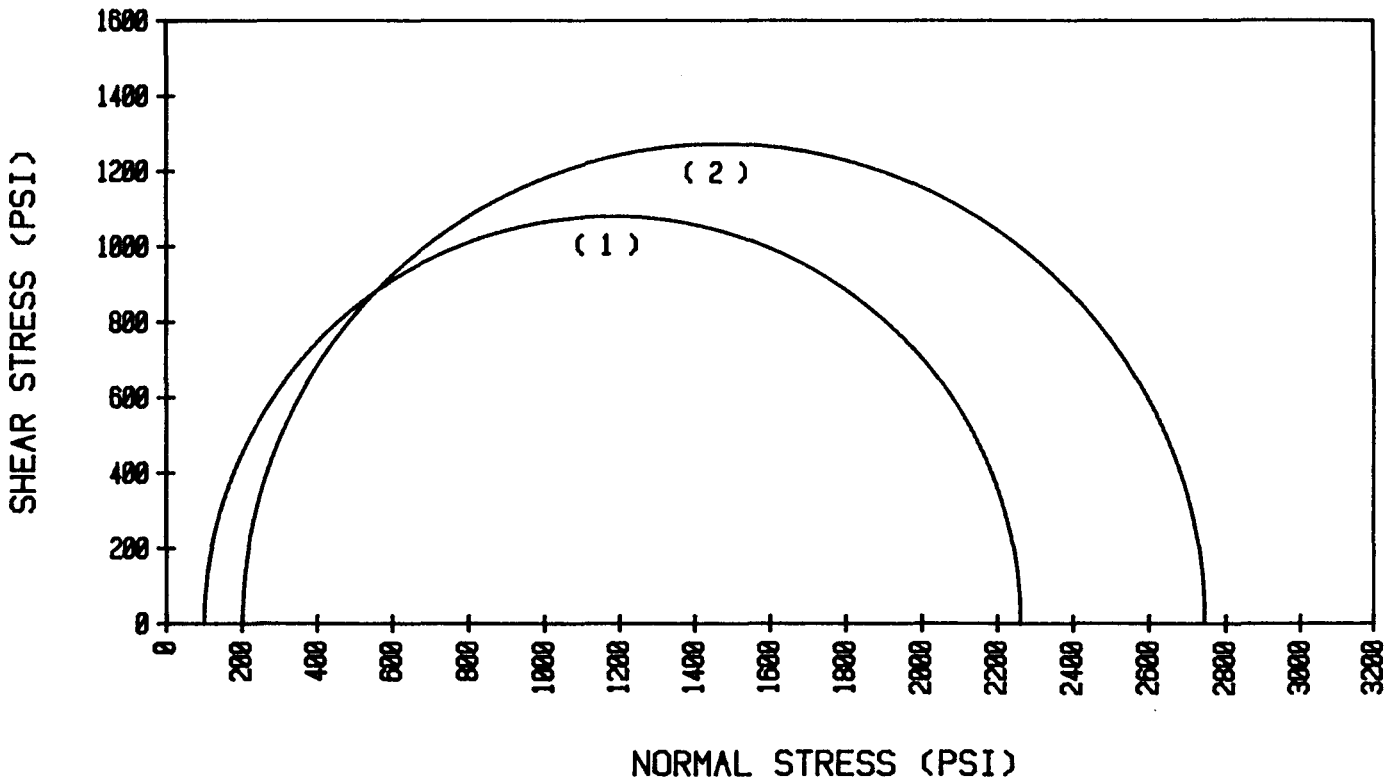
FIGURE


DEVIATOR STRESS vs LATERAL STRAIN
BORING: BE5
DEPTH: 49.1 ft
DEVIATOR STRESS (PSI)
500
400
300
200
100
0
-0.6
-0.5
-0.4
-0.3
-0.2
-0.1
0.0
0.1
LATERAL STRAIN (%)
ROCK TYPE: AUSTIN CHALK
INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 16.7
DRY UNIT WEIGHT (PCF): 115.1
DEG. OF SATURATION (%): 97.2
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 100
TEST TYPE: TRIAXIAL COMPRESSION TEST
(ASTM D 2664)
GFILE: LAT500; DATE: 03-28-90
····· JACKET-LVDT (2)


DEVIATOR STRESS vs AXIAL STRAIN
BORING: BE5
DEPTH: 49.1 ft
0.0
0.2
0.4
0.6
0.8
1.0
AXIAL STRAIN (%)
ROCK TYPE: AUSTIN CHALK
INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 16.7
DRY UNIT WEIGHT (PCF): 115.1
DEG. OF SATURATION (%): 97.2
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 100
TEST TYPE: TRIAXIAL COMPRESSION TEST
(ASTM D 2664)
GFILE: AXRY600; DATE: 03-28-90 CAL 2
····· JACKET-LVDT (3)
OOOOO PLATEN-DIAL GAUGE

BORING NO.: BE5
DEPTH RANGE (FT): 145.0-145.9
AUSTIN CHALK LIMESTONE

BORING INCLINATION (DEG): VERTICAL
TEST TYPE: TRIAXIAL COMPRESSION (ASTM D2664)



SEE STRESS - STRAIN PLOTS
FOR INDIVIDUAL SAMPLE DATA

(1) DEPTH (FT): 145.0
(2) DEPTH (FT): 145.5

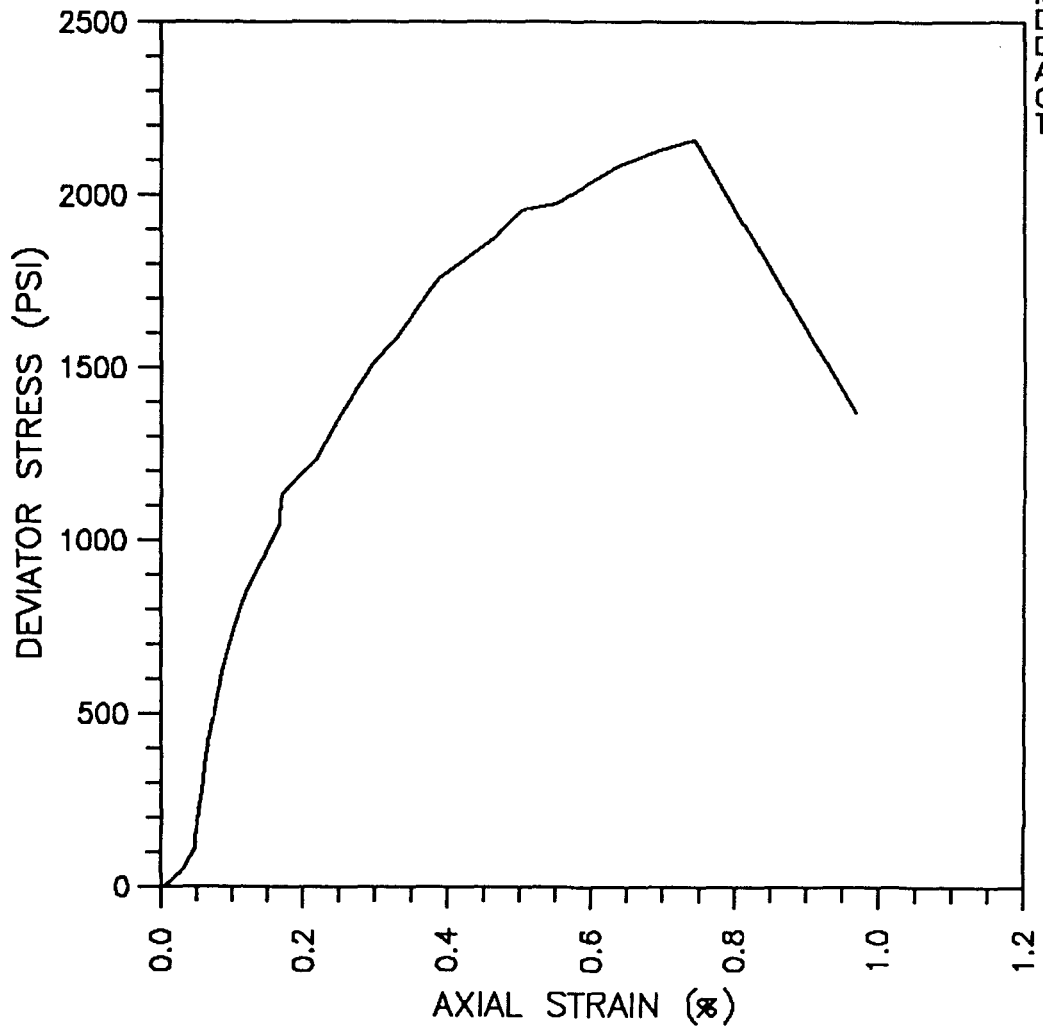
TEXAS SSC SITE

MOHR CIRCLE PLOT

MASON-JOHNSTON & ASSOCIATES, INC.
GEOLOGISTS-ENGINEERS

JOB NO.: 5530.17 | FIGURE

BORING NO.: BE5
DEPTH (FT): 145.0
AUSTIN CHALK LIMESTONE



INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 10.4
DRY UNIT WEIGHT (PCF): 129.4
DEG. OF SATURATION (%): 94.6
ASSUMED SPECIFIC GRAVITY: 2.69
CONFINING PRESSURE (PSI): 100
TEST TYPE: TRIAXIAL COMPRESSION
(ASTM D 2664)

TANGENT MODULUS AT 50%
ULTIMATE STRESS:
3.913 x10E5 PSI

FAILURE MODE:
SHEAR PLANE AT 20 DEG

TEXAS SSC SITE

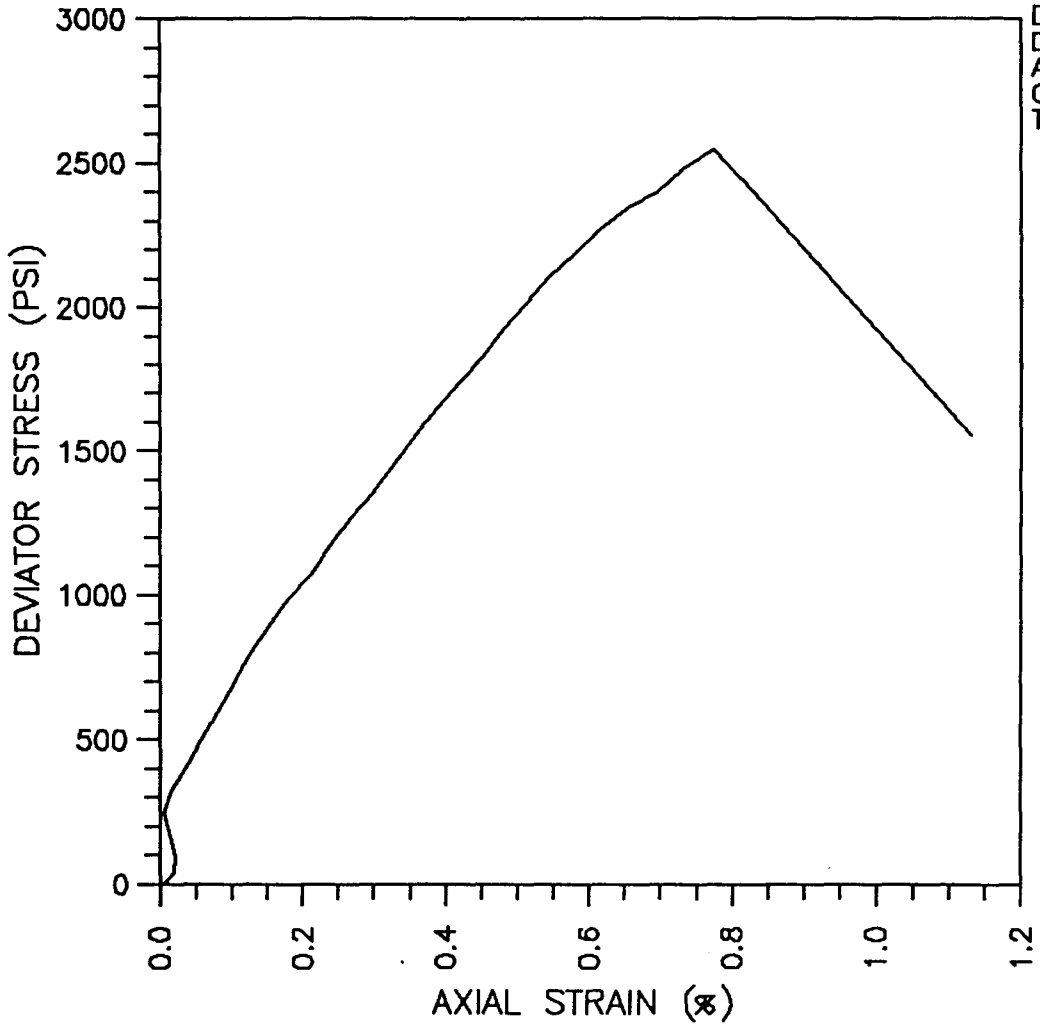
STRESS-STRAIN PLOT

MASON-JOHNSTON & ASSOCIATES, INC.
GEOLOGISTS-ENGINEERS

JOB NO.: 5530.17

FIGURE

BORING NO.: BE5
DEPTH (FT): 145.5
AUSTIN CHALK LIMESTONE



INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 10.1
DRY UNIT WEIGHT (PCF): 130.8
DEG. OF SATURATION (%): 96.3
ASSUMED SPECIFIC GRAVITY: 2.69
CONFINING PRESSURE (PSI): 200
TEST TYPE: TRIAXIAL COMPRESSION
(ASTM D 2664)

TANGENT MODULUS AT 50%
ULTIMATE STRESS:
3.226 x10E5 PSI

FAILURE MODE:
SHEAR PLANE AT 20 DEG

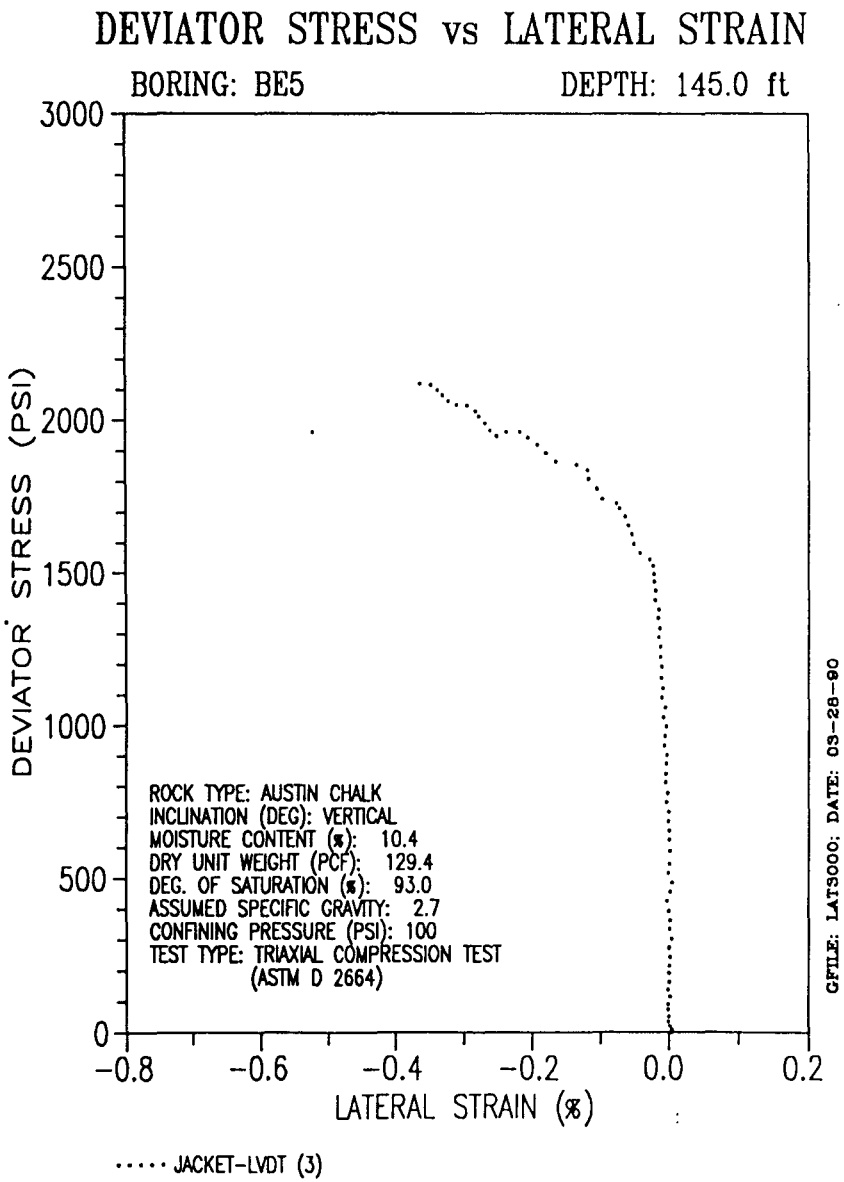
TEXAS SSC SITE

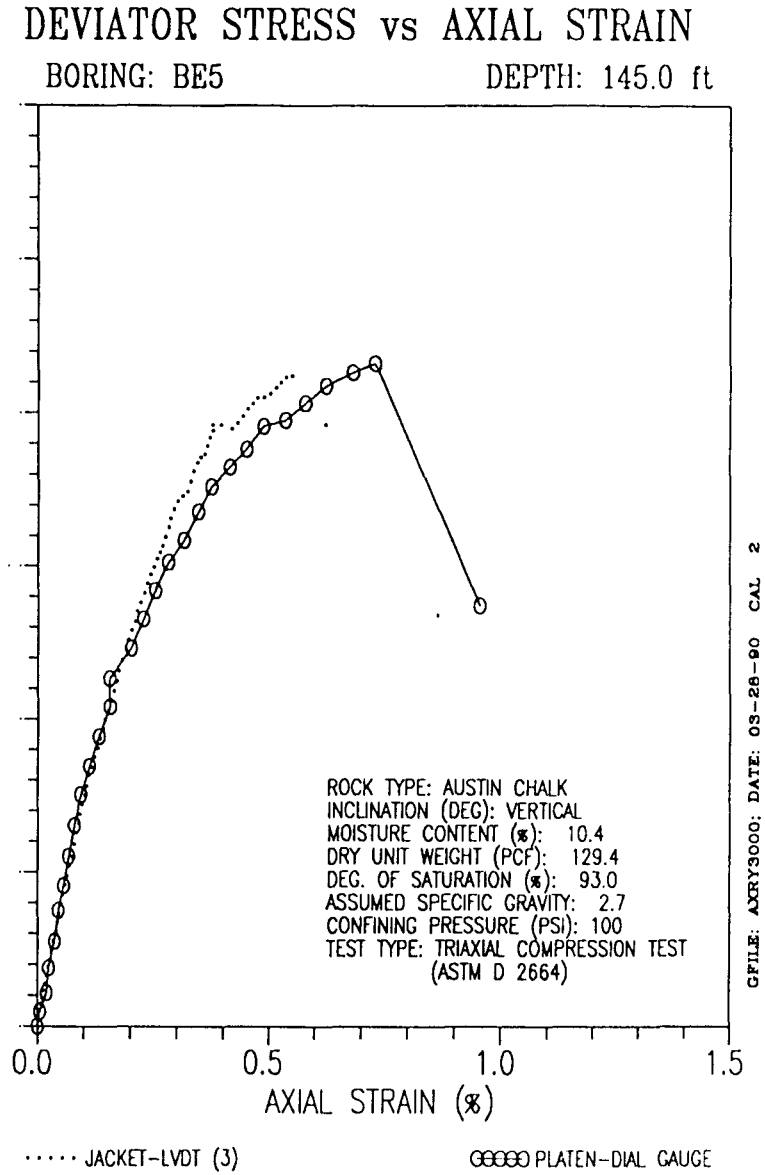
STRESS-STRAIN PLOT

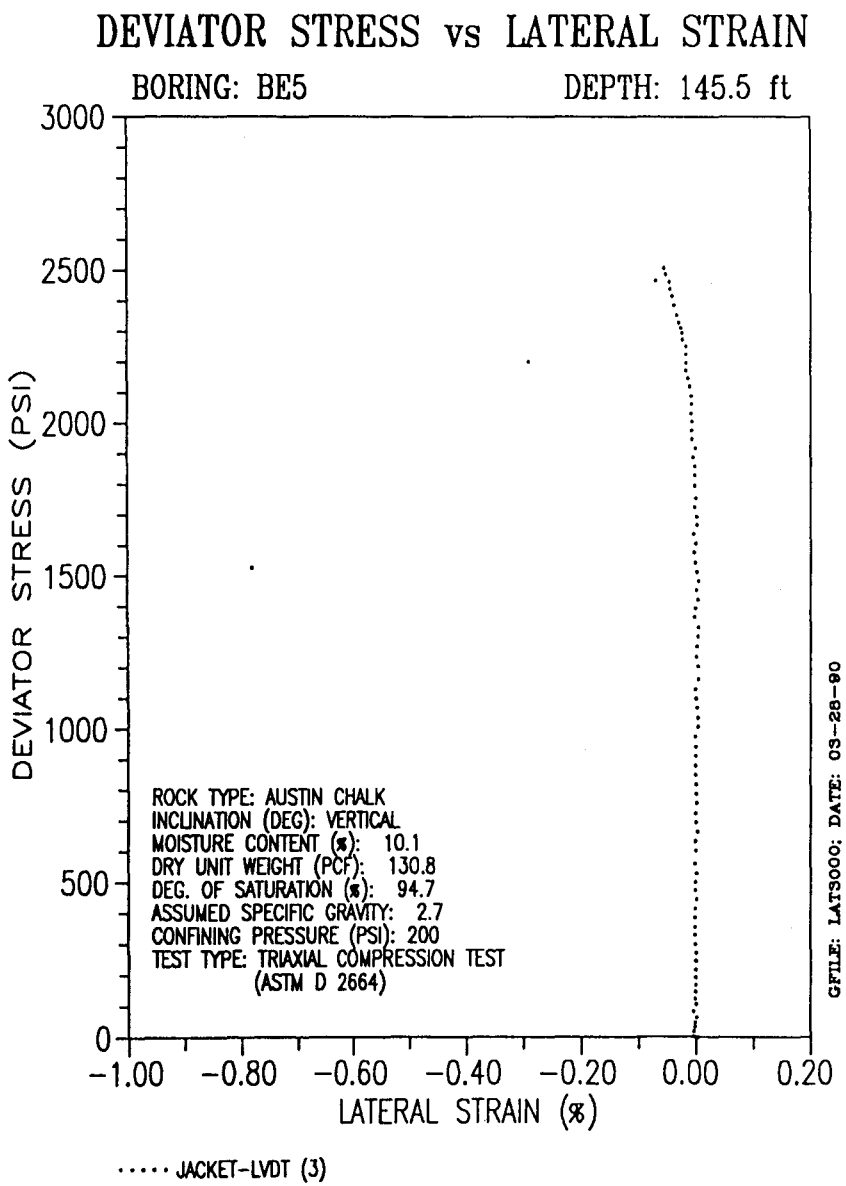
MASON-JOHNSTON & ASSOCIATES, INC.
GEOLOGISTS-ENGINEERS

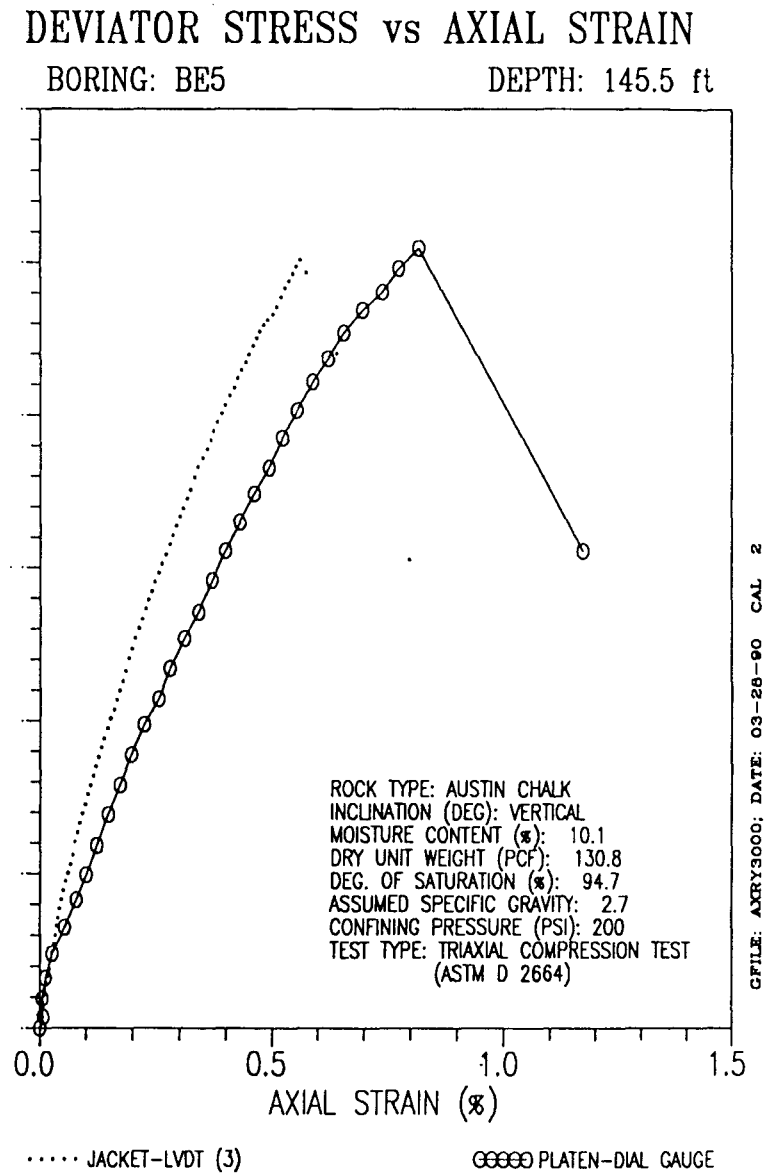
JOB NO.: 5530.17

FIGURE

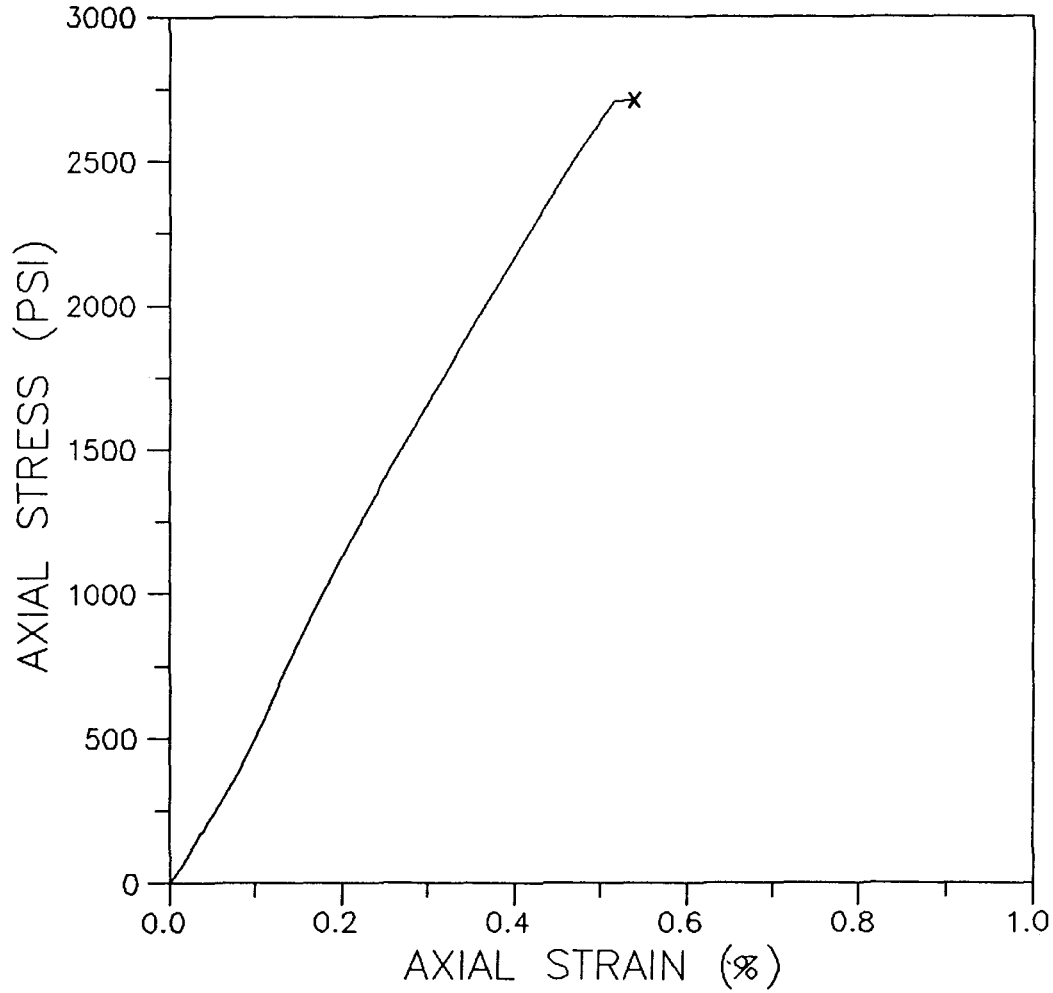

DEVIATOR STRESS vs LATERAL STRAIN
BORING: BE5
DEPTH: 145.0 ft
DEVIATOR STRESS (PSI)
3000
2500
2000
1500
1000
500
0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
LATERAL STRAIN (%)
ROCK TYPE: AUSTIN CHALK
INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 10.4
DRY UNIT WEIGHT (PCF): 129.4
DEG. OF SATURATION (%): 93.0
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 100
TEST TYPE: TRIAXIAL COMPRESSION TEST
(ASTM D 2664)
GFILE: LAT3000; DATE: 03-28-90
JACKET-LVDT (3)


DEVIATOR STRESS vs AXIAL STRAIN
BORING: BE5
DEPTH: 145.0 ft
0.0
0.5
1.0
1.5
AXIAL STRAIN (%)
ROCK TYPE: AUSTIN CHALK
INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 10.4
DRY UNIT WEIGHT (PCF): 129.4
DEG. OF SATURATION (%): 93.0
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 100
TEST TYPE: TRIAXIAL COMPRESSION TEST
(ASTM D 2664)
GFILE: AXRY3000; DATE: 03-28-90 CAL 2
JACKET-LVDT (3)
PLATEN-DIAL GAUGE


DEVIATOR STRESS vs LATERAL STRAIN
BORING: BE5
DEPTH: 145.5 ft
DEVIATOR STRESS (PSI)
3000
2500
2000
1500
1000
500
0
-1.00
-0.80
-0.60
-0.40
-0.20
0.00
0.20
LATERAL STRAIN (%)
ROCK TYPE: AUSTIN CHALK
INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 10.1
DRY UNIT WEIGHT (PCF): 130.8
DEG. OF SATURATION (%): 94.7
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 200
TEST TYPE: TRIAXIAL COMPRESSION TEST
(ASTM D 2664)
GFILE: LAT3000; DATE: 03-28-90
····· JACKET-LVDT (3)


DEVIATOR STRESS vs AXIAL STRAIN
BORING: BE5
DEPTH: 145.5 ft
0.0
0.5
1.0
1.5
AXIAL STRAIN (%)
ROCK TYPE: AUSTIN CHALK
INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 10.1
DRY UNIT WEIGHT (PCF): 130.8
DEG. OF SATURATION (%): 94.7
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 200
TEST TYPE: TRIAXIAL COMPRESSION TEST
(ASTM D 2664)
GFILE: AXRY3000; DATE: 03-28-90 CAL 2
····· JACKET-LVDT (3)
OOOOO PLATEN-DIAL GAUGE

BORING NO: BE5
DEPTH (FT): 145.1
AUSTIN CHALK



INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 10.5
DRY UNIT WEIGHT (PCF): 131.4
DEG. OF SATURATION (%): 100.5
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 0
TEST TYPE:UNCONFINED COMPRESSION
(ASTM D 2938)

TANGENT MODULUS AT 50%
ULTIMATE STRESS:
5.4 x 10E5 PSI

FAILURE MODE:
CONICAL BREAK

TEXAS SSC SITE

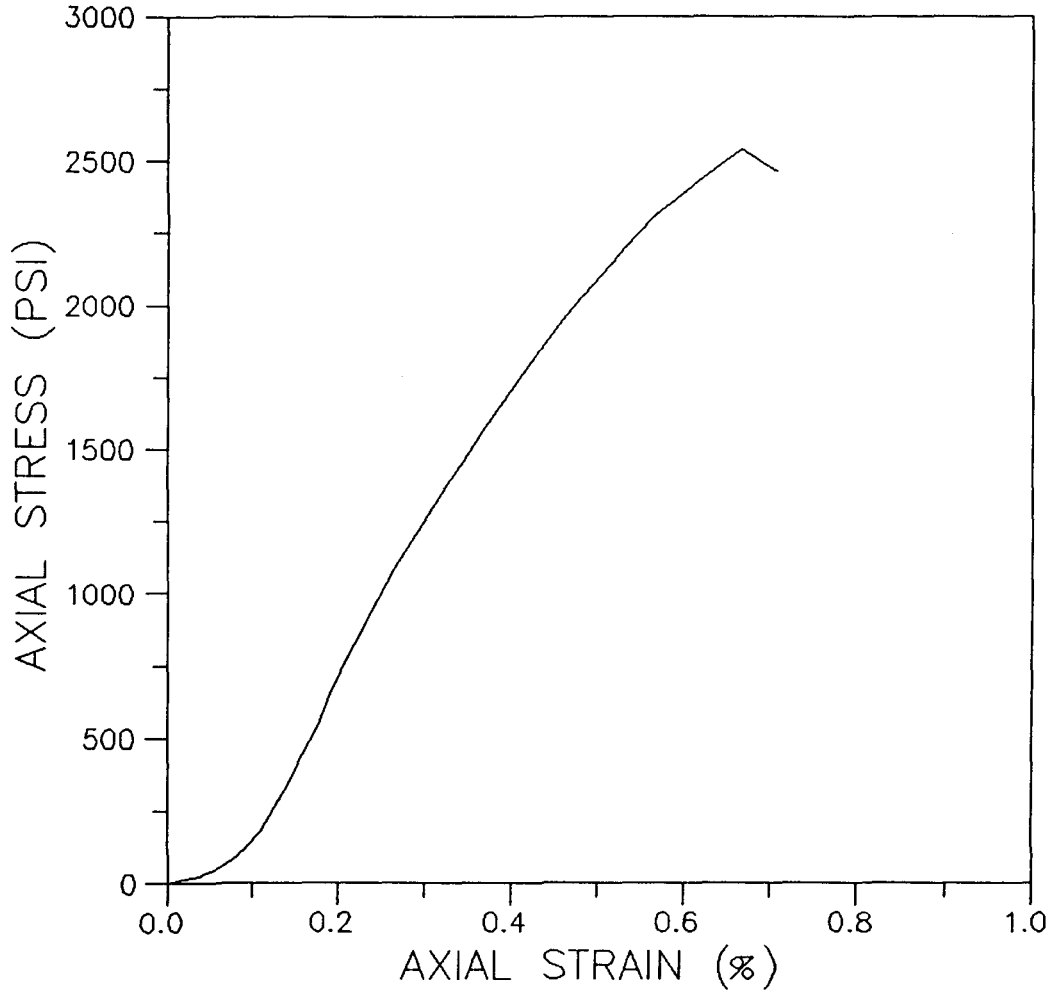
STRESS-STRAIN PLOT

SOUTHWESTERN LABORATORIES
DALLAS, TEXAS

JOB NO.: 89-192

FIGURE

BORING NO: BE5
DEPTH (FT): 171.4
AUSTIN CHALK



INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 10.4
DRY UNIT WEIGHT (PCF): 129.0
DEG. OF SATURATION (%): 91.8
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 0
TEST TYPE:UNCONFINED COMPRESSION
(ASTM D 2938)

TANGENT MODULUS AT 50%
ULTIMATE STRESS:
4.9 x 10E5 PSI

FAILURE MODE:
NO DISCERNIBLE FAILURE
PLANE

TEXAS SSC SITE

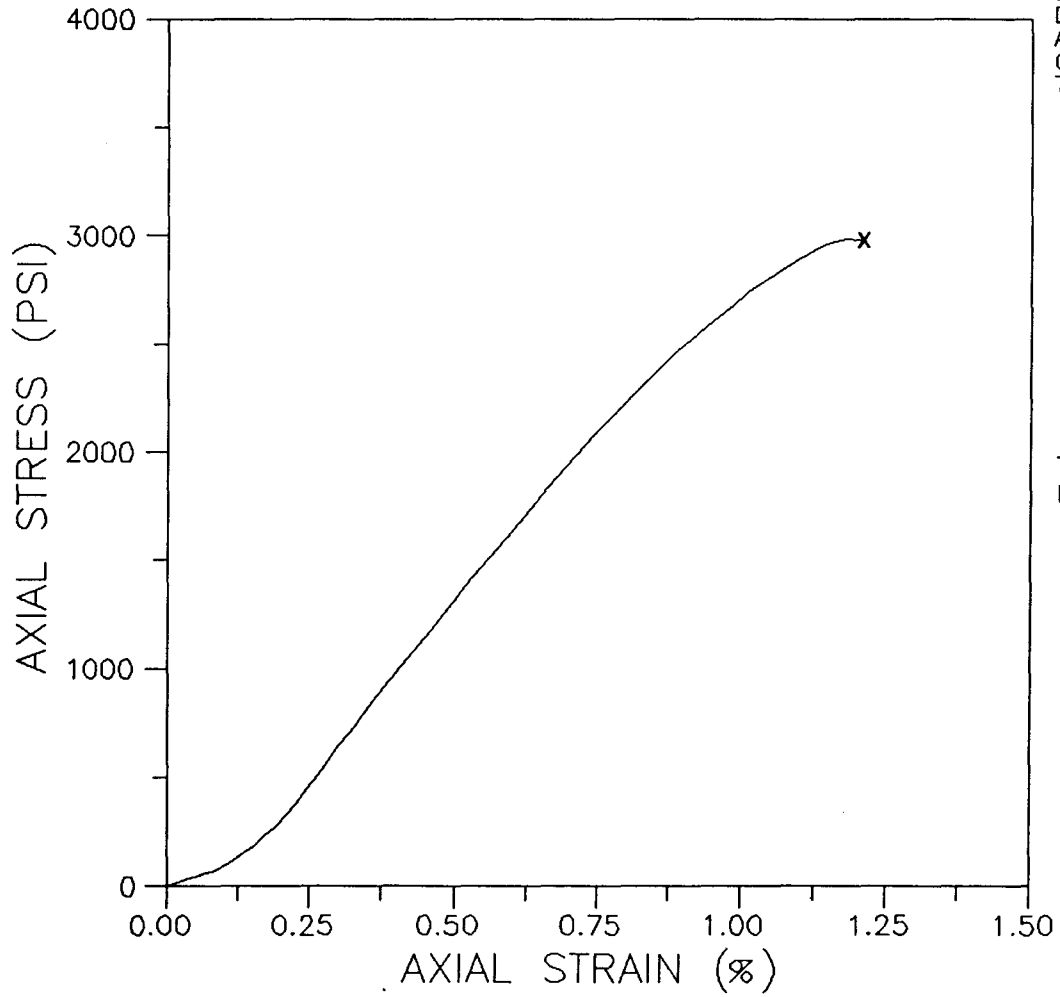
STRESS-STRAIN PLOT

SOUTHWESTERN LABORATORIES
DALLAS, TEXAS

JOB NO.: 89-192

FIGURE

BORING NO: BE5
DEPTH (FT): 195.5
AUSTIN CHALK



INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 10.1
DRY UNIT WEIGHT (PCF): 131.7
DEG. OF SATURATION (%): 97.6
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 0
TEST TYPE:UNCONFINED COMPRESSION
(ASTM D 2938)

TANGENT MODULUS AT 50%
ULTIMATE STRESS:
3.2 x 10E5 PSI

FAILURE MODE:
CONICAL BREAK

TEXAS SSC SITE

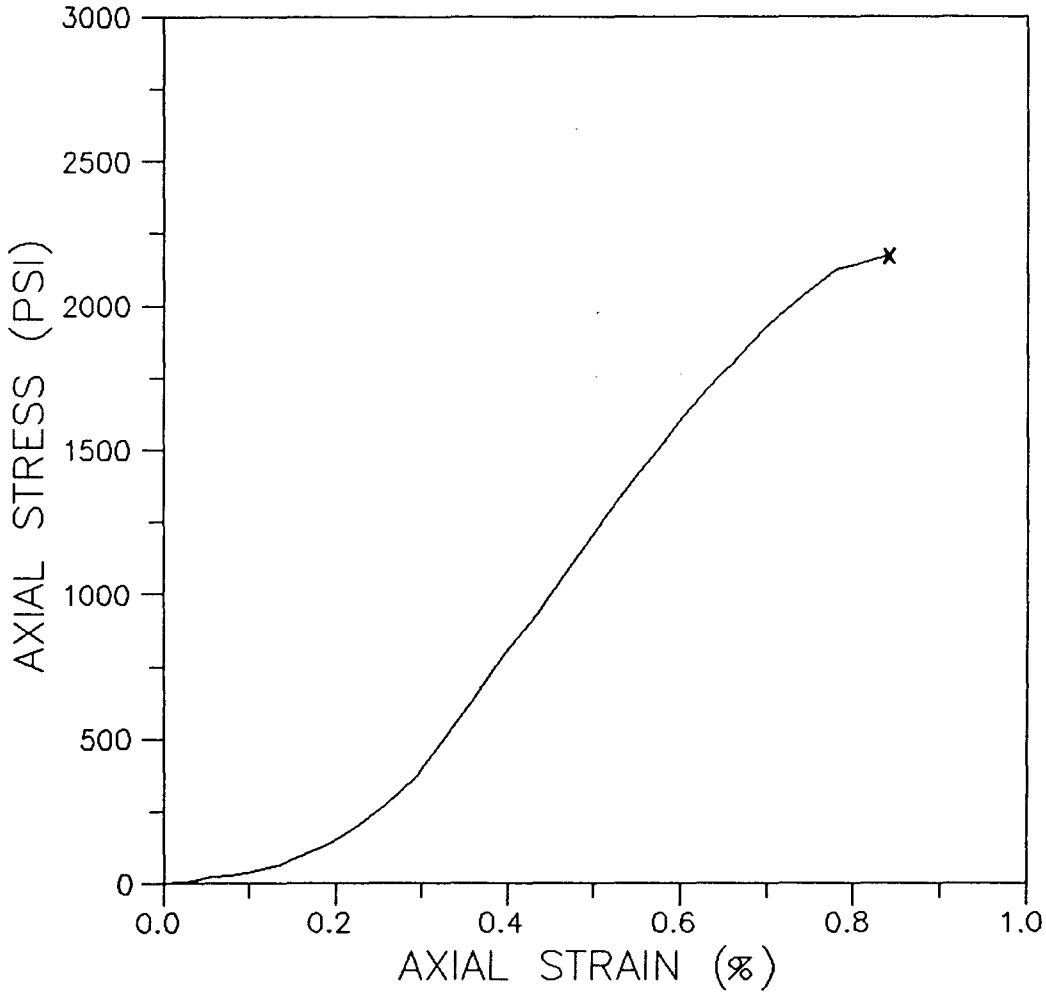
STRESS-STRAIN PLOT

SOUTHWESTERN LABORATORIES
DALLAS, TEXAS

JOB NO.: 89-192

FIGURE

BORING NO: BE5
DEPTH (FT): 271.3
AUSTIN CHALK



INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 12.1
DRY UNIT WEIGHT (PCF): 126.2
DEG. OF SATURATION (%): 97.5
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 0
TEST TYPE:UNCONFINED COMPRESSION
(ASTM D 2938)

TANGENT MODULUS AT 50%
ULTIMATE STRESS:
4.2 x 10E5 PSI

FAILURE MODE:
NO DISCERNIBLE FAILURE
PLANE

TEXAS SSC SITE

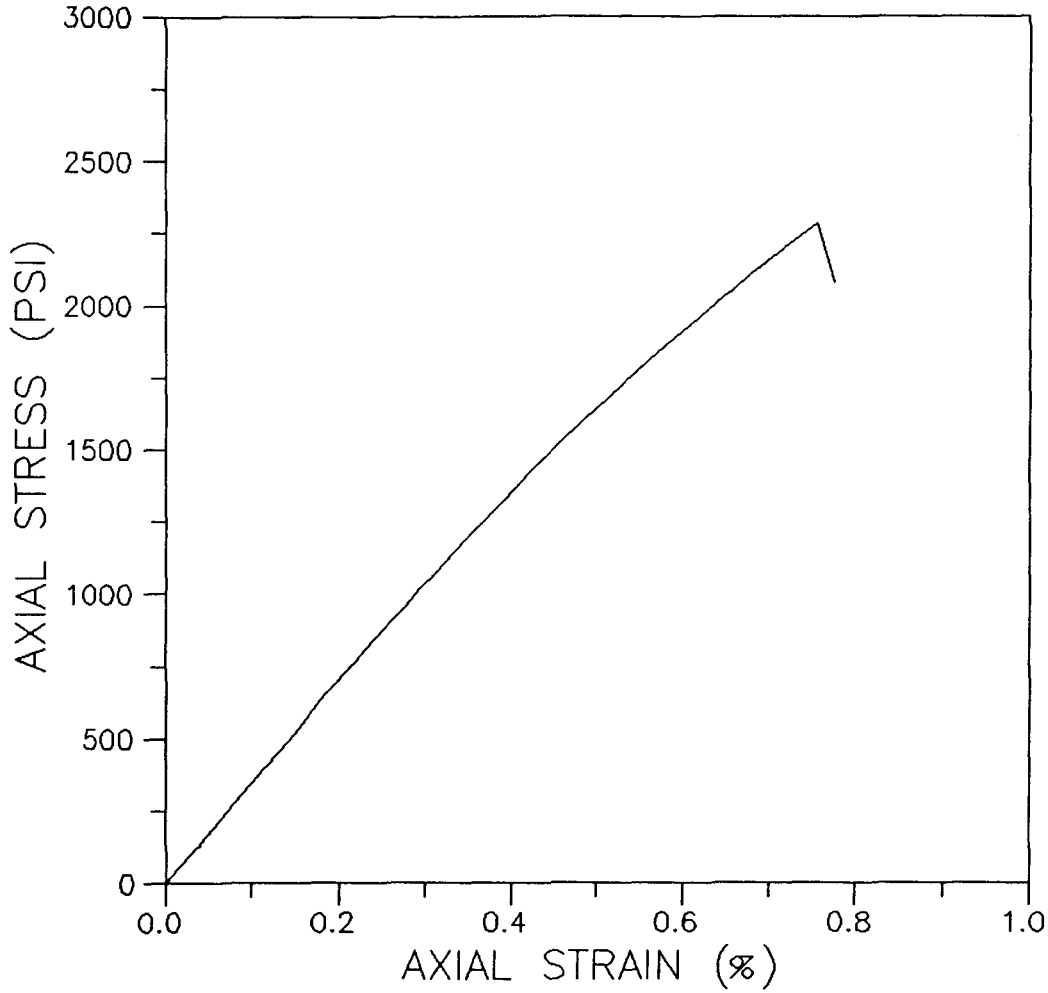
STRESS-STRAIN PLOT

SOUTHWESTERN LABORATORIES
DALLAS, TEXAS

JOB NO.: 89-192

FIGURE

BORING NO: BE5
DEPTH (FT): 320.8
AUSTIN CHALK



INCLINATION (DEG): VERTICAL
MOISTURE CONTENT (%): 10.2
DRY UNIT WEIGHT (PCF): 131.0
DEG. OF SATURATION (%): 96.3
ASSUMED SPECIFIC GRAVITY: 2.7
CONFINING PRESSURE (PSI): 0
TEST TYPE:UNCONFINED COMPRESSION
(ASTM D 2938)

TANGENT MODULUS AT 50%
ULTIMATE STRESS:
3.2 x 10E5 PSI

FAILURE MODE:
CONICAL BREAK

TEXAS SSC SITE

STRESS-STRAIN PLOT

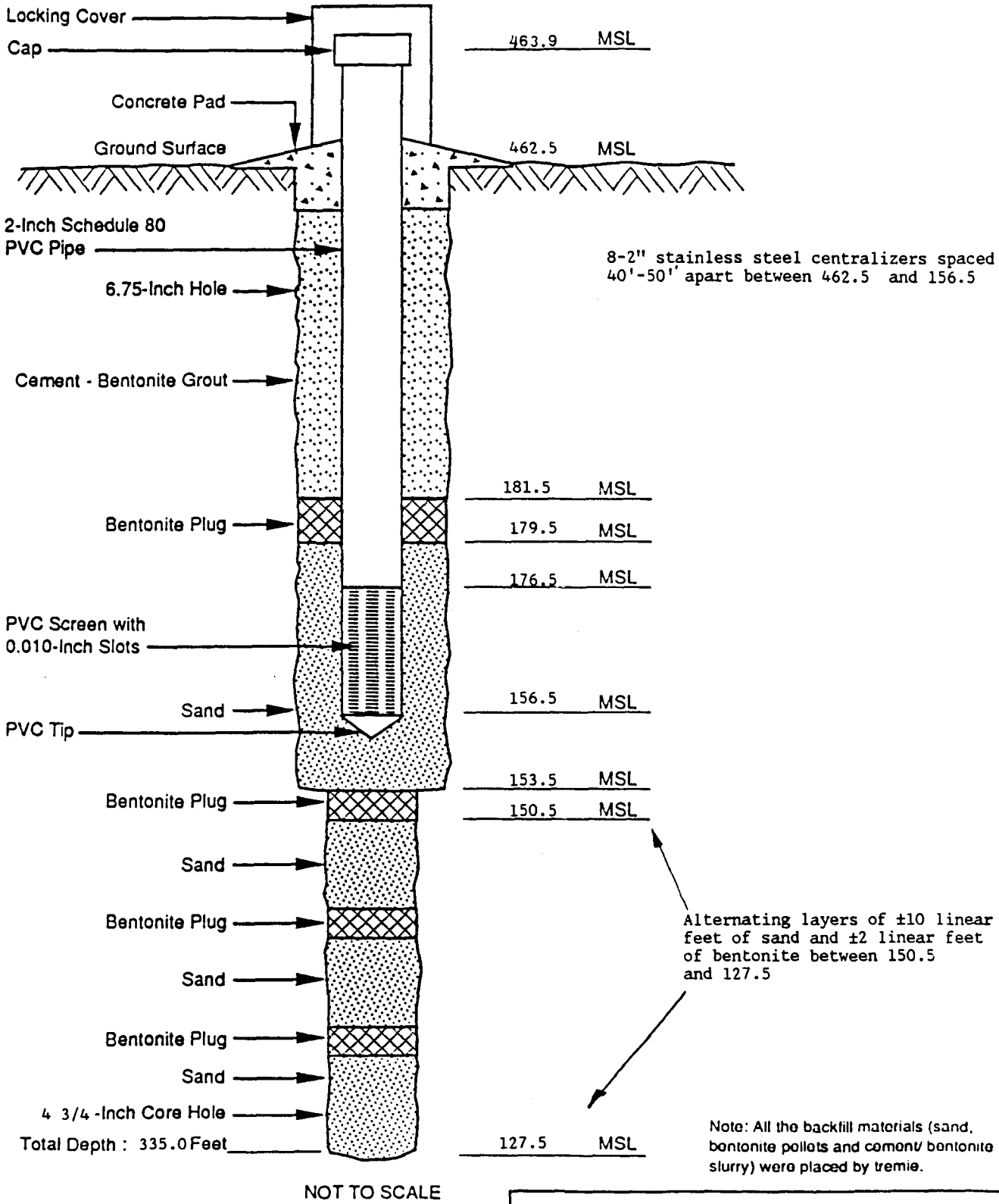
SOUTHWESTERN LABORATORIES
DALLAS, TEXAS

JOB NO.: 89-192

FIGURE

APPENDIX E

WELL AS-BUILT DIAGRAM



Boring: BE 5
Location: N 278,967
E 2,245,051
Date(s) Installed: 2-9/2-13-90
Well Construction
Supervising Geologist: Shawn Wood
Approved By: Shawn Wood **Date:** 5-14-90

"As Built"
Well Construction Diagram
Observation Well
No.
BE 5

5/90 Figure